# 2

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# 2 ENERGY

## 2.1 $CO_2$ EMISSIONS FROM STATIONARY COMBUSTION

### 2.1.1 Methodological issues

Carbon dioxide ($CO_2$) emissions from stationary combustion result from the release of the carbon in fuel during combustion. $CO_2$ emissions depend on the carbon content of the fuel. During the combustion process, most carbon is emitted as $CO_2$ immediately. However, some carbon is released as carbon monoxide (CO), methane ($CH_4$) or non-methane volatile organic compounds (NMVOCs), all of which oxidise to $CO_2$ in the atmosphere within a period of a few days to about 12 years. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines)* account for all the released carbon as $CO_2$ emissions. The other carbon-containing gases are also estimated and reported separately. The reasons for this intentional double counting are explained in the Overview of the *IPCC Guidelines.* Unoxidised carbon, in the form of particulate matter, soot or ash, is excluded from greenhouse gas emissions totals.

#### 2.1.1.1 CHOICE OF METHOD

There are three methods provided in the *IPCC Guidelines,* Chapter 1, Energy: two Tier 1 approaches (the 'Reference Approach' and the 'Sectoral Approach') and the Tier 2/Tier 3 approach (a detailed technology-based method, also called 'bottom-up' approach).

The Reference Approach estimates $CO_2$ emissions from fuel combustion in several steps:

- Estimation of fossil fuel flow into the country (apparent consumption);
- Conversion to carbon units;
- Subtraction of the amount of carbon contained in long-lived materials manufactured from fuel carbon;
- Multiplication by an oxidation factor to discount the small amount of carbon that is not oxidised;
- Conversion to $CO_2$ and summation across all fuels.

For the Tier 1 Sectoral Approach, total $CO_2$ is summed across all fuels (excluding biomass) and all sectors. For Tiers 2 and 3, the Detailed Technology-Based Approach, total $CO_2$ is summed across all fuels and sectors, plus combustion technologies (e.g. stationary and mobile sources). Both approaches provide more disaggregated emission estimates, but also require more data.

The choice of method is country-specific and is determined by the level of detail of the activity data available as illustrated in Figure 2.1, Decision Tree for Selecting the Method for Estimation of $CO_2$ Emissions from Stationary Combustion. The 'bottom-up' approach is generally the most accurate for those countries whose energy consumption data are reasonably complete.[1] Consequently, inventory agencies should make every effort to use this method if data are available.

Although continuous monitoring is generally recommended because of its high accuracy, it cannot be justified for $CO_2$ alone because of its comparatively high costs and because it does not improve accuracy for $CO_2$. It could, however, be undertaken when monitors are installed for measurements of other pollutants such as $SO_2$ or $NO_x$ where $CO_2$ is monitored as the diluent gas in the monitoring system.[2]

The Reference Approach provides only aggregate estimates of emissions by fuel type distinguishing between primary and secondary fuels, whereas the Sectoral Approach allocates these emissions by source category. The

[1] If the gap between apparent consumption and reported consumption is small, then energy consumption data are probably reasonably complete.

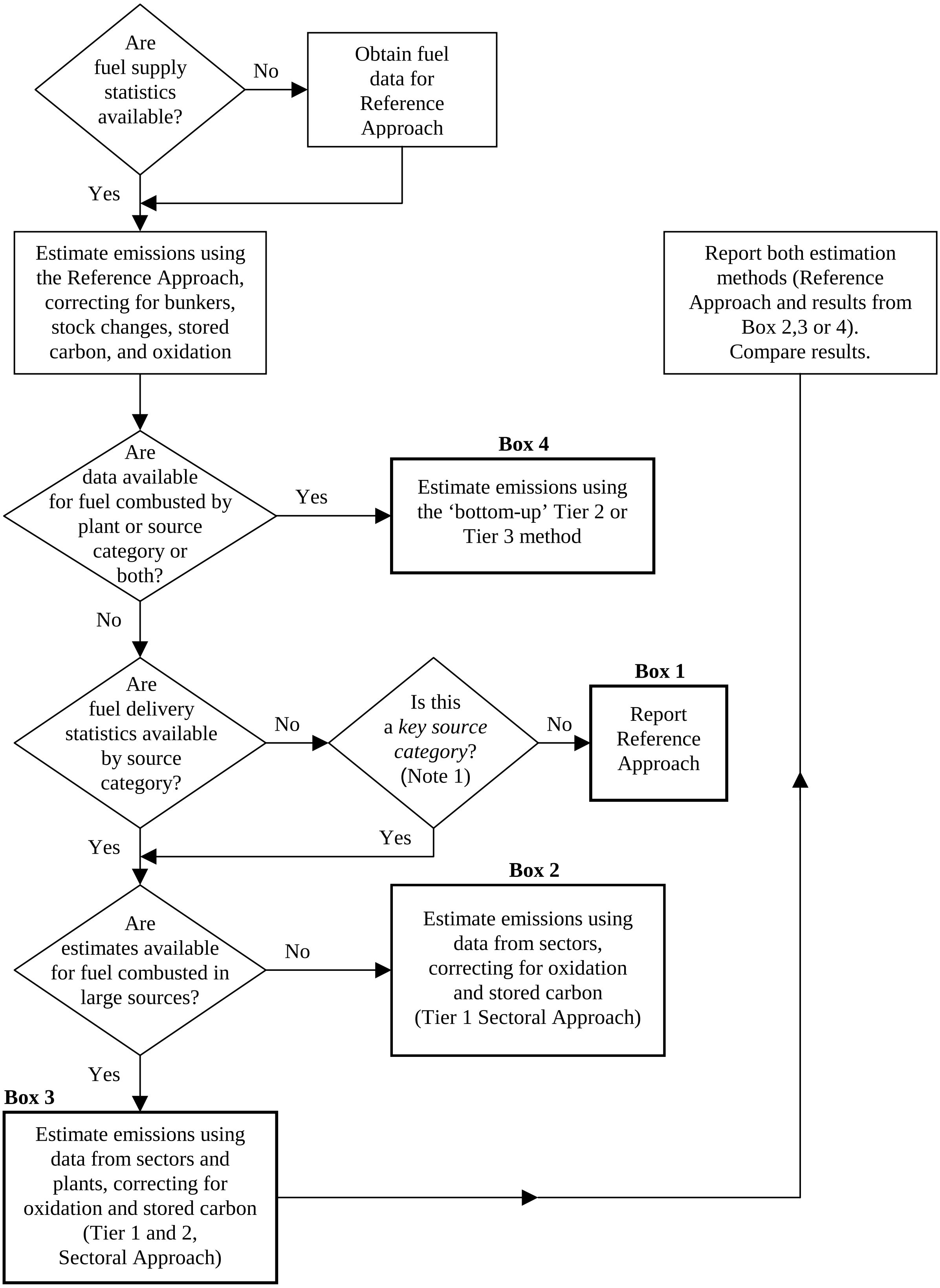
[2] If continuous emissions monitoring were used for certain industrial sources it would be difficult to differentiate emissions related to fuel combustion from emissions related to processing (e.g. cement kilns).

aggregate nature of the Reference Approach estimates means that stationary combustion emissions cannot be distinguished from mobile combustion emissions. Likewise, the Sectoral Approach is not always able to differentiate between different emission source categories within an economic activity (e.g. between use of gas or oil for heating or for off-road and other mobile machinery in the construction industry).

Estimates of emissions based on the Reference Approach will not be exactly the same as estimates based on the Sectoral Approach. The two approaches measure emissions at differing points and use slightly different definitions. However, the differences between the two approaches should not be significant.

For some countries, however, there may be large and systematic differences between estimates developed using the two approaches. This will normally indicate a systematic under or overcounting of energy consumption by one method or the other. If this occurs, it is *good practice* to consult with national statistical authorities and seek their advice on which method is the most complete and accurate indication of total consumption for each fuel, and use it.

**Figure 2.1 Decision Tree for Selecting the Method for Estimation of $CO_2$ Emissions from Stationary Combustion**




**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

### 2.1.1.2 CHOICE OF EMISSION FACTORS AND CALORIFIC VALUES

$CO_2$ emission factors (EF) for fossil fuel combustion depend upon the carbon content of the fuel. The carbon content of a fuel is an inherent chemical property (i.e. fraction or mass of carbon atoms relative to total number of atoms or mass) and does not depend upon the combustion process or conditions. The energy content (i.e. calorific value or heating value) of fuels is also an inherent chemical property. However, calorific values vary more widely between and within fuel types, as they are dependent upon the composition of chemical bonds in the fuel. Net calorific values (NCVs) measure the quantity of heat liberated by the complete combustion of a unit volume or mass of a fuel, assuming that the water resulting from combustion remains as a vapour, and the heat of the vapour is not recovered. Gross calorific values, in contrast, are estimated assuming that this water vapour is completely condensed and the heat is recovered. Default data in the *IPCC Guidelines* are based on NCVs.

Emission factors for $CO_2$ from fossil fuel combustion are expressed on a per unit energy basis because the carbon content of fuels is generally less variable when expressed on a per unit energy basis than when expressed on a per unit mass basis. Therefore, NCVs are used to convert fuel consumption data on a per unit mass or volume basis to data on a per unit energy basis.

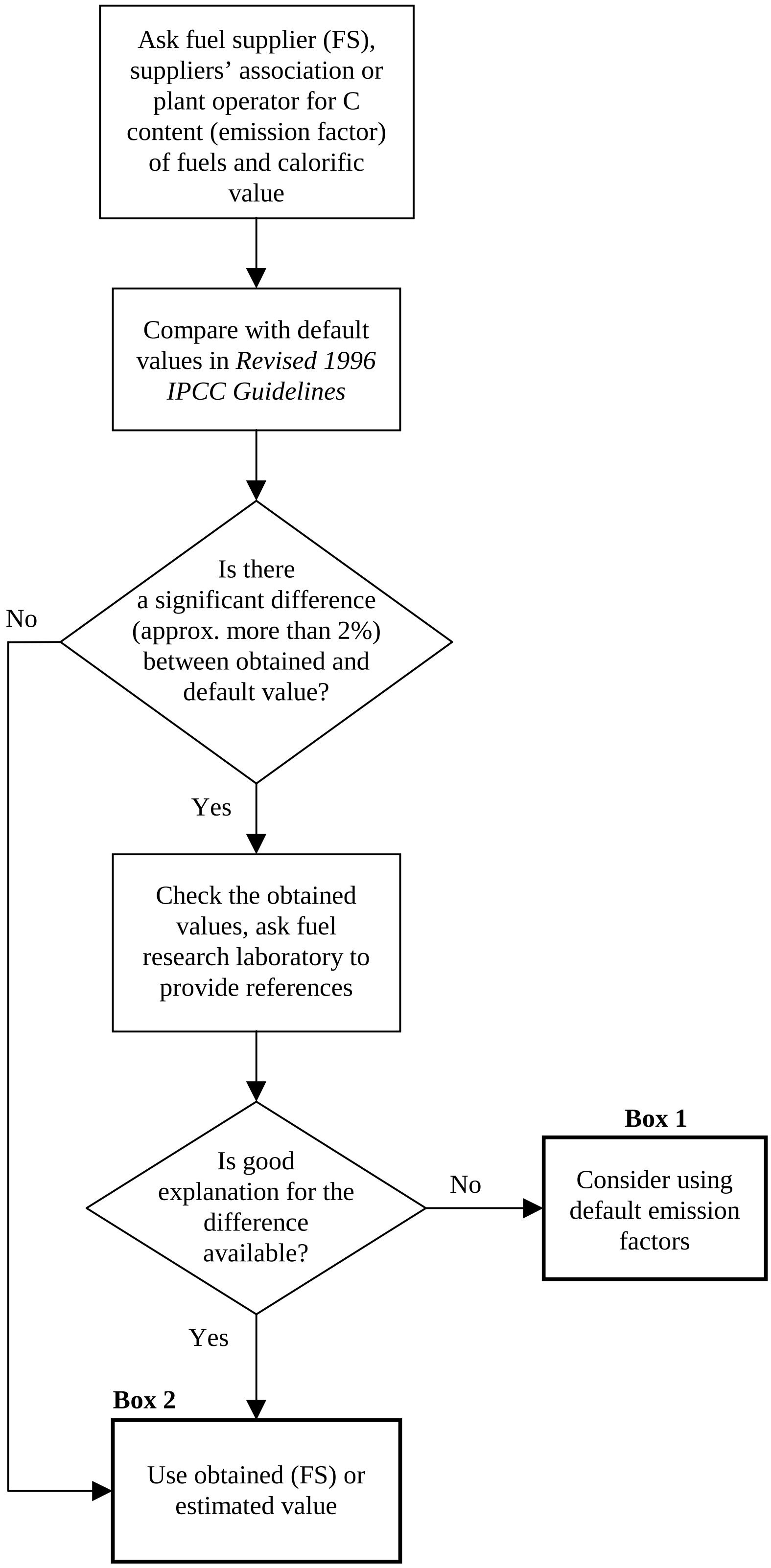
Carbon content values can be thought of as potential emissions, or the maximum amount of carbon that could potentially be released to the atmosphere if all carbon in the fuels were converted to $CO_2$. As combustion processes are not 100% efficient, though, some of the carbon contained in fuels is not emitted to the atmosphere. Rather, it remains behind as soot, particulate matter and ash. Therefore, an oxidation factor is used to account for the fraction of the potential carbon emissions remaining after combustion.

For traded fuels in common circulation, it is *good practice* to obtain the carbon content of the fuel and net calorific values from fuel suppliers, and use local values wherever possible. If these data are not available, default values can be used. Figure 2.2, Decision Tree for Selecting Calorific Values and Carbon Emission Factors illustrates the choice of emission factors.

It may be more difficult to obtain the carbon content and NCV for non-traded fuels, such as municipal solid waste (MSW) and for fuels that are not sold by heat content, such as crude oil. If necessary, default values are available. Values for MSW may be obtained by contacting operators of waste combustion plants for heat raising. The suggested default values for the NCV of municipal solid waste range from 9.5 to 10.5 GJ/t (based on information from Sweden and Denmark). The default carbon content of waste is given in Chapter 6, Waste of the *IPCC Guidelines*. For crude oil, information is available relating the carbon content to the density and the sulfur content of the crude oil (see Table 2.2, Typical API Gravities and Sulfur Contents for Various Crude Oil Streams and Table 2.3, Average API Gravity and Sulfur Content of Imported Crude Oil for Selected Countries Listed in Annex II of the UN Framework Convention on Climate Change). Information on NCVs for coal types in non-OECD countries is listed in Table 2.4, 1990 country-specific net calorific values. Default net calorific values for most other fuels are available in the Reference Manual of the *IPCC Guidelines* (Table 1-3, Net Calorific Values for Other Fuels).

Generally, default oxidation factors for gases and oils are known accurately. For coal, oxidation factors are dependent on the combustion conditions and can vary by several percent. It is *good practice* to discuss the factors with local users of coal and coal products. However, default factors are also provided in the *IPCC Guidelines*.

**Figure 2.2 Decision Tree for Selecting Calorific Values and Carbon Emission Factors**



### 2.1.1.3 CHOICE OF ACTIVITY DATA

Activity data for all tiers are the amount and type of fuel combusted. These data will often be available from national energy statistics agencies which collect them directly from the enterprises that consume the fuels or from individuals responsible for the combustion equipment. These data are also available from suppliers of fuels who record the quantities delivered and the identity of their customers usually as an economic activity code, or from a combination of these sources. Direct collection of fuel consumption data may occur through periodic surveys of a sample of enterprises, or, in the case of large combustion plants, through enterprise reports made to the national energy statistics agency or under emission control regulations. Fuel deliveries are well identified for gas, where metering is in place, and also for solid and liquid fuels, both of which are distributed to the household and the small commercial consumers market.

It is *good practice* to use fuel combustion statistics rather than delivery statistics where they are available.[3] Agencies collecting emission data from companies under an environmental reporting regulation could request fuel combustion data in this context. Fuel combustion data, however, are very seldom complete, since it is not practicable to measure the fuel consumption or emissions of every residential or commercial source. Hence, national inventories using this approach will generally contain a mixture of combustion data for larger sources and delivery data for other sources. The inventory agency must take care to avoid both double counting and omission of emissions when combining data from multiple sources.

Where confidentiality is an issue, direct discussion with the company affected often allows the data to be used. In cases where such permission is not given, aggregation of the fuel consumption or emissions with those from other companies is usually sufficient to conceal the identity of the company without understating emissions.

It is necessary to estimate the amount of carbon stored in products for the Reference Approach, and if no detailed calculation in the Industrial Processes sector is performed. It is *good practice* to obtain stored carbon factors by contacting the petrochemical industry that uses the feedstock. A list of fuels/products that accounts for the majority of carbon stored is given in the *IPCC Guidelines* together with default stored carbon factors. It should be used unless more detailed country-specific information is available. Where data are available for other fuels/ products, the estimation of stored carbon is strongly encouraged.[4] The default factor for stored carbon in lubricants may be overestimated because waste lubricants are often burned for energy. It is *good practice* to contact those responsible for recovering used oils in order to discover the extent to which used oils are burned in the country.

When using the Reference Approach, fuel supply statistics[5] should be used and there may be a choice of source for import and export data. Official customs figures or industry figures may be used. The compilers of national energy data will have made this choice based on their assessment of data quality when preparing national fuel balances. The choice may differ from fuel to fuel. Thus, it is *good practice* to consult with the national energy statistics agency when choosing between energy supply and delivery statistics in order to establish whether the criteria the agency has used in selecting the basis for import and export statistics of each fuel are appropriate for inventory use.

When activity data are not quantities of fuel combusted but instead deliveries to enterprises or main sub-categories, there is a risk of double counting emissions from the Industrial Processes, Solvents or Waste Sectors. Identifying double counting is not always easy. Fuels delivered and used in certain processes may give rise to by-products used as fuels elsewhere in the plant or sold for fuel use to third parties (e.g. blast furnace gas, derived from coke and other carbon inputs to blast furnaces). It is *good practice* to coordinate estimates between the stationary $CO_2$ source category and relevant industrial categories to avoid double counting or omissions. Appendix 2.1A.1 lists the categories and subcategories where fossil fuel carbon is reported, and between which double counting of fossil fuel carbon could, in principle, occur.

[3] Quantities of solid and liquid fuels delivered to enterprises will, in general, differ from quantities combusted by the amounts put into or taken from stocks held by the enterprise. Stock figures shown in national fuel balances may not include stocks held by final consumers, or may include only stocks held by a particular source category (for example electricity producers). Delivery figures may also include quantities used for mobile sources or as feedstock.

[4] The Frauenhofer Institute in Germany is currently undertaking an examination of carbon flows through petrochemical industries in a number of countries. It is hoped that this work will result in better estimates of the fraction of petrochemical feedstock stored within the products manufactured. The study will be completed by mid-2000.

[5] These are national production of primary fuels, and imports, exports and stock changes of all fuels. Oils used for international bunkers are treated like exports and excluded from supply.

For some source categories (e.g. combustion in the Agriculture Sector), there may be some difficulty in separating fuel used in stationary equipment from fuel used in mobile machinery. Given the different emission factors for non-$CO_2$ gases of these two sources, *good practice* is to derive energy use of each of these sources by using indirect data (e.g. number of pumps, average consumption, needs for water pumping). Expert judgement and information available from other countries may also be relevant.

### 2.1.1.4 COMPLETENESS

A complete estimate of emissions from fuel combustion must include emissions from all fuels and all source categories identified within the *IPCC Guidelines*. A reliable and accurate bottom-up $CO_2$ emissions estimate is important because it increases confidence in the underlying activity data. These, in turn, are important underpinnings for the calculation of $CH_4$ and $N_2O$ emissions from stationary sources.

All fuels delivered by fuel producers must be accounted for, so that sampling errors do not arise. Mis-classification of enterprises and the use of distributors to supply small commercial customers and households increase the chance of systematic errors in the allocation of fuel delivery statistics. Where sample survey data that provide figures for fuel consumption by specific economic sectors exist, the figures may be compared with the corresponding delivery data. Any systematic difference should be identified and the adjustment to the allocation of delivery data may then be made accordingly.

Systematic under-reporting of solid and liquid fuels may also occur if final consumers import fuels directly. Direct imports will be included in customs data and therefore in fuel supply statistics, but not in the statistics of fuel deliveries provided by national suppliers. If direct importing by consumers is significant, then the statistical difference between supplies and deliveries will reveal the magnitude. Once again, a comparison with consumption survey results will reveal which main source categories are involved with direct importing.

Experience has shown that the following activities may be poorly covered in existing inventories and their presence should be specifically checked:

- Change in producer stocks of fossil fuels;
- Combustion of waste for energy purposes. Waste incineration should be reported in the Waste source category, combustion of waste for energy purposes should be reported in the Energy source category;
- Energy industries’ own fuel combustion;
- Conversion of petrochemical feedstocks into petrochemical products (carbon storage);
- Fuel combustion for international aviation and marine transport (needed for the Reference Approach). Sections 2.4.1.3 and 2.5.1.3 of this chapter provide more guidance on this subject.

The reporting of emissions from coke use in blast furnaces requires attention. Crude (or pig) iron is typically produced by the reduction of iron oxides ores in a blast furnace, using the carbon in coke (sometimes other reducing agents) as both the fuel and reducing agent. Since the primary purpose of coke oxidation is to produce pig iron, the emissions should be considered as coming from an industrial process if a detailed calculation of industrial emissions is being undertaken. It is important not to double-count the carbon from the consumption of coke or other fuels. So, if these emissions have been included in the Industrial Processes sector, they should not be included in the Energy sector. However, there are countries where industrial emissions are not addressed in detail. In these instances, the emissions should be included in the Energy sector. In any case, the amount of carbon that is stored in the final product should be subtracted from the effective emissions.

### 2.1.1.5 DEVELOPING A CONSISTENT TIME SERIES

It is *good practice* to prepare inventories using the method selected in Figure 2.1, Decision Tree for Selecting the Method for Estimation of $CO_2$ Emissions from Stationary Combustion for all years in the time series. Where this is difficult due to a change of methods or data over time, estimates for missing data in the time series should be prepared based on backward extrapolation of present data. When changing from a Reference Approach to a higher tier approach, inventory agencies should establish a clear relationship between the approaches and apply this to previous years if data are lacking. Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques, provides guidance on various approaches that can be used in this case.

### 2.1.1.6 UNCERTAINTY ASSESSMENT

#### ACTIVITY DATA

The information in this section can be used in conjunction with the methods outlined in Chapter 6, Quantifying Uncertainties in Practice, to assess overall uncertainties in the national inventory. Chapter 6 explains how to use empirical data and expert judgement to obtain country-specific uncertainty.

The accuracy in determining emission estimates using the Sectoral Approach is almost entirely determined by the availability of the delivery or combustion statistics for the main source categories. The main uncertainty arises from:

- The adequacy of the statistical coverage of all source categories;
- The adequacy of the coverage of all fuels (both traded and non-traded).

Statistics of fuel combusted at large sources obtained from direct measurement or obligatory reporting are likely to be within 3% of the central estimate.[6] For the energy intensive industries, combustion data are likely to be more accurate. It is *good practice* to estimate the uncertainties in fuel consumption for the main sub-categories in consultation with the sample survey designers because the uncertainties depend on the quality of the survey design and size of sample used.

In addition to any systematic bias in the activity data as a result of incomplete coverage of consumption of fuels, the activity data will be subject to random errors in the data collection that will vary from year to year. Countries with good data collection systems, including data quality control, may be expected to keep the random error in total recorded energy use to about 2-3% of the annual figure. This range reflects the implicit confidence limits on total energy demand seen in models using historical energy data and relating energy demand to economic factors. Percentage errors for individual energy use activities can be much larger.

Overall uncertainty in activity data is a combination of both systematic and random errors. Most developed countries prepare balances of fuel supply and deliveries and this provides a check on systematic errors. In these circumstances, overall systematic errors are likely to be small. Experts believe that uncertainty resulting from the two errors is probably in the range of ±5%. For countries with less well-developed energy data systems, this could be considerably larger, probably about ±10%. Informal activities may increase the uncertainty up to as much as 50% in some sectors for some countries. See Table 2.6, Level of Uncertainty Associated with Stationary Combustion Activity Data, for more detailed uncertainty estimates.

#### EMISSION FACTORS

The uncertainty associated with EFs and NCVs results from two main elements, viz. the accuracy with which the values are measured, and the variability in the source of supply of the fuel and quality of the sampling of available supplies. There are few mechanisms for systematic errors in the measurement of these properties. Consequently, the errors can be considered mainly random. For traded fuels, the uncertainty is likely to be less than 5%. For non-traded fuels, the uncertainty will be higher and will result mostly from variability in the fuel composition.

Default uncertainty ranges are not available for stored carbon factors or coal oxidation factors. It is evident, however, that consultation with consumers using the fuels as raw materials or for their non-fuel characteristics is essential for accurate estimations of stored carbon. Similarly, large coal users can provide information on the completeness of combustion in the types of equipment they are using.

## 2.1.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Section 8.10.1 of Chapter 8, Quality Assurance and Quality Control.

It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

[6] The percentages cited in this section represent an informal polling of assembled experts aiming to approximate the 95% confidence interval around the central estimate.

Some examples of specific documentation and reporting which are relevant to this source category are provided below:

- The sources of the energy data used and observations on the completeness of the data set;
- The sources of the calorific values and the date they were last revised;
- The sources of emission factors and oxidation factors, the date of the last revision and any verification of the accuracy. If a carbon storage correction has been made, documentation should include the sources of the factor and how the figures for fuel deliveries have been obtained.

## 2.1.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8 and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory agencies are encouraged to use higher tier QA/QC for *key source categories* as identified in Chapter 7, Methodological Choice and Recalculation.

In addition to the guidance in Chapter 8, specific procedures of relevance to this source category are outlined below.

#### Comparison of emission estimates using different approaches

The inventory agency should compare estimates of $CO_2$ emissions from fuel combustion prepared using the Sectoral Tier 1 and Tier 2 Approach with the Reference Approach, and account for any significant differences. In this comparative analysis, emissions from fuels other than by combustion, that are accounted for in other sections of a GHG inventory, should be subtracted from the Reference Approach (See Appendix 2.1A.1).

#### Activity data check

- The inventory agency should construct national energy balances expressed in mass units, and mass balances of fuel conversion industries. The time series of statistical differences should be checked for systematic effects (indicated by the differences persistently having the same sign) and these effects eliminated where possible. This task should be done by, or in cooperation with, the national agency in charge of energy statistics.
- The inventory agency should also construct national energy balances expressed in energy units and energy balances of fuel conversion industries. The time series of statistical differences should be checked, and the calorific values cross-checked with IEA values (see Figure 2.2, Decision Tree for Selecting Calorific Values and Carbon Emission Factors). This step will only be of value where different calorific values for a particular fuel (for example, coal) are applied to different headings in the balance (such as production, imports, coke ovens and households). Statistical differences that change in magnitude or sign significantly from the corresponding mass values provide evidence of incorrect calorific values.
- The inventory agency should confirm that gross carbon supply in the Reference Approach has been adjusted for fossil fuel carbon from imported or exported non-fuel materials in countries where this is expected to be significant.
- Energy statistics should be compared with those provided to international organisations to identify inconsistencies.
- There may be routine collections of emissions and fuel combustion statistics at large combustion plants for pollution legislation purposes. If possible, the inventory agency can use these plant-level data to cross-check national energy statistics for representativeness.

#### Emission factors check

- The inventory agency should construct national energy balances expressed in carbon units and carbon balances of fuel conversion industries. The time series of statistical differences should be checked. Statistical differences that change in magnitude or sign significantly from the corresponding mass values provide evidence of incorrect carbon content.

- Monitoring systems at large combustion plants may be used to check the emission and oxidation factors in use at the plant.

**Evaluation of direct measurements**

- The inventory agency should evaluate the quality control associated with facility-level fuel measurements that have been used to calculate site-specific emission and oxidation factors. If it is established that there is insufficient quality control associated with the measurements and analysis used to derive the factor, continued use of the factor may be questioned.

# Appendix 2.1A.1 Reporting of emissions of fossil carbon-based molecules according to the *Revised 1996 IPCC Guidelines* source categories

The following table shows where fossil carbon is accounted for and may be used to help identify and eliminate double counting as discussed in Section 2.1.1.3. It may also help explain any difference between the Reference Approach and Sectoral Approach calculations.

TABLE 2.1

REPORTING OF EMISSIONS OF FOSSIL CARBON-CONTAINING MOLECULES ACCORDING TO THE *REVISED 1996 IPCC GUIDELINES* SOURCE CATEGORIES[7]

| From fossil fuel carbon | From other fossil carbon |
|---|---|
| **1A Fuel combustion** | |
| All fossil carbon for combustion purposes | |
| **1B Fugitive emissions** | |
| Escapes and releases from fossil carbon flows from extraction point through to final oxidation | |
| **2 Industrial Processes** | **2 Industrial Processes** |
| Ammonia | Cement |
| Silicon carbide | Lime production |
| Calcium carbide | Limestone use |
| Soda ash production, Solvay process (emissions from calcining) | Soda ash production (natural process) |
| Iron/steel and ferroalloys | Soda ash use |
| Aluminium | |
| Other metals (see *IPCC Guidelines* Reference Manual, Table 2-21, Production Processes for Some Metals) | |
| Production and use of halocarbons | |
| Organic chemical manufacture | |
| Asphalt manufacture and use | |
| Adipic acid | |
| **3 Solvents** | |
| **6 Waste** | |
| Short-life wastes comprising used oils, used solvents and plastics | |
| Long-life wastes comprising plastics entering heat raising and incineration and degradation in landfills (*products manufactured before the inventory year)* | |

[7] Numbers before source categories correspond to the numbering system of the *Revised 1996 IPCC Guidelines*, Reporting Instructions, Common Reporting Framework.

