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1 Introduction: understanding projections

Emission projections are used nationally and internationally to assess progress towards targets and to help model future health and ecosystem impacts. There are a number of guidance documents available for estimating projected emissions of greenhouse gases (United Nations Framework Convention on Climate Change (UNFCCC), 1999; UNFCCC, 2004; European Environment Agency (EEA), 2007) and air quality pollutants (Clean Air for Europe Programme (CAFE) 2006). This chapter has been drawn from these documents as well as the expertise in the Task Force on Emission Inventories and Projections' (TFEIP's) expert panel on projections.

It is stressed here that in this context a projection is not necessarily a prediction, but rather a method to perform a 'what-if' study. Projections inherently aim at contrasting different possible developments in the economy, behaviour and in technology, and projection compilers are encouraged to explore different scenarios. As such, projections are a tool to assess:

- what might happen if we take (or had taken) no action ('without measures'), what might be achieved with actions we are committed to ('with measures') ([1]) and what else could be done ('with additional measures'). These often need to be assessed under different economic projections;
- whether or not the policies in place are far reaching enough in order that emission targets are met.

The activities involved in estimating projections also provide a valuable contribution to establishing efficient and effective policies and measures through the development of an understanding of sources, economic drivers and the effectiveness of technologies and controls. Projections are usually much less certain than the historic inventory and require additional assumptions about growth in activities (for example, production, transport, population) and about technologies, efficiencies and controls that reduce the emissions per unit of activity.

This chapter is designed to provide some general guidance on projecting emissions that might accompany national inventory reporting under UNECE Convention on Long-range Transboundary air pollution (LRTAP Convention) ([2]) or under other policies and measures reporting such as the European Union's National Emission Ceilings Directive ([3]).

The material is intended both for countries establishing projected emission estimates for the first time and for countries with established projection approaches.

This chapter covers:

- the terminology used in projections and projections reporting;
- the methods used to project emissions;
- guidance on tackling common problems associated with gathering appropriate data on emission factors and activities and in ensuring consistency with historic emissions inventories.

([1]) As defined by the guidance material developed for EU Member State compilation and reporting of greenhouse gas (GHG) projections under the working group of the EC climate change committee provided in Minutes of the European Commission Climate Change Committee's WGII (National Programmes and Projections) Workshop on Reporting of GHG Projections under Monitoring Mechanism Decision 280/2004/EC, hosted by EEA in December 2006 (EEA, 2006).

([2]) Definitions concerning the reporting of projections under the LRTAP Convention are provided in the UNECE EMEP Emission Reporting Guidelines (ECE/EB.AIR/97) available online from the EMEP Centre on Emission Inventories and Projections (CEIP) website www.emep-emissions.at

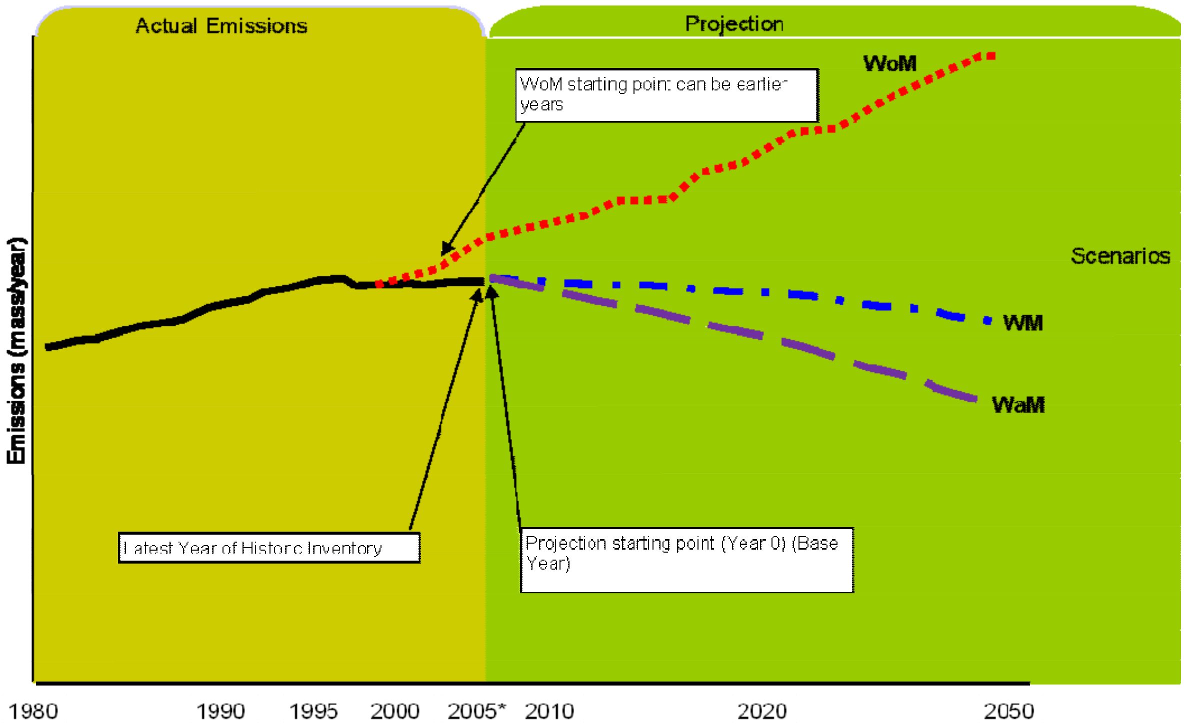
([3]) Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants (the NEC Directive), OJ L 309, 27.11.2007, p. 22

The chapter draws on information from a range of institutions. Where possible, additional documents have been identified and referenced so that users can find more detailed information. Sector-specific projection issues are described in brief in this chapter, whilst detailed information can be found in the sector-specific volumes of this Guidebook.

2 Terminology

Figure 1 illustrates the terminology used when projecting emissions. Most projections will include a number of different estimates (known as scenarios) comprising different combinations of assumptions. These assumptions will relate to changes in activity levels (for example, economic growth or decline) as well as the impacts of new technologies, techniques and practices. These may have been introduced as local, national or international efforts (known as 'policies and measures ([4])') designed to reduce emissions, ranging from emission controls for vehicles and industrial plant to incentives for cleaner fuels and technologies or changing behaviour.

Figure 1: Emissions projections



* Last year of the historic inventory

([4]) Policies and measures can be laws, agreements, or incentives to address (reduce) certain polluting activities or to enforce or encourage abatement or clean technology. Measures can be interrelated such as energy efficiency and emissions trading, where emission reductions can result from addressing both.

There are three scenario groups that are commonly used for reporting projected emissions and emission reduction potentials and this terminology should be used where appropriate. This terminology is in line with that described in the United Nations Economic Commission for Europe (UNECE) EMEP Emission Reporting Guidelines for reporting emissions data under the LRTAP Convention.

