CHAPTER 6

REFERENCE APPROACH

Authors

Karen Treanton (IEA)

Francis Ibitoye (Nigeria), Kazunari Kainou (Japan), Jos G. J. Olivier (Netherlands), Jan Pretel (Czech Republic), Timothy Simmons (UK), and Hongwei Yang (China)

Contributing Author

Roberta Quadrelli (IEA)

Contents

Equations

Figure

Tables

6 REFERENCE APPROACH

6.1 OVERVIEW

The Reference Approach is a top-down approach, using a country's energy supply data to calculate the emissions of CO_2 from combustion of mainly fossil fuels. The Reference Approach is a straightforward method that can be applied on the basis of relatively easily available energy supply statistics. Excluded carbon has increased the requirements for data to some extent. However, improved comparability between the sectoral and reference approaches continues to allow a country to produce a second independent estimate of CO_2 emissions from fuel combustion with limited additional effort and data requirements.

It is *good practice* to apply both a sectoral approach and the reference approach to estimate a country's CO_2 emissions from fuel combustion and to compare the results of these two independent estimates. Significant differences may indicate possible problems with the activity data, net calorific values, carbon content, excluded carbon calculation, etc. (see Section 6.8 for a more detailed explanation of this comparison).

6.2 SOURCE CATEGORIES COVERED

The Reference Approach is designed to calculate the emissions of CO_2 from fuel combustion, starting from high level energy supply data. The assumption is that carbon is conserved so that, for example, carbon in crude oil is equal to the total carbon content of all the derived products. The Reference Approach does not distinguish between different source categories within the energy sector and only estimates total CO_2 emissions from Source category 1A, Fuel Combustion. Emissions derive both from combustion in the energy sector, where the fuel is used as a heat source in refining or producing power, and from combustion in final consumption of the fuel or its secondary products. The Reference Approach will also include small contributions that are not part of 1A and this is discussed in Section 6.8.

6.3 ALGORITHM

The Reference Approach methodology breaks the calculation of carbon dioxide emissions from fuel combustion into 5 steps:

Step 1: Estimate Apparent Fuel Consumption in Original Units

Step 2: Convert to a Common Energy Unit

Step 3: Multiply by Carbon Content to Compute the Total Carbon

Step 4: Compute the Excluded Carbon

Step 5: Correct for Carbon Unoxidised and Convert to CO_2 Emissions

These steps are expressed in the following equation:

EQUATION 6.1
CO_2 EMISSIONS FROM FUEL COMBUSTION USING THE REFERENCE APPROACH

$$CO_2\ Emissions = \sum_{all\ fuels} \left[\begin{array}{l} ((Apparent\,Consumption_{fuel} \bullet Conv\,Factor_{fuel} \bullet CC_{fuel}) \bullet 10^{-3} \\ - Excluded\,Carbon_{fuel}) \bullet COF_{fuel} \bullet 44/12 \end{array} \right]$$

Where:

CO_2 Emissions = CO_2 emissions (Gg CO_2)

Apparent Consumption = production + imports – exports – international bunkers - stock change

Conv Factor (conversion factor) = conversion factor for the fuel to energy units (TJ) on a net calorific value basis

CC = carbon content (tonne C/TJ)
Note that tonne C/TJ is identical to kg C/GJ

Excluded Carbon =carbon in feedstocks and non-energy use excluded from fuel combustion emissions (Gg C)

COF (carbon oxidation factor)	= fraction of carbon oxidised. Usually the value is 1, reflecting complete oxidation. Lower values are used only to account for carbon retained indefinitely in ash or soot
44/12	= molecular weight ratio of CO_2 to C.

6.4 ACTIVITY DATA

The Reference Approach starts from statistics for production of fuels and their external (international) trade as well as changes in their stocks. From this information the "Apparent Consumption" is estimated. It also needs a limited number of values for the consumption of fuels used for non-energy purposes where carbon may be emitted through activities not covered or only partly covered under fuel combustion.