# Appendix 2.1A.2 Method to estimate carbon content based on API[8] gravity and sulfur content

The following formula is based on the analyses of 182 crude oil samples and may be used to estimate the carbon content of crude oil. (Source: USDOE/EIA. URL: http://www.eia.doe.gov/oiaf/1605/gg98rpt/appendixb.html)

**EQUATION 2.1**

$$\text{Carbon Content} = 76.99 + (10.19 \bullet \text{SG}) - (0.76 \bullet \text{Sulfur Content})$$

Where:

SG denotes the specific gravity of the oil

Carbon and Sulfur content are measured in percent by weight

Specific Gravity may be calculated from the API gravity figure using:

**EQUATION 2.2**

$$\text{SG} = 141.5 / (\text{API} + 131.5)$$

Inferred carbon content is calculated based on the specific gravities and the API values in the first 2 columns of the following table using the above formula. Note that inferred values may differ from measured values.

[8] API: Arbitrary scale designating an oil's specific gravity, or the ratio of the weights of equal volumes of oil and pure water; it is the standard specific gravity scale of the petroleum industry. As volume is dependent on temperature and pressure, these must be specified. In the United States they are generally 60 degrees F (16 degrees C) and one atmosphere (101.3 kPa) pressure. The API gravity scale, whose units are degrees API, does not vary linearly with the specific gravity or its related properties (e.g. viscosity), high specific gravity values give low API gravity values using the relationship

degrees API = (141.5 / specific gravity at 60 degrees F) – 131.5

Water with a specific gravity of 1 has an API gravity of 10 degrees. The API scale has the advantage of allowing hydrometers, which measure specific gravity, to be calibrated linearly. The Baumé scale, originally developed by Antoine Baumé for this purpose, was found to be in error and the API scale replaced it in 1921. The Baumé scale, still used in parts of Europe, is given by the relationship

degrees Baumé = (140 / specific gravity at 60 degrees F) – 130.

Source: adapted from Encyclopaedia Britannica.

**TABLE 2.2**

**TYPICAL API GRAVITY AND SULFUR CONTENT FOR VARIOUS CRUDE OIL STREAMS**

| | Crude Category | Typical API Gravity | | Typical Sulfur Content (% wt) | | Inferred Carbon Content (% wt) | |
|---|---|---|---|---|---|---|---|
| | | mean or lower value | upper value | mean or lower value | upper value | mean or lower value | upper value |
| **Middle East** | | | | | | | |
| Abu Dhabi | Murban | 39.8 | | 0.8 | | 84.8 | |
| | Umm Shaif | 37.5 | | 1.4 | | 84.5 | |
| | Upper Zakum | 34 | | 1.8 | | 84.3 | |
| | Lower Zakum | 40 | | 1.1 | | 84.6 | |
| | Other Abu Dhabi | 46.7 | | 0.8 | | 84.5 | |
| Dubai | Dubai | 31 | 32 | 1.9 | | 84.4 | 84.4 |
| Sharjah | | 62.5 | | 0.1 | | 84.3 | |
| Iran | Iranian Light | 34 | | 1.4 | | 84.6 | |
| | Iranian Heavy | 31 | | 1.6 | | 84.6 | |
| | Other Iran | 32.6 | | 2.1 | | 84.2 | |
| Iraq | Basrah Light | 34 | | 2.1 | | 84.1 | |
| | Kirkuk | 36 | | 2 | | 84.1 | |
| | Other Iraq | 36.1 | | 2 | | 84.1 | |
| Kuwait | Kuwait Blend | 30 | 31 | 2.5 | | 84.0 | 84.0 |
| Neutral Zone | Offshore (Khafji/Hout) | 28 | 33 | 1.9 | 2.9 | 83.6 | 84.6 |
| | Onshore | 23 | 25 | 3.3 | 3.9 | 83.2 | 83.8 |
| Oman | Oman | 34 | | 0.8 | | 85.1 | |
| Qatar | Qatar Marine | 36 | | 1.5 | | 84.5 | |
| | Qatar Land | 41 | | 1.2 | | 84.4 | |
| Saudi Arabia | Arab Light | 33 | 34 | 1.7 | | 84.4 | 84.5 |
| | Arab Medium | 30 | 31.5 | 2.3 | | 84.1 | 84.2 |
| | Arab Heavy | 27 | 28 | 2.8 | | 83.9 | 84.0 |
| | Berri (Extra Light) | 37 | 38 | 1.1 | 1.2 | 84.6 | 84.7 |
| | Other Saudi Arabia | 52.3 | | 0.7 | | 84.3 | |
| Syria | Syria Light | 36 | | 0.6 | | 85.1 | |
| | Souedie | 24 | | 3.9 | | 83.3 | |
| Yemen | Marib Light | 40 | | 0.1 | | 85.3 | |
| | Masila Blend | 30 | 31 | 0.6 | | 85.4 | 85.5 |
| | Other Yemen | 41 | | 0.4 | | 85.0 | |

**TABLE 2.2 (CONTINUED)**

**TYPICAL API GRAVITY AND SULFUR CONTENT FOR VARIOUS CRUDE OIL STREAMS**

| | Crude Category | Typical API Gravity | | Typical Sulfur Content (% wt) | | Inferred Carbon Content (% wt) | |
|---|---|---|---|---|---|---|---|
| | | mean or lower value | upper value | mean or lower value | upper value | mean or lower value | upper value |
| Other Middle East | | 31.7 | | 2.1 | | 84.2 | |
| **Africa** | | | | | | | |
| Algeria | Saharan Blend | 44 | | 0.1 | | 85.1 | |
| | Other Algeria | 45.1 | | 0.1 | | 85.1 | |
| Cameroon | | 32 | | 0.15 | | 85.7 | |
| Congo | | 37.4 | | 0.1 | | 85.5 | |
| Egypt | Medium/Light (30-40$^o$) | 31.1 | | 1.9 | | 84.4 | |
| | Heavy (<30$^o$ API) | 27.9 | | 2.1 | | 84.4 | |
| Gabon | Rabi/Rabi Kounga | 34 | | 0.1 | | 85.6 | |
| | Other Gabon | 32.1 | | 0.6 | | 85.3 | |
| Libya | Light (>40$^o$ API) | 41.7 | | 0.2 | | 85.2 | |
| | Medium (30-40$^o$ API) | 37.2 | | 0.3 | | 85.3 | |
| | Heavy (<30$^o$ API) | 26.2 | | 1.7 | | 84.8 | |
| Nigeria | Medium (<33$^o$ API) | 29.6 | | 0.2 | | 85.8 | |
| | Light (33-45$^o$ API) | 36.3 | | 0.2 | | 85.4 | |
| | Condensate (>45$^o$ API) | 46.1 | | 0.1 | | 85.0 | |
| Tunisia | | 36.1 | | 0.6 | | 85.1 | |
| Zaire | | 31 | | 0.2 | | 85.7 | |
| Other Africa | | 29.7 | | 0.2 | | 85.8 | |
| **Asia** | | | | | | | |
| Brunei | Seria Light | 36 | | 0.1 | | 85.5 | |
| | Champion | 25 | | 0.1 | | 86.1 | |
| China | Daqing (Taching) | 33 | | 0.1 | | 85.7 | |
| | Shengli | 24 | | 1 | | 85.5 | |
| | Other China | 32 | | 0.2 | | 85.7 | |
| Indonesia | Minas | 34 | | 0.1 | | 85.6 | |
| | Cinta | 33 | | 0.1 | | 85.7 | |
| | Handil | 33 | | 0.1 | | 85.7 | |
| | Duri | 20 | | 0.2 | | 86.4 | |
| | Arun Condensate | 54 | | 0.02 | | 84.7 | |
| | Other Indonesia | 38 | | 0.1 | | 85.4 | |
| Malaysia | Tapis | 44 | | 0.1 | | 85.1 | |
| | Labuan | 33 | | 0.1 | | 85.7 | |
| | Other Malaysia | 38.9 | | 0.1 | | 85.4 | |

**TABLE 2.2 (CONTINUED)**

**TYPICAL API GRAVITY AND SULFUR CONTENT FOR VARIOUS CRUDE OIL STREAMS**

| | **Crude Category** | **Typical API Gravity** | | **Typical Sulfur Content (% wt)** | | **Inferred Carbon Content (% wt)** | |
|---|---|---|---|---|---|---|---|
| | | **mean or lower value** | **upper value** | **mean or lower value** | **upper value** | **mean or lower value** | **upper value** |
| Other Asia | | 52.6 | | 0.04 | | 84.8 | |
| Australia | Gippsland | 45 | | 0.1 | | 85.1 | |
| | Other Australia | 41.1 | | 0.1 | | 85.3 | |
| Papua New Guinea | | 44.3 | | 0.04 | | 85.2 | |
| Russia | Urals | 31 | 32.5 | 1.2 | 1.4 | 84.7 | 85.0 |
| | Other Russia | 33.3 | | 1.2 | | 84.8 | |
| Azerbaijan | | 47.7 | | 0.01 | | 85.0 | |
| Kazakhstan | | 46.5 | | 0.5 | | 84.7 | |
| Ukraine | | 40.1 | | 0.9 | | 84.7 | |
| Other FSU | | 44.6 | | 0.2 | | 85.0 | |
| **Europe** | | | | | | | |
| Denmark | | 33 | 34.5 | 0.3 | | 85.4 | 85.5 |
| Norway | Statfjord | 37.5 | 38 | 0.28 | | 85.3 | 85.3 |
| | Gullfaks | 29.3 | 29.8 | 0.44 | | 85.6 | 85.6 |
| | Oseberg | 34 | | 0.3 | | 85.5 | |
| | Ekofisk | 43.4 | | 0.14 | | 85.1 | |
| | Other Norway | 32.3 | | 0.3 | | 85.6 | |
| United Kingdom | Brent Blend | 37 | 38 | 0.4 | | 85.2 | 85.2 |
| | Forties | 39 | 40 | 0.34 | | 85.1 | 85.2 |
| | Flotta | 34.7 | | 1 | | 84.9 | |
| | Other UK | 31.8 | | 0.5 | | 85.4 | |
| Other Europe | | 35.9 | | 1.3 | | 84.6 | |
| **North America** | | | | | | | |
| Canada | Light Sweet (>30$^o$ API) | 36.6 | | 0.2 | | 85.4 | |
| | Heavy (<30$^o$ API) | 23.4 | | not available | | | |
| United States | Alaska | 30.2 | | 1.1 | | 85.1 | |
| | Other United States | 39.5 | | 0.2 | | 85.3 | |

**TABLE 2.2 (CONTINUED)**

**TYPICAL API GRAVITY AND SULFUR CONTENT FOR VARIOUS CRUDE OIL STREAMS**

| | Crude Category | Typical API Gravity | | Typical Sulfur Content (% wt) | | Inferred Carbon Content (% wt) | |
|---|---|---|---|---|---|---|---|
| | | mean or lower value | upper value | mean or lower value | upper value | mean or lower value | upper value |
| **Latin America** | | | | | | | |
| Brazil | | 20.7 | | 0.5 | | 86.1 | |
| Colombia | Cano Limon | 30 | | 0.5 | | 85.5 | |
| | Other Colombia | 35.8 | | not available | | | |
| Ecuador | Oriente | 28 | 29 | 0.9 | 1.0 | 85.2 | 85.3 |
| | Other Ecuador | not available | | not available | | | |
| Mexico | Maya | 22.2 | | 3.3 | | 83.9 | |
| | Isthmus | 34.8 | | 1.5 | | 84.5 | |
| | Olmeca | 39.8 | | 0.8 | | 84.8 | |
| Peru | | 20.2 | | 1.3 | | 85.5 | |
| Venezuela | Light (>30$^o$ API) | 32.6 | | 1.1 | | 84.9 | |
| | Medium (22-30$^o$ API) | 27.7 | | 1.6 | | 84.8 | |
| | Heavy (17-22$^o$ API) | 19.5 | | 2.5 | | 84.6 | |
| | Extra Heavy (<17$^o$ API) | 14.5 | | 2.8 | | 84.7 | |

Source for API gravity and sulfur content: International Energy Agency.

**TABLE 2.3**

**AVERAGE API GRAVITY AND SULFUR CONTENT OF IMPORTED CRUDE OIL FOR SELECTED COUNTRIES LISTED IN ANNEX II OF THE UN FRAMEWORK CONVENTION ON CLIMATE CHANGE**

| | **Average API Gravity** | **Average Sulfur (% weight)** | **Inferred Carbon Content (% weight)** |
|---|---|---|---|
| Australia | 39.9 | 0.34 | 85.1 |
| Austria | 37.4 | 0.84 | 84.9 |
| Belgium | 32.8 | 1.25 | 84.8 |
| Canada | 32.4 | 0.90 | 85.1 |
| Denmark | 40.9 | 0.22 | 85.2 |
| Finland | 35.8 | 0.54 | 85.2 |
| France | 35.8 | 1.01 | 84.8 |
| Germany | 36.5 | 0.76 | 85.0 |
| Greece | 33.9 | 1.65 | 84.5 |
| Ireland | 36.9 | 0.25 | 85.4 |
| Italy | 34.1 | 1.15 | 84.8 |
| Japan | 34.8 | 1.51 | 84.5 |
| Netherlands | 33.3 | 1.45 | 84.6 |
| New Zealand | 34.4 | 1.01 | 84.9 |
| Norway | 33.3 | 0.39 | 85.4 |
| Portugal | 33.2 | 1.39 | 84.7 |
| Spain | 31.5 | 1.36 | 84.8 |
| Sweden | 34.5 | 0.76 | 85.1 |
| Switzerland | 39.4 | 0.46 | 85.1 |
| Turkey | 34.2 | 1.48 | 84.6 |
| United Kingdom | 35.9 | 0.64 | 85.1 |
| United States | 30.3 | not available | |

Average API gravity and sulfur content has been calculated from imports into the above countries in 1998. Values will change over time due to changes in crude streams that are imported. Any domestic crude oil consumed in the country would also need to be taken into account.

Source for API gravity and sulfur content: International Energy Agency.

# Appendix 2.1A.3
# 1990[a] country-specific net calorific values

The following table is an update from the table supplied in the *Revised 1996 IPCC Guidelines*. It contains more disaggregated information on coal. Some values have been revised by the International Energy Agency.

**TABLE 2.4**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | Albania | Algeria | Angola Cabinda | Argentina | Armenia | Australia | Austria | Azer-baijan | Bahrain | Bangla-desh | Belarus |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | | |
| Crude Oil | 41.45 | 43.29 | 42.75 | 42.29 | - | 43.21 | 42.75 | 42.08 | 42.71 | 42.16 | 42.08 |
| NGL | - | 43.29 | - | 42.50 | - | 45.22 | 45.22 | 41.91 | 42.71 | 42.71 | - |
| Refinery Feedst. | - | - | - | - | - | 42.50 | 42.50 | - | - | - | - |
| **COAL** | | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | | |
| Production | - | 25.75 | - | - | - | 28.34 | - | - | - | - | - |
| Imports | 27.21 | 25.75 | - | 30.14 | - | - | 28.00 | - | - | - | - |
| Exports | - | - | - | - | - | 28.21 | - | - | - | - | - |
| **Other Bituminous Coal and Anthracite[c]** | | | | | | | | | | | |
| Production | - | - | - | 24.70 | - | 24.39 | - | - | - | - | - |
| Imports | 27.21 | - | - | - | 18.58 | - | 28.00 | 18.58 | - | 20.93 | 25.54 |
| Exports | - | - | - | 24.70 | - | 25.65 | - | - | - | - | 25.54 |
| **Sub-Bituminous Coal** | | | | | | | | | | | |
| Production | - | - | - | - | - | 17.87 | - | - | - | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - | - |
| **Lignite** | | | | | | | | | | | |
| Production | 9.84 | - | - | - | - | 9.31 | 10.90 | - | - | - | - |
| Imports | - | - | - | - | - | - | 10.90 | - | - | - | - |
| Exports | 9.84 | - | - | - | - | - | 10.90 | - | - | - | - |
| **Coal Products** | | | | | | | | | | | |
| Patent Fuel | - | - | - | - | - | - | - | - | - | - | - |
| BKB | - | - | - | - | - | 21.00 | 19.30 | - | - | - | 8.37 |
| Coke Oven Coke | 27.21 | 27.21 | - | 28.46 | - | 25.65 | 28.20 | - | - | - | 25.12 |
| Gas Coke | - | - | - | - | - | - | - | - | - | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries.

OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | Belgium | Benin | Bolivia | Bosnia-Herze-govina | Brazil | Brunei | Bulgaria | Cameroon | Canada | Chile | China |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | | |
| Crude Oil | 42.75 | 42.58 | 43.33 | - | 45.64 | 42.75 | 42.62 | 42.45 | 42.79 | 42.91 | 42.62 |
| NGL | - | - | 43.33 | - | 45.22 | 42.75 | - | - | 45.22 | 42.87 | - |
| Refinery Feedst. | 42.50 | - | - | - | - | 41.87 | - | - | - | - | - |
| **COAL** | | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | | |
| Production | - | - | - | - | 26.42 | - | - | - | 28.78 | - | 20.52 |
| Imports | 29.31 | - | - | - | 30.69 | - | 24.70 | - | 27.55 | 28.43 | 20.52 |
| Exports | - | - | - | - | - | - | - | - | 28.78 | - | 20.52 |
| **Other Bituminous Coal and Anthracite** [c] | | | | | | | | | | | |
| Production | 25.00 | - | - | - | 15.99 | - | 24.70 | - | 28.78 | 28.43 | 20.52 |
| Imports | 25.00 | - | - | - | - | - | 24.70 | - | 27.55 | 28.43 | 20.52 |
| Exports | 25.00 | - | - | - | - | - | - | - | 28.78 | - | 20.52 |
| **Sub-Bituminous Coal** | | | | | | | | | | | |
| Production | 18.10 | - | - | - | - | - | - | - | 17.38 | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - | - |
| Exports | 18.20 | - | - | - | - | - | - | - | - | - | - |
| **Lignite** | | | | | | | | | | | |
| Production | - | - | - | 8.89 | - | - | 7.03 | - | 14.25 | 17.17 | - |
| Imports | 21.56 | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | 14.25 | - | - |
| **Coal Products** | | | | | | | | | | | |
| Patent Fuel | 29.31 | - | - | - | - | - | - | - | - | - | - |
| BKB | 20.10 | - | - | - | - | - | 20.10 | - | - | - | - |
| Coke Oven Coke | 29.31 | - | - | - | 30.56 | - | 27.21 | - | 27.39 | 28.43 | 28.47 |
| Gas Coke | - | - | - | - | - | - | - | - | - | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries. OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | Colombia | Congo | Costa Rica | Croatia | Cuba | Cyprus | Czech Republic | Democratic Republic of Congo | Denmark | Dominican Republic |
|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | |
| Crude Oil | 42.24 | 42.91 | 42.16 | 42.75 | 41.16 | 42.48 | 41.78 | 42.16 | 42.71 | 42.16 |
| NGL | 41.87 | - | - | 45.22 | - | - | - | - | - | - |
| Refinery Feedst. | - | - | - | - | - | - | - | - | 42.50 | - |
| **COAL** | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | |
| Production | 27.21 | - | - | - | - | - | 24.40 | - | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - |
| Exports | 27.21 | - | - | - | - | - | 27.46 | - | - | - |
| **Other Bituminous Coal and Anthracite[c]** | | | | | | | | | | |
| Production | 27.21 | - | - | 25.12 | - | - | 18.19 | 25.23 | - | - |
| Imports | - | - | 25.75 | 29.31 | 25.75 | 25.75 | 18.19 | 25.23 | 26.09 | 25.75 |
| Exports | 27.21 | - | - | - | - | - | 18.19 | - | 26.09 | - |
| **Sub-Bituminous Coal** | | | | | | | | | | |
| Production | - | - | - | - | - | - | 12.29 | - | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | 21.28 | - | - | - |
| **Lignite** | | | | | | | | | | |
| Production | - | - | - | - | - | - | 12.29 | - | - | - |
| Imports | - | - | - | 14.60 | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - |
| **Coal Products** | | | | | | | | | | |
| Patent Fuel | - | - | - | - | - | - | - | 29.31 | - | - |
| BKB | - | - | - | - | - | - | 21.28 | - | 18.27 | - |
| Coke Oven Coke | 20.10 | - | 27.21 | 29.31 | 27.21 | - | 27.01 | 27.21 | 31.84 | - |
| Gas Coke | - | - | - | - | - | - | - | - | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries.

OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | DPR of Korea | Ecuador | Egypt | El Salvador | Estonia | Ethiopia | Federal Republic of Yugoslavia | Finland | FYR of Macedonia | Former Yugoslavia | France |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | | |
| Crude Oil | 42.16 | 41.87 | 42.54 | 42.16 | - | 42.62 | 42.75 | 44.03 | 42.75 | 42.75 | 42.75 |
| NGL | - | 42.45 | 42.54 | - | - | - | - | - | - | - | 45.22 |
| Refinery Feedst. | - | - | - | - | - | - | - | 42.50 | - | - | 42.50 |
| **COAL** | | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | | |
| Production | 25.75 | - | - | - | - | - | - | - | - | - | 28.91 |
| Imports | 25.75 | - | 25.75 | - | - | - | - | 26.38 | 30.69 | 30.69 | 30.50 |
| Exports | - | - | - | - | - | - | - | - | 30.13 | - | - |
| **Other Bituminous Coal and Anthracite [c]** | | | | | | | | | | | |
| Production | 25.75 | - | - | - | - | - | 23.55 | - | - | 23.55 | 26.71 |
| Imports | - | - | 25.75 | - | 18.58 | - | 30.69 | 26.38 | 30.69 | - | 25.52 |
| Exports | 25.75 | - | - | - | 18.58 | - | - | - | - | - | 26.43 |
| **Sub-Bituminous Coal** | | | | | | | | | | | |
| Production | 17.58 | - | - | - | - | - | - | - | - | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - | - |
| **Lignite** | | | | | | | | | | | |
| Production | - | - | - | - | 9.44 | - | 8.89 | - | 8.89 | 8.89 | 17.94 |
| Imports | - | - | - | - | 9.44 | - | - | - | 16.91 | 16.91 | 17.94 |
| Exports | - | - | - | - | 9.44 | - | - | - | 16.90 | 16.90 | - |
| **Coal Products** | | | | | | | | | | | |
| Patent Fuel | - | - | - | - | - | - | - | - | - | - | 30.07 |
| BKB | - | - | - | - | 8.37 | - | - | - | - | 20.10 | 20.10 |
| Coke Oven Coke | 27.21 | - | 27.21 | - | 25.12 | - | - | 28.89 | - | 26.90 | 28.71 |
| Gas Coke | - | - | - | - | - | - | - | - | - | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries.
OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | Gabon | Georgia | Germany | Ghana | Greece | Guatemala | Haiti | Honduras | Hong Kong, China | Hungary | Iceland |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | | |
| Crude Oil | 42.62 | 42.08 | 42.75 | 42.62 | 42.75 | 42.45 | - | 42.16 | - | 41.00 | - |
| NGL | - | - | - | - | 45.22 | - | - | - | - | 45.18 | - |
| Refinery Feedst. | - | - | 42.50 | - | 42.50 | - | - | - | - | 42.08 | - |
| **COAL** | | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | | |
| Production | - | - | 28.96 | - | - | - | - | - | - | 29.61 | - |
| Imports | - | - | 28.96 | - | - | - | - | - | - | 30.76 | 29.01 |
| Exports | - | - | 28.96 | - | - | - | - | - | - | - | - |
| **Other Bituminous Coal and Anthracite** [c] | | | | | | | | | | | |
| Production | - | 18.58 | 24.96 | - | - | - | - | - | - | 13.15 | - |
| Imports | - | 18.58 | 26.52 | 25.75 | 27.21 | - | 25.75 | - | 25.75 | 21.50 | 29.01 |
| Exports | - | 18.58 | 31.71 | - | - | - | - | - | - | 20.15 | - |
| **Sub-Bituminous Coal** | | | | | | | | | | | |
| Production | - | - | - | - | - | - | - | - | - | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - | - |
| **Lignite** | | | | | | | | | | | |
| Production | - | - | 8.41 | - | 5.74 | - | - | - | - | 9.17 | - |
| Imports | - | - | 14.88 | - | - | - | - | - | - | 15.46 | - |
| Exports | - | - | 8.40 | - | - | - | - | - | - | - | - |
| **Coal Products** | | | | | | | | | | | |
| Patent Fuel | - | - | 31.40 | - | - | - | - | - | - | 16.80 | - |
| BKB | - | - | 20.58 | - | 15.28 | - | - | - | - | 21.23 | - |
| Coke Oven Coke | - | - | 28.65 | - | 29.30 | - | - | 27.21 | 27.21 | 27.13 | 26.65 |
| Gas Coke | - | - | - | - | - | - | - | - | - | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries.
OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | India | Indonesia | Iran | Iraq | Ireland | Israel | Italy | Ivory Coast | Jamaica | Japan | Jordan |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | | |
| Crude Oil | 42.79 | 42.66 | 42.66 | 42.83 | 42.83 | 42.54 | 42.75 | 42.62 | 42.16 | 42.62 | 42.58 |
| NGL | 43.00 | 42.77 | 42.54 | 42.83 | - | - | 45.22 | - | - | 46.05 | - |
| Refinery Feedst. | - | - | - | - | 42.50 | - | 42.50 | - | - | 42.50 | - |
| **COAL** | | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | | |
| Production | 19.98 | - | 25.75 | - | - | - | - | - | - | 30.63 | - |
| Imports | 25.75 | - | 25.75 | - | 29.10 | - | 30.97 | - | - | 30.23 | - |
| Exports | - | - | - | - | - | - | - | - | - | - | - |
| **Other Bituminous Coal and Anthracite[c]** | | | | | | | | | | | |
| Production | 19.98 | 25.75 | 25.75 | - | 26.13 | - | 26.16 | - | - | 23.07 | - |
| Imports | 25.75 | 25.75 | - | - | 29.98 | 26.63 | 26.16 | - | 25.75 | 24.66 | - |
| Exports | 19.98 | 25.75 | - | - | 26.13 | - | - | - | - | - | - |
| **Sub-Bituminous Coal** | | | | | | | | | | | |
| Production | - | - | - | - | - | - | - | - | - | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - | - |
| **Lignite** | | | | | | | | | | | |
| Production | 9.80 | - | - | - | - | 4.19 | 10.47 | - | - | - | - |
| Imports | - | - | - | - | 19.82 | - | 10.47 | - | - | - | - |
| Exports | - | - | - | - | 19.82 | - | - | - | - | - | - |
| **Coal Products** | | | | | | | | | | | |
| Patent Fuel | - | - | - | - | - | - | - | - | - | 27.05 | - |
| BKB | 20.10 | - | - | - | 20.98 | - | - | - | - | - | - |
| Coke Oven Coke | 27.21 | 27.21 | 27.21 | - | 32.66 | - | 29.30 | - | - | 28.64 | - |
| Gas Coke | - | - | - | - | - | - | - | - | - | 28.64 | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries.

OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | Kazakhstan | Kenya | Korea | Kuwait | Kyrgyzstan | Latvia | Lebanon | Libya | Lithuania | Luxem-bourg | Malaysia |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | | |
| Crude Oil | 42.08 | 42.08 | 42.71 | 42.54 | 42.08 | - | 42.16 | 43.00 | 42.08 | - | 42.71 |
| NGL | 41.91 | - | - | 42.62 | - | - | - | 43.00 | - | - | 43.12 |
| Refinery Feedst. | - | - | - | - | - | - | - | - | 44.80 | - | 42.54 |
| **COAL** | | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | | |
| Production | 18.58 | - | - | - | - | - | - | - | - | - | - |
| Imports | 18.58 | - | 27.21 | - | - | - | - | - | - | - | - |
| Exports | 18.58 | - | - | - | - | - | - | - | - | - | - |
| **Other Bituminous Coal and Anthracite[c]** | | | | | | | | | | | |
| Production | 18.58 | - | 19.26 | - | 18.58 | - | - | - | - | - | 25.75 |
| Imports | 18.58 | 25.75 | 27.21 | - | 18.58 | 18.58 | - | - | 18.59 | 29.30 | 25.75 |
| Exports | 18.58 | - | - | - | 18.58 | 25.12 | - | - | 18.59 | - | 25.75 |
| **Sub-Bituminous Coal** | | | | | | | | | | | |
| Production | - | - | - | - | - | - | - | - | - | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - | - |
| **Lignite** | | | | | | | | | | | |
| Production | 14.65 | - | - | - | 14.65 | - | - | - | - | - | - |
| Imports | 18.58 | - | - | - | 14.65 | - | - | - | - | 20.03 | - |
| Exports | 18.58 | - | - | - | - | - | - | - | - | - | - |
| **Coal Products** | | | | | | | | | | | |
| Patent Fuel | - | - | - | - | - | - | - | - | - | - | - |
| BKB | - | - | - | - | - | 8.37 | - | - | 8.37 | 20.10 | - |
| Coke Oven Coke | 25.12 | - | 27.21 | - | - | 25.12 | - | - | - | 28.50 | 27.21 |
| Gas Coke | - | - | - | - | - | - | - | - | - | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal - the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries.

OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | Malta | Mexico | Moldova | Morocco | Mozam-bique | Myanmar | Nepal | Nether-lands | Nether-lands Antilles | New Zealand | Nica-ragua |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | | |
| Crude Oil | - | 42.35 | - | 38.94 | - | 42.24 | - | 42.71 | 42.16 | 45.93 | 42.16 |
| NGL | - | 46.81 | - | - | - | 42.71 | - | 45.22 | - | 49.75 | - |
| Refinery Feedst. | - | - | - | - | - | - | - | - | - | 47.22 | - |
| **COAL** | | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | | |
| Production | - | 24.72 | - | - | - | - | - | - | - | 28.00 | - |
| Imports | - | 30.18 | - | - | - | - | - | 28.70 | - | 28.00 | - |
| Exports | - | 22.41 | - | - | - | - | - | - | - | 28.00 | - |
| **Other Bituminous Coal and Anthracite[c]** | | | | | | | | | | | |
| Production | - | - | - | 23.45 | 25.75 | 25.75 | - | - | - | 26.00 | - |
| Imports | 25.75 | - | 18.58 | 27.63 | 25.75 | 25.75 | 25.12 | 26.60 | - | - | - |
| Exports | - | - | - | - | - | - | - | 26.60 | - | - | - |
| **Sub-Bituminous Coal** | | | | | | | | | | | |
| Production | - | 18.20 | - | - | - | - | - | - | - | 21.30 | - |
| Imports | - | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - | - |
| **Lignite** | | | | | | | | | | | |
| Production | - | - | - | - | - | 8.37 | - | - | - | 14.10 | - |
| Imports | - | - | - | - | - | - | - | 20.00 | - | - | - |
| Exports | - | - | - | - | - | - | - | 20.00 | - | - | - |
| **Coal Products** | | | | | | | | | | | |
| Patent Fuel | - | - | - | - | - | - | - | 29.30 | - | - | - |
| BKB | - | - | - | - | - | - | - | 20.00 | - | - | - |
| Coke Oven Coke | - | 27.96 | 25.12 | 27.21 | - | 27.21 | - | 28.50 | - | - | - |
| Gas Coke | - | - | - | - | - | - | - | - | - | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries.
OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | Nigeria | Norway | Oman | Pakistan | Panama | Paraguay | Peru | Philip-pines | Poland | Portugal | Qatar |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | | |
| Crude Oil | 42.75 | 42.96 | 42.71 | 42.87 | 42.16 | 42.54 | 42.75 | 42.58 | 41.27 | 42.71 | 42.87 |
| NGL | 42.75 | 45.22 | 42.71 | 42.87 | - | - | 42.75 | - | - | - | 43.00 |
| Refinery Feedst. | - | 42.50 | - | - | - | - | - | - | 44.80 | 42.50 | - |
| **COAL** | | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | | |
| Production | - | - | - | - | - | - | - | - | - | - | - |
| Imports | - | - | - | 27.54 | - | - | 29.31 | - | - | 29.30 | - |
| Exports | - | - | - | - | - | - | - | - | - | - | - |
| **Other Bituminous Coal and Anthracite** [c] | | | | | | | | | | | |
| Production | 25.75 | 28.10 | - | 18.73 | - | - | 29.31 | 20.10 | 22.95 | - | - |
| Imports | - | 28.10 | - | - | 25.75 | - | - | 20.52 | 29.41 | 26.59 | - |
| Exports | 25.75 | 28.10 | - | - | - | - | - | - | 25.09 | - | - |
| **Sub-Bituminous Coal** | | | | | | | | | | | |
| Production | - | - | - | - | - | - | - | - | - | 17.16 | - |
| Imports | - | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - | - |
| **Lignite** | | | | | | | | | | | |
| Production | - | - | - | - | - | - | - | 8.37 | 8.36 | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | 9.00 | - | - |
| **Coal Products** | | | | | | | | | | | |
| Patent Fuel | - | - | - | - | - | - | - | - | 22.99 | - | - |
| BKB | - | - | - | - | - | - | - | - | 17.84 | - | - |
| Coke Oven Coke | 27.21 | 28.50 | - | 27.21 | - | - | 27.21 | 27.21 | 27.85 | 28.05 | - |
| Gas Coke | - | - | - | - | - | - | - | - | - | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries.
OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | Romania | Russia | Saudi Arabia | Senegal | Singa-pore | Slovak Republic | Slovenia | South Africa | Spain | Sri Lanka | Sudan |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | | |
| Crude Oil | 40.65 | 42.08 | 42.54 | 42.62 | 42.71 | 41.78 | 42.75 | 38.27 | 42.66 | 42.16 | 42.62 |
| NGL | - | - | 42.62 | - | - | 45.18 | - | - | 45.22 | - | - |
| Refinery Feedst. | - | - | - | - | - | - | 42.50 | - | 42.50 | - | - |
| **COAL** | | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | | |
| Production | 16.33 | 18.58 | - | - | - | - | - | 30.99 | 29.16 | - | - |
| Imports | 25.12 | 25.12 | - | - | - | 23.92 | 30.69 | - | 30.14 | - | - |
| Exports | - | 18.58 | - | - | - | - | - | 30.99 | - | - | - |
| **Other Bituminous Coal and Anthracite[c]** | | | | | | | | | | | |
| Production | 16.33 | 18.58 | - | - | - | - | - | 23.60 | 21.07 | - | - |
| Imports | 25.12 | 18.58 | - | - | - | 23.92 | 30.69 | - | 25.54 | 25.75 | - |
| Exports | - | 18.58 | - | - | - | - | - | 27.99 | 23.00 | - | - |
| **Sub-Bituminous Coal** | | | | | | | | | | | |
| Production | - | - | - | - | - | - | 8.89 | - | 11.35 | - | - |
| Imports | - | - | - | - | - | - | 16.91 | - | 11.35 | - | - |
| Exports | - | - | - | - | - | - | 16.90 | - | - | - | - |
| **Lignite** | | | | | | | | | | | |
| Production | 7.24 | 14.65 | - | - | - | 12.26 | 8.89 | - | 7.84 | - | - |
| Imports | 7.24 | - | - | - | 9.67 | 12.20 | 16.91 | - | - | - | - |
| Exports | - | 14.65 | - | - | - | 15.26 | 16.90 | - | - | - | - |
| **Coal Products** | | | | | | | | | | | |
| Patent Fuel | 14.65 | - | - | - | - | - | - | - | 29.30 | - | - |
| BKB | 14.65 | 20.10 | - | - | - | 21.28 | - | - | 20.22 | - | - |
| Coke Oven Coke | 20.81 | 25.12 | - | - | 27.21 | 27.01 | 26.90 | 27.88 | 30.14 | - | - |
| Gas Coke | - | - | - | - | - | - | - | - | - | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries. OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | Sweden | Switzerland | Syria | Tajikistan | Tanzania | Thailand | Trinidad and Tobago | Tunisia | Turkey | Turk-menistan | Ukraine |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | | |
| Crude Oil | 42.75 | 43.22 | 42.04 | 42.08 | 42.62 | 42.62 | 42.24 | 43.12 | 42.79 | 42.08 | 42.08 |
| NGL | - | - | - | 41.91 | - | 46.85 | - | 43.12 | - | 41.91 | - |
| Refinery Feedst. | 42.50 | 43.70 | - | - | - | - | - | - | 42.50 | - | - |
| **COAL** | | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | | |
| Production | - | - | - | - | 25.75 | - | - | - | 32.56 | - | 21.59 |
| Imports | 30.00 | - | - | - | - | - | - | - | 33.54 | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - | 21.59 |
| **Other Bituminous Coal and Anthracite[c]** | | | | | | | | | | | |
| Production | 14.24 | - | - | - | 25.75 | - | - | - | 30.04 | - | 21.59 |
| Imports | 26.98 | 28.05 | - | 18.58 | - | 26.38 | - | 25.75 | 27.89 | 18.58 | 25.54 |
| Exports | 26.98 | 28.05 | - | - | - | - | - | - | - | - | 21.59 |
| **Sub-Bituminous Coal** | | | | | | | | | | | |
| Production | - | - | - | 14.65 | - | - | - | - | 18.00 | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - | - |
| **Lignite** | | | | | | | | | | | |
| Production | - | - | - | - | - | 12.14 | - | - | 9.63 | - | 14.65 |
| Imports | 8.37 | - | - | - | - | - | - | - | 12.56 | - | 14.65 |
| Exports | - | - | - | - | - | - | - | - | - | - | 14.65 |
| **Coal Products** | | | | | | | | | | | |
| Patent Fuel | - | 28.05 | - | - | - | - | - | - | - | - | 29.31 |
| BKB | 20.10 | 20.10 | - | - | - | - | - | - | 20.93 | - | - |
| Coke Oven Coke | 28.05 | 28.05 | - | - | 27.21 | 27.21 | - | 27.21 | 29.31 | - | 25.12 |
| Gas Coke | - | - | - | - | - | - | - | - | 27.21 | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries.

OECD/IEA, Paris, 1998.

**TABLE 2.4 (CONTINUED)**

**1990[a] COUNTRY-SPECIFIC NET CALORIFIC VALUES[b]**

| *(Terajoule per kilotonne)* | United Arab Emirates | United Kingdom | United States | Uruguay | Uzbe-kistan | Venezuela | Vietnam | Yemen | Zambia | Zimbabwe |
|---|---|---|---|---|---|---|---|---|---|---|
| **OIL** | | | | | | | | | | |
| Crude Oil | 42.62 | 43.40 | 43.12 | 42.71 | 42.08 | 42.06 | 42.61 | 43.00 | 42.16 | - |
| NGL | 42.62 | 46.89 | 47.69 | - | 41.91 | 41.99 | - | - | - | - |
| Refinery Feedst. | - | 42.50 | 43.36 | - | 44.80 | - | - | - | - | - |
| **COAL** | | | | | | | | | | |
| **Coking Coal** | | | | | | | | | | |
| Production | - | 29.27 | 29.68 | - | - | - | - | - | 24.71 | 25.75 |
| Imports | - | 30.07 | - | - | - | - | - | - | - | - |
| Exports | - | 29.27 | 29.68 | - | - | - | - | - | - | - |
| **Other Bituminous Coal and Anthracite[c]** | | | | | | | | | | |
| Production | - | 24.11 | 26.66 | - | 18.58 | 25.75 | 20.91 | - | 24.71 | 25.75 |
| Imports | - | 26.31 | 27.69 | - | 18.58 | - | - | - | - | 25.75 |
| Exports | - | 27.53 | 28.09 | - | - | 25.75 | 20.91 | - | 24.71 | 25.75 |
| **Sub-Bituminous Coal** | | | | | | | | | | |
| Production | - | - | 19.43 | - | - | - | - | - | - | - |
| Imports | - | - | - | - | - | - | - | - | - | - |
| Exports | - | - | - | - | - | - | - | - | - | - |
| **Lignite** | | | | | | | | | | |
| Production | - | - | 14.19 | - | 14.65 | - | - | - | - | - |
| Imports | - | - | - | - | 14.65 | - | - | - | - | - |
| Exports | - | - | 14.19 | - | 14.65 | - | - | - | - | - |
| **Coal Products** | | | | | | | | | | |
| Patent Fuel | - | 26.26 | - | - | 29.31 | - | - | - | - | - |
| BKB | - | - | - | - | - | - | - | - | - | - |
| Coke Oven Coke | - | 26.54 | 27.47 | 27.21 | - | - | 27.21 | - | 27.21 | 27.21 |
| Gas Coke | - | - | - | - | - | - | - | - | - | - |

[a] For the former Soviet and Yugoslav Republics, 1996 numbers have been used.

[b] The NCVs are those used by the IEA in the construction of energy balances.

[c] In IEA statistics, Anthracite is combined with Other Bituminous Coal – the NCVs given above reflect this combination.

Source: Energy Balances of OECD Countries, and Energy Statistics and Balances of Non-OECD Countries. OECD/IEA, Paris, 1998.

# 2.2 NON-$CO_2$ EMISSIONS FROM STATIONARY COMBUSTION

## 2.2.1 Methodological issues

For stationary sources, some non-$CO_2$ emissions such as methane ($CH_4$), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC) result from the incomplete combustion of fuels. The *IPCC Guidelines* cover emissions of stationary combustion-related non-$CO_2$ greenhouse gases from five sectors (Energy and Manufacturing Industries, the Commercial/Institutional Sector, the Residential Sector and Agriculture/Forestry/Fishing sources). This section addresses only emissions of the direct greenhouse gases $CH_4$ and $N_2O$.

Fuel characteristics (including the calorific value), the type of technology (including the combustion, operating and maintenance regime, the size and the vintage of the equipment), and emission controls, are major factors determining rates of emissions of $CH_4$ and $N_2O$ gases from stationary sources. Moisture content, carbon fraction, and combustion efficiencies are also important factors to consider.

### 2.2.1.1 CHOICE OF METHOD

The *IPCC Guidelines* describe the following general approach to estimate emissions from fuel combustion for each greenhouse gas and sub-source category:

**EQUATION 2.3**

$$\text{Emissions} = \sum (\text{Emission Factor}_{abc} \bullet \text{Fuel Consumption}_{abc})$$

Where:

a = fuel type

b = sector activity

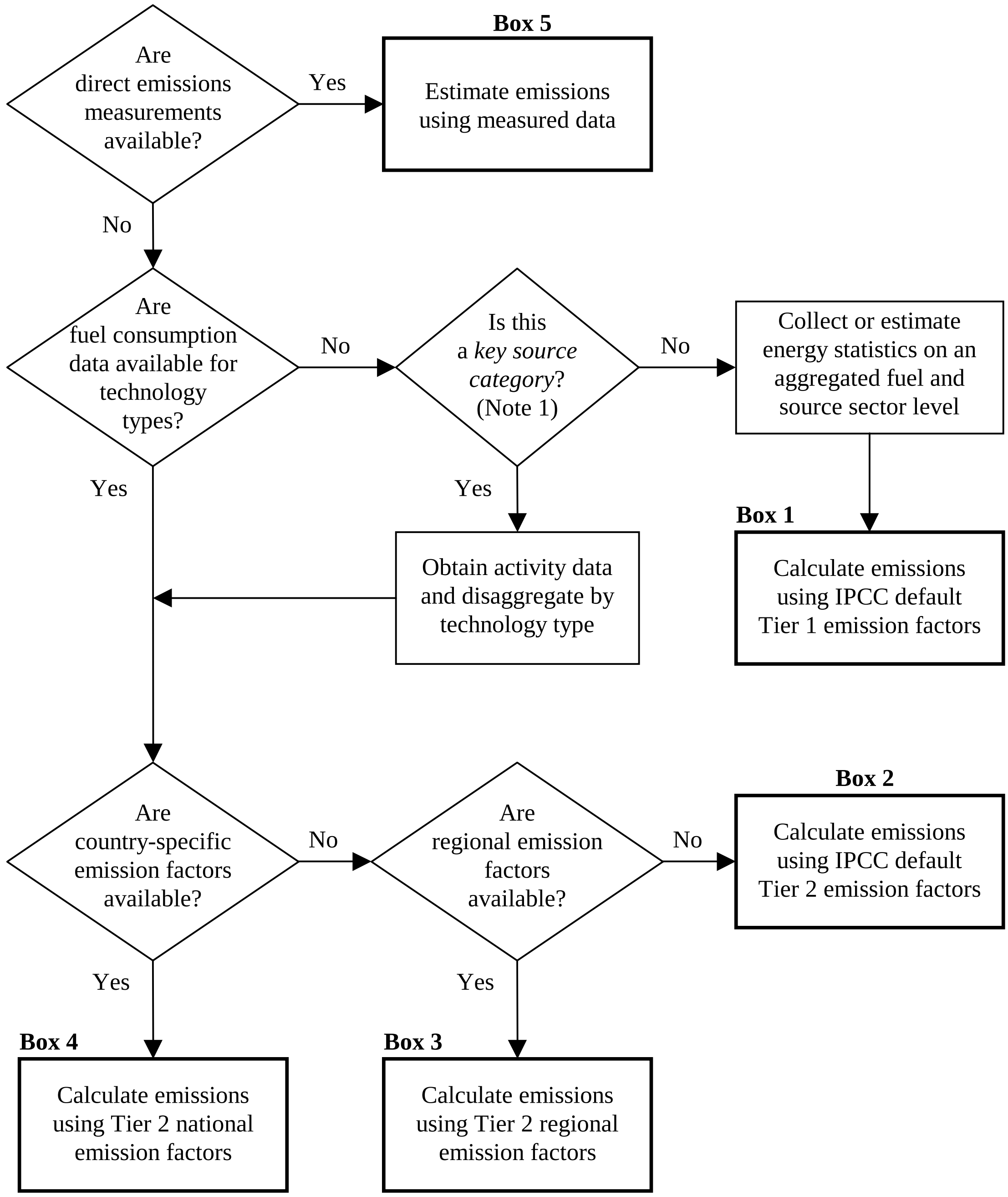
c = technology type

Given the dependence of emissions on unique combustion conditions and other characteristics, *good practice* is to disaggregate fuel consumption into smaller, more homogeneous categories, if data and specific emission factors are available. The *IPCC Guidelines* generally refer to such disaggregated estimation methods using country-specific emission factors as Tier 2, and more aggregated estimates as Tier 1 calculations. *Good practice* is to use the level of disaggregation that reflects the greatest level of detail in the energy statistics available in the country.

Figure 2.3, Decision Tree for Non-$CO_2$ Emissions from Stationary Combustion summarises *good practice* in methodological choice. It should be applied separately to each of the sub-source categories for each gas for which emissions exist in a country, because the availability of activity data and emission factors (and hence the outcome in terms of methodological choice) may differ significantly between sub-source categories.

Although continuous measurement of emissions is also consistent with *good practice*, continuous measurements of $CH_4$ and $N_2O$ alone are not justified because of their comparatively high cost and because practical continuous monitoring systems are not easily available. Sufficiently accurate results may be obtained by using periodic measurements for $CH_4$ and $N_2O$. These measurements would help to improve emission factors. If monitors are already installed to measure other pollutants, they may deliver some useful parameters such as fluxes.

**Figure 2.3 Decision Tree for Non-$CO_2$ Emissions from Stationary Combustion**




**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

**Note 2:** The decision tree and *key source category* determination should be applied to methane and nitrous oxide emissions separately.

Proper use of the decision tree requires an inventory agency to undertake, beforehand, a thorough survey of available national activity data and national or regional emission factor data, by relevant source category. For some sub-source categories, activity and emissions data may be sparse. In this case, it is *good practice* to improve data quality if an initial calculation with a default method indicates a significant contribution to total national emissions or the presence of a high level of uncertainty.

Where direct measurements are available, reporting of implied emission factors cross referenced by technology type would be helpful, since this information could help others to estimate national emissions.

### 2.2.1.2 CHOICE OF EMISSION FACTORS

*Good practice* is to use the most disaggregated technology-specific and country-specific emission factors available, particularly those derived from direct measurements at the different stationary combustion sources. Using the Tier 2 approach, there are three possible types of emission factors:

- National emission factors.[9] These emission factors may be developed by national programmes already measuring emissions of indirect greenhouse gases such as $NO_x$, CO and NMVOC for local air quality;
- Regional emission factors;[10]
- IPCC default emission factors, provided that a careful review of the consistency of these factors with the country conditions has been made. IPCC default factors may be used when no other information is available.

If national activity data are not sufficiently disaggregated to enable the use of Tier 2, then aggregate Tier 1 emission factors should be applied, provided that no other referenced data are available that are more representative of combustion conditions within the country.

Emission factors for biomass fuels are not as well developed as those for fossil fuels. Preliminary results from an international biomass emission factor research project, focusing on developing countries (e.g. India, Kenya, and China) show emission factors for small biomass devices and carbonisation that are different from the IPCC defaults. Given the importance of biomass in many countries, it is suggested that country experts consider the new well-researched emission factors as soon as they are published (Smith *et al*., 1993; Smith *et al*., 1999; Smith *et al*., 2000; Zhang *et al*., 1999; Zhang *et al*., 2000).

### 2.2.1.3 CHOICE OF ACTIVITY DATA

Due to the technology-specific nature of non-$CO_2$ formation, detailed fuel combustion technology statistics are needed in order to provide rigorous emission estimates. It is *good practice* to collect activity data in units of fuel used, and to disaggregate as far as possible into the share of fuel used by major technology types. Disaggregation can be achieved through a bottom-up survey of fuel consumption and combustion technology, or through top-down allocations based on expert judgement and statistical sampling. Specialised statistical offices or ministerial departments are generally in charge of regular data collection and handling. Inclusion of representatives from these departments in the inventory process could facilitate the acquisition of appropriate activity data.

*Good practice* for electricity autoproduction (self-generation) is to assign emissions to the source categories (or sub-source categories) where they were generated and to identify them separately from those associated with other end-uses such as process heat. In many countries, the statistics related to autoproduction are available and regularly updated. Therefore, activity data do not represent a serious obstacle to estimating non-$CO_2$ emissions in those countries.

For some source categories (e.g. energy use in agriculture), there may be some difficulties in separating fuel used in stationary equipment from fuel used in mobile machinery. Given the different emission factors of these two sources, *good practice* is to derive the energy use of each of these sources by using indirect data (e.g. number of pumps, average consumption, and needs for water pumping). Expert judgement and information available from other countries may also be relevant.

[9] Since the associated uncertainty ranges are dependent on the instrumentation used and on the frequency of measurements, these should be described and reported.

[10] The sources of the regional emission factors should be documented and the uncertainty ranges reported.

### 2.2.1.4 COMPLETENESS

Completeness should be established by cross-referencing to the source categories used for reporting $CO_2$ emissions from stationary combustion. The same source categories should be used in cases where choice is possible (e.g. emissions from coke used in blast furnaces that can be reported either with industrial emissions or under stationary combustion depending on national circumstances as explained in Section 2.1.1.3 and below). Cross-referencing with $CO_2$ categories will not necessarily cover non-$CO_2$ emissions from biomass fuels, since $CO_2$ emissions from biomass fuels are reported as memo items but not included in national totals. Therefore, the national energy statistics agencies should be consulted about use of biomass fuels, including possible use of non-commercially traded biomass fuels. Biomass related issues are particularly important for the quality of inventories in developing countries. A major effort is required by country experts in order to improve related non-$CO_2$ estimates.

The reporting of emissions from coke use in blast furnaces requires attention. Crude iron is typically produced by the reduction of iron oxide ores in a blast furnace, using the carbon in coke (sometimes other fuels) as both the fuel and reductant. Since the primary purpose of coke oxidation is to produce pig iron, the emissions should be considered as coming from an industrial process if a detailed calculation of industrial emissions is being undertaken. It is important not to double-count the carbon from the combustion of coke. Therefore, if these emissions have been included in the Industrial Processes sector, they should not be included in the Energy sector. However, there are countries where industrial emissions are not addressed in detail. In these instances, the emissions should be included with Energy. *Good practice* is to state clearly whether non-$CO_2$ emissions from coke use in blast furnaces have been allocated to Energy or to Industrial Processes, to indicate that no double counting has occurred.

Uncontrolled situations that might affect estimates and sectoral distribution (e.g. statistical differences or thefts) require special consideration. Inventory agencies are encouraged to make the most appropriate interpretation of the related emissions.

### 2.2.1.5 DEVELOPING A CONSISTENT TIME SERIES

As improved emission factors and emission estimation methods are developed over time, base year emission estimates determination will be an important issue for non-$CO_2$ emissions from stationary combustion. *Good practice guidance* on ensuring time series consistency and base year determination is provided in Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques.

Many countries, particularly developing ones, do not undertake annual surveys. Where data are missing for an inventory year, it may be necessary to estimate activity data through extrapolation for the current year or interpolation between years. These extrapolations or interpolations require regular cross-checking with survey data collected at least every three to five years. Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques, describes in more detail methods for making such calculations.

Biomass data may be incomplete, particularly for small combustion devices. If the data are missing for the inventory year, inventory agencies could extrapolate to the relevant year based on past trends, or interpolate, again using the methods described in Chapter 7.[11] Additional cross-checking should be done to ensure the consistency of the estimates with related data that are available annually (e.g. wood production potential from forests, and annual dung production).

### 2.2.1.6 UNCERTAINTY ASSESSMENT

Default uncertainty ranges for non-$CO_2$ stationary combustion emissions are not provided in the *IPCC Guidelines*. It is *good practice* to quantify the uncertainties associated with the inventory results regardless of the tier adopted.

[11] Two recent meetings at the IEA addressed the issues of gathering and modelling biomass energy data. The findings are published in (i) Biomass Energy: Key Issues and Priority Needs. Conference Proceedings. IEA/OECD, Paris, France. 3-5 February 1997; (ii) Biomass Energy: Data, Analysis and Trends. Conference Proceedings. IEA/OECD, Paris, France. 23-24 March 1998.

## EMISSION FACTOR UNCERTAINTIES

The default uncertainties shown in Table 2.5, derived from the EMEP/CORINAIR Guidebook ratings (EMEP/CORINAIR, 1999), may be used in the absence of country-specific estimates.

**TABLE 2.5**

**DEFAULT UNCERTAINTY ESTIMATES FOR STATIONARY COMBUSTION EMISSION FACTORS**

| **Sector** | **$CH_4$** | **$N_2O$** |
|---|---|---|
| Public Power, co-generation and district heating | 50-150% | Order of magnitude[a] |
| Commercial, Institutional & Residential combustion | 50-150% | Order of magnitude |
| Industrial combustion | 50-150% | Order of magnitude |
| Agriculture/forestry/fishing | Not reported | Not reported |

[a] I.e. having an uncertainty range from one-tenth of the mean value to ten times the mean value.

Source: Judgement by Expert Group (see Co-chairs, Editors and Experts; Stationary Combustion).

While these default uncertainties can be used for the existing emission factors (whether country-specific or taken from the *IPCC Guidelines*), there may be an additional uncertainty associated with applying emission factors that are not representative of the combustion conditions in the country. It is *good practice* to obtain estimates of these uncertainties from national experts taking into account the guidance concerning expert judgements provided in Chapter 6, Quantifying Uncertainties in Practice.

## ACTIVITY DATA UNCERTAINTIES

Aggregate data related to energy consumption by fuel type are generally estimated accurately. There is more uncertainty for biomass and traditional fuels. Uncertainties associated with sectoral (or sub-sectoral) distribution of fuel use are also generally higher, and will vary with the approach (survey or extrapolation) used and the specificity of the country's statistical systems.

The activity data uncertainty ranges shown in Table 2.6, Level of Uncertainty Associated with Stationary Combustion Activity Data, may be used when reporting uncertainties. It is *good practice* for inventory agencies to develop, if possible, country-specific uncertainties using expert judgement or statistical analysis.

**TABLE 2.6**

**LEVEL OF UNCERTAINTY ASSOCIATED WITH STATIONARY COMBUSTION ACTIVITY DATA**

| | **Well Developed Statistical Systems** | | **Less Developed Statistical Systems** | |
|---|---|---|---|---|
| **Sector** | **Surveys** | **Extrapolations** | **Surveys** | **Extrapolations** |
| Public Power, co-generation and district heating | less than 1% | 3-5% | 1-2% | 5-10% |
| Commercial, institutional, residential combustion | 3-5% | 5-10% | 10-15% | 15-25% |
| Industrial combustion (Energy intensive industries) | 2-3% | 3-5% | 2-3% | 5-10% |
| Industrial combustion (others) | 3-5% | 5-10% | 10-15% | 15-20% |
| Biomass in small sources | 10-30% | 20-40% | 30-60% | 60-100% |

The inventory agency should judge which type of statistical system best describes their national circumstances.

Source: Judgement by Expert Group (see Co-chairs, Editors and Experts; Stationary Combustion).

## 2.2.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Section 8.10.1 of Chapter 8, Quality Assurance and Quality Control.

It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and the steps in their calculation may be retraced.

The current IPCC reporting format (spreadsheet tables, aggregate tables) provides a balance between the transparency requirement and the level of effort that is realistically achievable by the inventory agency. *Good practice* involves some additional effort to fulfil the transparency requirements completely. In particular, if Tier 2 (or a more disaggregated approach) is used, additional tables showing the activity data that are directly associated with the emission factors should be prepared.

Most energy statistics are not considered confidential. If inventory agencies do not report disaggregated data due to confidentiality concerns, it is *good practice* to explain the reasons for these concerns, and report the data in a more aggregated form.

For a highly disaggregated stationary non-$CO_2$ estimate, it may be necessary to cite many different references or documents. It is *good practice* to provide citations for these references, particularly if they describe new methodological developments or emission factors for particular technologies or national circumstances.

It is *good practice* to state clearly whether non-$CO_2$ emissions from coke (or other fuels) used in crude iron production have been allocated to the Energy or to the Industrial Processes Sector, to show that no double counting has occurred. The attribution of emissions from blast furnaces and other industrial processes should be consistent between $CO_2$ and non-$CO_2$ emissions (see Section 2.1.1.4).

## 2.2.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8 and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory agencies are encouraged to use higher tier QA/QC for *key source categories* as identified in Chapter 7, Methodological Choice and Recalculation.

In addition to the guidance in Chapter 8, specific procedures of relevance to this source category are outlined below.

#### Comparison of emission estimates using different approaches

- If a Tier 2 approach with country-specific factors is used, the inventory agency should compare the result to emissions calculated using the Tier 1 approach with default IPCC factors. This type of comparison may require aggregating Tier 2 emissions to the same sector and fuel groupings as the Tier 1 approach. The approach should be documented and any discrepancies investigated.
- If possible, the inventory agency should compare the consistency of the calculations in relation to the maximum carbon content of fuels that are combusted by stationary sources. Anticipated carbon balances should be maintained throughout the combustion sectors, and the non-$CO_2$ estimates should not contradict maximum theoretical quantities based on the total carbon content of the fuels.

#### Review of emission factors

- If country-specific emission factors are used, the inventory agency should compare them to the IPCC defaults, and explain and document differences.
- The inventory agency should compare the emission factors used with site or plant level factors, if these are available. This type of comparison provides an indication of how reasonable and representative the national factor is.

#### Review of direct measurements

- If direct measurements are used, the inventory agency should ensure that they are made according to good measurement practices including appropriate QA/QC procedures. Direct measurements should be compared to the results derived from using IPCC default factors.

#### Activity data check

- The inventory agency should compare energy statistics with those provided to international organisations to identify any inconsistencies that require explanation.
- If secondary data from national organisations are used, the inventory agency should ensure that these organisations have appropriate QA/QC programmes in place.

#### External review

- The inventory agency should carry out a review involving national experts and stakeholders in the different fields related to emissions from stationary sources, such as: energy statistics, combustion efficiencies for different sectors and equipment types, fuel use and pollution controls. In developing countries, expert review of emissions from biomass combustion is particularly important.