Without measures (WoM)

A WoM projection shall exclude all policies and measures implemented, adopted or planned after the year chosen as the starting year for this projection. For example, if the starting year for a projection was 2000, then the impact of Euro 3 regulations on passenger cars would be taken into account in a WOM scenario, as Euro 3 was adopted prior to this date. However, the impact of Euro 4 would not be taken into account as this legislation was not implemented until after the year 2000. This scenario was formerly known as ‘Business as Usual’.

With measures (WM)

A WM projection shall include implemented and adopted policies and measures. It will include the most likely economic and energy projections and the impacts of existing policies and measures irrespective of whether their primary objective was the mitigation of air emissions or not (consistent with UNFCCC, 1999). It is good practice for the starting point of the ‘with measures’ scenarios to be the latest year of the historic inventory. This scenario is also sometimes referred to as ‘with existing measures’. This scenario was formerly known as ‘Policies in Place’.

With additional measures (WAM)

A WAM projection shall include planned but not yet adopted policies and measures. ‘With additional measures’ presents a picture of the expected outcome of emissions if, on top of WM, planned policies and measures with a realistic chance of being adopted and implemented in time to influence the emissions are included. As with the ‘With Measures’ scenario it is good practice for the starting point of the ‘with additional measures’ scenario to be the latest year of the historic inventory. This scenario was formerly known as ‘policies in the pipeline’.

> **NOTE:** In some cases, other and sometimes conflicting terms and interpretations are used (for example, ‘Business as Usual’ is sometimes used by countries to refer to the ‘With Measures’ Scenario). It is good practice when documenting scenarios to refer to the ‘WM, WoM, WaM’ scenario terminology in order to be clear on what the projection represents.

In addition to these three terms, the following terms are also sometimes used:

Maximum feasible reduction (MFR)

Maximum feasible reduction is a variant on the ‘with additional measures’ scenario that includes the furthest reaching action that can be achieved through all possible technical and non-technical measures. Sometimes maximum feasible non-technical reduction (MFNTR) and maximum feasible technical reduction (MFTR) are presented separately.

MFNTR includes measures such as changes in economic drivers (e.g. fuel price rises), measures aimed at fuel switching and behavioural change (e.g. awareness raising). MFTR includes measures such as full application of abatement and control or the encouragement of new technologies.

Current reduction plans (CRP)

A current reduction plan is not a scenario, but is a politically determined intention to reach a specific national emission reduction target (or 'emission ceiling'), as defined in the various protocols of the LRTAP Convention. It should include a strategy of how the reduction will be achieved. However, such an emission reduction target is not regarded as an emission projection. It may have originated from a particular scenario estimated at the time of setting targets, which have now been superseded.

Box 1. Cost effectiveness

Cost-effectiveness is one type of policy tool used to prioritise actions. A tonne of a pollutant abated per unit cost is usually used as the basis on which decisions are made, but strictly speaking, cost-effectiveness should be judged on an impact basis, such as health effects reduced per unit cost. To do this, the costs of implementing measures should be calculated as well as the achievable reductions and used to prioritise the actions. The marginal cost curve in terms of a plot of total quantity of pollution avoided against the marginal cost of reduction (in unit currency/tonne) can form the basis for a consistent calculation of costs effectiveness. The following references provide some methods for assessing the costs of environmental protection measures that can be applied to emissions reduction estimates for particular measures. In some cases, regional considerations and health impact assessments may override the natural order of measures presented in any cost curve.

Further reading

Guidelines for Defining and Documenting Data on Costs of Possible Environmental Protection Measures, Technical Report No 27, the EEA, DK. Marlowe, I., King, K., Boyd, R., Bouscaren, R. and Pacyna, J. (1999).

US EPA A Standard Procedure for Cost Analysis of Pollution Control Operations, Volumes I and II, ORD, Industrial Environmental Research Laboratory, US Environmental Protection Agency, Uhl, V. (1979), Washington, DC.

US EPA: EPA Air Pollution Control Cost Manual, Sixth Edition, US Environmental Protection Agency, Research Triangle Park, NC. Mussatti, D. (editor) (2002).

European Environment Agency 2005: Cost-Effectiveness of Environmental Policies: An inventory of applied ex-post evaluation studies with a focus on methodologies, guidelines and good practice Specific Agreement No 3475/B2004.EEA Conclusions, April 2005
www.ecologic.de/projekte/3ea/panacea/inc/downloads/1731_Cost-effectiveness_conclusions.pdf

OECD Cost-Benefit Analysis and the Environment: Recent development, Organisation for Economic Cooperation and Development, Paris. Pearce, D., Atkinson, G. and Mourato, S. (2006)

World Bank (1999) Environmental Assessment Sourcebook, World Bank, Washington, DC.

3 Methodological choice

Emission projections are, as with emission inventories, a function of a rate of activity (activity data) combined with an emission rate (or emission factor), or controls applicable to the source. However, with projections a number of elements that make up the activity data and emission factor cannot be measured or counted and have to be estimated or modelled using assumptions about future activities including behavioural or structural changes and future emission rates.

Future activity

Future activity assumptions are based on a range of datasets including projections of industrial growth, population growth, changes in land use patterns, and transportation demand. Energy models often combine the above basic growth factors with energy price information to estimate energy demand by sector and fuel. These models can be used as a core dataset as long as the assumptions underpinning them are consistent with national economic strategies, policies and measures.