6.4.1 Apparent consumption

The first step of the Reference Approach is to estimate apparent consumption of fuels within the country. This requires a supply balance of primary and secondary fuels (fuels produced, imported, exported, used in international transport (bunker fuels) and stored or removed from stocks). In this way carbon is brought into the country from energy production and imports (adjusted for stock changes) and moved out of the country through exports and international bunkers. In order to avoid double counting it is important to distinguish between primary fuels, which are fuels found in nature such as coal, crude oil and natural gas, and secondary fuels or fuel products, such as gasoline and lubricants, which are derived from primary fuels. A complete list of fuels is provided in Section 1.4.1.1 of the Energy Volume Introduction chapter.

To calculate the supply of fuels to the country, the following data are required for each fuel and inventory year:

- the amounts of primary fuels produced[1] (production of secondary fuels and fuel products is not included);
- the amounts of primary and secondary fuels imported;
- the amounts of primary and secondary fuels exported;
- the amounts of primary and secondary fuels used in international bunkers;
- the net increases or decreases in stocks of primary and secondary fuels.

The apparent consumption of a primary fuel is, therefore, calculated from the above data as:

EQUATION 6.2
APPARENT CONSUMPTION OF PRIMARY FUEL

$$\begin{aligned} Apparent\,Consumption_{fuel} = \; & Production_{fuel} + Imports_{fuel} - Exports_{fuel} \\ & - International\,Bunkers_{fuel} - Stock\,Change_{fuel} \end{aligned}$$

An increase in stocks is a positive stock change which withdraws supply from consumption. A stock reduction is a negative stock change which, when subtracted in the equation, causes an increase in apparent consumption.

The total apparent consumption of primary fuels will be the sum of the apparent consumptions for each primary fuel.

Apparent consumption of secondary fuels should be added to apparent consumption of primary fuels. The production (or manufacture) of secondary fuels should be ignored in the calculations because the carbon in these fuels is already included in the supply of primary fuels from which they were derived; for instance, the estimate for apparent consumption of crude oil already contains the carbon from which gasoline would be refined. Apparent consumption of a secondary fuel is calculated as follows:

[1] Production of natural gas is measured after purification and extraction of NGLs and sulphur. Extraction losses and quantities re-injected, vented or flared are not included. Production of coal includes the quantities extracted or produced calculated after any operation for removal of inert matter. Production of oil includes marketable production and excludes volumes returned to formation.

EQUATION 6.3
APPARENT CONSUMPTION OF SECONDARY FUEL

$$Apparent\,Consumption_{fuel} = Imports_{fuel} - Exports_{fuel} - International\,Bunkers_{fuel} - Stock\,Change_{fuel}$$

Note that this calculation can result in negative numbers for apparent consumption of a given fuel. This is possible and it indicates a net export or stock increase of that fuel in the country.

The total apparent consumption of secondary fuels will be the sum of the apparent consumptions for each secondary fuel.

6.4.2 Conversion to energy units

Often oil and coal data are expressed in metric tonnes. Natural gas may be expressed in cubic meters or in a heat value such as BTU on a gross or net calorific value basis[2]. For the purposes of the Reference Approach, the apparent consumption should be converted to terajoules on a net calorific value basis. However, since the intention of the Reference Approach is to verify the estimates made using a more detailed approach, if the country has used gross calorific values in their detailed calculations, then it is preferable to do so also in the calculations for the Reference Approach. When selecting a country-specific calorific value for the Reference Approach based on detailed consumption values, *good practice* suggests that a weighted average be used. See the Introduction chapter of this Volume for a detailed description of the conversion to energy units (Section 1.4.1.2).