# 2.3 MOBILE COMBUSTION: ROAD VEHICLES

## 2.3.1 Methodological issues

Road transport emits significant amounts of carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$), as well as several other pollutants such as carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), sulfur dioxide ($SO_2$), particulate matter (PM) and oxides of nitrate ($NO_x$), which cause or contribute to local or regional air pollution problems. This chapter covers *good practice* in the development of estimates for the direct greenhouse gases $CO_2$, $CH_4$ and $N_2O$.

### 2.3.1.1 CHOICE OF METHOD

Emissions of $CO_2$ are best calculated on the basis of the amount and type of fuel combusted and its carbon content. Emissions of $CH_4$ and $N_2O$ are more complicated to estimate accurately because emission factors depend on vehicle technology, fuel and operating characteristics. Both distance-based activity data (e.g. vehicle-kilometers travelled) and disaggregated fuel consumption may be considerably less certain than overall fuel consumption.

Figure 2.4, Decision Tree for $CO_2$ Emissions from Road Vehicles and Figure 2.5, Decision Tree for $CH_4$ and $N_2O$ Emissions from Road Vehicles outline the process to calculate emissions from the Transport Sector. Two alternative approaches can be used, one based on vehicle kilometres travelled and the other based on fuel consumption. The inventory agency should choose the method on the basis of the existence and quality of data. Models can help ensure consistency and transparency because the calculation procedures are fixed in the software. It is *good practice* to clearly document any modifications to standardised models.

**Figure 2.4 Decision Tree for $CO_2$ Emissions from Road Vehicles**

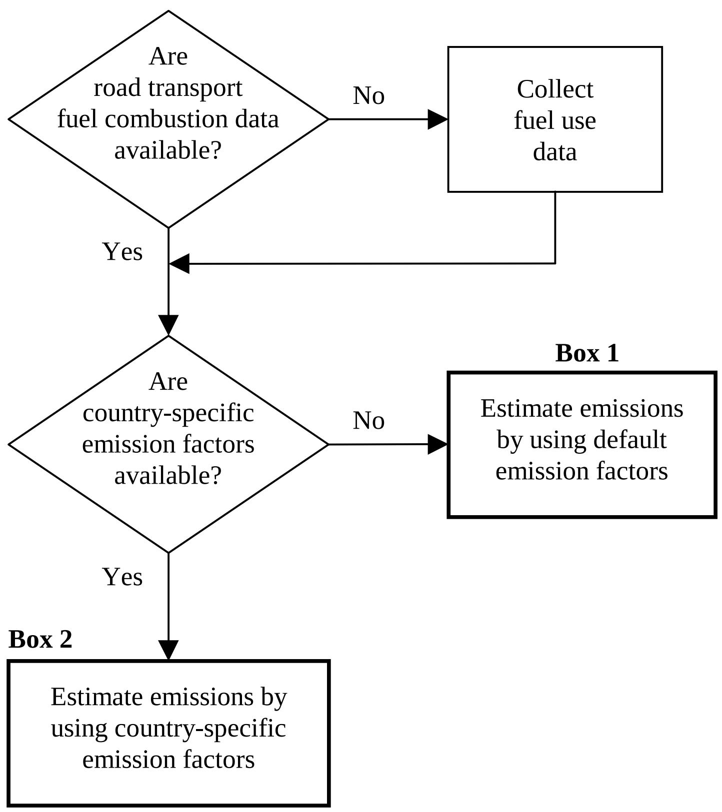
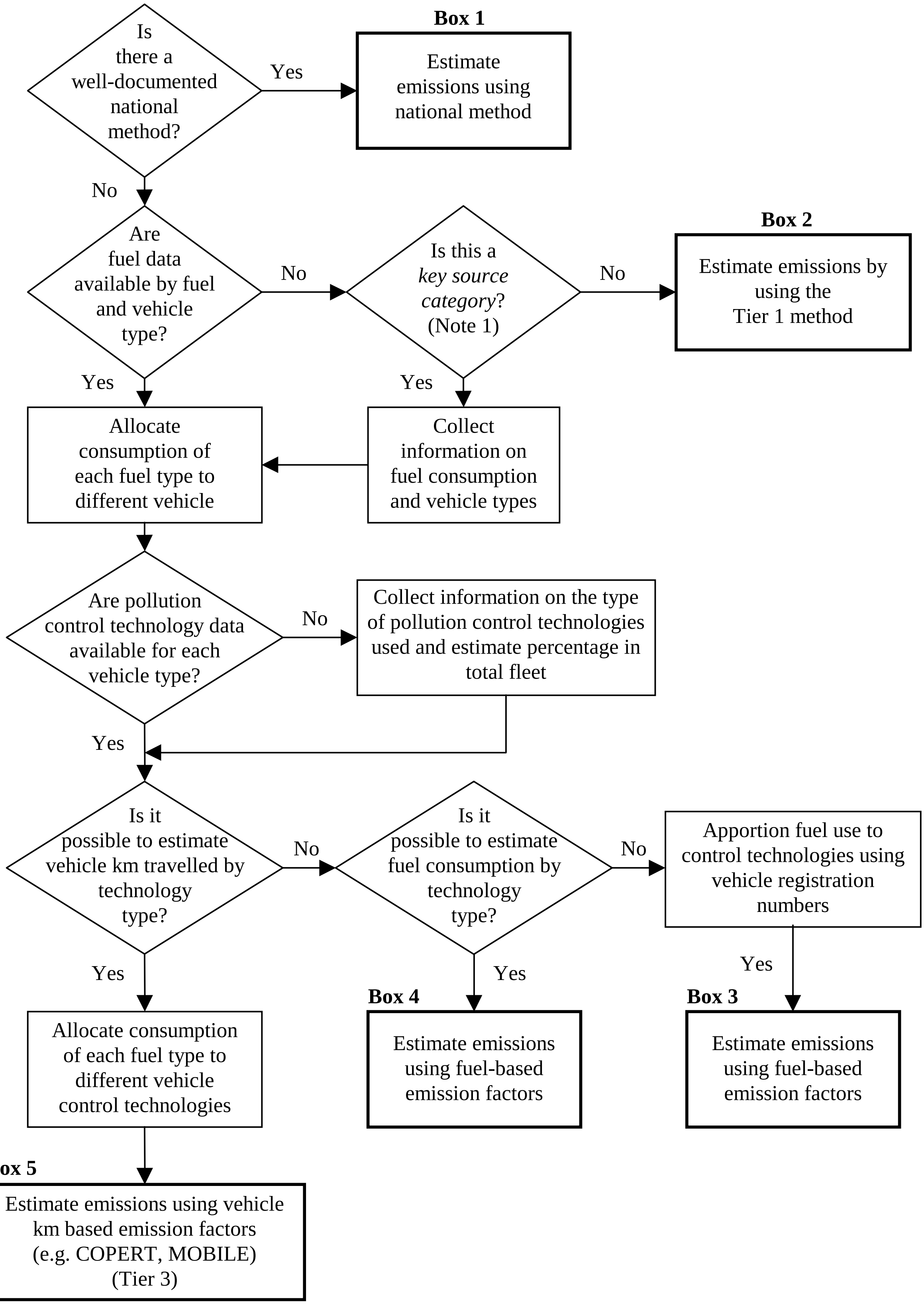


**Figure 2.5 Decision Tree for $CH_4$ and $N_2O$ Emissions from Road Vehicles**




**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

**Note 2:** The decision tree and *key source category* determination should be applied to methane and nitrous oxide emissions separately.

## $CO_2$ EMISSIONS

The *IPCC Guidelines* provide two methods to estimate $CO_2$ emissions from Road Transport. The Tier 1, or 'top down' approach calculates $CO_2$ emissions by estimating fuel consumption in a common energy unit, multiplying by an emission factor to compute carbon content, computing the carbon stored, correcting for unoxidised carbon and finally converting oxidised carbon to $CO_2$ emissions. The approach is shown in Equation 2.4.

**EQUATION 2.4**

$$\text{Emissions} = \sum_j [(\text{Emission Factor}_j \bullet \text{Fuel consumed}_j) - \text{Carbon Stored}] \bullet \text{Fraction Oxidised}_j \bullet 44/12$$

Where j = fuel type

Alternatively, a Tier 2, or 'bottom-up' approach estimates emissions in two steps. The first step (Equation 2.5) is to estimate fuel consumed by vehicle type i and fuel type j.

**EQUATION 2.5**

$$\text{Fuel Consumption}_{ij} = n_{ij} \bullet k_{ij} \bullet e_{ij}$$

Where:

i = vehicle type

j = fuel type

n = number of vehicles

k = annual kilometres travelled per vehicle

e = average litres consumed per kilometre travelled

The second step is to estimate total $CO_2$ emissions by multiplying fuel consumption by an appropriate emission factor for the fuel type and vehicle type (Equation 2.6).

**EQUATION 2.6**

$$\text{Emissions} = \sum_i \sum_j (\text{Emission Factor}_{ij} \bullet \text{Fuel Consumption}_{ij})$$

It is *good practice* to calculate $CO_2$ emissions on the basis of fuel consumption statistics using the Tier 1 (top down) approach. This is illustrated in the decision tree in Figure 2.4, Decision Tree for $CO_2$ Emissions from Road Vehicles. Except in rare cases (e.g. where there is extensive fuel smuggling), the top-down approach is more reliable for $CO_2$ estimates and is also much simpler to implement. The main issue is to ensure that double counting of agricultural and off-road vehicles is avoided.

It is also *good practice* to use the Tier 2 (bottom up) approach in parallel for the following reasons:

- First, use of these two approaches provides an important quality check. Significant differences between the results of the top-down and bottom-up approaches indicate that one or both approaches may have errors, and there is a need for further analysis. Areas of investigation to pursue when reconciling top down and bottom-up approaches are listed in Section 2.3.3, Inventory quality assurance/quality control (QA/QC).
- Second, a reliable and accurate bottom-up $CO_2$ emissions estimate increases confidence in the underlying activity data used for the bottom-up inventory. These in turn are important underpinnings for the 'bottom-up' calculation of $CH_4$ and $N_2O$ emissions from road transport.

When calculating emissions using both the top-down and bottom-up approaches in parallel, it is *good practice*, where feasible, to develop the bottom-up estimates independently from the top-down estimates.

### $CH_4$ AND $N_2O$ EMISSIONS

$CH_4$ and $N_2O$ emissions depend primarily on the distribution of emission controls in the fleet. *Good practice* is to use a bottom-up approach taking into account the various emission factors for different pollution control technologies. This approach should be applied if this is a *key source category*, as defined in Chapter 7, Methodological Choice and Recalculation.

## 2.3.1.2 CHOICE OF EMISSION FACTORS

In the *IPCC Guidelines*, $CO_2$ emission factors are developed on the basis of the carbon content of the fuel. It is *good practice* to follow this approach using country-specific data if possible. Default emission factors provided in the *IPCC Guidelines* may be used if there are no locally available data.

Developing emission factors for $CH_4$ and $N_2O$ is more difficult because these pollutants require technology-based emission factors rather than aggregate default emission factors. It is *good practice* to calculate an emission factor for each fuel type and vehicle type (e.g. passenger cars, light trucks, heavy trucks, motorcycles) based on the local mix of engine types and the distribution of installed control technologies. Further refinements in the factors can then be made if additional local data (e.g. on average driving speeds, temperatures, altitude, pollution control devices) are available. It is *good practice* to document the basis for the data.

Recently published data indicate that the default emission factors in the *IPCC Guidelines* for US gasoline vehicles should be updated.[12] Based on this test data, the $N_2O$ emission factors in the *IPCC Guidelines* for US vehicles (Tables I-27, Estimated Emission Factors for US Gasoline Passenger Cars to Table I-33, Estimated Emission Factors for US Motorcycles in the Reference Manual) should be replaced by the tables below.

**TABLE 2.7**

**UPDATED EMISSION FACTORS FOR USA GASOLINE VEHICLES**

| Control Technology | Emission Factor | |
|---|---|---|
| | (g $N_2O$/kg fuel) | (g $N_2O$/MJ) |
| Low Emission Vehicle (low sulfur fuel) | 0.20 | 0.0045 |
| Three-Way Catalyst (USA Tier 1) | 0.32 | 0.0073 |
| Early Three-Way Catalyst (USA Tier 0) | 0.54 | 0.012 |
| Oxidation Catalyst | 0.27 | 0.0061 |
| Non-Catalyst Control | 0.062 | 0.0014 |
| Uncontrolled | 0.065 | 0.0015 |

Source: Harvey Michael, (1999), US Environmental Protection Agency. Personal communication to Michael Walsh.

Notes:
Tier 0 and Tier 1 in this table refer to tiers used in the USA methodology, not to the IPCC tiers. These data have been rounded to two significant digits.

A database of technology dependent emission factors based on European data is available in the Copert tool at http://etc-ae.eionet.eu.int/etc-ae/index.htm.

To convert to g/km, multiply emission factor (g/kg) by the fuel density in kg/l and then divide by fuel economy in km/l. For example, if the emission factor is 0.32 g/kg, fuel density is 0.75 kg/l and fuel economy is 10 km/l, then the emission factor in g/km is (0.32 g/kg • 0.75 kg/l) / 10 km/l = 0.024 g/km.

In the *IPCC Guidelines*, Tables 1-37, Estimated Emission Factors for European Diesel Passenger Cars, to Table 1-39, Estimated Emission Factors for European Diesel Heavy-duty Vehicles, list $N_2O$ emission factors for European diesels of 0.01, 0.02, and 0.03 g/km for cars, light trucks, and heavy duty vehicles respectively. These factors are order of magnitude estimates roughly following fuel economy differences. Emission factors from other countries may differ from the data provided in Table 2.7. The average value 0.172 g/kg is recommended for all USA diesel vehicles regardless of control technology**.** This corresponds to 0.0039 g/MJ, assuming 44 MJ/kg.

12 In order to refine the $N_2O$ emission factors, the USEPA Office of Mobile Sources carried out an evaluation of available data supplemented by limited testing in June and July 1998. They determined emission factors for Early Three-Way Catalyst and previous vehicles primarily from the published literature. For (advanced) Three-Way Catalyst vehicles and Low-Emission Vehicle Technology, data were used from the testing program. USEPA also assessed the limited data that exist for trucks.

### 2.3.1.3 CHOICE OF ACTIVITY DATA

The first step in estimating $CO_2$ emissions using the top-down approach is to determine total fuel use in the transportation sector by major fuel type. These data should be available from national energy statistics. Following this, several issues must be addressed, including:

- Provision of data for fuels with minor distribution such as compressed natural gas or biofuels. These data should also be available from the national authority responsible for the energy statistics. According to the *IPCC Guidelines*, $CO_2$ emissions from biofuels are reported as memo items but not included in national totals. Non-$CO_2$ emissions from biofuels should be included in national totals.
- Provision of data to distinguish between fuel use for on-road vehicles from fuel use for off-road vehicles, which are reported in different source categories in the *IPCC Guidelines*. Two alternatives are suggested:
  - (i) A bottom-up calculation of fuel used by each road vehicle type. The difference between the road vehicle total (bottom-up) and the total transportation fuel used is ascribed to the off-road sector; or
  - (ii) The bottom-up calculation of fuel used by each road type is supplemented by special studies to determine off-road fuel use. The total fuel use in the transportation sector (top-down estimate) is then disaggregated according to each vehicle type and the off-road sector in proportion to the bottom-up estimates.
- Data for fuel that is sold for transportation uses but which then may be used for other purposes (or the opposite).
- Estimates of smuggling of fuels into or out of a country.

Some inventory agencies have or will have greater confidence in vehicle fuel consumption data by vehicle type and technology while others prefer vehicle kilometres. Either approach is acceptable so long as the basis for the estimates is clearly documented.

If non-$CO_2$ emissions from mobile sources are a *key source category*, more information is needed on factors that influence emissions such as:

- Vehicle type (cars, light duty trucks, heavy duty trucks and motorcycles) distribution in fleet;
- Emission control technologies fitted to vehicle types in the fleet;
- Fleet age distribution;
- Climate;
- Altitude of operation;
- Maintenance effects.

If the distribution of fuel use by vehicle and fuel type is unknown, it should be estimated based on the number of vehicles by type. If the number of vehicles by vehicle and fuel type is not known, it must be estimated from national statistics. If local data on annual kilometres travelled per vehicle and average fuel economies by vehicle and fuel type are available, they should be used.

### 2.3.1.4 COMPLETENESS

Lubricants should be accounted for in other emissions categories, as very little is combusted directly in the transportation sector.

Regarding the problem of purchase and consumption of fuels in different countries (i.e. fuel in tanks that are crossing a border) and the question of allocation, the *IPCC Guidelines* state: 'Emissions from road vehicles should be attributed to the country where the fuel is loaded into the vehicle.'

Oxygenates and other blending agents should be carefully accounted for in making $CO_2$ estimates, if used in large quantities. It is important that all fossil carbon is accounted for, and that carbon from biomass is reported as a memo item but not included in national $CO_2$ totals, as required by the *IPCC Guidelines*.

### 2.3.1.5 DEVELOPING A CONSISTENT TIME SERIES

With the use of models and updates or revisions of models, it is important that time series remain consistent. When models are revised, it is *good practice* to recalculate the complete time series. A consistent time series with regard to initial collection of fleet technology data could be difficult. Extrapolation, possibly supported by the use of proxy data will be necessary in this case for early years. Inventory agencies should refer to the discussion Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques for general guidance.

### 2.3.1.6 UNCERTAINTY ASSESSMENT

Carbon dioxide is usually responsible for over 97% of the $CO_2$-equivalent emissions from the transportation sector.[13] Expert judgement suggests that the uncertainty of the $CO_2$ estimate is approximately ±5%, based on studies with reliable fuel statistics.[14] The primary source of uncertainty is the activity data rather than emission factors.

Nitrous oxide usually contributes approximately 3% to the $CO_2$-equivalent emissions from the transportation sector. Expert judgement suggests that the uncertainty of the $N_2O$ estimate may be more than ±50%.The major source of uncertainty is related to the emission factors.

Methane usually contributes less than 1% of the $CO_2$-equivalent emissions from the transportation sector. Experts believe that there is an uncertainty of ±40% in the $CH_4$ estimate. The major source of uncertainty is again emission factors.

To reduce uncertainty, a comprehensive approach is needed that reduces uncertainties of emission factors as well as activity data, especially with regard to the bottom-up approach. By encouraging the use of locally estimated data, inventories will improve despite the large uncertainties that may surround national data.

Chapter 6, Quantifying Uncertainties in Practice, describes how to use national empirical data and expert judgement to estimate uncertainties, and how to combine uncertainty estimates for the inventory as a whole.

## 2.3.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Section 8.10.1 of Chapter 8, Quality Assurance and Quality Control.

It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

Confidentiality is not likely to be a major issue with regard to road emissions, although it is noted that in some countries the military use of fuel may be kept confidential. The composition of some additives is confidential, but this is only important if it influences greenhouse gas emissions.

## 2.3.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8 and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory agencies are encouraged to use higher tier QA/QC for *key source categories* as identified in Chapter 7, Methodological Choice and Recalculation.

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[13] According to 1990 data for Annex I countries in the UNFCCC secretariat's database on GHG emissions, updated September 1999.

[14] The percentages cited in this section represent an informal polling of assembled experts aiming to approximate the 95% confidence interval around the central estimate.

In addition to the guidance in Chapter 8, specific procedures of relevance to this source category are outlined below.

**Comparison of emissions using alternative approaches**

For $CO_2$ emissions, the inventory agency should compare estimates using both the top-down and bottom-up approaches. Any anomalies between the emission estimates should be investigated and explained. The results of such comparisons should be recorded for internal documentation. Revising the following assumptions could narrow a detected gap between the approaches:

- Off-road/non transportation fuel uses;
- Annual average vehicle mileage;
- Vehicle fuel efficiency;
- Vehicle breakdowns by type, technology, age, etc.;
- Use of oxygenates/biofuels/other additives;
- Fuel use statistics;
- Fuel sold/used.

**Review of emission factors**

If IPCC default factors are used, the inventory agency should ensure that they are applicable and relevant to the categories. If possible, the IPCC default factors should be compared to local data to provide further indication that the factors are applicable.

For non-$CO_2$ emissions, the inventory agency should ensure that the original data source for the local factors is applicable to the category and that accuracy checks on data acquisition and calculations have been performed. Where possible, the IPCC default factors and the local factors should be compared. If the IPCC default factors were used to estimate $N_2O$ emissions, the inventory agency should ensure that the revised emission factors in Table 2.7, Updated Emission Factors for USA Gasoline Vehicles were used in the calculation.

**Activity data check**

The inventory agency should review the source of the activity data to ensure applicability and relevance to the category. Where possible, the inventory agency should compare the data to historical activity data or model outputs to look for anomalies. The inventory agency should ensure the reliability of activity data regarding fuels with minor distribution, fuel used for other purposes, on and off-road traffic, and illegal transport of fuel in or out of the country. The inventory agency should also avoid double counting of agricultural and off-road vehicles.

**External review**

The inventory agency should perform an independent, objective review of the calculations, assumptions, and documentation of the emissions inventory to assess the effectiveness of the QC programme. The peer review should be performed by expert(s) who are familiar with the source category and who understand the inventory requirements. The development of the factors for the non-$CO_2$ emission estimates is particularly important due to the associated uncertainty.

# 2.4 MOBILE COMBUSTION: WATER-BORNE NAVIGATION

## 2.4.1 Methodological issues

This source category includes all emissions from fuels used to propel water-borne vessels, including hovercraft and hydrofoils. Water-borne navigation gives rise to emissions of carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$), as well as carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), sulfur dioxide ($SO_2$), particulate matter (PM) and oxides of nitrate ($NO_x$). This section focuses on the direct greenhouse gases $CO_2$, $CH_4$, and $N_2O$.

Parties to the UNFCCC have not made a final decision yet on the allocation to national GHG inventories of emissions from fuels used for international aviation and from international marine bunkers. For the moment, all emissions from these fuels are to be excluded from national totals, and are to be reported separately.

### 2.4.1.1 CHOICE OF METHOD

The *IPCC Guidelines* present two methodological tiers for estimating emissions of $CO_2$, $CH_4$, and $N_2O$ from water-borne navigation. Both Tier 1 and Tier 2 rely on essentially the same analytical approach which is to apply emission factors to fuel consumption activity data. The fuel consumption data and emission factors in the Tier 1 method are fuel type and mode-specific (e.g. oil used for navigation). The Tier 2 method presents a variety of emission factors based on research in the United States and Europe, requiring varying degrees of specificity in the classification of modes (e.g. ocean-going ships and boats), fuel type (e.g. gasoline), and even engine type (e.g. diesel). Figure 2.6, Decision Tree for Emissions from Water-borne Navigation helps in making a choice between the two tiers.

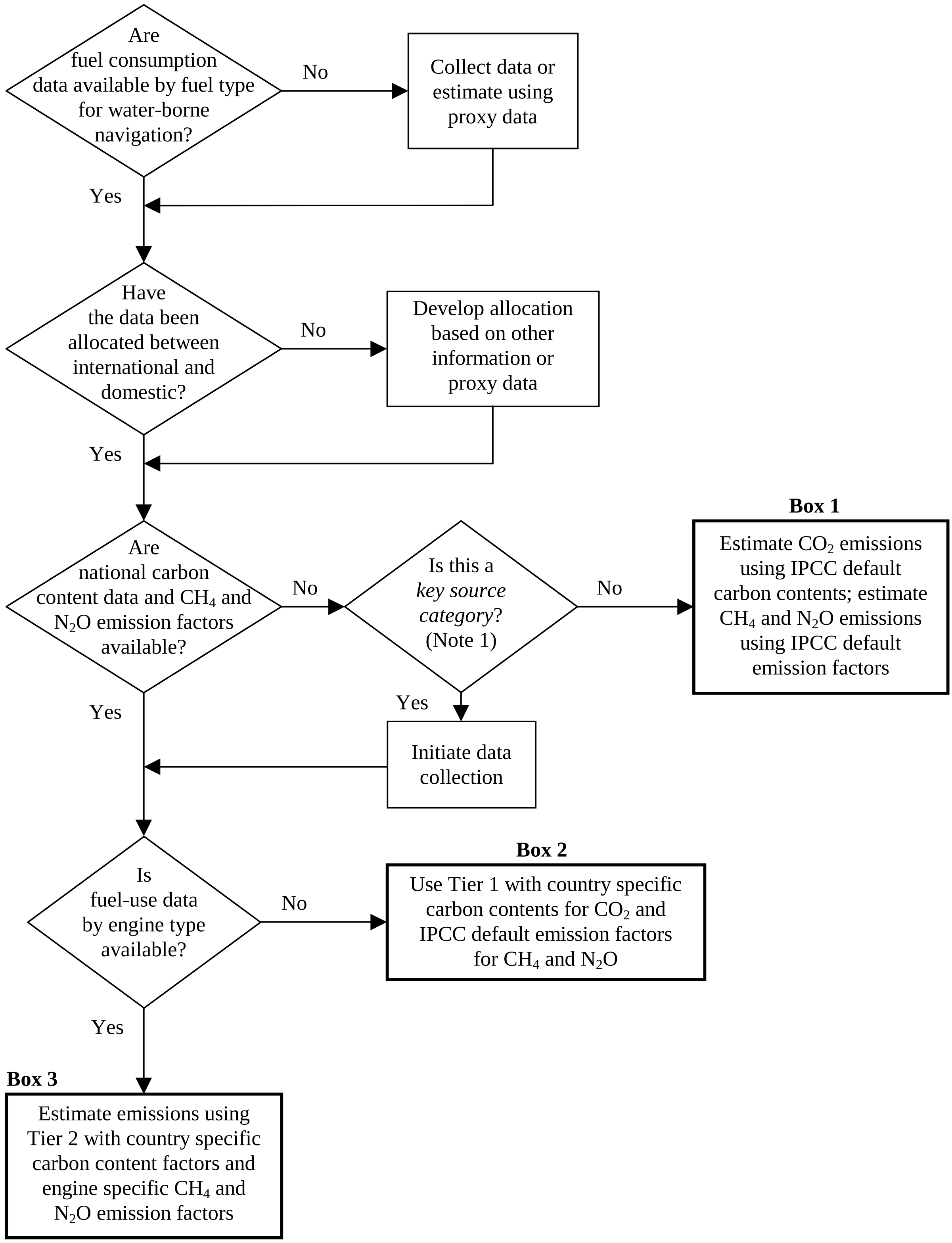
*Good practice* is to use Tier 1 for $CO_2$, and Tier 2 for $CH_4$ and $N_2O$. Tier 1 for $CO_2$ emissions is based on fuel consumption by fuel type, the carbon content of the fuel, and the fraction of the fuel left unoxidised. Tier 2 for non-$CO_2$ emissions also uses fuel consumption by fuel type, but provides a variety of generic and country-specific emission factors for selected fuel, engine, and vehicle types. National approaches may also be *good practice* if they are well documented and have been peer reviewed.

Until the uncertainties in the $CH_4$ and $N_2O$ emission factors are reduced, more detailed methods will not necessarily reduce uncertainties in the emission estimates. Despite this limited reduction in uncertainty, however, these methods are likely to be desirable in the longer term for a number of other reasons. One reason is to harmonise with other emission inventory efforts that are more detailed. More detailed methods are also better able to account for changes in technologies and therefore emission factors in the future. If improved engine-specific and fuel-specific emission factors become available, a historic database of disaggregated fuel use will allow the backcasting of a trend to the base year.

#### MILITARY

The *IPCC Guidelines* do not provide a distinct method for calculating military marine emissions. Emissions from military marine fuel use can be estimated using the same 'hybrid' approach recommended for non-military shipping (i.e. Tier 1 approach for $CO_2$, Tier 2 approach for $CH_4$ and $N_2O$). However, military marine navigation may include unique operations, situations, and technologies without a civilian analogue (e.g. aircraft carriers, very large auxiliary power plants, and unique engine types). Therefore, inventory agencies should consult military experts to determine the most appropriate emission factors.

**Figure 2.6 Decision Tree for Emissions from Water-borne Navigation**




**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

### 2.4.1.2 CHOICE OF EMISSION FACTORS

Carbon dioxide emission factors are based on the fuel type and carbon content as well as the fraction of fuel left unoxidised. It is *good practice* to use national carbon content and fraction oxidised factors for $CO_2$ when available. Default values can also be used when no other information is available (*IPCC Guidelines*, Workbook, Table 1-2, Carbon Emission Factors and Table 1-4, Fraction of Carbon Oxidised).

There is limited information on the emission factors for $CH_4$ and $N_2O$ from marine shipping. The *IPCC Guidelines* provide factors for the USA and the EU as well as factors developed by Lloyd's Register (Table 1-47, Estimated Emission Factors for US Non-road Mobile Sources to Table 1-49, Estimated Emission Factors for European Non-road Mobile Sources and Machinery, Reference Manual). Large ocean-going cargo ships are driven primarily by large, slow speed and medium speed diesel engines and occasionally by steam and gas turbines. For $CH_4$ and $N_2O$ emissions from large marine diesel engines consuming distillate or residual fuel oils, it is *good practice* to use the factors developed by Lloyd's Register. These factors are based on the most recent and extensive set of test data. As marine shipping engines are predominantly diesel, and do not vary by country, national emission factors are not likely to yield improved emission estimates unless they are based on peer reviewed studies. For other vessels, such as recreational craft on inland waterways, national emission factors should be used if available. Alternatively, the IPCC default factors from Lloyds, the USA or the EU can be used. The difference in emission rates illustrates the importance of characterising fleet engine types and fuel use for regional scale emissions.

#### MILITARY

Currently, emission factors for $N_2O$ and $CH_4$ for military vessels are not available. The default emission factors for civilian shipping should be used unless national data are available of sufficient quality, taking into account the advice in Chapter 8, Quality Assurance and Quality Control.