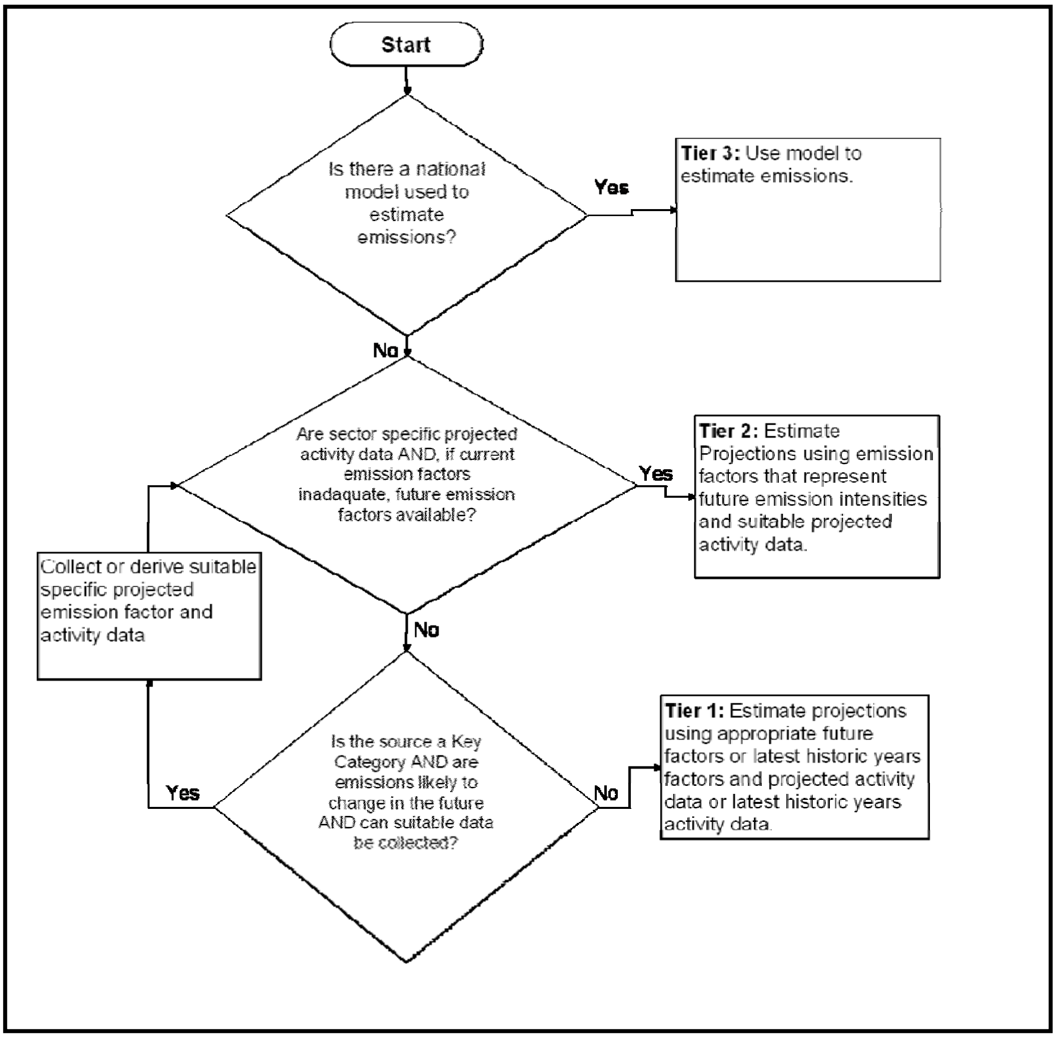
Future emission factors

Future emission factors should reflect technological advances, environmental regulations, deterioration in operating conditions and any expected changes in fuel formulations. Rates of penetration of new technologies and/or controls are important in developing the right sectoral emission factors for any particular projection year.

It is good practice for a tiered approach to be used when projecting emissions as indicated in the decision tree below. Key categories ([5])or sources where changes in technology or controls are expected to be significant should be estimated using Tier 2 or Tier 3 methods. Where national models are used they must incorporate underlying activity/energy data that is consistent with other relevant projected datasets and ensure that relevant policies and measures are incorporated appropriately.

([5]) A trend key category analysis will be particularly important for assessing key categories in projections. (see General guidance Chapter 2, Key category analysis and methodological choice).

Figure 2. Decision tree showing the recommended approach for developing emissions projections



Tier 3

Tier 3 projections use detailed models to provide emissions projections, taking account of a number of complex variables and parameters. However, these models must use input data that is consistent with national economic, energy and activity projections used elsewhere in the projected emissions estimates. For example, a road traffic model needs to reconcile vehicle kilometres and vehicle fuel efficiency against an energy model based on energy demand to provide a consistent national picture of vehicle emissions.

Tier 2

Tier 2 projections would be expected to take account of future activity changes for the sector based on national activity projections and where appropriate (where measures are applied to a source) take account of future changes to emission factors. Expect to stratify your source category in order to apply the appropriate new technology or control factors to sub-sectors. This can be done by applying the detailed equations presented in subsection 3.1 below.

Tier 1

Tier 1 projection methods can be applied to non-key categories and sources not expected to have future measures applied. Tier 1 projections will only assume generic or zero growth rates and basic projected or latest year's historic emission factors.

3.1 Formulae

The following general formula for projecting emissions for each source is based on projecting forward an existing historic emissions inventory ([6]). The basic function can be used for both Tier 1 and 2 methods and involves two key elements (the activity growth factor and the future emission factor) and will need to be applied in varying forms of complexity depending on the need to incorporate future technologies and controls.

The simplest form is:

$$E_n = (AD_s * GF_n) * (EF_n) \qquad (1)$$

Future Activity	Future EF

Where:

E_n	=	the source emission calculated for the projected year n;
AD_s	=	the activity data for a historic year chosen as the starting year for the projection;
GF_n	=	the growth factor for the activity from the starting year to projected year n;
EF_n	=	an emission factor appropriate for the future emission rate of the source as a whole in year n.

Where no changes are expected to the emission factor EF_n or the source is not a key category, EF_n can be set to the latest historic emission factor. Where a source responds to a simple global measure (for example, a change in the sulphur content of the fuel), EF_n can simply be applied to the whole sector. However, where a policy or measure applied to a source is complex and has an incremental effect on the overall sector's emissions performance, or contains a number of different technologies or controls, the following equation will be needed to derive an appropriate national average factor EF_n that takes account of the penetration of that technology or control.

$$EF_n = \frac{\sum_{t=1..p} EF_t * AD_t}{AD_n} \qquad (2)$$

Where:

EF_n	=	the emission factor appropriate for the source as a whole in year n;
EF_t	=	the emission factor for a sub-set of the source using a specific technology or control;
AD_t	=	the projected activity data (consumption/production) for a particular technology or control within a source;
p	=	the total number of technologies;

([6]) This ensures that the emission projection is consistent with the historic emissions inventory.

AD_n = the projected activity for the whole source in year n (=AD_s * GF_n).

$$AD_n = \sum_{t=1..p} AD_t$$

New activity sources will have to be treated separately. Further information is provided in Section 5 of the present chapter.

In some complex detailed sectors, such as the power generation sector, there can be an interaction between the emission factors assumed for pollutant control technologies and the projected activity data. For example in electricity generation, the underlying activity data may be future electricity demand. The energy production of the power sector must be consistent with the electricity demand and the efficiency of the future mix of power stations. However, the control measures applied (e.g. flue gas desulphurisation (FGD), selective catalytic reduction (SCR), carbon capture and storage) will affect the efficiency of the power stations and hence fuel consumption. Thus the assumed mix of emission factors affects the fuel consumption data. In such cases for Tier 3 methods, it will be important to use the assumed mix of abatement technologies as an input to the energy production model used to predict energy consumption in the sector.

3.2 Understanding available technologies

When considering Tier 2 or 3 methods, the details of current technologies and controls and how this affects emission factors should be taken into account. Technology-specific emission factors can be found in the individual sectoral chapters of this Guidebook. However, emission factors for future technologies that have not been introduced may not yet be available. Suitable data may be available from national test measurement activities, indicated as limit levels in draft legislation, or from industry, from BREF notes that provide details of possible technologies, or from the UNECE/CLRTAP Expert Group on Techno-Economic Issues (EGTEI, with information available at www.citepa.org/forums/egtei/egtei_index.htm).

Useful information on quantifying policies and measures may also be available from Working Group II's (national programmes and projections) activities of the European Union greenhouse gas (EU GHG) monitoring mechanism committee. Further information is also available on the European Topic Centre on Air and Climate Change (ETC/ACC) website: http://air-climate.eionet.europa.eu/

Where no data is available but the inventory expert believes emission reductions will be achieved, expert judgement can be applied to derive an appropriate emission factor. The assumptions and data used to form this judgement should be well documented.

More details of sector specific approaches are identified in 0.