6.5 CARBON CONTENT

The carbon content of the fuel may vary considerably both among and within primary fuel types:

- For natural gas, the carbon content depends on the composition of the gas which, in its delivered state, is primarily methane, but can include small quantities of ethane, propane, butane, CO_2 and heavier hydrocarbons. Natural gas flared at the production site will usually be "wet", i.e., containing far larger amounts of non-methane hydrocarbons. The carbon content will be correspondingly different.
- For crude oil, the carbon content may vary depending on the crude oil's composition (e.g. depending on API gravity and sulphur content). For secondary oil products, the carbon content for light refined products such as gasoline is usually less than for heavier products such as residual fuel oil.
- For coal, the carbon content per tonne varies considerably depending on the coal's composition of carbon, hydrogen, sulphur, ash, oxygen, and nitrogen.

Since the carbon content is closely related to the energy content of the fuel, the variability of the carbon content is small when the activity data are expressed in energy units.

Since carbon content varies by fuel type, data should be used for detailed categories of fuel and product types. The default values for carbon content given in the Introduction chapter of the Energy Volume are suggested only if country-specific values are not available. When selecting a country-specific carbon content for the Reference Approach based on detailed consumption values, *good practice* suggests that a weighted average be used.

For a given fuel, the country-specific carbon content may vary over time. In this instance, different values may be used in different years.

6.6 EXCLUDED CARBON

The next step is to exclude from the total carbon the amount of carbon which does not lead to fuel combustion emissions, because the aim is to provide an estimate of fuel combustion emissions (Source category 1A).

---

[2] The difference between the "net" and the "gross" calorific value for each fuel is the latent heat of vaporisation of the water produced during combustion of the fuel. For the purposes of the IPCC Guidelines, the default carbon emission factors have been given on a net calorific value basis. Some countries may have their energy data on a gross calorific value basis. If these countries wish to use the default emission factors, they may assume that the net calorific value for coal and oil is about 5% less than the gross value and for natural gas is 9 to 10% less.

Carbon excluded from fuel combustion is either emitted in another sector of the inventory (for example as an industrial process emission) or is stored in a product manufactured from the fuel. In the 1996 Guidelines, carbon in the apparent consumption that does not lead to fuel combustion emissions has been referred to as "stored carbon" but, as the above definition makes clear, stored carbon is only part of the carbon to be excluded from "total carbon" in the *2006 IPCC Guidelines.*

The main flows of carbon concerned in the calculation of excluded carbon are those used as feedstock, reductant or as non-energy products. Table 6.1 sets out the main products in each group.[3] If countries have other fossil fuel carbon products which should be excluded they should be taken into consideration and documented.

TABLE 6.1
PRODUCTS USED AS FEEDSTOCKS, REDUCTANTS AND FOR NON-ENERGY PURPOSES

Feedstock	Naphtha
	LPG (butane/propane)
	Refinery gas
	Gas/diesel oil and Kerosene
	Natural gas
	Ethane
Reductant	Coke oven coke (metallurgical coke) and petroleum coke
	Coal and coal tar/pitch
	Natural gas
Non-energy products	Bitumen
	Lubricants
	Paraffin waxes
	White spirit

6.6.1 Feedstock

Carbon emissions from the use of fuels listed above as feedstock are reported within the source categories of the Industrial Processes and Product Use (IPPU) chapter. Consequently, all carbon in fuel delivered as feedstock is excluded from the total carbon of apparent energy consumption. Most of the fuels used as feedstock are also used for heat raising in refineries or elsewhere. For example, gas oil or natural gas may be delivered for heat raising purposes in addition to any feedstock uses. It is therefore essential that only the quantities of fuel delivered for feedstock use are subtracted from the total carbon of apparent energy consumption. The distinction between the feedstock use of fuels and use for fuel combustion needs careful consideration.

Processing feedstock may produce by-product gases or oils. Equally, part of a feedstock supply to a process may be used to fuel the process. The reporting of emissions from the combustion of by-product (or 'off') gases from petrochemical processing or iron and steel manufacture or from the direct use of the feedstock as a fuel is guided by the principle formulated in Section 1.2 of the Introduction chapter of this Volume for allocating fuel combustion emissions between the IPPU and the fuel combustion sectors. Application of the principle will mean that some countries will report some of the feedstock carbon as fuel combustion emissions in their inventories. However, as simplicity is an objective of the Reference Approach, complete exclusion of the feedstock carbon should be maintained there. It is *good practice* that any discrepancies that this generates between the Reference Approach and Sectoral Approach be quantified and explained at the reporting stage.