### 2.4.1.3 CHOICE OF ACTIVITY DATA

Data on fuel consumption by fuel type and (for $N_2O$ and $CH_4$) engine type are required to estimate emissions. In addition, in the current reporting procedures, emissions from domestic water-borne navigation are reported separately from international navigation which requires disaggregating the activity data to this level. For consistency, it is *good practice* to use similar definitions of domestic and international activities in the aviation and water-borne navigation estimates. These definitions are presented in Table 2.8, Criteria for Defining International or Domestic Marine Transport, and are consistent with the *IPCC Guidelines*. They are more precise, however, in order to make them workable with respect to the sources of activity data. The definitions in Table 2.8 are independent of the nationality or flag of the carrier.

**TABLE 2.8**

**CRITERIA FOR DEFINING INTERNATIONAL OR DOMESTIC MARINE TRANSPORT**

| Journey Type | Domestic | International |
|---|---|---|
| Originates and terminates in same country | Yes | No |
| Departs from one country and arrives in another | No | Yes |
| Departs in one country, makes a 'technical' stop in the same country without dropping or picking up any passengers or freight, then departs again to arrive in another country | No | Yes |
| Departs in one country, stops in the same country and drops and picks up passengers or freight, then departs finally arriving in another country | Domestic segment | International segment |
| Departs in one country, stops in the same country and only picks up more passengers or freight and then departs finally arriving in another country | No | Yes |
| Departs in one country with a destination in another country, and makes an intermediate stop in the destination country where no passengers or cargo are loaded | No | Both segments international |

Fuel use data may be obtained using several approaches. The most feasible approach will depend on the national circumstances, but some of the options provide more accurate results than others. Several likely sources of actual fuel or proxy data are listed below, in order of typically decreasing reliability:

- National energy statistics from energy or statistical agencies;
- Surveys of shipping companies;
- Surveys of fuel suppliers (e.g. quantity of marine fuels delivered to port facilities);
- Surveys of individual port and marine authorities;
- Surveys of fishing companies;
- Equipment counts, especially for small gasoline powered fishing and pleasure craft;
- Import/export records;
- Ship movement data and standard passenger and freight ferry schedules;
- Passenger counts and cargo tonnage data;
- International Maritime Organisation (IMO), engine manufacturers, or Jane's Military Ships Database.

It may be necessary to combine these data sources to get full coverage of shipping activities.

#### MILITARY

Due to confidentiality issues (see completeness and reporting), many inventory agencies may have difficulty obtaining data for the quantity of fuel used by the military. Military activity is defined here as those activities using fuel purchased by or supplied to the military authority of the country. It is *good practice* to apply the rules defining civilian national and international operations in navigation to military operations where they are comparable. Where they are not comparable, decisions on national and international operations should be explained. Data on military fuel use may be obtained from government military institutions or fuel suppliers. If data on fuel split are unavailable, all the fuel sold for military activities should be treated as domestic.

According to Decision 2/CP3 of the Conference of the Parties (COP), multilateral operations should not be included in national totals but reported separately, although there is no clear operational definition of ‘multilateral operation’ available at this time.

### 2.4.1.4 COMPLETENESS

For water-borne navigation emissions, the methods are based on total fuel use. Since countries generally have effective accounting systems to measure total fuel consumption, the largest area of possible incomplete coverage of this source category is likely to be associated with misallocation of navigation emissions in another source category. For instance, for small watercraft powered by gasoline engines, it may be difficult to obtain complete fuel use records and some of the emissions may be reported as industrial (when industrial companies use small watercraft), other off-road mobile or stationary power production. Estimates of water-borne emissions should include not only fuel for marine shipping, but also for passenger vessels, ferries, recreational watercraft, other inland watercraft, and other gasoline-fuelled watercraft. Misallocation will not affect completeness of the total $CO_2$ emissions inventory. It will affect completeness of the total non-$CO_2$ emissions inventory, because non-$CO_2$ emission factors differ between source categories.

Completeness may also be an issue where military data are confidential, unless military fuel use is aggregated with another source category.

There are additional challenges in distinguishing between domestic and international emissions. As each country's data sources are unique for this category, it is not possible to formulate a general rule regarding how to make an assignment in the absence of clear data. *Good practice* is to specify clearly the assumptions made so that the issue of completeness can be evaluated.

### 2.4.1.5 DEVELOPING A CONSISTENT TIME SERIES

For *good practice* guidance on determining base year emissions and ensuring consistency in the time series, see Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques. It is *good practice* to determine fuel use using the same method for all years. If this is not possible, data collection should overlap sufficiently in order to check for consistency in the methods employed.

If it is not possible to collect activity data for the base year (e.g. 1990), it may be appropriate to extrapolate data backwards using trends in freight and passenger kilometres, total fuel used or supplied, or import/export records.

Emissions of $CH_4$ and $N_2O$ will depend on engine type and technology. Unless technology-specific emission factors have been developed, it is *good practice* to use the same fuel-specific set of emission factors for all years.

Mitigation activities resulting in changes in overall fuel consumption will be readily reflected in emission estimates if actual fuel activity data are collected. Mitigation options that affect emission factors, however, can only be captured by using engine-specific emission factors, or by developing control technology assumptions. Changes in emission factors over time should be well documented.

### 2.4.1.6 UNCERTAINTY ASSESSMENT

#### ACTIVITY DATA

Much of the uncertainty in emissions estimates is related to the difficulty of distinguishing between domestic and international fuel consumption. With complete survey data, the uncertainty may be low, while for estimations or incomplete surveys the uncertainties may be considerable. The uncertainty will vary widely from country to country and is difficult to generalise. The use of global data sets may be helpful in this area, and it is expected that reporting will improve for this category in the future.

#### EMISSION FACTORS

Experts believe that $CO_2$ emission factors for fuels are generally well determined within ±5%, as they are primarily dependent on the carbon content of the fuel.[15] The uncertainty for non-$CO_2$ emissions, however, is much greater. The uncertainty of the $CH_4$ emission factor may be as a high as a factor of two. The uncertainty of the $N_2O$ emission factor may be an order of magnitude (i.e. a factor of 10).

## 2.4.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Section 8.10.1 of Chapter 8, Quality Assurance and Quality Control.

It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

Some examples of specific documentation and reporting issues relevant to this source category are provided below.

Emissions related to water-borne navigation are reported in different categories depending on their nature. For *good practice*, the categories to use are:

- Civilian domestic activities;
- Military domestic activities;
- International bunker fuels;
- Fishing.

The *IPCC Guidelines* require that emissions from international navigation be reported separately from domestic, and not be included in the national total.

Emissions related to commercial fishing are not reported under water-borne navigation. These emissions are to be reported under the Agriculture/Forestry/Fishing category in the Energy sector. By definition, all fuel supplied to commercial fishing activities in the reporting country is considered domestic, and there is no international bunker fuel category for commercial fishing, regardless of where the fishing occurs.

Military marine emissions should be clearly specified to improve the transparency of national greenhouse gas inventories.

[15] The uncertainty ranges cited in this section represent an informal polling of assembled experts aiming to approximate the 95% confidence interval around the central estimate.

In addition to reporting emissions, it is *good practice* to provide:

- Source of fuel and other data;
- Method used to separate domestic and international navigation;
- Emission factors used and their associated references;
- Analysis of uncertainty or sensitivity of results or both to changes in input data and assumptions.

## 2.4.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8 and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory agencies are encouraged to use higher tier QA/QC for *key source categories* as identified in Chapter 7, Methodological Choice and Recalculation.

In addition to the guidance in Chapter 8, specific procedures of relevance to this source category are outlined below.

#### Comparison of emissions using alternative approaches

If possible, the inventory agency should compare estimates determined for water-borne navigation using both Tier 1 and Tier 2 approaches. The inventory agency should investigate and explain any anomaly between the emission estimates. The results of such comparisons should be recorded.

#### Review of emission factors

The inventory agency should ensure that the original data source for national factors is applicable to each category and that accuracy checks on data acquisition and calculations have been performed. For the IPCC default factors, the inventory agency should ensure that the factors are applicable and relevant to the category. If possible, the IPCC default factors should be compared to national factors to provide further indication that the factors are applicable and reasonable.

If emissions from military use were developed using data other than default factors, the inventory agency should check the accuracy of the calculations and the applicability and relevance of the data.

#### Check of activity data

The source of the activity data should be reviewed to ensure applicability and relevance to the category. Where possible, the data should be compared to historical activity data or model outputs to look for anomalies. Data could be checked with productivity indicators such as fuel per unit of marine traffic performance (freight and passenger kilometres) compared with other countries.

In preparing the inventory estimates, the inventory agency should take steps to ensure reliability of the activity data used to allocate emissions between domestic and international water-borne navigation and to ensure that all fuel sold in the country for water-borne navigation is accounted for in the estimates. A comparison of the activity data should be conducted between multiple references due to the high uncertainty associated with this data.

#### External review

The inventory agency should carry out an independent, objective review of calculations, assumptions or documentation or both of the emissions inventory to assess the effectiveness of the QC programme. The peer review should be performed by expert(s) who are familiar with the source category and who understand national greenhouse gas inventory requirements.

# 2.5 MOBILE COMBUSTION: AIRCRAFT

## 2.5.1 Methodological issues

The IPCC source category for civil aviation includes emissions from all civil commercial use of airplanes (international and domestic) consisting of scheduled and charter traffic for passengers and freight, including air taxiing, as well as general aviation[16] (e.g. agricultural airplanes, private jets or helicopters). Methods discussed in this section can be used also to estimate emissions from military aviation, but emissions should be reported under the IPCC category 1A 5 'Other'. Stationary combustion and ground transport at airports are to be included in other appropriate categories.

Aircraft emit carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$), as well as carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), sulfur dioxide ($SO_2$), particulate matter (PM) and nitrogen oxides ($NO_x$). This section focuses on the direct greenhouse gases $CO_2$, $CH_4$ and $N_2O$. For more information on the impact of aviation on the global atmosphere see IPCC (1999).

Parties to the UNFCCC have not made a final decision yet on the allocation to national GHG inventories of emissions from fuels used for international aviation and from international marine bunkers. For the moment, all emissions from these fuels are to be excluded from national totals, and are to be reported separately.

### 2.5.1.1 CHOICE OF METHOD

One Tier 1 and two Tier 2 methods (designated Tier 2a and 2b) are outlined in the *IPCC Guidelines*. All methods are based on distinguishing between domestic fuel use and international fuel use. Tier 1 is purely fuel based, while the Tier 2 methods are based on the number of landing/take-off cycles (LTOs) and fuel use. The $CO_2$ estimate depends on carbon content of fuel and the fraction oxidised and therefore should not vary significantly with the tier. Given the current limited knowledge of emission factors, more detailed methods will not significantly reduce uncertainties for $CH_4$ and $N_2O$ emissions. However, reasons for choosing to use a higher tier include estimation of emissions jointly with other pollutants (e.g. $NO_x$), harmonisation of methods with other inventories, and the possibility of accounting for changes in technologies (and therefore emission factors) in the future.

All three methods will capture changes in technology that influence fuel consumption. However, only Tier 2b can capture the effects on $CH_4$ and $N_2O$ emissions of changing emission factors. National approaches can also be used if they are well documented and have been peer reviewed. The choice of method will depend on national circumstances particularly the availability of data (see the decision trees in Figure 2.7 and Figure 2.8).

The simple Tier 1 method is based on an aggregate figure of fuel consumption for civil aviation multiplied by average emissions factors. The emissions factors have been averaged over all flying phases based on the assumption that 10% of the fuel[17] is used in the LTO[18] (landing/take-off) phase of the flight. Emissions are calculated according to Equation 2.7:

**EQUATION 2.7**

$$\text{Emissions} = \text{Fuel Consumption} \bullet \text{Emission Factor}$$

The Tier 2 method is only applicable for jet fuel use in jet engines. Aviation gasoline is only used in small aircraft and generally represents less than 1% of fuel consumption from aviation. In the Tier 2 method a

16 ICAO's 'Manual on the ICAO Statistics Programme' defines 'general aviation' as all civil operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire. For ICAO statistical purposes, the general aviation activities are classified into instructional flying, business and pleasure flying, aerial work and other flying.

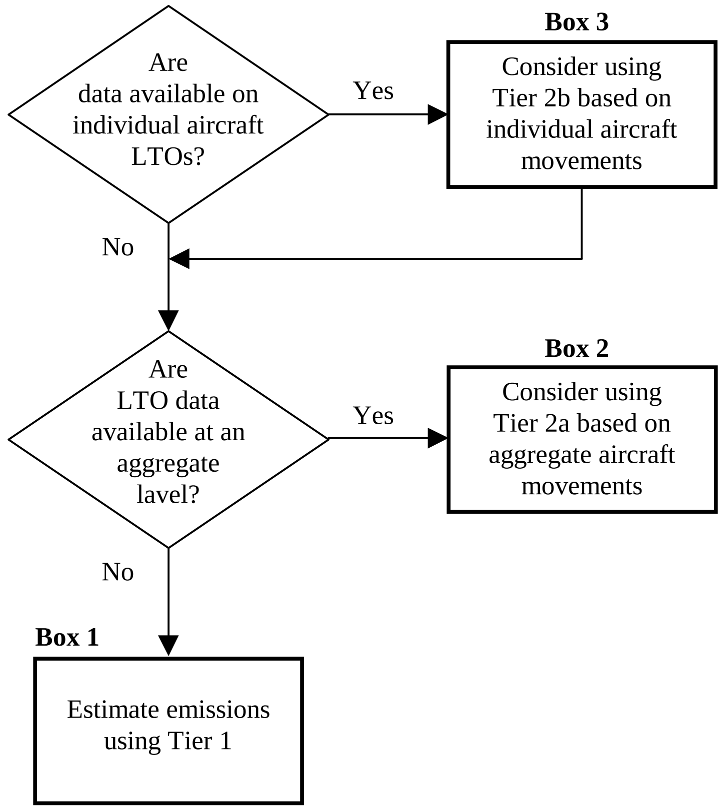
17 Source: Olivier, 1995. This percentage will vary according to national circumstances and countries are encouraged to make their own assessment.

18 Both a single landing together with a single take-off define one LTO operation that includes all activities near the airport that take place under an altitude of 914 m (3000 feet): engines running idle, taxi-in and out, take-off, climbing and descending. Aircraft operations above 914 m are defined as 'cruise'.

distinction is made between emissions below and above 914 m (3000 feet) to increase the accuracy of the estimates as emission factors and fuel use factors vary between phases of the flight. The emissions in these two flying phases are estimated separately, in order to harmonise with methods that were developed for air pollution programmes that cover only emissions below 3000 feet. Emissions and fuel used in the LTO phase are estimated from statistics on the number of LTOs (aggregate or per aircraft type) and default emission factors or fuel use factors per LTO cycle (average or per aircraft type).

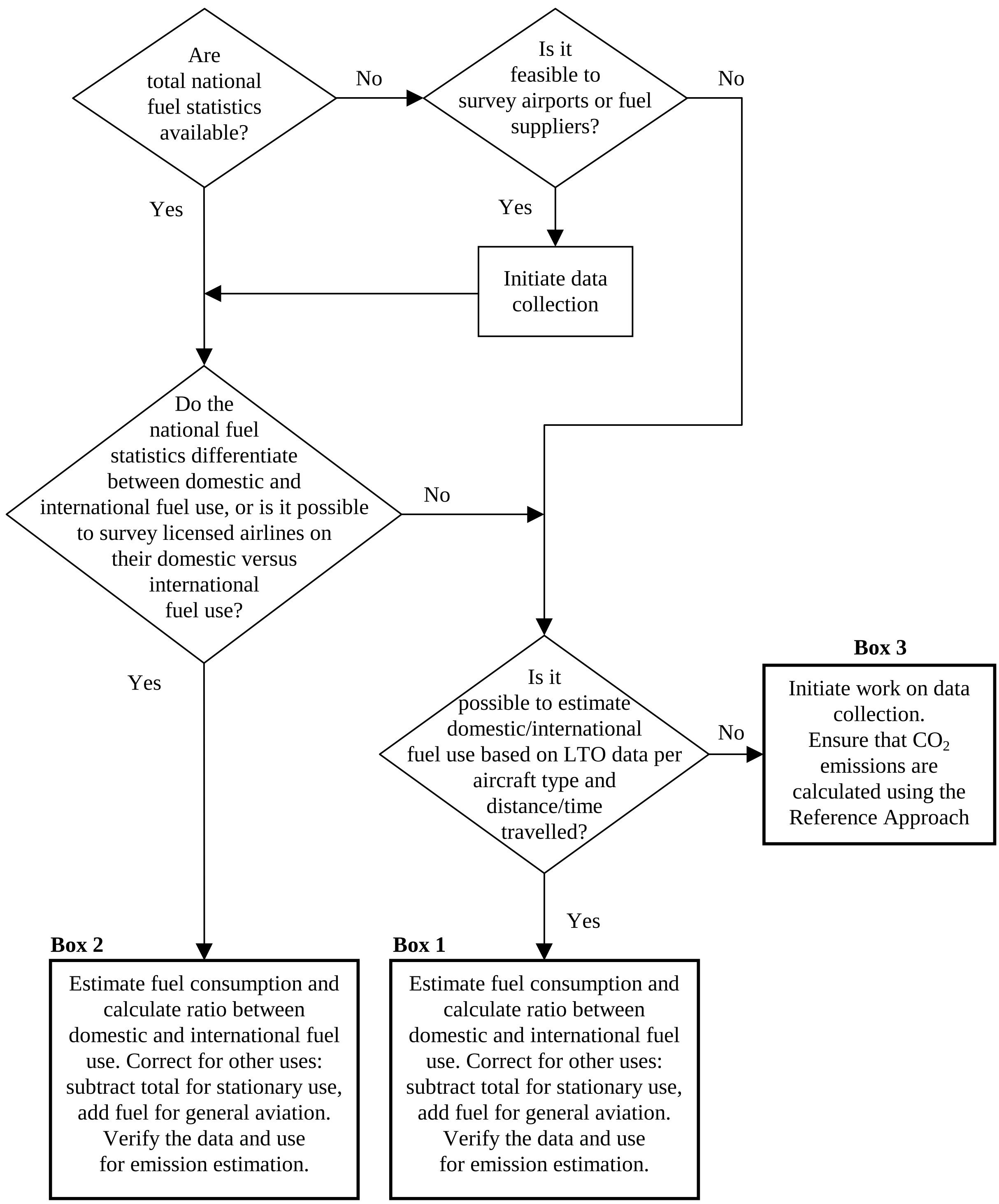
There may be significant discrepancies between the results of a bottom-up approach and a top-down fuel-based approach for aircraft. An example is presented in Daggett *et al*. (1999).

**Figure 2.7 Methodology Decision Tree for Aircraft**




**Note 1:** There is no key source decision in this decision tree because there is no gain in inventory quality by moving from Tier 1 to Tier 2 if activity data are not complete. Inventory agencies should use the most appropriate method, given the availability of data.

**Figure 2.8 Activity Data Decision Tree for Aircraft**



Both Tier 2 approaches use Equations 2.8 to 2.11 to estimate emissions:

**EQUATION 2.8**

$$\text{Emissions} = \text{LTO Emissions} + \text{Cruise Emissions}$$

Where

**EQUATION 2.9**

$$\text{LTO Emissions} = \text{Number of LTOs} \bullet \text{Emission Factor}_{LTO}$$

**EQUATION 2.10**

$$\text{LTO Fuel Consumption} = \text{Number of LTOs} \bullet \text{Fuel Consumption per LTO}$$

**EQUATION 2.11**

$$\text{Cruise Emissions} = (\text{Total Fuel Consumption} - \text{LTO Fuel Consumption}) \bullet \text{Emission Factor}_{CRUISE}$$

These equations can be applied at either the aggregated level of all aircraft (Tier 2a) or at the level of individual aircraft types (Tier 2b). For the Tier 2b approach, the estimate should include all aircraft types frequently used for domestic and international aviation. For the Tier 2a approach, all aircraft are included and the *IPCC Guidelines* provide aggregate emission factors per LTO. The aggregated emission factors are proposed for national and international aviation separately, and for an old and average fleet.

Cruise emissions depend on the length of the flight among other variables. In the Tier 2 method the fuel used in the cruise phase is estimated as total fuel use minus fuel used in the LTO phase of the flight as shown in Equation 2.11. Fuel use is estimated for domestic and international aviation separately. The estimated fuel use is multiplied by aggregate emission factors (average or per aircraft type) in order to estimate the emissions.

The resource demand for the various tiers depends on the number of air traffic movements and the availability of the data in the country. Tier 1 and Tier 2a, based on aggregate LTO data, should not require considerable resources, while Tier 2b, based on individual aircraft, may be very time consuming.

## 2.5.1.2 CHOICE OF EMISSION FACTORS

It is *good practice* to use emission factors from the *IPCC Guidelines*. National emission factors for $CO_2$ should not deviate much from the default values because the quality of jet fuel is well defined. However, there is limited information on the emission factors for $CH_4$ and $N_2O$ from aircraft, and the IPCC default values are similar to values found in the literature. Since aircraft technologies do not vary by country, national emission factors should generally not be used unless based on peer reviewed studies.

Within this sector, different types of aircraft/engine combinations have specific emission factors and these factors may also vary according to distance flown. It has been assumed that all aircraft have the same emission factors for $CH_4$ and $N_2O$ based on the rate of fuel consumption. This assumption has been made because more disaggregated emission factors are not available.

### MILITARY

Emissions from military aviation may be estimated by the Tier 1 approach (total fuel use and average emission factors). However, the term ‘military aircraft’ covers very different technologies (e.g. transport planes, helicopters and fighters) and the use of a more detailed method is encouraged if data are available. No emission factors for $N_2O$ and $CH_4$ have been developed for military aviation. However, many types of military transport aircraft and helicopters have fuel and emissions characteristics similar to civil types. The default emission factors for civil aircraft should be used for military aviation unless better data are available. For fuel use factors see ‘Choice of activity data’ below.

### 2.5.1.3 CHOICE OF ACTIVITY DATA

According to the *IPCC Guidelines*, emissions from domestic aviation are reported separately from international aviation. For this reason, it is necessary to disaggregate fuel use into domestic and international components. Table 2.9, Distinction between Domestic and International Flights presents *good practice* in flight classification. These definitions are a precision of the ones given the *IPCC Guidelines*. These definitions should be applied irrespective of the nationality of the carrier.[19]

**TABLE 2.9**

**DISTINCTION BETWEEN DOMESTIC AND INTERNATIONAL FLIGHTS**

| | **Domestic** | **International** |
|---|---|---|
| Depart and arrive in same country | Yes | No |
| Depart from one country and arrive in another | No | Yes |
| Depart in one country, stop in the same country without dropping or picking up any passengers or freight, then depart again to arrive in another country | No | Yes |
| Depart in one country, stop in the same country and drop and pick up passengers or freight, then depart finally arriving in another country | Domestic stage | International stage |
| Depart in one country, stop in the same country, only pick up more passengers or freight and then depart finally arriving in another country | No | Yes |
| Departs in one country with a destination in another country, and makes an intermediate stop in the destination country where no passengers or cargo are loaded. | No | Both segments international |

For consistency, it is *good practice* to use similar definitions of domestic and international activities in the aviation and water-borne navigation estimates.

Fuel use data distinguished between domestic and international aviation may be obtained in different ways. What is feasible will depend on national circumstances, but some data sources (e.g. energy statistics or surveys) will give more accurate results than others. The following data sources should be evaluated:

Bottom-up data can be obtained from surveys of airline companies for fuel used, or estimates from aircraft movement data and standard tables of fuel consumed or both.

Top-down data can be obtained from national energy statistics or surveys of:

- Airports for data covering the delivery of aviation kerosene and aviation gasoline;
- Fuel suppliers (quantity of aviation fuel delivered);
- Refineries (production of aviation fuels), to be corrected for import and export.

Fuel consumption factors for aircraft (fuel used per LTO and per nautical mile cruised) can be used for estimates and may be obtained from the airline companies. Table 2.10, Fuel Use and Average Sector Distance for Representative Types of Aircraft, shown in Appendix 2.5A.1 shows the data derived for the sixteen aircraft types used to represent the world's commercial passenger fleet in the ANCAT/EC2 global inventory[20] (ANCAT/EC2, 1998) plus three aircraft which subsequently came into revenue service (Falk, 1999). Similar data could be

[19] The treatment of domestic and international aviation, both in the *IPCC Guidelines* and in Table 2.9 above, differs from that recommended to states by the International Civil Aviation Organization for the purposes of classifying flight stages when reporting air carrier statistical data (ICAO, 1997). In this context, ICAO defines as domestic, all flight stages flown between domestic points by an air carrier whose principal place of business is in that state and therefore (i) includes flight stages between domestic points that precede a flight stage to another country, and (ii) excludes flights between domestic points by foreign carriers.

[20] The ANCAT/EC2 global inventory was a programme that was part-funded by the EC to produce a world-wide 3D gridded inventory of fuel used and $NO_x$ produced from civil commercial and bizjet aircraft, cargo planes and military operations. The base year was 1991/92 and the forecast year was 2015. The data were gridded into $1^o \bullet 1^o \bullet 1$ km boxes by summing individual movements. The results of the ANCAT/EC2 and NASA inventories were similar to each other.

obtained from other sources (e.g. EMEP/CORINAIR inventory guidebook, second edition, 1999). The equivalent data for turboprop and piston engine aircraft need to be obtained from other sources. The relationship between actual aircraft and representative aircraft is shown in Table 2.11, Correspondence between Representative Aircraft and Other Aircraft Types in Appendix 2.5A.2.

Aircraft movement data may be obtained from:

- Statistical offices or transport ministries as a part of national statistics;
- Airport records;
- ATC (Air Traffic Control) records, for example EUROCONTROL statistics;
- OAG (Official Airline Guide), published by Reed Publishing (monthly) which contains timetable passenger and freight movements, but does not contain non-scheduled traffic (e.g. passenger charter and non-scheduled freight operations);
- Passenger numbers and cargo tonnage data (these are not very reliable because of variations in load factor and type of aircraft used).

Note that some of these sources do not cover all flights (e.g. charter flights may be excluded). On the other hand, airline guide data may count some flights more than once (Baughcum *et al*., 1996). Whatever data source is used, inventory agencies must assure completeness. If fuel data for domestic aviation are not readily available, both data collection and estimation will usually be time consuming to perform.

#### MILITARY

Due to confidentiality concerns, it may be difficult to obtain data covering the quantity of fuel used by the military. This will have consequences for transparency and possibly completeness. Military activity is defined as those activities for which aviation fuel has been purchased by, or supplied to, the military authority of the country. It is *good practice* to apply the rules defining civilian national and international operations in aviation to military operations where they are comparable. Where they are not comparable, it is *good practice* to explain decisions on national and international operations. Unless better information is available, all the fuel should be allocated as domestic. Data on military fuel use may be sought from the military authorities themselves and the fuel suppliers.

The *IPCC Guidelines* do not provide a method to assess the quantity of fuel from military aviation although military fuel use should be available from national data sources. An estimate of fuel used for military aviation is given in ANCAT/EC2 (1998) (transport and tanker, fighter/bomber and light aircraft/helicopters) together with the method used to obtain it. Methods for estimating $CH_4$ and $N_2O$ emissions are not included.

Alternatively, fuel use may be estimated from the hours in operation. Default fuel consumption factors are given in Table 2.12, Fuel Consumption Factors for Military Aircraft shown in Appendix 2.5A.3.

According to COP Decision 2/CP3 a multilateral operation should not be included in national totals but reported separately, although there is no clear operational definition of ‘multilateral operation’ available at this time.

### 2.5.1.4 COMPLETENESS

Regardless of method, it is important to account for all fuel sold for aviation in the country. The methods are based on total fuel use, and should completely cover $CO_2$ emissions. However, the Tier 2 methods focus on passenger and freight carrying scheduled and charter flights, and not all aviation. In addition, they do not automatically include non-scheduled flights and general aviation such as agricultural airplanes, private jets or helicopters, which should be added if the quantity of fuel is significant. Completeness may also be an issue where military data are confidential, unless military fuel use is aggregated with another source category.

### 2.5.1.5 DEVELOPING A CONSISTENT TIME SERIES

Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques provides more information on how to develop emission estimates in cases where the same data sets or methods cannot be used during every year of the time series. If activity data are unavailable for the base year (e.g. 1990) an option may be to extrapolate data to this year by using changes in freight and passenger kilometres, total fuel used or supplied, or the number of LTOs (aircraft movements).

Emissions trends of $CH_4$ and $NO_x$ (and by inference $N_2O$) will depend on aircraft engine technology and the change in composition of a country's fleet. This change in fleet composition may have to be accounted for in the future, and this is best accomplished using the Tier 2b method based on individual aircraft types for 1990 and subsequent years. If fleet composition is not changing, the same set of emission factors should be used for all years.

Every method should be able to reflect accurately the results of mitigation options that lead to changes in fuel use. Only the Tier 2b method, based on individual aircraft, can capture the effect of mitigation options that result in lower emission factors.

### 2.5.1.6 UNCERTAINTY ASSESSMENT

#### ACTIVITY DATA

The uncertainty in the reporting will be strongly influenced by the accuracy of the data collected on domestic aviation separately from international aviation. With complete survey data, the uncertainty may be very low (less than 5%) while for estimates or incomplete surveys the uncertainties may become large, perhaps a factor of two for the domestic share.[21]

#### EMISSION FACTORS

The $CO_2$ emission factors should be within a range of ±5%, as they are dependent only on the carbon content of the fuel and fraction oxidised. The uncertainty of the $CH_4$ emission factor may be as a high as a factor of 2. The uncertainty of the $N_2O$ emission factor may be of several orders of magnitude (i.e. a factor of 10, 100 or more).

## 2.5.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Section 8.10.1 of Chapter 8, Quality Assurance and Quality Control.

It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

Some examples of specific documentation and reporting relevant to this source category are provided below.