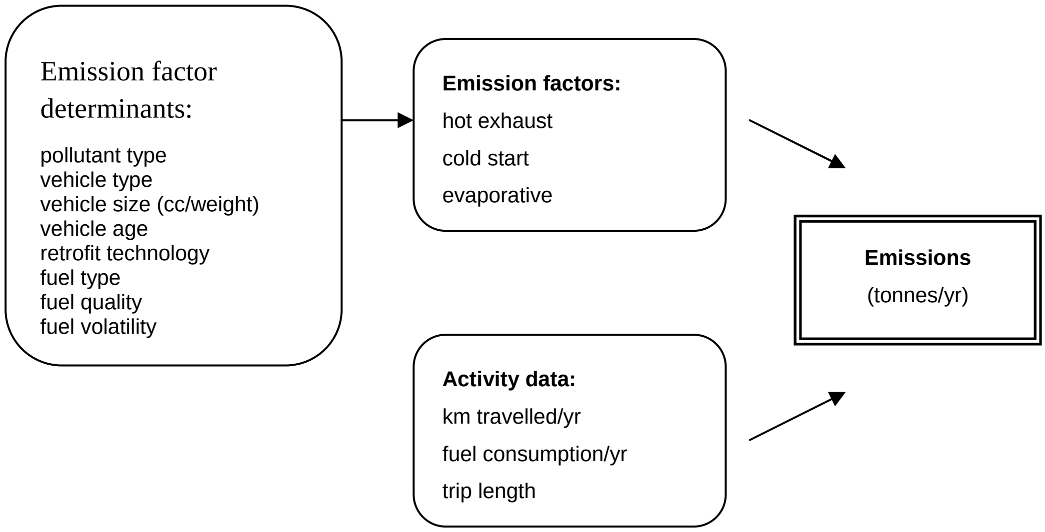
3.3 Stratification

Stratification involves breaking down a sector to its component subsectors and projecting emissions at this level of detail. There will be many cases where historic emissions cannot be projected using simple growth factors and future emission factors because of complexities in the mix between new and existing emission performance and therefore they need to be broken down further. Stratification helps to account for penetration of measures over a number of years by sub-dividing the sector into its components, so that a measure can be applied to the appropriate fraction of the sector's activity for each year of the projection. Two examples where stratification is appropriate are shown in the box below.

BOX 1

EXAMPLES OF STRATIFICATION:

Road transport — it is likely that a detailed model will be required to project emissions from this sector, as there are many variables that will affect future emissions. A schematic of the determinants are shown below:



Therefore, for this sector it is not appropriate to adopt the simple methodology described in subsection 3.1 above and emissions need to broken down to a more detailed level in order to apply the appropriate emission factors and activity data.

Power generation SO_2 — when projecting emissions from the coal-fired power generation sector, plant must be stratified into flue gas desulphurisation (FGD) and non-FGD plant for each year that projections are being compiled, in order that the appropriate emission reduction factor is applied for the fraction of fuel burned in FGD plant.

Stratification is only required in cases where emission controls or new technologies are applied to subsectors.

3.4 Simplification

In many cases, the detail of future activity projections (for example, employment, transport, energy use) will not be as comprehensive as underlying inventory data. For example, fuel types are often not broken down in as much detail (e.g. the increase/ decrease in solid fuel may be provided) or sectors are more highly aggregated (e.g. a projection for industry gas may not separate out all of the individual sectors within the inventory). In other cases, indicators rather than projected changes in activity may have to be used. Where appropriate, these more aggregated datasets can be used to derive growth factors (GF_n) that can be applied to a number of individual sectors. Care should be taken to ensure that the growth factor is representative of the individual sector. An example of where simplification might or might not apply is shown in the box below. In this example the level of detail provided by the energy model is at an aggregated 'industry–Gas' level. As there is no further breakdown to provide the detail necessary for the sectors in the historic inventory, the relevant inventory sectors will be projected using the 'industry–gas' growth rate.

BOX 2

EXAMPLE OF SIMPLIFICATION:

Historic inventory source / fuel combination:		GF_n:
domestic — coal	→	domestic — coal
collieries combustion — gas	→	industry — gas
lime production — gas	→	industry — gas
other industrial combustion —gas	→	industry — gas

3.5 Checks and controls: verification and QA/QC

The best practice principles for emission inventory compilation also apply for projections. Therefore, the resulting projections will need to be transparent, accurate, consistent, complete, and comparable.

It is important to ensure that resulting emission projections have similar verification and QA/QC as applied to the historic inventory. In addition to following the general guidance on good practice in Chapter 6, Inventory management, improvement and QA/QC, it is recommended to pursue the following checks and procedures listed below.

- The energy related emissions should be checked to ensure that energy consumption by fuel derived for the individual sectors in the projected emissions match the energy consumption used as input to the estimates. The overall energy balance used to derive the projected inventory should also be consistent with the energy balance from the input data.
- Compare projected trends in data (emissions or activity) with historic trends — if there are significant differences then the compiler will need to explain why. This is based on a general observation that national emissions/activity data tend to change gradually (though not always, e.g. N_2O emissions in the chemical industry). The rationale for large step changes should be provided or methods revised to take out erroneous projected data or methods.
- It is good practice to reference all data sources within the spreadsheets / databases so that the input data is traceable.
- A check should be made to compare the emissions generated in the latest dataset against previous projection versions. A designated checker should identify sources where there have been significant changes and satisfy themselves that the projections are correct and that the revisions are transparent.
- For a number of countries, national projections can be crosschecked against some international datasets. For example, the energy model PRIMES ([7]) provides a centralised view on energy demand across Europe and the GAINS model provides projections for a number of pollutants and sectors (see subsection 3.7.2 of the present chapter).
- Check previous projections against results in the historic emissions inventory; for example how far off were projections for 2000 and 2005 compared to the historic inventory results and what were the sources of the differences.

([7]) PRIMES partial equilibrium model covers many European countries www.e3mlab.ntua.gr

3.6 Dealing with gaps in projected data

For key categories it is good practice to fill any projection gaps with national projected estimates through the development of new models or accessing new data on national projections. Where matching projected statistics (e.g. projections of fuel combustion and cement production in cement plant to match historic statistics) are unavailable, 'surrogate' projections (e.g. housing growth) can be used to help project future activity. For non-key categories, where no appropriate data or surrogates are available for a source sector, it is good practice to assume that the projected value is the same as for the latest historic year of the inventory. This approach can be applied to the activity data and/or the emission factors, where no other data is available.

Issues relating to non-disclosure may be encountered (at a sectoral or spatial level) that may impose barriers to acquiring data. As only highly aggregated output data is needed for reporting, signing of non-disclosure or confidentiality agreements or asking the data supplier to derive aggregated datasets may improve the accessibility of this data. It will be important that issues relating to this are identified and dealt with in consultation with the national statistical authority.