[3] Detailed bottom-up methods for estimating emissions from use of fuels for feedstock, reductant or other non-energy use are provided in Volume 3, Chapter 5.

6.6.2 Reductant

COKE OVEN COKE AND PETROLEUM COKE

Cokes manufactured from coals and oil products may be used for fuel combustion or industrial processes, most notably in the iron and steel and non-ferrous metals industries. When used as a reductant in industrial processes the coke is heated with inorganic oxides and reduces them carrying away the oxygen in the carbon monoxide and dioxide. The 'off gases' so produced may be combusted on site to help heat the process or combusted elsewhere in another source category. In the latter case, the emissions are reported as fuel combustion. Section 1.2 of the Introduction chapter of this Volume provides guidance on the principles of the reporting. However, as data for this activity are not always readily available and, in order to preserve the simplicity of the Reference Approach, quantities of coke delivered for the iron and steel and non-ferrous metals industries should be excluded from total carbon. The effect of this will be reflected as a difference between the Reference Approach and Sectoral Approach when the comparison is made. See Section 6.8.

COAL AND COAL TAR/PITCH

Pulverised coal may be injected into blast furnaces as a reductant and coal is similarly used as a reductant in some titanium dioxide manufacturing processes. The carbon will largely enter the by-product gases associated with the processes and the emissions covered under the activity where the gases are burned. For the pulverised coal this will be mainly within the iron and steel industry and reported under IPPU. Only where some blast furnace gas is transferred to another industry as fuel will the emissions be classified as Energy sector and the portion of the emissions attributable to the pulverised coal and other injected hydrocarbons will be very small.

The distillation of coal in coke ovens to produce coke leads to the production of tars and light oils recovered from coke oven gas. The light oils include benzene, toluene, xylene and non-aromatics as well as lesser amounts of other chemicals. Tars include naphthalene, anthracene, and pitch. The light oils are valuable as solvents and as basic chemicals. The related emissions are assumed covered under IPPU.

Pitches are often used as binders for anode production. Heavier oils associated with pitches may be used for dyestuffs, wood preservatives or in road oils for asphalt laying. All of these activities are covered under IPPU and their related emissions are excluded from fuel combustion.

If there are coke manufacturing plants where the oils or tars are burned for heat raising, it is suggested that any instances of this activity in a country be taken into account to explain differences between the Reference Approach and a Sectoral Approach when the reconciliation is made.

NATURAL GAS

In some iron and steel plants natural gas may be injected into blast furnaces as a reductant in the iron making process. The classification of the emissions related to the injection of gas is identical to that made for pulverised coal discussed above and these amounts should be excluded.

6.6.3 Non-energy products use

BITUMEN

Bitumen/asphalt is used for road paving and roof covering where the carbon it contains remains stored for long periods of time. Consequently, there are no fuel combustion emissions arising from the deliveries of bitumen within the year of the inventory.

LUBRICANTS

Lubricating oil statistics usually cover not only use of lubricants in engines but also oils and greases for industrial purposes and heat transfer and cutting oils. All deliveries of lubricating oil should be excluded from the Reference Approach. This avoids a potential double count of emissions from combustion of waste lubricants covered in the Reference Approach under "other fossil fuels" but ignores the inclusion of emissions from lubricants in two-stroke engines. See the discussion under 'Simplifications in the Reference Approach' in Section 6.8.