The *IPCC Guidelines* require that inventory agencies report emissions from international aviation separately from domestic aviation, and exclude international aviation from national totals. It is expected that all countries have aviation activity and should therefore report emissions from this category. Though countries covering small areas might not have domestic aviation, emissions from international aviation should be reported.

Transparency would be improved if inventory agencies report emissions from LTO separately from cruise operations (defined here as operations above 3000 feet or 914 m).

Emissions from military aviation should be clearly specified, so as to improve the transparency on national greenhouse gas inventories.

In addition to the standard reporting required in the *IPCC Guidelines*, provision of the following data would increase transparency:

- Sources of fuel data and other essential data (e.g. fuel consumption factors) depending on the method used;
- The number of flight movements split between domestic and international;
- Emission factors used, if different from default values. Data sources should be referenced.

Inventory agencies should provide the definition of international and domestic that has been used and document why and how it was applied.

Confidentiality may be a problem if only one or two airline companies operate domestic transport in a given country. Confidentiality may also be a problem for reporting military aviation in a transparent manner.

[21] The uncertainty ranges cited in this section represent an informal polling of assembled experts aiming to approximate the 95% confidence interval around the central estimate.

## 2.5.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8 and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory agencies are encouraged to use higher tier QA/QC for *key source categories* as identified in Chapter 7, Methodological Choice and Recalculation.

In addition to the guidance in Chapter 8, specific procedures of relevance to this source category are outlined below.

#### Comparison of emissions using alternative approaches

The inventory agency should compare the emission estimates for aircraft using both Tier 1 and Tier 2 approaches. Any anomaly between the emission estimates should be investigated and explained. The results of such comparisons should be recorded for internal documentation.

#### Review of Emission factors

If national factors are used rather than the default values, directly reference the QC review associated with the publication of the emission factors, and include this review in the QA/QC documentation to ensure that the procedures are consistent with *good practice*. If possible, the inventory agency should compare the IPCC default values to national factors to provide further indication that the factors are applicable. If emissions from military use were developed using data other than the default factors, the accuracy of the calculations and the applicability and relevance of the data should be checked.

#### Activity data check

The source of the activity data should be reviewed to ensure applicability and relevance to the source category. Where possible, the inventory agency should compare current data to historical activity data or model outputs to look for anomalies. In preparing the inventory estimates, the inventory agency should ensure the reliability of the activity data used to allocate emissions between domestic and international aviation.

Data could be checked with productivity indicators such as fuel per unit of traffic performance (per passenger km or ton km). Where data from different countries are being compared, the band of data should be small.

#### External review

The inventory agency should perform an independent, objective review of calculations, assumptions or documentation of the emissions inventory to assess the effectiveness of the QC programme. The peer review should be performed by expert(s) (e.g. aviation authorities, airline companies, and military staff) who are familiar with the source category and who understand inventory requirements.

# Appendix 2.5A.1 Fuel use and average sector distance for representative types of aircraft

**TABLE 2.10**

**FUEL USE AND AVERAGE SECTOR DISTANCE FOR REPRESENTATIVE TYPES OF AIRCRAFT**

| | Aircraft | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **A310** | **A320** | **A330 300 LR** | **A340** | **BAC1-11** | **BAe 146** | **B727** | **B737 100-200** | **B737 400** |
| **Average sector distance in nautical miles (nm)** | | | | | | | | | |
| Total flight | 1 228 | 663 | 1 087 | 2 860 | 465 | 327 | 583 | 504 | 531 |
| Climb | 81 | 159 | 113 | 111 | 143 | 106 | 117 | 127 | 100 |
| Cruise | 1 034 | 393 | 832 | 2 615 | 234 | 152 | 384 | 291 | 339 |
| Descent | 113 | 111 | 142 | 134 | 88 | 69 | 82 | 86 | 92 |
| **Fuel use (kg)** | | | | | | | | | |
| Total flight | 12 160 | 4 342 | 15 108 | 37 317 | 2 965 | 2 272 | 6 269 | 3 747 | 3 750 |
| LTO (flight < 3000 ft) | 1 541 | 802 | 2 232 | 2 020 | 682 | 570 | 1 413 | 920 | 825 |
| Flight minus LTO (flight > 3000 ft) | 10 620 | 3 539 | 12 876 | 35 298 | 2 284 | 1 702 | 4 856 | 2 827 | 2 925 |
| **Fuel use (kg per nm)** | | | | | | | | | |
| Flight minus LTO (flight > 3000 ft) | 8.65 | 5.34 | 11.85 | 12.34 | 4.91 | 5.21 | 8.33 | 5.61 | 5.51 |

These data should be used with care as national circumstances may vary from those assumed in this table. In particular, distances travelled and fuel consumption may be affected by national route structures, airport congestion and air traffic control practices. Fuel consumption may also be affected by wind. For example, since westbound transatlantic flights usually take more time and burn more fuel than eastbound ones, use of the averages in the table (or those in the *IPCC Guidelines*) may underestimate fuel consumption of westbound flights (reported by e.g. European countries) and overestimate eastbound (reported by e.g. USA or Canada).

**TABLE 2.10 (CONTINUED)**

**FUEL USE AND AVERAGE SECTOR DISTANCE FOR REPRESENTATIVE TYPES OF AIRCRAFT**

| | **Aircraft** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **B747 100-300** | **B747 400** | **B757** | **B767 300 ER** | **B777** | **F28** | **F100** | **DC9** | **DC10-30** | **MD 82-88** |
| **Average sector distance in nautical miles (nm)** | | | | | | | | | | |
| Total flight | 2 741 | 2 938 | 958 | 1 434 | 1 579 | 295 | 360 | 384 | 2 118 | 557 |
| Climb | 152 | 95 | 106 | 100 | 112 | 131 | 118 | 118 | 117 | 161 |
| Cruise | 2 480 | 2 727 | 744 | 1 205 | 1 325 | 91 | 158 | 182 | 1 902 | 306 |
| Descent | 109 | 116 | 108 | 129 | 141 | 73 | 84 | 84 | 99 | 90 |
| **Fuel use (kg)** | | | | | | | | | | |
| Total flight | 60 705 | 58 325 | 8 111 | 14 806 | 23 627 | 2 104 | 2 597 | 3 202 | 35 171 | 4 872 |
| LTO (flight < 3000 ft) | 3 414 | 3 402 | 1 253 | 1 617 | 2 563 | 666 | 744 | 876 | 2 381 | 1 003 |
| Flight minus LTO (flight > 3000 ft) | 57 291 | 54 923 | 6 858 | 13 189 | 21 064 | 1 438 | 1 853 | 2 326 | 32 790 | 3 869 |
| **Fuel use (kg per nm)** | | | | | | | | | | |
| Flight minus LTO (flight > 3000 ft) | 20.90 | 18.69 | 7.16 | 9.20 | 13.34 | 4.87 | 5.15 | 6.06 | 15.48 | 6.95 |

Source: ANCAT/EC2 and UK Department of Trade and Industry (DTI/EID3cC/199803).

# Appendix 2.5A.2 Correspondence between representative aircraft and other aircraft types

**TABLE 2.11**
**CORRESPONDENCE BETWEEN REPRESENTATIVE AIRCRAFT AND OTHER AIRCRAFT TYPES**

| Generic aircraft type | ICAO | IATA aircraft in group | Generic aircraft type | ICAO | IATA aircraft in group | Generic aircraft type | ICAO | IATA aircraft in group | Generic aircraft type | ICAO | IATA aircraft in group |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BAe 146 | BA46 | 141 | Airbus A320 | A320 | 320 | Boeing 747-400 | B744 | 744 | McDonnell Douglas DC10 | DC10 | D10 |
| | | 143 | | | 32S | Boeing 757 | | 757 | | | D11 |
| | | 146 | | | 321 | | | 75F | | | D1C |
| | | 14F | Airbus A319 | A319 | 319 | | | TR2 | | | D1F |
| Airbus A310 | A310 | 310 | Airbus A330 | A330 | 330 | Boeing 767 | | 762 | | | L10 |
| | | 312 | | | 332 | | | 763 | | | L11 |
| | | 313 | | | 333 | | | 767 | | | L12 |
| | | A31 | Airbus A340 | A340 | 340 | | | AB3 | | | L15 |
| Boeing 727-100 | B721 | 721 | | | 342 | | | AB6 | | | M11 |
| Boeing 727-200 | B722 | 722 | | | 343 | | | A3E | | | M1F |
| Boeing 727-300 | B727 | 727 | BAe 111 | BA11 | B11 | | | ABF | McDonnell Douglas DC8 | | DC8 |
| | | 72A | | | B15 | | | AB4 | | | D8F |
| | | 72F | | | CRV | Boeing 777 | | 777 | | | D8M |
| | | 72M | | | F23 | Boeing 777-200 | B772 | 772 | | | D8S |
| | | 72S | | | F24 | Boeing 777-300 | B773 | 773 | | | 707 |
| | | TU5 | | | YK4 | McDonnell Douglas DC-9 | | D92 | | | 70F |
| Boeing 737-200 | B732 | 732 | Boeing 747-100-300 | B741 | 741 | | | D93 | | | IL6 |
| Boeing 737-500 | B735 | 735 | | B742 | 742 | | | D94 | | | B72 |
| | | 73A | | B743 | 743 | | | D95 | | | |
| | | 73B | | | 747 | | | D98 | | | |
| | | 73F | | | 74D | | | D9S | | | |
| | | 73M | | | 74E | | | DC9 | | | |
| | | 73S | | | 74F | | | F21 | | | |
| | | D86 | | | A4F | | | TRD | | | |
| | | JET | | | 74L | | | YK2 | | | |
| | | DAM | | | 74M | McDonnell Douglas M81-88 | MD81-88 | M80 | | | |

**TABLE 2.11 (CONTINUED)**
**CORRESPONDENCE BETWEEN REPRESENTATIVE AIRCRAFT AND OTHER AIRCRAFT TYPES**

| Generic aircraft type | ICAO | IATA aircraft in group | Generic aircraft type | ICAO | IATA aircraft in group | Generic aircraft type | ICAO | IATA aircraft in group | Generic aircraft type | ICAO | IATA aircraft in group |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Boeing 737-300 | B733 | 733 | | | IL7 | | | M82 | | | |
| Boeing 737-700 | B737 | 737 | | | ILW | | | M83 | | | |
| Fokker 100 | F100 | 100 | | | NIM | | | M87 | | | |
| Fokker F-28 | F28 | F28 | | | VCX | | | M88 | | | |
| | | TU3 | | | C51 | | | | | | |

MD90 goes as MD81-88 and B737-600 goes as B737-400. DC8 goes as double the B737-100.

Source: Falk (1999b) and EMEP/CORINAIR (1999).

# Appendix 2.5A.3 Fuel consumption factors for military aircraft

**TABLE 2.12**

**FUEL CONSUMPTION FACTORS FOR MILITARY AIRCRAFT**

| Group | Sub-group | Representative type | Fuel flow (kg/hour) |
|---|---|---|---|
| Combat | Fast Jet - High Thrust | F16 | 3 283 |
| | Fast Jet - Low Thrust | Tiger F-5E | 2 100 |
| Trainer | Jet trainers | Hawk | 720 |
| | Turboprop trainers | PC-7 | 120 |
| Tanker/Transport | Large Tanker/Transport | C-130 | 2 225 |
| | Small Transport | ATP | 499 |
| Other | MPAs, Maritime Patrol | C-130 | 2 225 |

Source: Tables 3.1 and 3.2 of ANCAT/EC2 1998, British Aerospace/Airbus.

**TABLE 2.13**

**ANNUAL AVERAGE FUEL CONSUMPTION PER FLIGHT HOUR FOR UNITED STATES MILITARY AIRCRAFT ENGAGED IN PEACETIME TRAINING OPERATIONS**

| Aircraft Type | Aircraft Description | Fuel Use (Litres per Hour) |
|---|---|---|
| A-10A | Twin engine light bomber | 2 331 |
| B-1B | Four engine long-range strategic bomber. Used by USA only | 13 959 |
| B-52H | Eight engine long-range strategic bomber. Used by USA only. | 12 833 |
| C-12J | Twin turboprop light transport. Beech King Air variant. | 398 |
| C-130E | Four turboprop transport. Used by many countries. | 2 956 |
| C-141B | Four engine long-range transport. Used by USA only | 7 849 |
| C-5B | Four engine long-range heavy transport. Used by USA only | 13 473 |
| C-9C | Twin engine transport. Military variant of DC-9. | 3 745 |
| E-4B | Four engine transport. Military variant of Boeing 747. | 17 339 |
| F-15D | Twin engine fighter. | 5 825 |
| F-15E | Twin engine fighter-bomber | 6 951 |
| F-16C | Single engine fighter. Used by many countries. | 3 252 |
| KC-10A | Three engine tanker. Military variant of DC-10 | 10 002 |
| KC-135E | Four engine tanker. Military variant of Boeing 707. | 7 134 |
| KC-135R | Four engine tanker with newer engines. Boeing 707 variant. | 6 064 |
| T-37B | Twin engine jet trainer. | 694 |
| T-38A | Twin engine jet trainer. Similar to F-5. | 262 |

These data should be used with care as national circumstances may vary from those assumed in this table. In particular, distances travelled and fuel consumption may be affected by national route structures, airport congestion and air traffic control practices.

Source: US Environmental Protection Agency, Inventory of US Greenhouse Gas Emissions and Sinks, 1990-1998, EPA-236-R-00-001 (Forthcoming, April 2000). Data provided by the US Department of Defense.

# 2.6 FUGITIVE EMISSIONS FROM COAL MINING AND HANDLING

## 2.6.1 Methodological issues

The geological process of coal formation also produces methane ($CH_4$), some of which remains trapped in the coal seam until it is mined. Generally, deeper underground coal seams contain more *in-situ* methane than shallower surface seams. Consequently, the majority of emissions come from deep underground mines. Additional emissions come from open-pit mines and post-mining activities.

### 2.6.1.1 CHOICE OF METHOD

Those coal-mining countries whose major production is from underground mining, particularly longwall operations, the emissions from this sub-source category will dominate and efforts should focus on this part of the overall coal estimate. However, where there is extensive open-cut mining such as in Australia, emissions from this activity can also be significant. Figure 2.9, Decision Tree for Surface Coal Mining and Handling, to Figure 2.11, Decision Tree for Post-mining provide guidance in choosing the appropriate method for all sources of coal mine methane. The *IPCC Guidelines* give the following general equation for estimating emissions:

**EQUATION 2.12**

Emissions = Coal Production (Surface or Underground) • Emission Factor

The Tier 2 approach is to use country or basin-specific emission factors that reflect the average methane content of coal actually mined. The Tier 1 default approach requires that countries choose from a global average range of emission factors, and is more uncertain as a consequence. For underground mines, actual measurement data may be available. Although not specified explicitly as Tier 3 in the coal chapter of the *IPCC Guidelines*, the use of measurement data is generally regarded as a Tier 3 approach.

Total annual emissions are calculated according to the following equation:

**EQUATION 2.13**

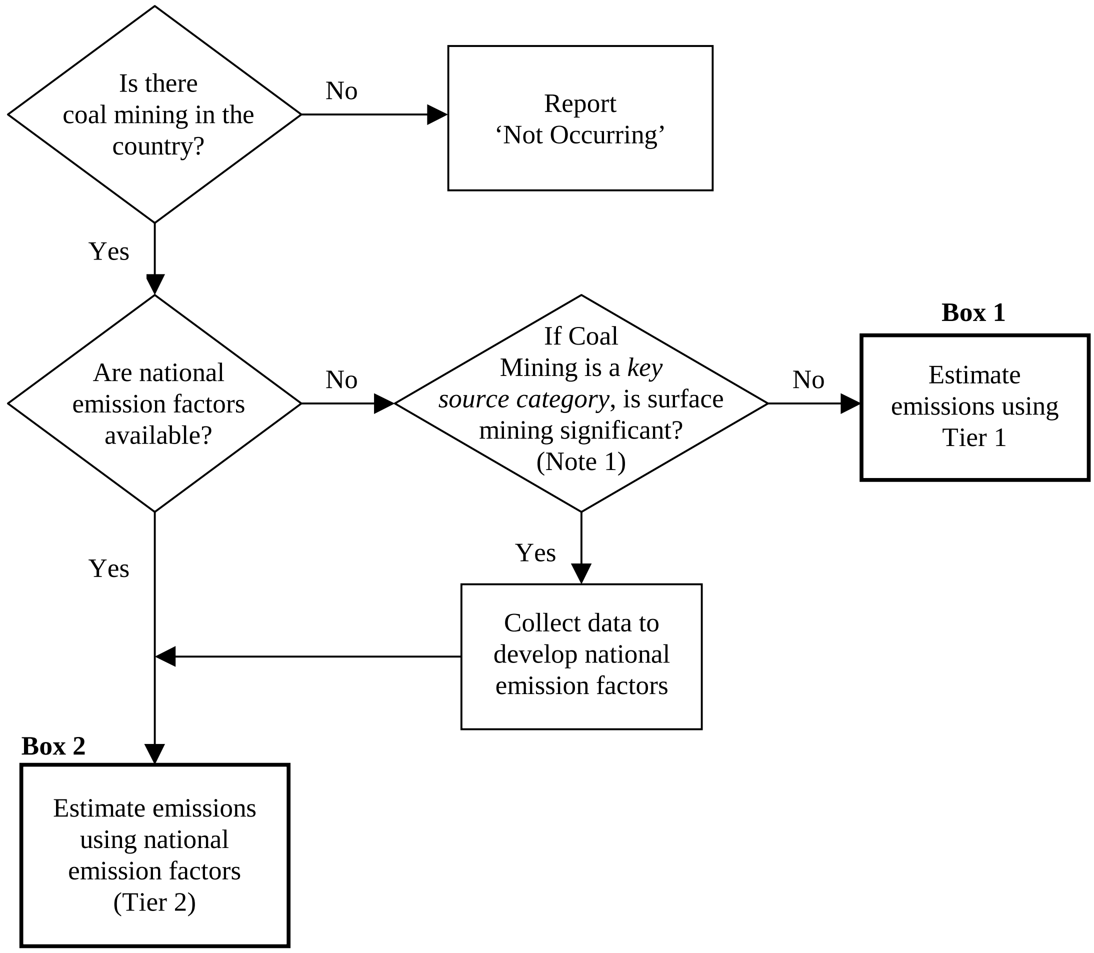
Total Emissions = Underground Mining Emissions + Surface Mining Emissions + Post-Mining Emissions – Methane Recovered and Used or Flared

#### UNDERGROUND MINING

Emissions from underground mining come from ventilation systems and degasification systems. Ventilation systems are a safety requirement at underground mines and dilute the ambient methane concentration of mine air below a dangerous level by flushing the mine with air from the surface. Degasification systems are wells drilled before, during, and after mining to drain methane from the coal seam itself.

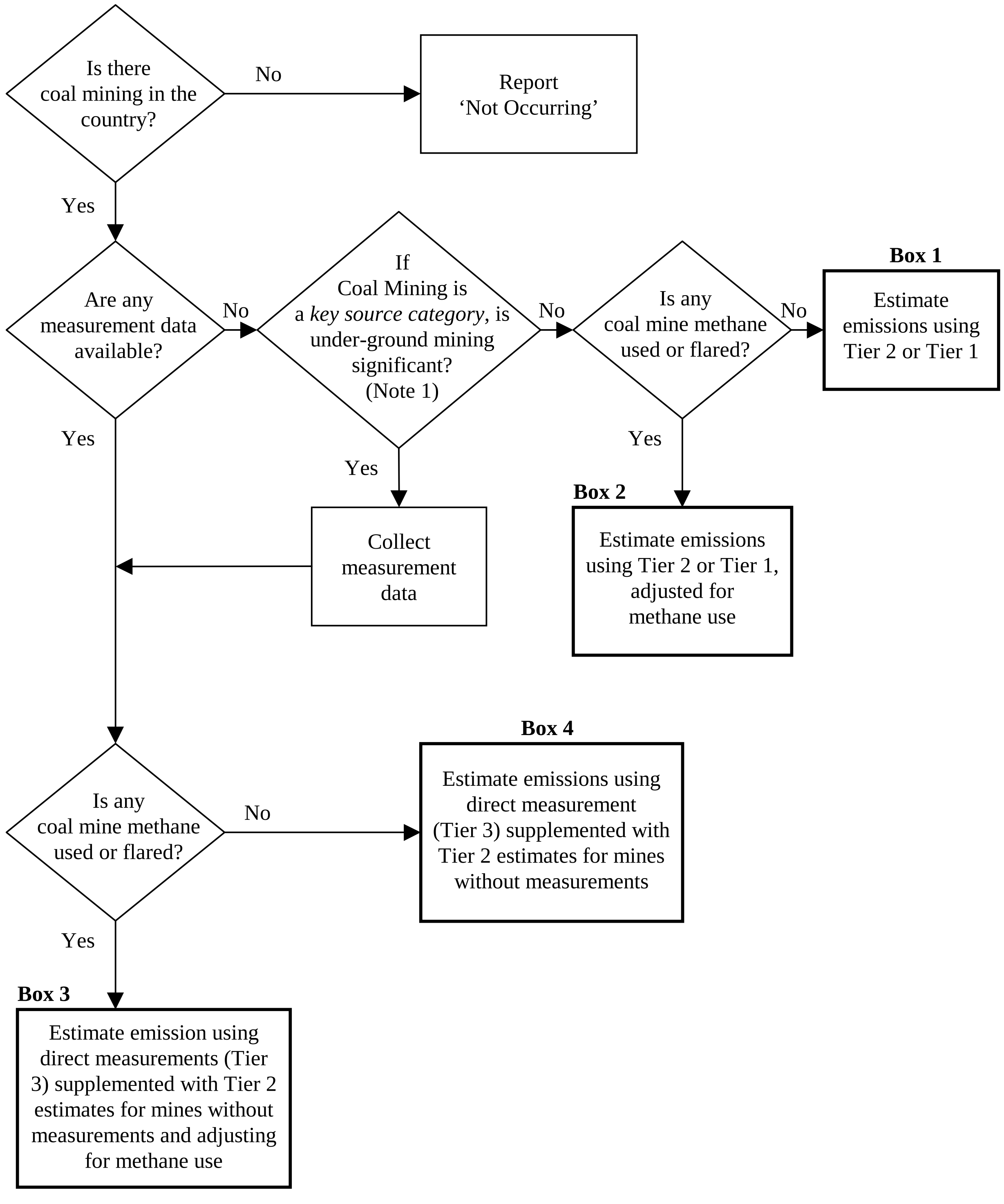
For countries with underground mining operations, it is *good practice* to collect data for the Tier 3 method if the mine-specific measurement data are available for safety reasons. Mine-specific data, based on ventilation air measurements and degasification system measurements, reflect actual emissions on a mine-by-mine basis, and therefore produce a more accurate estimate than emission factors. This is due to the variability of *in-situ* gas content of coal and its geological environment. As emissions vary greatly over the course of a year, *good practice* is to collect measurement data at least every two weeks to smooth out variations. Daily measurements would ensure a higher quality estimate. Continuous monitoring of emissions represents the highest stage of emission monitoring, and is implemented in some modern longwall mines, but it is not necessary for *good practice*.

**Figure 2.9 Decision Tree for Surface Coal Mining and Handling**



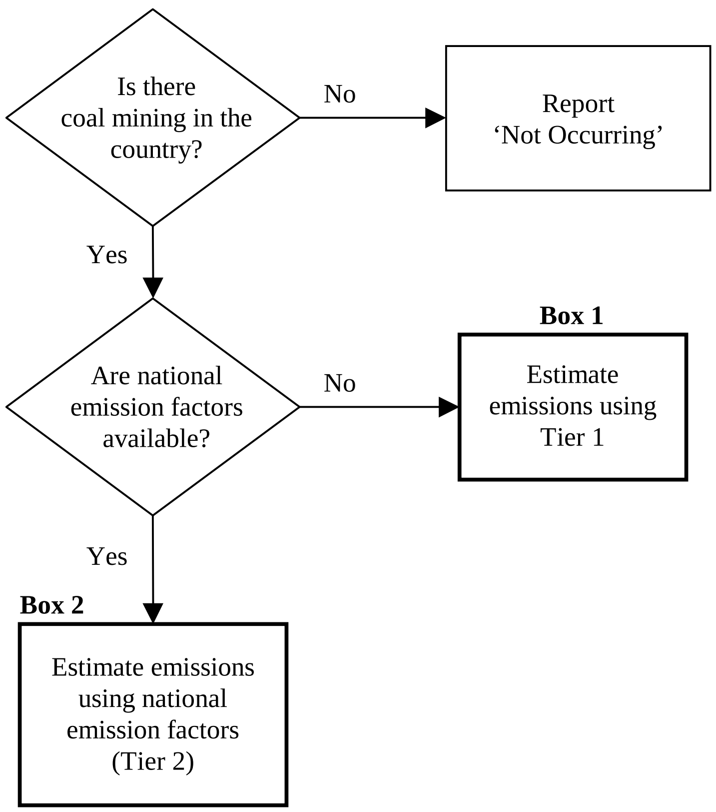

**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

**Figure 2.10 Decision Tree for Underground Coal Mining and Handling**




**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

**Figure 2.11 Decision Tree for Post-mining**




High quality measurements of methane drained by degasification systems should also be available from mine operators for those mines where drainage is practised. If detailed data on drainage rates are absent, *good practice* is to obtain data on the efficiency of the systems (i.e. the fraction of gas drained) or to make an estimate of this fraction from a range (e.g. 30-50%, typical of many degasification systems). Another option is to compare conditions with associated mines where data are available. In cases where drainage occurs years in advance of mining, methane recovery should be accounted for in the year in which the source coal seam is extracted. Methane recovered from degasification systems and vented to the atmosphere prior to mining should be added to the amount of additional methane released through ventilation systems so that the total estimate is complete. In some cases, because degasification system data are considered confidential, it may be necessary to estimate degasification system collection efficiency, and then subtract known reductions to arrive at the net degasification system emissions.

An alternative hybrid Tier 3 - Tier 2 approach is appropriate in situations when mine-specific measurement data are available only for a subset of underground mines. For example, if only gassy mines report data, emissions from the remaining mines can be calculated with Tier 2 emission factors. These factors could be based on specific emission rates derived from Tier 3 data if the mines are operating within the same basin as the Tier 3 mines, or on the basis of mine-specific properties, such as the average depth of the coal mines.

Comprehensive mine-by-mine (i.e. Tier 3) data may be available for some but not all years. If there have been no major changes in the population of active mines, emissions can be scaled to production for the missing years. If there were changes in the mine population, the mines involved can be removed from the scaling extrapolation and handled separately. However, care must be taken in scaling because the coal being mined, the virgin exposed coal and the disturbed mining zone have different emission rates. Furthermore, mines may have a high background emission level that is independent of production.

When no mine-by-mine data are available, inventory agencies should employ the Tier 2 method (country or basin-specific emission factors). For some countries, it may be necessary to separate the mine production into production from larger mines (Tier 2) and smaller independent mines (Tier 1) if smaller mines exhibit significantly different methane emission patterns (e.g. shallower seams).

### SURFACE MINING

It is not feasible to collect mine-by-mine Tier 3 measurement data for surface mines. The alternative is to collect data on surface mine production and apply emission factors. For countries with significant coal production and multiple coal basins, disaggregation to the basin level will improve accuracy. Given the uncertainty of production-based emission factors, picking emission factors from the range specified by the *IPCC Guidelines* can provide a reasonable estimate.

### POST-MINING

Methane still present in the coal after mining will escape to the atmosphere eventually. Measurement of post-mining emissions is not feasible, however, so an emission factor approach must be used. The Tier 2 and Tier 1 methods in the *IPCC Guidelines* should be reasonable for this source, given the difficulty of obtaining better data.

### RECOVERY OF METHANE FOR UTILISATION OR FLARING

If methane is drained from coal seams and subsequently flared or used as a fuel, it is *good practice* to subtract this amount from the total estimate of emissions. (Emissions from combustion of recovered methane should be accounted for appropriately in the combustion section.) Where utilisation data are not directly available from mine operators, gas sales could be used as a proxy. If gas sales are unavailable, the alternative is to estimate the amount of utilised methane from the known efficiency specifications of the drainage system.

In some countries, it is common practice to drain and utilise coal bed methane many years prior to mining. In other instances, gas wells are drilled in coal seams that are too deep to be mined. Fugitive emissions up to the point of utilisation should be counted in coal mining activities. Subsequent downstream emissions should be allocated to the source category appropriate to the manner of utilisation. Examples include oil and natural gas when the methane is fed to the natural gas grid and to electricity autoproducers when used to generate electricity. Note that where coal seam methane is recovered with no intention of mining the coal, emissions fall within the oil and natural gas source category.

The estimate of $CH_4$ emissions from coal mining may or may not need to be corrected for the amount of gas released depending on whether:

- The coal is extracted a few years later and the $CH_4$ emissions estimate for that year is based on average emission factors that do not take account of early gas draining; in this case a correction is needed for the year of extraction;
- The coal is extracted a few years later and the $CH_4$ emissions estimate is based on direct emissions measurements. In this case no correction is needed;
- The coal is never extracted (e.g. due to changes in plans or because it was never the intention). In this case no correction is needed.

Flaring is an option for reducing methane emissions from coal mines, and is practised at some coal mines. Data on the amount of methane flared should be obtained from mine operators with the same frequency of measurement as pertains to underground mine emissions generally.

## 2.6.1.2 CHOICE OF EMISSION FACTORS

### UNDERGROUND MINING

Tier 3: The Tier 3 method does not use production-based emission factors, but rather actual measurement data that account for the temporal and spatial variability in coal mine emissions. As this is by far the most reliable method, inventory agencies should make every effort to collect these data if underground mining is a *key sub-source category*.

Tier 2: Country-specific emission factors can be obtained from sample ventilation air data, or from a quantitative relationship that accounts for the gas content of the coal seam and the surrounding strata affected by the mining process. For a typical longwall operation, the amount of gas released comes from the coal being extracted and from the coal and any other gas bearing strata 150 m above and 50 m below the mined seam. Where such relationships are used, they should be peer-reviewed and well documented.