3.7 Data sources

The complexity of emissions projections will depend on the level of data available in the country. As a minimum, for good practice, national government sources of data should be used for all key categories in preference to other national or international datasets. A key data source is national energy models, which combine economic-based energy demand criteria with energy price information. These models often provide a number of different energy demand scenarios based on different economic and price elasticity criteria. Where the data on energy demand projections can be aligned to sectors and fuels in the inventory, they can be used as growth factors for the activity data in the emission projections. Examples of datasets are provided below.

3.7.1 National sources

National projected emissions should aim to be consistent with other national activity projections (for example, agricultural productivity, population growth, energy demand and supply and industrial production). It is good practice to use these national datasets, where they exist, as a starting point for the projections. The following organisations may be able to provide information:

- **statistical departments**: socio-economic projections data (economic growth, population, production/consumption);
- **government departments:** sector-specific data on activities and policies and measures should be gathered from the different government departments. Available datasets could include agriculture activity and livestock, agricultural practices and emissions, traffic projections, energy supply and demand;
- **regulators:** plant upgrade plans, emission limits (BREFs);
- **industry and industrial trade associations'** views on growth and technological implementation. It should be noted, though, that views could sometimes be political and resistant to change;
- **vehicle and engine manufacturers and regulators.**

Any policies and measures designed to meet national and international commitments for emission reductions (e.g. directives, protocols, etc.) should also be used as a key input to emission projections. These may provide assumptions about plant/vehicle replacement, implementation of new technologies and controls from the industry and regulators and include factors on penetration of technologies, population, economic and transport growth. Where possible, projections should also include assumptions about the impact of non-technical measures (e.g. low emission zones and carbon trading) and indirect impacts of other policies and measures (e.g. air quality directives and climate change activities). These are complex elements to include in projected emissions estimates. Where possible, assumptions on the impact of these measures on the activity rates and on the technologies used should be quantified and documented. If regulatory impact assessments are carried out, then these should have basic information about the likely impacts on emissions into the future.

Future emission factors should be based on measured data for in service technologies and abatement. Where this is not possible (for example, for emerging technologies), future emission factors should be estimated using expert judgement or based on limit levels from regulators and industry and flagged to have a higher level of uncertainty. For example, using emission limit levels, the emission limit value defined by the large combustion plant directive (Directive 2001/80/EC) for new coal plant is 200 mg/Nm^3 NO_x as NO_2 (@6%O_2). Applying an appropriate volume factor for coal of 364 m^3/GJ (NCV) (Graham et al., 2007) gives a projected emission factor of 72.8 g/GJ coal consumed.

More details of sector specific approaches are identified in 0.

3.7.2 International sources

Some international datasets can be used where national data are unavailable. These datasets may be able to provide projected activity data and or emission factors; however there may be a number of inconsistencies with national views. Examples include, but are not limited to, the following:

Activity data

- Projections of energy consumption / supply can be obtained from the following models:
  - PRIMES www.e3mlab.ntua.gr/
  - POLES www.enerdata.fr/enerdatauk/tools/Model_POLES.html
  - SCENES www.transforum-eu.net/
  - TIMES www.etsap.org/Tools.asp
- Agricultural projections can be obtained from:
  - The CAPRI model www.ilr1.uni-bonn.de/agpo/rsrch/capri/caprifp4_e.htm
  - The Food and Agriculture Organisation www.fao.org/
  - The European Fertilizer Manufacturer Association (www.efma.org)
  - The International Fertilizer Industry Association www.fertilizer.org
- Transport projections can be obtained from:
  - The TREMOVE model www.tremove.org/
- Solvent emission projections are available from:
  - The European Council of paint, printing ink and artist’s colours industry (CEPE) www.cepe.org
  - UN production statistics http://unstats.un.org/UNSD/industry/ics_intro.asp
- In addition to the above examples, the GAINS model http://gains.iiasa.ac.at can be used to obtain Country specific activity projections for all sectors.

Emission factors

- Current and emerging technologies and their impact on emissions:
  - The Expert Group on Techno-Economic Issues (Provides detailed sector specific data for industrial processes) www.citepa.org/forums/egtei/egtei_index.htm
  - NH_3 expert group www.unece.org/env/lrtap/ExpertGroups/aa/welcome.htm
  - European Agriculture Gaseous Emissions Inventory Researches Network (EAGER) www.eager.ch/Members.htm
  - BREF documents http://eippcb.jrc.es/reference/
  - GAINS (see above)
- Information on example penetration rates for different technologies:
  - GAINS (see above)
  - SCENES (see above)

More details of sector specific approaches are identified at the end of this document.

4 Sensitivities and uncertainties

It is important to distinguish between uncertainties and sensitivities, as these two terms are sometimes incorrectly used. Sensitivity analysis can be used to identify parameters that have a significant impact on the resulting emissions projections, while uncertainty analysis gives uncertainty bands for projected emissions. Although both approaches improve emission projections, it is good practice to first carry out a sensitivity analysis followed by an uncertainty analysis. The latter, however, is likely to require more resources.

Sensitivities

Emission projections are always modelled or based on hypothetical expectations of future events. Because a form of modelling is employed to all projected estimates; the sensitivities of that model also need to be understood and communicated.

Sensitivity analysis (SA) is the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation, and of how the given model depends upon the information fed into it (Saltelli et al., 2000). It quantifies the variation in model output that is caused by specific model inputs (Cullen & Frey, 1999).

The sensitivities can be assessed by analysing the emissions projections reaction to changes in underlying input data — for example, vehicle scrappage rates, economic growth and temperature change. Sensitivity analysis should provide details of the most important parameters and the vulnerability of these parameters to change. This will give an expected range of likely future emissions for any particular scenario.

The goal of sensitivity analysis is to understand the quantitative sources of uncertainty in model calculations and to identify those sources that contribute the largest amount of uncertainty in a given outcome of interest.

The sensitivity analysis can be used to answer, for instance, the following questions:

- what is the rank order of importance among the model inputs?

- are there two or more inputs to which the output has similar sensitivity, or is it possible to clearly distinguish and discriminate among the inputs with respect to their importance?
- which inputs are most responsible for the best (or worst) outcomes of the output?
- is the model response appropriate?

The sensitivity analysis applied to emission projections could be applied to only some emission sources or to all the activities included in the projections. The choice of an appropriate sensitivity analysis method depends on the objectives of the analysis, the characteristics of the model, and other considerations such as ease of implementation and resource availability to conduct the analysis (Frey et al., 2004). For example, when the objective of sensitivity analysis is to identify key categories of uncertainty and apportion variance in an output to individual inputs, the choice of methods further depends on model characteristics. If a model is linear, correlation methods and regression analysis methods are appropriate. If the model is nonlinear, ANOVA (ANalysis Of Variance) or other methods capable of dealing with interactions are better choices. When there are categorical inputs, CART (Classification And Regression Trees; Breiman et al., 1984) may be more appropriate. When the objective of sensitivity analysis is to identify factors contributing to high emissions in order to develop control strategies, ANOVA and CART should be considered since these methods can provide insight into conditions that lead to high emissions.

Further information on conducting a sensitivity analysis can be found at: http://sensitivity-analysis.jrc.ec.europa.eu/

Uncertainties

The 2006 Intergovernmental Panel on Climate Change (IPCC) Guidance describes an uncertainty as a 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.