PARAFFIN (PETROLEUM) WAXES

All quantities of paraffin waxes are excluded from the Reference Approach. Within the many uses for paraffin waxes there are two main uses which lead to fuel combustion as defined in Section 1.2. These are the burning of candles in heating or warming devices (for example, chafing dishes) and the incineration of wax-coated materials amongst other waste in municipal waste plants with heat recovery. Use of candles for lighting is considered mainly a decorative purpose and not fuel combustion. Emissions from combustion of waxes in municipal waste plants with heat recovery are already included in the Reference Approach (under "Other fossil fuels") so the relevant wax quantities should be excluded. Data on the contribution from the remaining small source of energy are very difficult to obtain so, within the Reference Approach, these sources are excluded from fuel combustion.

WHITE SPIRIT

White spirit leads to solvent emissions which are not fuel combustion emissions and therefore should be excluded.

6.6.4 Method

The quantity of carbon to be excluded from the estimation of fuel combustion emissions is calculated according to following equation.

EQUATION 6.4
CARBON EXCLUDED FROM FUEL COMBUSTION EMISSIONS

$$Excluded\ Carbon_{fuel} = Activity\ \ Data_{fuel} \bullet CC_{fuel} \bullet 10^{-3}$$

Where:

Excluded Carbon = carbon excluded from fuel combustion emissions (Gg C)

Activity Data = activity data (TJ)

CC = carbon content (tonne C/TJ)

The activity data for each relevant product are given in Table 6.2.

TABLE 6.2
ACTIVITY DATA FOR EXCLUDED CARBON FLOWS

Fuel	Activity data[1]
LPG, ethane, naphtha, refinery gas[2], gas/diesel oil, kerosene	Deliveries to petrochemical feedstocks[3]
Bitumen	Total deliveries
Lubricants	Total deliveries
Paraffin waxes[2]	Total deliveries
White spirit[2]	Total deliveries
Cokes	
Calcined petroleum coke	Total deliveries
Coke oven coke	Deliveries to the iron and steel and non-ferrous metals industries
Coal Tar	
Light oils from coal	Deliveries to chemical industry
Coal tar/pitch	Deliveries to chemical industry and construction
Natural gas	Deliveries to petrochemical feedstocks and for the direct reduction of iron ore in the iron and steel industry

Notes:

[1] Deliveries refers to the total amount of fuel delivered and is not the same thing as apparent consumption (where the production of secondary fuels is excluded).

[2] Refinery gas, paraffin waxes and white spirit are included in “other oil”.

[3] For the purposes of the Reference Approach, the deliveries used as activity data should be net of any oils returned to refineries from petrochemical processing.

6.7 CARBON UNOXIDISED DURING FUEL COMBUSTION

A small part of the fuel carbon entering combustion escapes oxidation but the majority of this carbon is later oxidised in the atmosphere. It is assumed that the carbon that remains unoxidised (e.g. as soot or ash) is stored indefinitely. For the purposes of the Reference Approach, unless country-specific information is available, a default value of 1 (full oxidation) should be used.