Tier 1: Inventory agencies choosing from the emission factor range (10-25 $m^3$/tonne) in the Tier 1 methodology should consider country-specific variables such as depth of major coal seams. As gas content of coal usually increases with depth, the low end of the range should be chosen for average mining depths of <200 m, and for depths of > 400 m the high value is appropriate. For intermediate depths, intermediate values can be chosen.

#### SURFACE MINING

There are few measurements of methane emissions from surface mining. They are difficult and expensive to carry out and no routine methods are currently available. Data on *in-situ* gas contents before overburden removal are also very scarce, and in freshly uncovered coal the gas content is often close to zero. Where local data on emissions are available, they should be used.

For the Tier 1 approach, it is *good practice* to use the low end of the specific emission range for those mines with average overburden depths of <25 m and the high end for overburden depths over 50 meters. For intermediate depths, intermediate values for the emission factors may be used. In the absence of data on overburden thickness, it is *good practice* to use an emission factor towards the high end of the range, namely 1.5 $m^3$/tonne.

#### POST-MINING EMISSIONS – UNDERGROUND

Measurements on coal as it emerges on a conveyor from a mine without pre-mining degasification indicate that 25-40% of the *in-situ* gas is still in the coal (Williams and Saghafi, 1993). For mines that practice pre-drainage, the amount of gas in coal will be less by some unknown amount.

For mines with no pre-drainage, but with knowledge of the *in-situ* gas content, it is reasonable to set the post mining emission factor at 30% of this value. For mines with pre-drainage, an emission factor of 10% of the *in-situ* gas content is suggested. Where there are no *in-situ* gas content data or where pre-drainage is practised, but to an unknown extent, a reasonable approach is to increase overall underground emissions by 3% (Williams *et al*., 1993; Riemer, 1999).

#### POST-MINING EMISSIONS – SURFACE MINING

Unless there are data to the contrary, emissions from this sub-source category are assumed to be negligible, as the gas content of surface coal are typically very low. Emissions can be viewed as being accommodated within the surface emission factor.

### 2.6.1.3 CHOICE OF ACTIVITY DATA

For the Tier 3 method, coal production data are not necessary because actual measurements are available. However, it is *good practice* to collect and report these data to illustrate the relationship, if any, between underground coal production and actual emissions on an annual basis.

The activity data for Tiers 1 and 2 are coal production. Mine operators are likely to know more about coal production than methane emissions, but inventory agencies need to consider how the information is collected. For example, using cleaned coal production data instead of raw coal production data will change the final emissions estimate because emission factors are expressed in cubic meters per ton. Variable moisture content is another important issue.

If the data on raw coal production are available these should be used. If coal is not sent to a coal preparation plant or washery (used to upgrade the raw ‘run of mine’ coal by removing some of the mineral matter), then raw coal production equals the amount of saleable coal.

Where coal is upgraded, some coal is rejected in the form of coarse discards containing high mineral matter and also in the form of unrecoverable fines. The amount of waste is typically around 20% of the weight of raw coal feed, but may vary considerably by country. Where activity data are in the form of saleable coal, some effort should be made to determine the amount of production that is washed. Raw coal production is then estimated by increasing the amount of ‘saleable coal’ by the fraction lost through washing.

An alternative approach that may be more suitable for mines whose raw coal output contains rock from the roof or floor as a deliberate part of the extraction process, is to use saleable coal data, provided the emission factors used refer to clean coal not raw coal. This should be noted in the inventory.

## 2.6.1.4 COMPLETENESS

### UNDERGROUND MINING

The estimate of emissions from underground mining should include both ventilation systems and degasification systems when both are present.

### ABANDONED MINES

No method currently exists for estimating emissions from this sub-source category. For mines that are flooded, emissions are likely to be prevented, but some leakage is likely in mines that are sealed mechanically. *Good practice* is to record the date of mine closure and the method of sealing. Data on the size and depth of such mines would be useful for any post hoc estimation.

### $CO_2$ IN SEAM GAS

Countries with significant quantities of $CO_2$ in their coal seam gas should make efforts to evaluate or quantify these emissions.

### COAL FIRES, COMBUSTION AND OXIDATION OF WASTE COAL AND OTHER CARBONACEOUS MATERIALS ($CO_2$)

IPCC recognises that there are emissions from these sub-source categories, but does not provide methods. Emissions could be significant, but are very difficult to estimate.

## 2.6.1.5 DEVELOPING A CONSISTENT TIME SERIES

In cases where an inventory agency moves from a Tier 1 or Tier 2 to a Tier 3 method, it may be necessary to calculate implied emissions factors for years with measurement data, and apply these emission factors to coal production for years in which these data do not exist. It is important to consider if the composition of the mine population has changed dramatically during the interim period, because this could introduce uncertainty. For mines that have been abandoned since 1990, data may not be archived if the company disappears. These mines should be treated separately when adjusting the time series for consistency. For *good practice guidance* on ensuring time series consistency, see Chapter 7, Methodological Choice and Recalculation.

## 2.6.1.6 UNCERTAINTY ASSESSMENT

### EMISSIONS

#### Tier 3

Methane emissions from underground mines have a significant natural variability. Spot measurements of [$CH_4$] (the square brackets denote concentration) in ventilation air are probably accurate to ±20% depending on the equipment used. Time series data or repeat measurements will significantly reduce the uncertainty of annual emissions to ±5% for continuous monitoring, and 10-15% for every two weeks.[22] Ventilation airflows are usually fairly accurately known (±2%).

Spot measurement of [$CH_4$] in drained gas (degasification systems) is likely to be accurate to ±2% because of its higher concentration. Measurements should be made with a frequency comparable to those for ventilation air to get representative sampling. Degasification flows are probably known to ±5%. Degasification flows based on gas sales are also likely to have an uncertainty of at least ±5% due to the tolerances in pipeline gas quality.

As the gas liberated (gas make) by longwall mining can vary by a factor of two during the life of a longwall panel (a 1-2 km long x 200 m wide block of coal that is extracted in the course of 6-9 months by a single longwall machine), it is necessary to make frequent measurements of underground mine emissions. Frequent measurements will also reduce the intrinsic errors in the measurement techniques. Mines with multiple longwall

[22] The uncertainty ranges cited in this section represent an informal polling of assembled experts aiming to approximate the 95% confidence interval around the central estimate.

machines will be less subject to such wide fluctuations. There may also be uncertainty concerning utilisation of any methane gas drained years before the source coal seam is extracted.

For a single longwall operation, with continuous or daily emission measurements, the accuracy of monthly or annual average emissions data is probably ±5%. The accuracy of spot measurements performed every two weeks is ±10%, at 3-monthly intervals ±30%. Aggregating emissions from mines based on the less frequent type of measurement procedures will reduce the uncertainty caused by fluctuations in gas make. However, as fugitive emissions are often dominated by contributions from only a small number of mines, it is difficult to estimate the extent of this improvement.

### Tiers 1 and 2

If a Tier 2 emission factor for underground mining is derived from Tier 3 data, then the errors or uncertainty in the Tier 3 data can flow through to the derived emission factor for Tier 2. The following table gives some impression of likely uncertainties:

**TABLE 2.14**

**LIKELY UNCERTAINTIES OF COAL MINE METHANE EMISSION FACTORS**

| Method | Underground | Surface | Post-Mining |
|---|---|---|---|
| Tier 2 | ±50-75% | factor of 2 | ±50% |
| Tier 1 | factor of 2 | factor of 3 | factor of 3 |

Source: Judgement by Expert Group (see Co-chairs, Editors and Experts; Fugitive Emissions from Coal Mining and Handling).

## ACTIVITY DATA

Coal production: Tonnages are likely to be known to 1-2%, but if raw coal data are not available, then the uncertainty will increase to about ±5%, when converting from saleable coal production data. The data are also influenced by moisture content, which is usually present at levels between 5-10%, and may not be determined with great accuracy.

Apart from measurement uncertainty, there can be further uncertainties introduced by the nature of the statistical databases that are not considered here. In countries with a mix of regulated and unregulated mines, activity data may have an uncertainty of ±10%.

## 2.6.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Section 8.10.1 of Chapter 8, Quality Assurance and Quality Control.

It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

To ensure transparency, the following information should be supplied:

- Emissions by underground, surface, and post-mining components of $CH_4$ and $CO_2$ (where appropriate), the method used for each of the sub-source categories, the number of active mines in each sub-source category and the reasons for the chosen EFs (e.g. depth of mining, data on *in-situ* gas contents etc.). The amount of drained gas and the degree of any mitigation or utilisation should be presented with a description of the technology used, where appropriate.
- Activity data: Specify the amount and type of production, underground and surface coal, listing raw and saleable amounts where available.
- Where issues of confidentiality arise, the name of the mine need not be disclosed. Most countries will have more than three mines, so mine-specific production cannot be back calculated from the emission estimates.

## 2.6.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8 and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory agencies are encouraged to use higher tier QA/QC for *key source categories* as identified in Chapter 7, Methodological Choice and Recalculation.

In addition to the guidance in Chapter 8, specific procedures of relevance to this source category are outlined below.

#### Comparison of emissions using alternative approaches

The inventory agency should compare the emission estimates for fugitive methane emissions from coal mining and handling using both Tier 1 and Tier 2 approaches. If direct measurements are available, these should also be compared to the Tier 1 and 2 estimates. Large discrepancies between the emission estimates should be investigated and explained. The results of such comparisons should be recorded for internal documentation.

#### Review of direct emission measurements

If direct measurements are used to develop country-specific emission factors, it should be established whether measurements at the sites were made according to internationally recognised, standard methods. If the measurement practices fail this criterion, then the use of these emissions data should be carefully evaluated, uncertainty estimates reconsidered, and qualifications documented. Frequent measurements are usually required by regulatory bodies. In the absence of such regulations, measurements should be done frequently enough (weekly if possible), as emissions rates may vary considerably over the year.

#### Emission factors check

The inventory agency should compare measurement-based factors to IPCC defaults and factors developed by other countries with similar coal mining and handling characteristics. The QA/QC review associated with the original data should be directly referenced in the documentation.

If IPCC default factors are used, the inventory agency should ensure that they are applicable and relevant to the category. If possible, the IPCC default factors should be compared to national or local data to provide further indication that the factors are applicable.

#### Activity data check

The inventory agency should ensure that the data reflects raw coal production. Where possible, the data should be compared to historical activity data to look for anomalies. Compare activity data between multiple references (e.g. national statistics and mill-level data). To check methane utilisation consistency, gas or electricity sales could be used as a cross-check.

#### External review

The inventory agency should arrange for an independent, objective review of calculations, assumptions, and/or documentation of the emissions inventory to be performed to assess the effectiveness of the QC programme. The peer review should be performed by expert(s) who are familiar with the source category and who understand inventory requirements.

# 2.7 FUGITIVE EMISSIONS FROM OIL AND GAS OPERATIONS

## 2.7.1 Methodological issues

Fugitive emissions from oil and natural gas activities include all emissions from the exploration, production, processing, transport, and use of oil and natural gas, and from non-productive combustion (e.g. flaring and waste-gas incineration). It excludes use of oil and gas or derived products to provide energy for internal use, in energy production, processing and transport. The latter are considered fuel consumption and are addressed separately in the *IPCC Guidelines* (Sections 1.3 to 1.5).

Fugitive emissions of methane ($CH_4$), carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$) from oil and gas operations are a source of direct and indirect greenhouse gas emissions in many countries. Unfortunately, these emissions are difficult to quantify accurately. This is largely due to the diversity of the industry, the large number and variety of potential emission sources, the wide variations in emission-control levels, and the limited availability of emission-source data. The main emission assessment issues are:

- The use of simple production-based emission factors introduces excessive error;
- The application of rigorous bottom-up approaches requires expert knowledge and detailed data that may be difficult and costly to obtain;
- Measurement programmes are time consuming and very costly to perform.

If a rigorous bottom-up approach is chosen, then it is *good practice* to involve technical representatives from the industry in the development of the inventory.

### 2.7.1.1 CHOICE OF METHOD

The *IPCC Guidelines* describe two methods to calculate $CH_4$ emissions from both the oil and gas industries (called Tier 1 and Tier 3), and one additional method (called Tier 2) to calculate $CH_4$ emissions only from oil systems. The Tier 3 method is a rigorous source-specific evaluation, requiring detailed inventories of infrastructure, and detailed bottom-up emission factors. The Tier 2 approach for $CH_4$ emissions from the oil industry is based on a mass balance estimate of the maximum amount of $CH_4$ that could be emitted. The Tier 1 method uses aggregate production-based emission factors and national production data.[23]

*Good practice* is to disaggregate the industry into the applicable segments and subcategories indicated in Table 2.15, Major Categories and Subcategories in the Oil and Gas Industry, and then evaluate the emissions separately for each of these parts. The approach to estimate emissions from each segment should be commensurate with the emissions level and the available resources. Consequently, it may be appropriate to apply different approaches to different parts of the industry, and possibly even include some direct monitoring of emission sources. The overall approach, over time, should be one of progressive refinement to address the areas of greatest uncertainty and consequence, and to capture the impact of specific control measures.

Figure 2.12 provides a general decision tree for Natural Gas Systems for selecting an appropriate approach for a given segment of the natural gas system. Similarly, Figures 2.13 and 2.14 apply to oil production and transport systems, and to oil upgraders and refineries, respectively.

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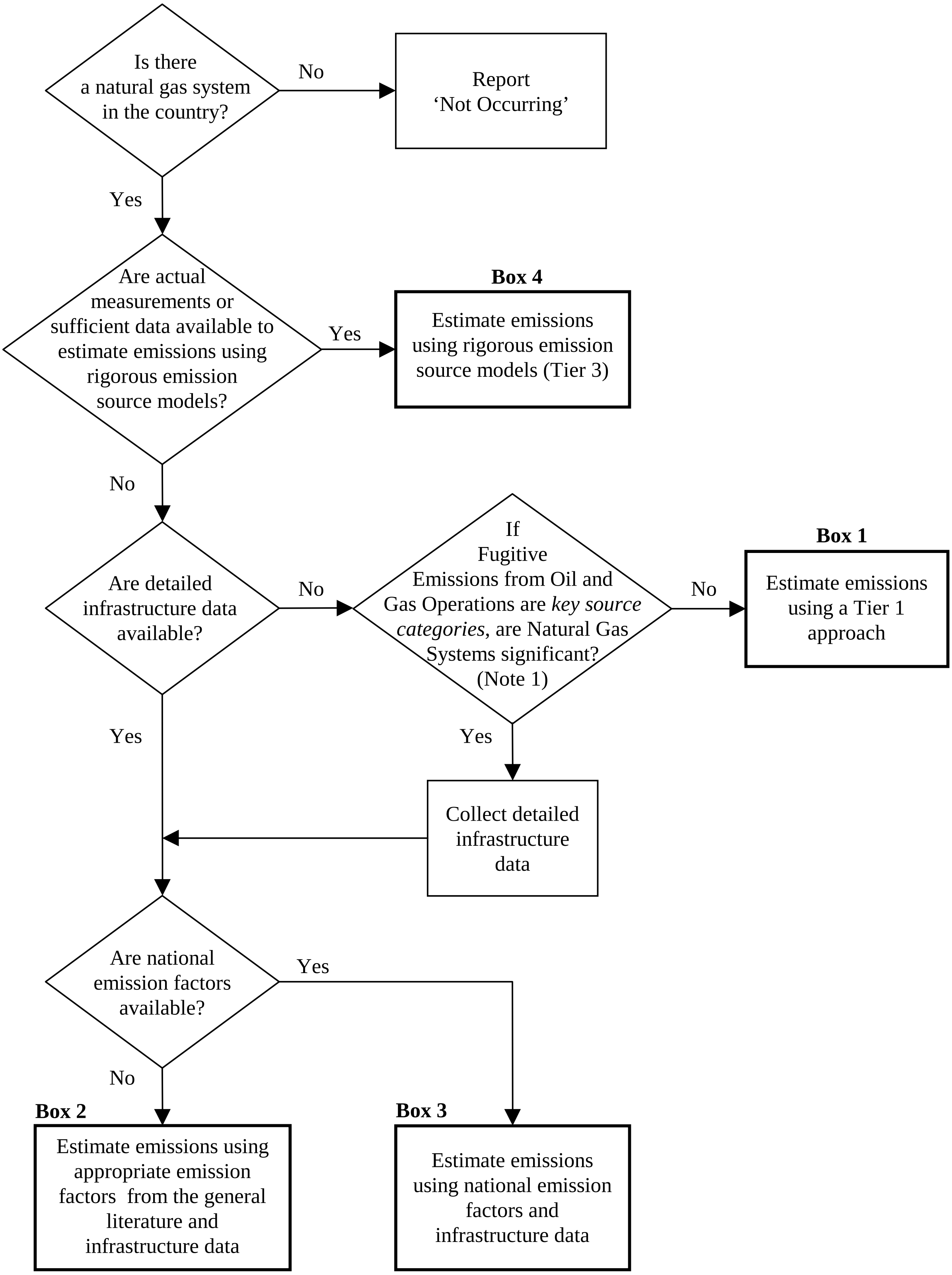
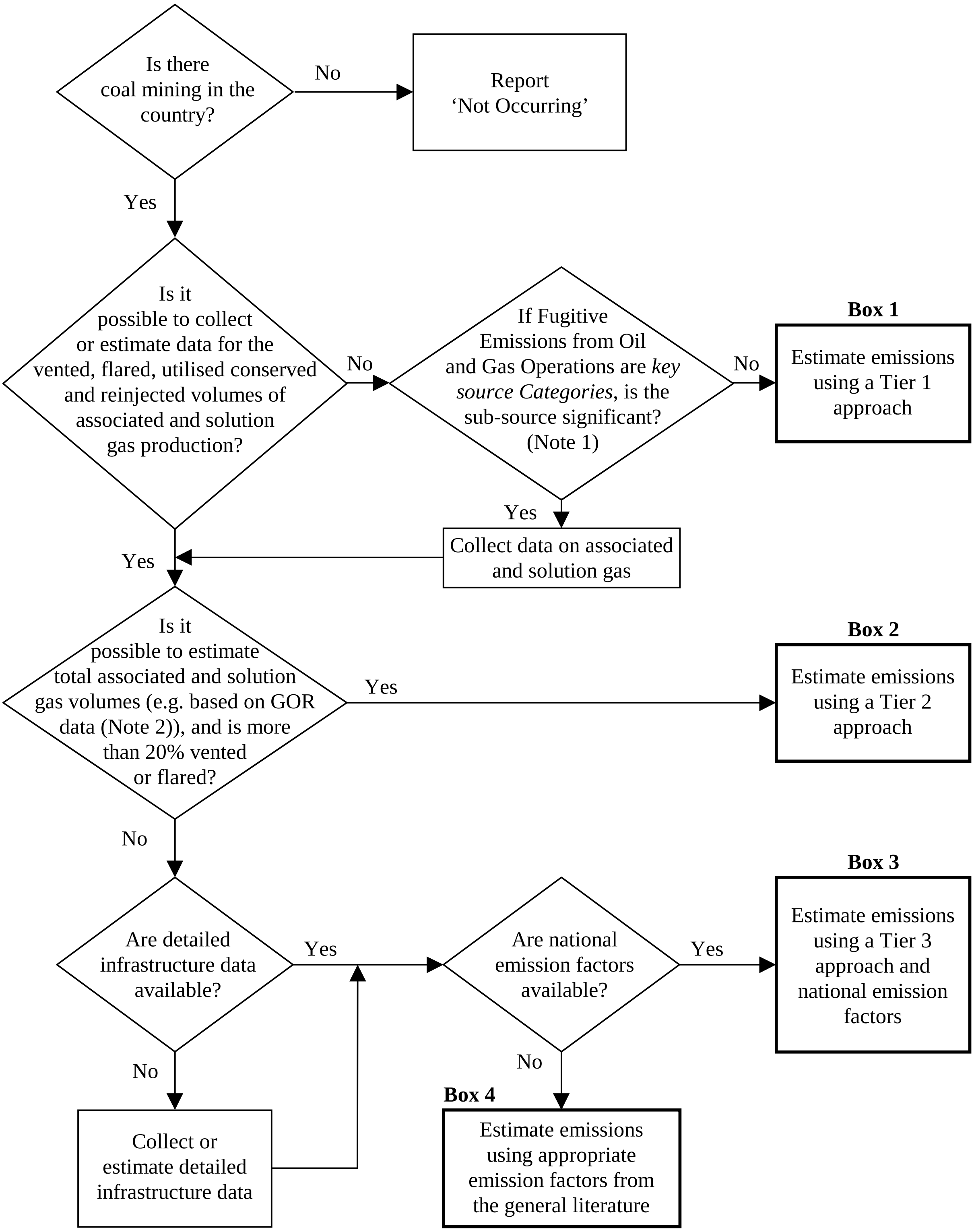
[23] There is no Tier 2 method for natural gas systems in the *IPCC Guidelines*.

**Figure 2.12 Decision Tree for Natural Gas Systems**




**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

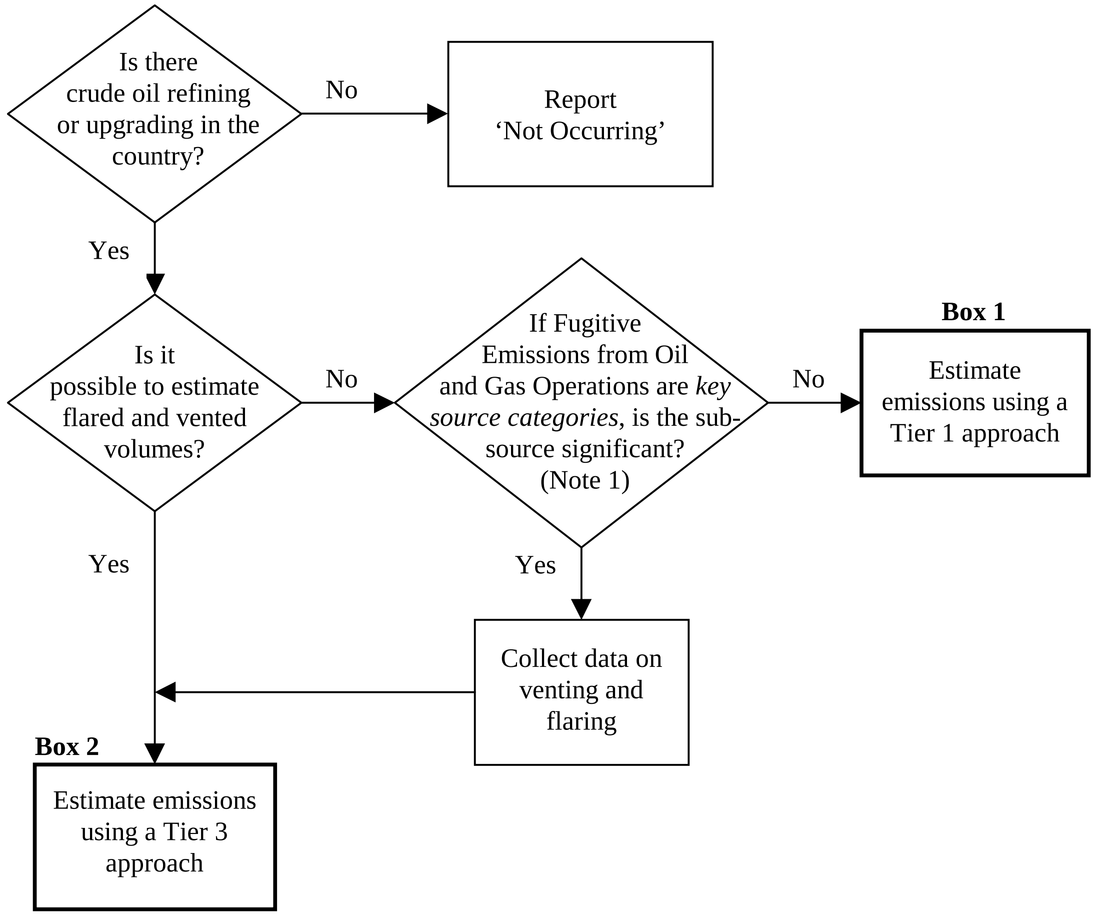
**Figure 2.13 Decision Tree for Crude Oil Production and Transport**




**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

**Note 2:** GOR stands for Gas/Oil Ratio.

**Figure 2.14 Decision Tree for Crude Oil Refining and Upgrading**




**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

**TABLE 2.15**

**MAJOR CATEGORIES AND SUBCATEGORIES IN THE OIL AND GAS INDUSTRY**

| Industry Segment | Sub-Categories |
|---|---|
| Wells | Drilling<br>Testing<br>Servicing |
| Gas Production | Dry Gas[a]<br>Sweet Gas[b]<br>Sour Gas[c] |
| Gas Processing | Sweet Gas Plants<br>Sour Gas Plants<br>Deep-cut Extraction Plants |
| Gas Transmission & Storage | Pipeline Systems<br>Storage Facilities |
| Gas Distribution | Rural Distribution<br>Urban Distribution |
| Liquefied Gases Transport | Condensate<br>Liquefied Petroleum Gas (LPG)<br>Liquefied Natural Gas (LNG) (including associated liquefaction and gasification facilities) |
| Oil Production | Conventional Oil<br>Heavy Oil (Primary Production)<br>Heavy Oil (Enhanced Production)<br>Crude Bitumen<br>Synthetic Crude Oil (From Oilsands)<br>Synthetic Crude Oil (From Oil Shales) |
| Oil Upgrading | Crude Bitumen<br>Heavy Oil |
| Waste Oil Reclaiming | None |
| Oil Transport | Marine<br>Pipelines<br>Tanker Trucks and Rail Cars |
| Oil Refining | Heavy Oil<br>Conventional and Synthetic Crude Oil |

[a] Dry gas is natural gas that does not require any hydrocarbon dew-point control to meet sales gas specifications. However, it may still require treating to meet sales specifications for water and acid gas (i.e. $H_2S$ and $CO_2$) content. Dry gas is usually produced from shallow (less than 1000 m deep) gas wells.
[b] Sweet gas is natural gas that does not contain any appreciable amount of $H_2S$ (i.e. does not require any treatment to meet sales gas requirements for $H_2S$).
[c] Sour gas is natural gas that must be treated to satisfy sales gas restrictions on $H_2S$ content.

It is *good practice* to use the Tier 3 approach which will produce the most accurate emissions estimate. However, the ability to use a Tier 3 approach will depend on the availability of detailed production statistics and infrastructure data, and it may not be possible to apply it under all circumstances. A Tier 2 (mass balance) approach is primarily intended for application to oil systems where the majority of the associated and solution gas production is vented or flared. While much less reliable when applied to oil systems with gas conservation or to gas systems, a crude mass balance approach based on national production statistics may sometimes offer a greater degree of confidence than that offered by the Tier 1 approach. In such cases, the net balancing term (i.e. unaccounted-for losses) may be comparable to total fugitive emissions from non-venting or flaring sources. The Tier 1 approach is susceptible to substantial uncertainties and may easily be in error by an order-of-magnitude or more. For this reason, it should only be used as a last resort option.

## 2.7.1.2 CHOICE OF EMISSION FACTORS

Emission factors for conducting Tier 2 and Tier 3 assessments are not provided in the *IPCC Guidelines* due to the large amount of such information. Moreover, these data are continually being updated to include additional measurement results and to reflect development and penetration of new control technologies and requirements. Regular reviews of the literature should be conducted to ensure that the best available factors are being used, and the references for the chosen values should be clearly documented. Typically, emission factors are developed and published by environmental agencies and industry associations, and it will be necessary to develop inventory estimates in consultation with these organisations.

The selected emission factors must be valid for the given application and be expressed on the same basis as the activity data. It also may be necessary to apply other types of factors to correct for site and regional differences in operating conditions and design and maintenance practices, for example:

- Composition profiles of gases from particular oil and gas fields to correct for the amount of $CH_4$, raw $CO_2$ and other target pollutants in the emissions;
- Annual operating hours to correct for the amount of time a source is in active service;
- Efficiencies of the specific control measures used.

The following are additional matters to consider in choosing emission factors:

- It is important to assess the applicability of the selected factors for the target application to ensure similar/comparable source behaviour and characteristics;
- In the absence of better data, it may sometimes be necessary to apply factors reported for other regions that practice similar levels of emission control and feature comparable types of equipment;
- Where measurements are performed to develop new emission factors, only recognised or defensible test procedures should be applied. The method and quality assurance (QA)/quality control (QC) procedures should be documented, the sampled sources should be representative of typical variations in the overall source population, and a statistical analysis should be conducted to establish the 95% confidence interval on the average results.

New Tier 1 emission factors are presented in Table 2.16, Refined Tier 1 Emission Factors based on North American Data. Although still a simplified means of estimating fugitive emissions, the new factors allow for improved correlation of emissions with commonly-available activity data, and may be expected to limit uncertainties to within an order of magnitude. The improved correlations are achieved through increased disaggregation of the industry and, in several cases, by switching to different activity parameters. For example, fugitive emissions from gas transmission and distribution systems do not correlate well with throughput, and are better related to lengths of pipeline.

The new factors are derived from detailed emission inventory results for Canada and the United States, and are presented as examples. Notwithstanding this, these values may be applied to regions outside of North America that practice similar levels of emissions control and feature comparable types and quality of equipment. Even where moderate regional differences exist, the new factors may still offer more reliable results than that obtained from use of the factors given in the *IPCC Guidelines*. Nonetheless, it is *good practice* to consider the impact of regional differences before adopting a specific set of factors. In the absence of data for a particular industry segment or where conditions in the United States and Canada are not representative, the emission factors given in the *IPCC Guidelines*, Reference Manual Tables 1-57, Summary of Methane Emission Factors, and Table 1-58, Revised Regional Emission Factors for Methane from Oil and Gas Activities should be used.

In general, the developed factors reflect the following practices and state of the oil and gas industry:

- Most associated gas is conserved;
- Sweet waste gas is vented;
- Sour waste gas is flared;
- Many gas transmission companies are voluntarily implementing programmes to reduce methane losses due to fugitive equipment leaks;
- The oil and gas industry is mature and actually in decline in many areas;
- System reliability is high;
- Equipment is generally well maintained and high-quality components are used;
- Line breaks and well blowouts are rare;
- The industry is highly regulated and these regulations are generally well enforced.

**TABLE 2.16**

**REFINED TIER 1 EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM OIL AND GAS OPERATIONS BASED ON NORTH AMERICAN DATA**

| Category | Sub-Category | Emission Type | Default emission factor[a,b] | | | Units of Measure |
|---|---|---|---|---|---|---|
| | | | $CH_4$ | $CO_2$ | $N_2O$ | |
| Wells | Drilling | All[c] | 4.3E-07 | 2.8E-08 | 0 | Gg per number of wells drilled |
| | Testing | All | 2.7E-04 | 5.7E-03 | 6.8E-08 | Gg per number of wells drilled |
| | Servicing | All | 6.4E-05 | 4.8E-07 | 0 | Gg/yr per number of producing and capable wells |
| Gas Production | All | Fugitives[d] | 2.6E-03 to 2.9E-03 | 9.5E-05 | 0 | Gg per $10^6$ $m^3$ gas production |
| | | Flaring[e] | 1.1E-05 | 1.8E-03 | 2.1E-08 | Gg per $10^6$ $m^3$ gas production |
| Gas Processing | Sweet Gas Plants | Fugitives | 6.9E-04 to 10.7E-04 | 2.7E-05 | 0 | Gg per $10^6$ $m^3$ gas receipts |
| | | Flaring | 1.3E-05 | 2.1E-03 | 2.5E-08 | Gg per $10^6$ $m^3$ gas receipts |
| | Sour Gas Plants | Fugitives | 2.1E-04 | 2.9E-05 | 0 | Gg per $10^6$ $m^3$ gas receipts |
| | | Flaring | 2.9E-05 | 4.6E-03 | 5.4E-08 | Gg per $10^6$ $m^3$ gas receipts |
| | | Raw $CO_2$ Venting | 0 | 7.1E-02 | 0 | Gg per $10^6$ $m^3$ gas receipts |
| | Deep-cut Extraction Plants | Fugitives | 1.0E-05 | 3.0E-07 | 0 | Gg per $10^6$ $m^3$ gas receipts |
| | | Flaring | 6.2E-06 | 9.7E-04 | 1.2E-08 | Gg per $10^6$ $m^3$ gas receipts |
| Gas Transmission & Storage | Transmission | Fugitives[f] | 2.1E-03 to 2.9E-03 | 1.6E-05 | 0 | Gg per year and per km of transmission pipeline |
| | | Venting[g] | 0.8E-03 to 1.2E-03 | 8.5E-06 | 0 | Gg per year and per km of transmission pipeline |
| | Storage | All | 4.3E-04 to 42.0E-04 | 0 | 0 | Gg per year and per $10^6$ $m^3$ gas withdrawals |
| Gas Distribution | All | All | 5.2E-04 to 7.1E-04 | 0 | 0 | Gg per year and per km of distribution mains |
| Natural Gas Liquids Transport | Condensate | All | 1.1E-04 | 7.2E-06 | 0 | Gg per $10^3$ $m^3$ Condensate and Pentanes Plus |
| | Liquefied Petroleum Gas | All | 0 | 4.3E-04 | 2.2E-09 | Gg per $10^3$ $m^3$ LPG |
| Oil Production | Conventional Oil | Fugitives | 1.4E-03 to 1.5E-03 | 2.7E-04 | 0 | Gg per $10^3$ $m^3$ conventional oil production |
| | | Venting | 6.2E-05 to 270E-05 | 1.2E-05 | 0 | Gg per $10^3$ $m^3$ conventional oil production |
| | | Flaring | 0.5E-05 to 27E-05 | 6.7E-02 | 6.4E-07 | Gg per $10^3$ $m^3$ conventional oil production |
| | Heavy Oil | Fugitives | 0.8E-04 to 12E-04 | 6.7E-06 | 0 | Gg per $10^3$ $m^3$ heavy oil production |
| | | Venting | 2.1E-02 to 2.7E-02 | 5.0E-05 | 0 | Gg per $10^3$ $m^3$ heavy oil production |
| | | Flaring | 0.5E-04 to 2.0E-04 | 4.9E-02 | 4.6E-07 | Gg per $10^3$ $m^3$ heavy oil production |

**TABLE 2.16 (CONTINUED)**

**REFINED TIER 1 EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM OIL AND GAS OPERATIONS BASED ON NORTH AMERICAN DATA**

| Category | Sub-Category | Emission Type | Default emission factor[a,b] | | | Units of Measure |
|---|---|---|---|---|---|---|
| | | | $CH_4$ | $CO_2$ | $N_2O$ | |
| Oil Production (continued) | Crude Bitumen | Fugitives | 1.0E-04 | 1.2E-04 | 0 | Gg per $10^3$ $m^3$ crude bitumen production |
| | | Venting | 1.0E-03 | 1.2E-03 | 0 | Gg per $10^3$ $m^3$ crude bitumen production |
| | | Flaring | 8.8E-05 | 2.2E-02 | 2.4E-07 | Gg per $10^3$ $m^3$ crude bitumen production |
| | Synthetic Crude (from Oilsands) | All | 2.3E-03 | 0 | 0 | Gg per $10^3$ $m^3$ synthetic crude production from oilsands |
| | Synthetic Crude (from Oil Shale) | All | NA | NA | NA | Gg per $10^3$ $m^3$ synthetic crude production from oil shale |
| Oil Upgrading | All | All | ND | ND | ND | Gg per $10^3$ $m^3$ oil upgraded |
| Oil Transport | Pipelines | All | 5.4E-06 | 4.9E-07 | 0 | Gg per $10^3$ $m^3$ oil transported by pipeline |
| | Tanker Trucks and Rail Cars | Venting | 2.5E-05 | 2.3E-06 | 0 | Gg per $10^3$ $m^3$ oil transported by Tanker Truck |
| | Loading of Off-shore Production on Tanker Ships | Venting | NA[h] | NA[h] | NA[h] | Gg per $10^3$ $m^3$ oil transported by Tanker Truck |

NA - Not Applicable ND - Not Determined

[a] While the presented emission factors may all vary appreciably between countries, the greatest differences are expected to occur with respect to venting and flaring, particularly for oil production due to the potential for significant differences in the amount of gas conservation and utilisation practised.

[b] The range in values for fugitive emissions is attributed primarily to differences in the amount of process infrastructure (e.g. average number and sizes of facilities) per unit of gas throughput.

[c] 'All' denotes all fugitive emissions as well as venting and flaring emissions.

[d] 'Fugitives' denotes all fugitives emissions including those from fugitive equipment leaks, storage losses, use of natural gas as the supply medium for gas-operated devices (e.g. instrument control loops, chemical injection pumps, compressor starters, etc.), and venting of still-column off-gas from glycol dehydrators.

[e] 'Flaring' denotes emissions from all continuous and emergency flare systems. The specific flaring rates may vary significantly between countries. Where actual flared volumes are known, these should be used to determine flaring emissions rather than applying the presented emission factors to production rates. The emission factors for direct estimation of $CH_4$, $CO_2$ and $N_2O$ emissions from reported flared volumes are 0.012, 2.0 and 0.000023 Gg, respectively, per $10^6$ $m^3$ of gas flared based on a flaring efficiency of 98% and a typical gas analysis at a gas processing plant (i.e. 91.9% $CH_4$, 0.58% $CO_2$, 0.68% $N_2$ and 6.84% non-methane hydrocarbons by volume).

[f] The larger factor reflects the use of mostly reciprocating compressors on the system while the smaller factor reflects mostly centrifugal compressors.

[g] 'Venting' denotes reported venting of waste associated and solution gas at oil production facilities and waste gas volumes from blowdown, purging and emergency relief events at gas facilities. Where actual vented volumes are known, these should be used to determine venting emissions rather than applying the presented emission factors to production rates. The emission factors for direct estimation of $CH_4$ and $CO_2$ emissions from reported vented volumes are 0.66 and 0.0049 Gg, respectively, per $10^6$ $m^3$ of gas vented based on a typical gas analysis for gas transmission and distribution systems (i.e. 97.3% $CH_4$, 0.26% $CO_2$, 1.7% $N_2$ and 0.74% non-methane hydrocarbons by volume).

[h] While no factors are available for marine loading of offshore production for North America, Norwegian data indicate a $CH_4$ emission factor of 1.0 to 3.6 Gg/$10^3$ $m^3$ of oil transferred (derived from data provided by Norwegian Pollution Control Authority, 2000).

Sources: Canadian Association of Petroleum Producers (1999); GRI/US EPA (1996); US EPA (1999).

### 2.7.1.3 CHOICE OF ACTIVITY DATA

The activity data required to estimate fugitive emissions from oil and gas activities may include production statistics, infrastructure data (e.g. inventories of facilities/installations, process units, pipelines, and equipment components), and reported emissions from spills, accidental releases, and third-party damages. The basic activity data required for each tier and each type of primary source are summarised in Table 2.17, Typical Activity Data Requirements for each Assessment Approach by Type of Primary Source Category. Specific matters to consider in compiling this information include the following:

- Production statistics should be disaggregated to capture changes in throughputs (e.g. due to imports, exports, reprocessing, withdrawals, etc.) in progressing through oil and gas systems.
- Production statistics or disposition analyses[24] may not agree between different reporting agencies even though they are based on the same original measurement results (e.g. due to possible differences in terminology and potential errors in summarising these data). These discrepancies may be used as an indication of the uncertainty in the data. Additional uncertainty will exist if there is any inherent bias in the original measurement results (for example, sales meters are often designed to err in favour of the customer, and liquid handling systems will have a negative bias due to evaporation losses). Random metering and accounting errors may be assumed to be negligible when aggregated over the industry.
- Production statistics provided by national bureaux should be used in favour of those available from international bodies, such as the IEA or the UN, due to their generally better reliability and disaggregation. Regional, provincial/state and industry reporting groups may offer even more disaggregation.
- Reported vented and flared volumes may be highly suspect since these values are usually estimates and not based on actual measurements. Additionally, the values are often aggregated and simply reported as flared volumes. Operating practices of each segment of the industry should be reviewed to determine if the reported volumes are actually vented or flared, or to develop appropriate apportioning of venting relative to flaring. Audits or reviews of each industry segment should also be conducted to determine if all vented/flared volumes are actually reported (for example, solution gas emissions from storage tanks and treaters, emergency flaring/venting, leakage into vent/flare systems, and blowdown and purging volumes may not necessarily be accounted for).
- Infrastructure data are more difficult to obtain than production statistics. Information concerning the numbers and types of major facilities and the types of processes used at these facilities may often be available from regulatory agencies and industry groups, or directly from the actual companies.
- Information on minor facilities (e.g. numbers of field dehydrators and field compressors) usually is not available, even from oil and gas companies. Consequently, assumptions must be made, based on local design practices, to estimate the numbers of these facilities. This may require some fieldwork to develop appropriate estimation factors or correlations.
- Many companies use computerised inspection-and-maintenance information management systems. These systems can be a very reliable means of counting major equipment units (e.g. compressor units, process heaters and boilers, etc.) at selected facilities. Also, some departments within a company may maintain databases of certain types of equipment or facilities for their own specific needs (e.g. tax accounting, production accounting, insurance records, quality control programmes, safety auditing, license renewals, etc.). Efforts should be made to identify these potentially useful sources of information.

[24] A disposition analysis provides a reconciled accounting of produced hydrocarbons from the wellhead, or point of receipt, through to the final sales point or point of export. Typical disposition categories include flared/vented volumes, fuel usage, system losses, volumes added to/removed from inventory/storage, imports, exports, etc.

**TABLE 2.17**

**TYPICAL ACTIVITY DATA REQUIREMENTS FOR EACH ASSESSMENT APPROACH FOR FUGITIVE EMISSIONS FROM OIL AND GAS OPERATIONS BY TYPE OF PRIMARY SOURCE CATEGORY**

| **Assessment Tier** | **Primary Source Category** | **Minimum Required Activity Data** |
|---|---|---|
| 1 | All | Oil and Gas Throughputs |
| 2 | Oil Systems | Gas to Oil Ratios<br>Flared and Vented Volumes<br>Conserved Gas Volumes<br>Reinjected Gas Volumes<br>Utilised Gas Volumes<br>Gas Compositions |
| 3 | Process Venting/Flaring | Reported Volumes<br>Gas Compositions<br>Proration Factors for Splitting Venting from Flaring |
| | Storage Losses | Solution Gas Factors<br>Liquid Throughputs<br>Tank Sizes<br>Vapour Compositions |
| | Equipment Leaks | Facility/Installation Counts by Type<br>Processes Used at Each Facility<br>Equipment Component Schedules by Type of Process Unit<br>Gas/Vapour Compositions |
| | Gas-Operated Devices | Schedule of Gas-operated Devices by Type of Process Unit<br>Gas Consumption Factors<br>Type of Supply Medium<br>Gas Composition |
| | Accidental Releases & Third-Party Damages | Incident Reports/Summaries |
| | Gas Migration to the Surface & Surface Casing Vent Blows | Average Emission Factors & Numbers of Wells |
| | Drilling | Number of Wells Drilled<br>Reported Vented/Flared Volumes from Drill Stem Tests<br>Typical Emissions from Mud Tanks |
| | Well Servicing | Tally of Servicing Events by Types |
| | Pipeline Leaks | Type of Piping Material<br>Length of Pipeline |
| | Exposed Oilsands/Oil Shale | Exposed Surface Area<br>Average Emission Factors |

Component counts by type of process unit may vary dramatically between facilities and countries due to differences in design and operating practices. Thus, while initially it may be appropriate to use values reported in the general literature, countries should strive to develop their own values.

Use of consistent terminology and clear definitions is critical in developing counts of facilities and equipment components, and to allow any meaningful comparisons of the results with others.

Some production statistics may be reported in units of energy (based on their heating value) and will need to be converted to a volume basis, or vice versa, for application of the available emission factors. Typically, where production values are expressed in units of energy, it is in terms of the gross (or higher) heating value of the product. However, where emission factors are expressed on an energy basis it is normally in terms of the net (or lower) heating value of the product. To convert from energy data on a GCV basis to a NCV basis, the International Energy Agency assumes a difference of 5% for oil and 10% for natural gas. Individual natural gas streams that are either very rich or high in impurities may differ from the average value given above. Emission factors and activity data must be consistent with each other.

In comparing fugitive emissions from the oil and gas industry in different countries it is important to consider the impact of oil and gas imports and exports, as well as the types of oil and gas activities and the levels of emission control. Otherwise, emissions viewed on either a per-unit-consumption or a per-unit-production basis will be misleading.

Production activities will tend to be the major contributor to fugitive emissions from oil and gas activities in countries with low import volumes relative to consumption and export volumes. Gas transmission and distribution and petroleum refining will tend to be the major contributors to these emissions in countries with high relative import volumes. Overall, net importers will tend to have lower specific emissions than net exporters.

## 2.7.1.4 COMPLETENESS

Completeness is a significant issue in developing an inventory of fugitive emissions for the oil and gas industry. It can be addressed through direct comparisons with other countries and, for refined inventories, through comparisons between individual companies in the same industry segment and subcategory. This requires use of consistent definitions and classification schemes. In Canada, the upstream petroleum industry has adopted a benchmarking scheme that compares the emission inventory results of individual companies in terms of production-energy intensity and production-carbon intensity. Such benchmarking allows companies to assess their relative environmental performance. It also flags, at a high level, anomalies or possible errors that should be investigated and resolved.

The indicative factors presented in Table 2.18 may be used to help assess completeness and to qualify specific methane losses as being low, medium or high. Specific methane losses which are appreciably less than the low benchmark or greater than the high benchmark should be explained. The ranking of specific methane losses relative to the presented activity data should not be used as a basis for choosing the most appropriate assessment approach; rather, total emissions (i.e. the product of activity data and emission factors), the complexity of the industry and available assessment resources should all be considered.

**TABLE 2.18**

**CLASSIFICATION OF GAS LOSSES AS LOW, MEDIUM OR HIGH AT SELECTED TYPES OF NATURAL GAS FACILITIES**

| Facilities | Activity data | Yearly emission factors | | | |
|---|---|---|---|---|---|
| | | **Low** | **Medium** | **High** | **Units of Measure** |
| Production and Processing | Net gas production (i.e. marketed production) | 0.05 | 0.2 | 0.7 | % of net production |
| Transmission Pipeline Systems | Length of transmission pipelines | 200 | 2 000 | 20 000 | $m^3$/km/yr |
| Compressor Stations | Installed compressor capacity | 6 000 | 20 000 | 100 000 | $m^3$/MW/yr |
| Underground Storage | Working capacity of underground storage stations | 0.05 | 0.1 | 0.7 | % of working gas capacity |
| LNG Plant (liquefaction or regasification) | Gas throughput | 0.005 | 0.05 | 0.1 | % of throughput |
| Meter and Regulator Stations | Number of stations | 1 000 | 5 000 | 50 000 | $m^3$/station/yr |
| Distribution | Length of distribution network | 100 | 1 000 | 10 000 | $m^3$/km/yr |
| Gas Use | Number of gas appliances | 2 | 5 | 20 | $m^3$/appliance/yr |

Source: Adapted from currently unpublished work by the International Gas Union, and based on data for a dozen countries including Russia and Algeria.

Smaller individual sources, when aggregated nationally over the course of a year, may often be significant total contributors. Therefore, *good practice* is not to disregard them unless their collective contribution to total fugitive emissions is proven to be negligible. Conversely, once a thorough assessment has been done, a basis exists for simplifying the approach and better allocating resources in the future to best reduce uncertainties in the results.

### 2.7.1.5 DEVELOPING A CONSISTENT TIME SERIES

Ideally, emission estimates will be prepared for the base year and subsequent years using the same method. Where some historical data are missing it should still be possible to use source-specific measurements combined with backcasting techniques to establish an acceptable relationship between emissions and activity data in the base year. Approaches for doing this will depend on the specific situation, and are discussed in general terms in Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques.

While establishing base year emission levels is meaningful and important at a regional or national level, it is often a misleading indicator at the company level due to frequent mergers, divestitures and acquisitions in many areas. This may be an issue where national inventories are developed based on a rollup of company-level inventories, and some extrapolations or interpolations are required.

Where changes in methods and emission factors are substantial, the whole time series should be recalculated and reported in a transparent manner.

### 2.7.1.6 UNCERTAINTY ASSESSMENT

Sources of error occur in the following areas:

- Measurement errors;
- Extrapolation errors;
- Inherent uncertainties of the selected estimation techniques;
- Missing or incomplete information regarding the source population and activity data;

- Poor understanding of temporal and seasonal variations in the sources;
- Over or under accounting due to confusion or inconsistencies in category divisions and source definitions;
- Misapplication of activity data or emission factors;
- Errors in reported activity data;
- Missed accounting of intermediate transfer operations and reprocessing activities (e.g. repeat dehydration of gas streams [in the field, at the plant, and following storage], treating of slop and foreign oil receipts) due to poor or no documentation of such activities;
- Variances in the effectiveness of control devices and missed accounting of control measures;
- Data-entry and calculation errors.

Due to the complexity of the oil and gas industry, it is difficult to quantify the net uncertainties in the overall inventories, emission factors and activity data. While some semi-quantitative analyses have been conducted, a more thorough quantitative analysis is warranted.

High-quality refined emissions factors for most gases may be expected to have errors in the order of ±25 percent.[25] Factors based on stochiometric ratios may be much better (e.g. errors of ±10%). Gas compositions are usually accurate to within ±5% on individual components. Flow rates typically have errors of ±3% or less for sales volumes and ±15% or more for other volumes.

A high-quality bottom-up (Tier 3) inventory of fugitive methane losses from either oil or gas activities might be expected to have errors of ±25 to ±50%. In comparison, default production-based emission factors for methane losses may easily be in error by an order of magnitude or more. Inventories of fugitive $CH_4$ and $CO_2$ emissions from venting and flaring activities will be quite reliable if the raw gaseous composition and actual vented and flared volumes are accurately known. Estimates of fugitive $N_2O$ emissions will be least reliable but will only be a minor contributor to total fugitive greenhouse gas emissions from oil and gas activities.

Estimates of emission reductions from individual control actions may be accurate to within a few percent to ±25% depending on the number of subsystems or sources considered.

## 2.7.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Section 8.10.1 of Chapter 8, Quality Assurance and Quality Control.

It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

Some examples of specific documentation and reporting relevant to this source category are provided below.

Documentation is particularly important where a Tier 3 approach is used since the *IPCC Guidelines* do not describe a standard Tier 3 approach for the oil and gas sector. There is a wide range in what potentially may be classified as a Tier 3 approach, and correspondingly, in the amount of uncertainty in the results.

If available, summary performance and activity indicators should be reported to help put the results in perspective (e.g. total production levels and transportation distances, net imports and exports, and specific energy, carbon and emission intensities). Reported emission results should also include a trend analysis to show changes in emissions and activity data over time. The expected accuracy of the results should be stated and the areas of greatest uncertainty clearly noted. This is critical for proper interpretation of the results and any claims of net reductions.

The current trend by some government agencies and industry associations is to develop detailed methodology manuals and reporting formats for specific segments and subcategories of the industry. This is perhaps the most practical means of maintaining, documenting and disseminating the subject information. However, all such initiatives must conform to the common framework established in the *IPCC Guidelines* so that the emission results can be compared across countries.

[25] The percentages cited in this section represent an informal polling of assembled experts aiming to approximate the 95% confidence interval around the central estimate.

Since emission factors and estimation procedures are continually being improved and refined, it is possible for changes in reported emissions to occur without any real changes in actual emissions. Accordingly, the basis for any changes in results between inventory updates should be clearly discussed and those due strictly to changes in methods and factors should be highlighted.

The issue of confidential business information will vary from region to region depending on the number of firms in the market and the nature of the business. The significance of this issue tends to increase in progressing downstream through the oil and gas industry. A common means to address such issues where they do arise is to aggregate the data using a reputable independent third party.

## 2.7.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8 and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory agencies are encouraged to use higher tier QA/QC for *key source categories* as identified in Chapter 7, Methodological Choice and Recalculation.

In addition to the guidance in Chapter 8, specific procedures of relevance to this source category are outlined below.

Emission inventories for large, complex oil and gas industries will be susceptible to significant errors due to missed or unaccounted sources. To minimise such errors, it is important to obtain active industry involvement in the preparation and refinement of these inventories.

### Review of direct emission measurements

If direct measurements are used to develop country-specific emission factors, the inventory agency should establish whether measurements at the sites were made according to recognised standard methods. If the measurement practices fail this criterion, then the use of these emissions data should be carefully evaluated, estimates reconsidered, and qualifications documented.

### Emission factors check

The inventory agency should compare measurement-based factors to IPCC default factors and factors developed by other countries with similar industry characteristics. If IPCC default factors are used, the inventory agency should ensure that they are applicable and relevant to the category. If possible, the IPCC default factors should be compared to national or local data to provide further indication that the factors are applicable.

### Activity data check

Several different types of activity data may be required for this source category, depending on which method is used. The inventory agency should check different types of activity data against each other to assess reasonableness. Where possible, multiple sources of data (i.e. from national statistics and industry organisations) should be compared. Significant differences in data should be explained and documented. Trends in main emission drivers and activity data over time should be checked and any anomalies investigated.

### External review

Emission inventories for large, complex oil and gas industries will be susceptible to significant errors due to missed or unaccounted for sources. To minimise such errors, it is important to obtain active industry involvement in the preparation and refinement of these inventories.

# REFERENCES

## NON-$CO_2$ EMISSIONS FROM STATIONARY COMBUSTION


EMEP/CORINAIR (1999). *Atmospheric Emission Inventory Guidebook*, 2nd edition. European Environment Agency, Copenhagen, Denmark.

Intergovernmental Panel on Climate Change (IPCC) (1997). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, J.T. Houghton *et al*., IPCC/OECD/IEA, Paris, France.

Smith, K.R., Pennise D.M., Khummongkol P., Chaiwong V., Ritgeen K.., Zhang J., Panyathanya W., Rasmussen R.A., Khalil M.A.K., and Thorneloe S.A. (1999). *Greenhouse Gases from Small-scale Combustion Devices in Developing Countries. Phase III: Charcoal-Making Kilns in Thailand.* EPA-600/R-99-109. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C., USA.

Smith K.R., Uma R., Kishore V.V.N., Lata K., Joshi V., Zhang J., Rasmussen R.A. and Khalil M.A.K. (2000). *Greenhouse Gases from Small-scale Combustion Devices in Developing Countries, Phase IIa: Household Stoves in India*. EPA-600/R-00-052. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C., USA.

Zhang J., Smith K.R., Ma Y., Ye S., Weng X., Jiang F., Qi W., Khalil M.A.K., Rasmussen R.A., and Thorneloe S.A. 'Greenhouse gases and other pollutants from household stoves in China: A database for emission factors'. *Atmospheric Environment* (forthcoming).

Zhang J., Smith K.R., Uma R., Ma Y., Kishore V.V.N., Lata K., Khalil M.A.K., Rasmussen R.A., and Thorneloe S.A. (1999). 'Carbon monoxide from cookstoves in developing countries: 1. Emission factors'. *Chemosphere: Global Change Science,* 1 (1-3), pp. 353-366.

Zhang J., Smith K.R., Uma R., Ma Y., Kishore V.V.N., Lata K., Khalil M.A.K., Rasmussen R.A., and Thorneloe S.A. (1999). 'Carbon monoxide from cookstoves in developing countries: 2. Potential chronic exposures'. *Chemosphere: Global Change Science,* 1 (1-3), pp. 367-375.

Zhang J. and Smith K.R. (1999). 'Emissions of carbonyl compounds from various cookstoves in China'. *Environmental Science and Technology*, 33 (14), pp. 2311-2320.


## MOBILE COMBUSTION: AIRCRAFT


ANCAT/EC2 (1998). *ANCAT/EC2 Global Aircraft Emissions Inventories for 1991/92 and 2015.* R. M. Gardner, report by the ECAC/ANCAT and EC Working Group, ECAC-EC, ISBN 92-828-2914-6.

Baughcum S. L., Tritz T. G., Henderson S. C. and Pickett D. C. (1996). *Scheduled Civil Aircraft Emission Inventories for 1992: Database Development and Analysis.* NASA Contractor Report 4700.

Daggett, D.L. *et al*. (1999). *An Evaluation of Aircraft Emissions Inventory Methodology by Comparison With Reported Airline Data.* NASA CR-1999-209480, NASA Center for AeroSpace Information, 7121 Standard Drive, Hanover, MD 21076-1320, USA.

EMEP/CORINAIR (1999). *Atmospheric Emission Inventory Guidebook*, 2nd edition. European Environment Agency, Copenhagen, Denmark.

Falk (1999). *Estimating The Fuel Used And $NO_x$ Produced From Civil Passenger Aircraft From ANCAT/EC2 Inventory Data*. Report No DTI/EID3c/199803, Department of Transport and Industry, UK.

Falk (1999b). *Estimating the fuel used and $NO_x$ produced from civil passenger aircraft from ANCAT/EC2 inventory data.* Table 2 of DTI Report DTI/EID3c/199803, Department of Transport and Industry, UK.

ICAO (1997). *Statistics Division - Report of the Ninth Session*, Montreal, 22-26 September 1997. Document no. 9703, STA/9 (1997) International Civil Aviation Organization, Montreal, Canada, 1998.

Intergovernmental Panel on Climate Change IPCC (1997). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories,* J.T. Houghton *et al*., IPCC/OECD/IEA, Paris, France.

IPCC (1999). *Aviation and the Global Atmosphere.* Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Olivier J.G.J. (1995). *Scenarios for Global Emissions from Air Traffic.* Report No. 773 002 003, National Institute of Public Health and Environment (RIVM), Bilthoven, The Netherlands.

UNFCCC (1999). *Methods Used To Collect Data, Estimate And Report Emissions From International Bunker Fuels*. Draft report from the secretariat to the United Nations Framework Convention on Climate Change, April 21 1999.

## FUGITIVE EMISSIONS FROM COAL MINING AND HANDLING

Intergovernmental Panel on Climate Change (IPCC) (1997). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, J.T. Houghton *et al*., IPCC/OECD/IEA, Paris, France.

Riemer P. (1999). 'Technologies for Abatement of Methane Emissions'. *Methane emissions from coal mining*, Volume 1, Chapter 4, IEAGHG/SR7, restricted circulation.

Williams D.J. and A. Saghafi (1993). 'Methane emissions from coal mining - a perspective'. *Coal J*., 41, pp. 37-42.

Williams, D. J., Saghafi, A., Lange, A. L. and Drummond, M. S. (1993). *Methane emissions from open-cut mines and post-mining emissions from underground coal.* CET/IR 173, CSIRO Division of Coal and Energy Technology, unrestricted investigation report to the Department of Environment, Sports and Territories, Australia.

## FUGITIVE EMISSIONS FROM OIL AND GAS OPERATIONS

Canadian Association of Petroleum Producers (1999). *$CH_4$ and VOC Emissions from the Canadian Upstream Oil and Gas Industry*. Canadian Association of Petroleum Producers, Calgary, AB, Canada.

GRI/US EPA (1996). *Methane Emissions from the Natural Gas Industry*. Report No. EPA-600/R-96-080, GRI / United States Environmental Protection Agency.

Intergovernmental Panel on Climate Change (IPCC) (1997). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, J.T. Houghton *et al*., IPCC/OECD/IEA, Paris, France.

USEPA (1999). *Methane Emissions from the U.S. Petroleum Industry*. EPA Report No. EPA-600/R-99-010, p. 158, prepared by Radian International LLC for United States Environmental Protection Agency, Office of Research and Development.