Any projection of emissions will be uncertain. There will be uncertainties in both the future activity and future emission factors. Each of these variables must be assessed. For some source categories, a lack of specific projected growth, or a poor understanding of future emission factors, will increase the uncertainty associated with the estimates presented. Acquiring a better understanding of the uncertainty associated with projected inventory estimates is an important step in helping to prioritize future work and improving the overall quality of the projections.

Further information on uncertainty methodologies can be found at the IPCC website. A guidance document on good practice guidance and uncertainty management was published in 2000. This is available from www.ipcc-nggip.iges.or.jp/ However, few countries have applied these methodologies to emission projections (Lumbreras et al., 2009).

5 Steps to estimating emission projections

The following steps provide an outline of the activities necessary to compile emission projections.

Step 1) **Establish a starting point:** the starting point should be an officially submitted inventory based on national statistics and an understanding of the current levels of technologies and controls included in the latest years of the emissions estimates.

Step 2) **Identify important sources:** priorities for developing the detail and complexity of projections should be set based on a basic understanding of the important future sources. The list of priority sources should be established by looking at the key categories for the historic inventory (those that are large in the latest year and those that are showing signs of increasing — for example, aviation has seen a large increase in recent years and is likely to continue to increase into the future). This exercise should also involve an element of horizon scanning to identify possible future sources not currently in the inventory.

Step 3) **Initial trawl for projections data:** gather necessary activity projections from government departments, regulators and information on policies and measures to create a basic emission projection. Use the data collection activity as an opportunity to build a cross-government working group (for example, transport, agriculture, energy, industry trade and regulation) with an interest in the projections outputs. Work with policy makers to quantify emission reductions for measures (so that this can be used as consistent input for projections). Where there are gaps in government data for certain sectors, use other national datasets from industry and/or trade associations. Any possible new emission sources should be identified at this stage. It is good practice to consider the full scope of pollutants during this exercise so that the impacts of measures taken for one pollutant can be included in the projections for others. Where possible, air quality projections should be undertaken at the same time and have a methodology that is consistent with greenhouse gas emission projections. For information on sources of data, please see subsection 3.7 of the present chapter on data sources.

Step 4) **Compile an initial WM projection:** make a first estimate of projections using the data gathered in the initial trawl and the methods presented above. Estimates may not initially be complete with projections data gaps for some sectors. Gaps in projection data should be addressed according to subsection 3.6 of the present chapter and circulated to the relevant Government departments for comment. Initial projections should include a first estimate **with measures scenario** (where possible using data provided on technologies and controls consistent with any implemented policies and measures). It may also be helpful to compile a **without measures scenario** to put any considered measures into context.

Step 5) **Engage with policy makers and data providers:** the initial WM and, where applicable, WoM scenarios, should be used to engage with policy makers and data providers and enhance the flow of information by illustrating the expected course of emissions and any uncoupling from economic projections. The approach taken should be well documented. It is useful to get national agreement on the most likely economic scenarios and policies and measures that are to be included in the with measures scenario and how the implementation of these will be present in the projection estimates. Assessment and presentation of sensitivity and / or uncertainty in the projections will help to engage with policy makers, stakeholders and data providers and help refine further improvement priorities. For further information on conducting a sensitivity analysis or uncertainty assessment, see Section 4 of the present chapter.

Step 6) **Iteratively improve the projections for important sources:** following the preparation of initial projections, an idea of the most important sources will be clarified and interest in correctly accounting for their future emissions established. These sectors can then be refined through the introduction of additional activity data, where appropriate, new studies and modelling and more detailed stratification to ensure that estimates are representative of Government expectations and actions. A picture of the expected emissions reductions will begin to appear as more detailed information on policies and measures is included and the country can begin to evaluate if the current level of action (policies and measures) will achieve any planned reduction targets.

Step 7) **Develop a with additional measures scenario:** add into the projections, additional options for emission reductions that could be considered to help meet established or planned targets.

6 Documentation: guidance on documentation of assumptions

The methodology and data sources used in compiling an emission projection scenario should be well documented. It should include enough information to allow readers to understand the underlying assumptions and to reconstruct the calculations for each of the estimates included.

In addition to following Chapter 6, Inventory management, improvement and QA/QC chapter, the following information should be included in projection-specific documentation:

- detailed data to aid transparency including: values and sources of activity data used, growth factors used, emission factors, details of tiers, sector definitions, sector stratification, assumptions made in deriving future EFs;
- description of the methodology followed for each sector;
- information on the QA / QC undertaken;
- any major issues regarding the quality of input data, methods or processing and how they were addressed or are planned to be addressed;
- identify areas where further improvements would be beneficial;
- contact information for obtaining the data sources, where applicable.

Documentation of estimation methods for projections should follow the general guidance in Chapter 6, Inventory management, improvement and QA/QC. It is good practice to include a description of the reasons for trends, revisions, policies and measures included, methods, data sources and assumptions as part of the inventory QA/QC documentation or published as part of a national inventory report.

7 References

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8 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on Projections. Please refer to the TFEIP website (www.tfeip-secretariat.org/) for contact details of the current expert panel leaders.

Sectoral overview of methods

The sections below provide general guidance on the approach for estimating projections for the main sectors. There is a focus on the activity data needed as well as on identifying the likely areas for development of specific future factors incorporating changes to technology, practices and abatement. Where available, specific technology emission factors and methodologies for estimating emissions are included in the sectoral volumes of this Guidebook. Where technologies, controls or other changes are unlikely to affect emission factors, they can be kept the same as for the latest year of the inventory. The examples of projection tools and models given in this appendix refer mostly to work done for European countries.

A1 Energy: stationary combustion

Emission projections from the stationary combustion sector should be based on any available national energy projections based on fuel production and demand models as well as knowledge of future emission factors accounting for fuel quality and future combustion technology and abatement. In this case, it is important to check the consistency of the reference year for the energy projections with the last inventory year. In some cases detailed plant-by-plant projections may be available. If consistent with national energy projections, these data can be used as the basis for deriving future emission factors for particular sectors.

A1.1 Activity data

Where national energy projections are unavailable, projections from the International Energy Agency (IEA) and from the PRIMES model (for European countries) can be used. However, consistency of these models with underlying national economic and demographic projections and existing policies and measures should be investigated and the differences highlighted.

Where energy demand projections are not available, basic future activity change should be projected using economic (e.g. production, income) and demographic projections (e.g. population, households etc) datasets, but they should be avoided for the key categories. These datasets should be available from national statistical sources.

The methods, described above for simplification, stratification and gap filling will need to be employed to derive projected combustion activity datasets. It is important to ensure that, where possible, fuel type as well as total fuel consumption by sector is explicitly modelled in order to enable appropriate emission factors to be applied and the projections to reflect fuel switching effects.

A1.2 Emission factors

Future emission factors should be estimated for the sectors or fuels for which controls or new technologies are expected. This could include the following:

- domestic and commercial heating system improvements and new boiler technology;
- industrial technology improvements (e.g. combined cycle gas turbines, over fire air) or controls (e.g. flue gas desulphurisation (FGD), dust filters, selective catalytic reduction);
- fuel quality (e.g. reduced sulphur, ash or lead content).

Indirect impacts of technologies on pollutant emissions (e.g. FGD on particulate emissions) should also be considered.

In order to estimate emissions, improvements need to be specified in terms of their emission factor per unit of fuel consumed (or other suitable statistic) and their penetration rate (e.g. % of total fuel consumed by a sector using a particular control or technology) so that a future year specific emission factor for the sector can be calculated.

A2. Energy: transport

Transport emission projections should reflect the countries expectation on road, rail, air and sea traffic. These will include expected growth in transportation of passengers and freight as well as developments in vehicle and engine technology and fuel quality. The paragraphs 0 and 0 below deal with the generic considerations for activity data and emission factors for all transport sectors, while the following paragraphs 0 to 0 identify specific issues for the different transport subheadings.

A2.1 Activity data

Future transport activity will preferably come from national transport models. These models will be designed to predict the density and destinations of transport for congestion and infrastructure development. Some important issues for projections will include the specification of engine technology (for example, Euro 1, Euro II Euro III standards, etc.), vehicle type and fuel type as well as traffic volumes. This level of detail will take into account vehicle/engine replacement rates to provide an insight into the penetration of new technologies and controls. Where this level of detail is unavailable it will need to be filled in using expert judgement from transport experts using simple fleet model assumptions; in any one year the fleet changes as some vehicles are scrapped and new ones enter the fleet, so the introduction of new vehicles is related to the scrappage rate of old vehicles plus any growth in vehicles overall. Trends in overall activity should be projected forward using figures that relate as closely as possible to the transport sector (such as transport usage, vehicle/tonne/passenger-km, vehicle sales, etc.). Where these are not available, parameters such as GDP or population could be used as a last resort. Where possible, these activity projections should be checked for consistency with energy consumption projections.

The TREMOVE model **(**www.tremove.org**)** can be used as a starting point for transport activity and even emission projections. Based on EU-level datasets it produces emission estimates for many air quality pollutants as well as activity data at five yearly intervals up to 2020 for road, trains, planes and inland ships.

A2.2 Emission factors

Changes in emission factors are very important in transport projections. Factors that should be considered in deriving the future emission factors and applied broadly to all sectors of transport emissions are detailed below.

- **Vehicle and engine standards**. New vehicles and engines have to meet emission standards. These are being laid down for the future. At this stage it is impossible to be precise about the way vehicles and engines will meet future regulations. This is usually handled by assuming that future vehicles and engines will just meet the future legislation. This has been a reasonable assumption in the past. It is possible to assume that a specific technology is used with specific emission rates, however its introduction cannot be guaranteed.
- **Abatement technology**. For several non-road transport sectors (for example, shipping and rail) abatement technologies are increasingly being fitted. These will reduce emissions according to the specification of the abatement technology. Where possible, these technologies should be accounted for in the projections.

- **Fuel quality**. Fuel quality measures will generally affect the complete sector/fuel from the date of introduction. Improvements that will affect emission factors will include:
  - reductions in fuel volatility (measured as Reid vapour pressure (RVP)), which will reduce evaporative emissions. Vapour recovery control systems will reduce evaporative emissions further from vehicles and gasoline storage and distribution;
  - reductions in the sulphur content of road transport fuels, which have enabled improved vehicle exhaust catalysts and have reduced sulphur and particulate emissions. In the road transport sector, the introduction of ‘sulphur free fuels’ with sulphur levels below 10 ppm was required by 1 January 2009 under the Directive 2003/17/EC. Therefore, no further improvements are expected while this Directive is in force;
  - reductions in the lead content of gasoline, which have been necessary for the introduction of catalysts and this has also lead to further reductions of particulate matter emissions. Within Europe, Directive 98/70/EC banned leaded petrol from the market from 2000 onwards. Again, no further improvements are expected while this Directive is in force.
- **Inspection and maintenance programmes (I and M)**. Designed to ensure vehicles operate according to their specified standards and do not degrade on emission performance with age. Often a large proportion of the emissions come from a relatively small fraction of a poorly maintained fleet. Where possible projections should account for a percentage of poorly operating vehicles and be explicit about what is included in the assumptions.
- **Retirement programmes**. The rate of retirement, and therefore the rate of penetration of new vehicles, need to be considered in order to account for an accurate estimate of emissions from the fleet.
- **Traffic management**. Measures taken to encourage vehicle users not to use the vehicles as much, i.e. to reduce the activity levels or to encourage use of newer less polluting vehicles should be considered. If only small areas are affected then there may be little effect nationally as vehicles are displaced onto other roads.
- **Other policy measures.** The government can take other measures that influence passenger and freight transport, for example measures regarding fuel prices, land-use planning, parking facilities and parking prices.

The subheadings below provide some more specific information on the different transport sectors.

A2.3 Road transport

Road transport emissions will require particular attention as they are a significant source of emissions. Transport volumes are generally increasing over time as populations and economies grow, and there are a number of complex measures established to control emissions.

Particular care should be used in stratifying the road transport sector so that the important sub-sectors (engine size, vehicle technology, fuel type, driving cycles (speeds)) can be identified and appropriate emission factors applied.

The sectoral chapters of this guidebook provide details of methods for estimating transport emissions including complex models that support projections.

A2.4 Air

Projections from aviation are important because aircraft use is expected to rise and therefore this will become a more dominant source in the future.

Airports and national aviation authorities will have projections of passenger and freight traffic. Extrapolating this in terms of the number and types of aircraft with a split between international and domestic flights will be important. However, where this data is unavailable, data on projections are available from the International Civil Aviation Organization.

Both the technology and efficiency of the aircraft are improving, driven by fuel price increases and emissions legislation (e.g. NO_x). Details of the future aircraft types and engine technology will be important factors for projecting future emissions.

It is important to collect data that maintains a consistent split between domestic and international aircraft emissions in the projected inventory as well as to be able to present emissions by landing and take-off (LTO) cycles.

A2.5 Shipping

Shipping activity is expected to increase substantially in the future and with emissions from land-based sources declining, shipping will become an increasingly important source of SO_2, NO_x and particulate matter emissions. The modelling of future emissions is complicated by the fact that large ships can be 're-engined' and retrofitted with abatement technologies during the life of the ship.

Projected shipping activity should be available from national departments (in terms of ship arrivals or number of passengers or tonnes of freight landed). Where possible, these data need to include details of the ship engine technology, abatement, fuel type and fuel quality specifications as well as the usage of that ship (for example freight, chemicals, etc.) so that the time in port and other related emission variables can be determined. Expert judgement based on the sectoral guidance in Chapter 1.A.3.d Navigation of this Guidebook may be required to determine some of these parameters.

Importantly, changes to fuel quality will need to be accommodated in the emission factors for projections. These will have an immediate effect from the date of implementation of the standards. The International Maritime Organisation (IMO) and the International Convention for the Prevention of Pollution from Ships (MARPOL) are a good source of information on future parameters for shipping projections. www/imo.org

A2.6 Rail

Rail activity projections can be derived from national projections on specific freight and passenger numbers, if available. Often projections of passenger/freight-tonne mileage data are available and can be used to scale historic activity data accordingly. Where this data is not available, more general population or GDP projections can be used or emissions assumed to be the same as the latest historic year (where rail is not a key category).

Emission factors need to account for any change in the split in train kilometres between electric and diesel lines, new diesel technology in the rail fleet and/or changes to fuel quality (for example the sulphur content). It is worth noting that use of high-speed locomotives, may actually be less fuel efficient than 'traditional' locomotives, partly due to the fact that they are, in general, required to meet more stringent safety requirements.

A2.7 Off road

Off road projections will be dependent on the economic activity or productivity of the individual sectors as well as national or international technology and/or fuel quality legislation.

Projecting future activity in the off-road sector can be difficult as usage data (both historically and for the future) by machinery type is often not available. If fuel consumption data is available from national energy models, this data should be used after checking it is consistent with historic emission estimates. However, national energy model data will usually be aggregated into a few sectors and fuel types and will need to be stratified so that the appropriate engine technologies can be applied. The methods presented in the off road chapter of this guidebook can be used to derive projected estimates by taking account of future legislation on mobile engines. Where specific sub-sector activity data projection is unavailable (for example number of or fuel demand from agricultural vehicles, air support, forestry machinery or industrial generators), projected activity data can be derived for the different sub-sectors using the following datasets:

- agricultural off road: arable lands crops, employment in the agricultural sector or economic productivity indicators;
- industrial off-road: industry employment economic productivity indicators;
- domestic off-road: household or population projections;
- airport support: aviation transport growth.

A number of countries may also have specific legislation to control engine emissions or fuel quality (for example the sulphur content) that should be taken into account. For example, in Europe, the implementation of the EU NRMM Directive ([8]) should be taken into account.

Generally, modern machinery is more fuel-efficient than older plant. Where possible this should be taken into account when estimating energy consumption for the application of energy consumption-based emission factors.

A3. Industrial processes

For projections of industrial processes, production rates (for example cement/clinker), process performance and technologies, and properties of input material need to be considered where these may change into the future. Generally, emissions from large industrial processes are well characterised for historic emissions as they are based on measured or detailed plant-specific calculations. Therefore the impacts of specific changes or changes in demand for manufacturing are important.

A3.1 Activity data

Activity projections should be based on available national projections on production or raw material consumption making sure it is consistent with any economic assumptions underpinning energy consumption projections for the same industries. It is often possible to use energy consumption/production projections (for example crude oil inputs for refinery processes or energy consumption for cement production) to develop suitable growth factors for some sectors. Where production/consumption information is unavailable or inappropriate, economic assumptions (such as those underpinning energy consumption projections including GDP or employment) can be used. For non-key categories, a Tier 1 approach could be used maintaining the last year value or assuming a constant growth for future years.

It is good practice to check the consistency between related activities. For instance, fertilizer production should be linked to the amount of fertilizer used in agriculture, or production of

([8]) Directive 97/68/EC (as amended by Directive 2002/88/EC and 2004/26/EC) relating to measures against the emissions of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery - 'NRMM Directive'.

construction materials (cement, bricks and tiles, etc.) should be related to projections of the number of households.

A3.2 Emission factors

Where controls or new technologies are expected, appropriate future emission factors should be developed. These will usually require the stratification of activity data in order to apply appropriate emission factors available for specific technologies or controls. Industry regulators and trade associations will be best placed to provide details of likely future technologies, controls and control efficiencies. Care should be taken to ensure that these measures are consistent with the scenario being estimated (i.e. only including the technologies that are expected under With Measures for a With Measures scenario) and that factors are not biased or set to limit levels. Where country specific information is available, technology-specific and control-specific emission factors presented in the industrial process chapters of this Guidebook can be used.

A4. Solvent use

A global market for solvent products makes projections on a national sectoral basis difficult and solvent balances based on production versus consumption can introduce significant uncertainties.

Projections of emissions from solvent use will need to be representative of the consumption rates of solvents or other drivers influencing it (for example, the production of bulk chemicals, specific goods and demand for services). Furthermore, envisaged technological developments including both primary (for example process optimisation) and secondary control measures need to be considered to capture the evolution of sector average emission factors. It is advisable to engage with industry representatives or trade associations to develop appropriate national projected estimates of emissions.

A4.1 Activity data

Where consumption rates have not been specifically projected by industry or national statistics, they can be estimated using appropriate sector-specific economic-based growth factors (for example, employment or GDP for industrial usage, and population for domestic solvent use). Care should be taken to ensure that these growth rates are consistent with any national economic, demographic or energy projections.

A4.2 Emission factors

Future emission factors should reflect the implementation of legislation as well as product trends that affect the solvent content of various products. Attaining specified emission limits will require either process modification/optimisation (primary measures) or the installation of adsorption or incineration units (secondary measures). In the case of product-specific requirements, for example paints and inks, manufacturers may need to develop new formulations to achieve the prescribed solvent content. Emission factors can be applied from the date of introduction of legislation on contents, but should consider whether stocks and stockpiling (important for the product-specific legislation) is going to be significant and if so apply some factoring for the early years while stocks are used up. Where emission reductions are expected for sectors employing recovery and controls (for example large vehicle spraying or solvent production plants employing incineration or advanced recovery techniques), rates of recovery and plans for installation of control plant should be investigated with regulators and the industry.

Where country-specific information is not available, technology- and control-specific emission factors presented in the solvent use chapter of this Guidebook can be used.

A5. Agriculture

Projections for the agricultural sector will need to consider livestock, fertilizer application rates and land-use changes in the future.

A5.1 Activity data

Projections of livestock numbers including the management practice, as well as the expected crop yields and fertilizer use should be available from national government departments concerned with food production. Specific regional policies or initiatives may have a significant impact on emissions, for example the Common Agricultural Policy (CAP). These impacts will need to be determined through the involvement of national CAP contact points.

Where national projections are unavailable, there are a number of international sources of information on agricultural projections including:

- the Common Agricultural Policy Regionalised Impact (CAPRI) analysis model developed by EuroCare.;
- projections of fertilizer use in the EU plus Scandinavia and a few Central and Eastern European Countries (CEECs) are produced by the European Fertilizer Manufacturers Association (EFMA) up to ten years ahead.

Additional sources of information are provided in subsection 3.7.2 of the present chapter.

A5.2 Emission factors

Emissions projections will need to incorporate assumptions about changing practices in arable and livestock farming and the impacts of these on future emission factors (for example, not only projected numbers but also projected yields of for example milk). Methods described in the higher tiers (2 and 3) agriculture chapters of this Guidebook should be used to help apply the relevant variables to account for future policies and measures that will change practices (for example, manure management and fertilizer use).

Where emissions are not key sources and there are no national data on future changes in practices, the latest year’s emission factors can be applied to projected activity data to estimate emissions.