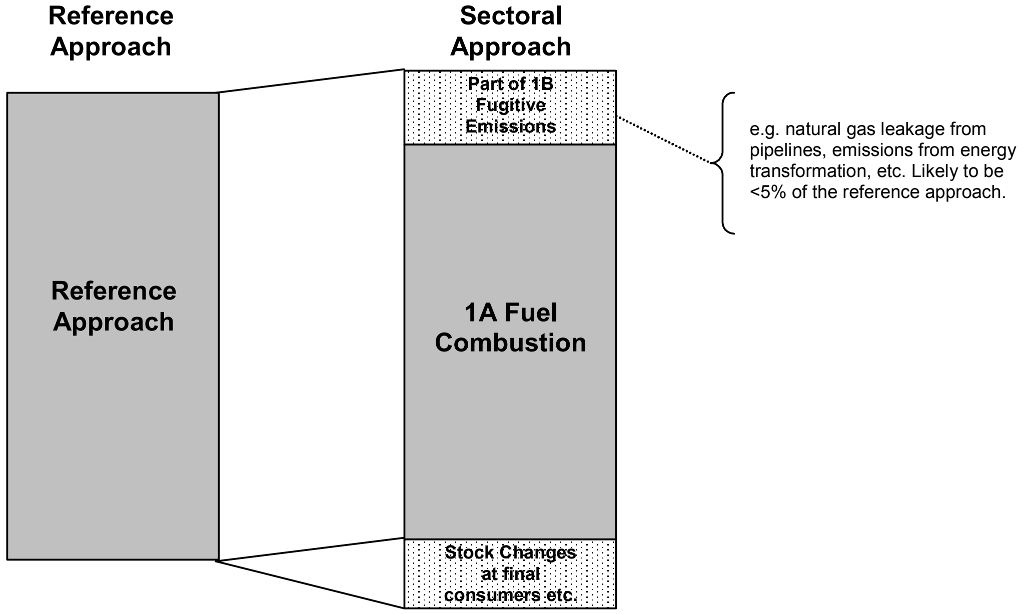
6.8 COMPARISON BETWEEN THE REFERENCE APPROACH AND A SECTORAL APPROACH

The Reference Approach and the Sectoral Approach often have different results because the Reference Approach is a top-down approach using a country’s energy supply data and has no detailed information on how the individual fuels are used in each sector.

The Reference Approach provides estimates of CO_2 to compare with estimates derived using a Sectoral Approach. Since the Reference Approach does not consider carbon captured, the results should be compared to the CO_2 emissions before those amounts are subtracted out. Theoretically, it indicates an upper bound to the Sectoral Approach ‘1A Fuel Combustion’, because some of the carbon in the fuel is not combusted but will be emitted as fugitive emissions (as leakage or evaporation in the production and/or transformation stage).

Calculating CO_2 emissions with the two approaches can lead to different results for some countries. Typically, the gap between the two approaches is relatively small (5 per cent or less) when compared to the total carbon flows involved. In cases where 1) fugitive emissions are proportional to the mass flows entering production and/or transformation processes, 2) stock changes in final consumer level are not significant and 3) statistical differences in the energy data are limited, the Reference Approach and the Sectoral Approach should lead to similar evaluations of the CO_2 emissions trends.

Figure 6.1 Reference approach versus sectoral approach



When significant discrepancies and/or large time-series deviation do occur, the main reasons are listed below.

- Large **statistical differences** between the energy supply and the energy consumption in the basic energy data. Statistical differences arise from the collection of data from different parts of the fuel flow from its supply origins to the various stages of downstream conversion and use. They are a normal and proper part of a fuel balance. Large random statistical differences must always be examined to determine the reason for the difference but equally important smaller statistical differences which systematically show an excess of supply over demand (or vice versa) should be pursued.

- Significant **mass imbalances** between crude oil and other feedstock entering refineries and the (gross) petroleum products manufactured.

- The use of **approximate net calorific and carbon content values** for primary fuels which are converted rather than combusted. For example, it may appear that there is no conservation of energy or carbon depending on the calorific value and/or the carbon content chosen for the crude oil entering refineries and for the mix of products produced from the refinery for a particular year. This may cause an overestimation or underestimation of the emissions associated with the Reference Approach.

- The **misallocation of the quantities of fuels used for conversion into derived products** (other than power or heat) **or quantities combusted in the energy sector**. When reconciling differences between the Reference Approach and a Tier 1 Sectoral Approach it is important to ensure that the quantities reported in the transformation and energy sectors (e.g. for coke ovens) reflect correctly the quantities used for conversion and for fuel use, respectively, and that no misallocation has occurred. Note that the quantities of fuels converted to derived products should have been reported in the transformation sector of the energy balance. If any derived products are used to fuel the conversion process, the amounts involved should have been reported in the energy sector of the energy balance. In Tier 1 Sectoral Approach the inputs to the transformation sector should not be included in the activity data used to estimate emissions.

- **Missing information on combustion of certain transformation outputs**. Emissions from combustion of secondary fuels produced in integrated processes (for example, coke oven gas) may be overlooked in Tier 1 Sectoral Approach if data are poor or unavailable. The use of secondary fuels (the output from the transformation process) should be included in the Sectoral Approach for all secondary products. Failure to do so will result in an underestimation of the Sectoral Approach.

- **Simplifications in the Reference Approach.** There are small quantities of carbon which should be included in the Reference Approach because their emissions fall under fuel combustion. These quantities have been excluded where the flows are small or not represented by a major statistic available within energy data. Examples of quantities not accounted for in the Reference Approach include lubricants used in two-stroke engines, blast furnace and other by-product gases which are used for fuel combustion outside their source category of production and combustion of waxed products in waste plants with heat recovery. On the other hand, there are flows of carbon which should be excluded from the Reference Approach but for reasons similar to the above no practical means can be found to exclude them without over complicating the calculations. These include coals and other hydrocarbons injected into blast furnaces as well as cokes used as reductants in the manufacture of inorganic chemicals. The effects of these simplifications will be seen in the discrepancy between the Reference Approach and a Sectoral Approach and if data are available, their magnitudes can be estimated.

- Missing **information on stock changes** that may occur at the final consumer level. The relevance of consumer stocks depends on the method used for the Sectoral Approach. If delivery figures are being used (this is often the case) then changes in consumers' stocks are irrelevant. If, however, the Sectoral Approach is using actual consumption of the fuel, then this could cause either an overestimation or an underestimation of the Reference Approach.
- High **distribution losses** for gas will cause the Reference Approach to be higher than the Sectoral Approach,
- **Unrecorded consumption** of gas or other fuels may lead to an underestimation of the Sectoral Approach.
- The treatment of **transfers** and **reclassifications of energy products** may cause a difference in the Sectoral Approach estimation since different net calorific values and emission factors may be used depending on how the fuel is classified.
- It should be noted that for **countries that produce and export large amounts of fuel**, the uncertainty on the residual supply may be significant and could affect the Reference Approach.

6.9 DATA SOURCES

The IPCC approach to the calculation of emission inventories encourages the use of fuel statistics collected by an officially recognised national body, as this is usually the most comprehensive and accessible source of activity data. In some countries, however, those charged with the task of compiling inventory information may not have ready access to the entire range of data available within their country and may wish to use data specially provided by their country to the international organisations whose policy functions require knowledge of energy supply and use in the world. There are, currently, two main sources of international energy statistics: the International Energy Agency (IEA), and the United Nations (UN). Information on international data sources is given in the Introduction chapter of the Energy Volume (Section 1.4.1.3).

6.10 UNCERTAINTIES

If the Reference Approach is the primary accounting method for the CO_2 from fuel combustion, then it is *good practice t*o carry out an uncertainty analysis.

6.10.1 Activity data

Overall uncertainty in activity data is a combination of both systematic and random errors. Most developed countries prepare balances of fuel supply and this provides a check on systematic errors. In these circumstances, overall systematic errors are likely to be small. However, incomplete accounting may occur in places where individuals and small producers are extracting fossil fuel (generally coal) for their own use and it does not enter into the formal accounting system. However, experts believe that uncertainty resulting from errors in the activity data of countries with well-developed statistical systems is probably in the range of ±5% for a given fuel. For countries with less well-developed energy data systems, this could be considerably larger, probably about ±10% for a given fuel.

6.10.2 Carbon content and net calorific values

The uncertainty associated with the carbon content and the net calorific values results from two main elements, 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. Consequently, the errors can be considered mainly random. The uncertainty will result mostly from variability in the fuel composition. For traded fuels, the uncertainty is likely to be less than for non-traded fuels (see Tables 1.2 and 1.3).

6.10.3 Oxidation factors

Default uncertainty ranges are not available for oxidation factors. Uncertainties for oxidation factors may be developed based on information provided by large consumers on the completeness of combustion in the types of equipment they are using.

References

IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (2000)

Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories