Working paper No. 3 (d) (2000)

PRELIMINARY OPTIONS FOR METHODOLOGIES TO APPLY ADJUSTMENTS UNDER ARTICLE 5.2 OF THE KYOTO PROTOCOL

Fugitive emissions from fuels

Expert report

prepared for the

UNFCCC secretariat

20 February 2000

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INTRODUCTION

Adjustments required under Article 5.2 of the Kyoto Protocol are to be made when inventory data filed with UNFCCC are either incomplete or are calculated in a manner that is not consistent with the Revised 1996 IPCC Guidelines and any guidance on good practice agreed upon by the Conference of the Parties (COP). The purpose of these adjustments is to facilitate better monitoring of emission trends and reductions relative to baseline values, and to promote fairness in reporting. The focus is primarily on Annex B Parties to the Convention since they have made quantified emission limitation or reduction commitments under the Kyoto Protocol. Adjustments will only be assessed when countries fail to correct deficiencies identified in their inventories. Accordingly, any changes, corrections, or additions that a country may make to its inventory are not deemed to be adjustments and are subject to the same methodological and good practice requirements as the inventory itself.

This paper identifies and evaluates a variety of potential methodologies for making adjustments to correct deficiencies in reported fugitive emissions from fuels. The key methodological issues are noted and discussed, and the results of recent discussions relating to Good Practice are considered. The discussions are divided into generic and source-specific matters.

Fugitive emissions from fuels are divided into two main source categories (see Summary Table 7A of the Revised 1996 IPCC Guidelines and Tables 1, 2(1), 3, 4, 5 and 6 of the Common Reporting Format):

- **Solid Fuels** - this category is subdivided into fugitive methane emissions from coal mining and from solid fuel transformation or handling.

- **Oil and Natural Gas** - this category accounts for all direct GHG emissions, except those from fuel combustion, that may be attributed to oil and gas exploration, production, processing/refining, transmissions and final distribution activities. For reporting purposes, the category is subdivided into three categories: fugitive emissions from gas systems, fugitive emissions from oil systems, and venting and flaring emissions from oil and gas systems.

Overall, a flexible adjustment methodology is needed to accommodate the different situations that may occur and the complexities of the oil and gas industry. It is not possible to provide a single approach that can be expected to give meaningful results for all cases, and, in general, the amount of fugitive emissions from fuels does not correlate well with national indices. A proposed decision tree for working through the adjustment process is provided. The basic strategy is to apply simple, interpolation and extrapolation methods wherever these can be expected to provide reasonable results. Otherwise, an IPCC emission-factor approach is taken and problem-specific procedures are presented for bridging any data gaps or deficiencies that may occur. The methods considered for bridging data gaps include interpolations, extrapolations, mass balances, relating certain types of activities to national indices, application of default values, and inferences based on activity levels in upstream or downstream portions of the industry sector. Options that were considered, but ultimately abandoned, also are discussed for completeness.

2.0 GENERAL METHODOLOGICAL ISSUES

The general methodological issues to be considered in making adjustments are as follows:

- Adjustments are intended to provide a reasonable indication of the amount of emissions from a given category, but in a manner that protects all other parties that submitted complete, verifiable inventories. Accordingly, the adjustment should be "conservative (i.e., downward biased when applied to the baseline year and upward biased when applied to all other years).

- The methodology for making adjustments should be simple to use and rely on readily-available information. At the same time, some flexibility is needed to suite the available resources and the significance of the adjustment, while attempting to preserve the transparency and verifiability of the results. Typically, the effort need to make adjustments should not be appreciably different than that required to apply a Tier-1 IPCC approach.

- The methodology should be objective (i.e., the adjustment should not depend on the person performing the estimation).

- It is expected that the need for adjustments will normally arise from a lack of sufficient information to apply existing IPCC inventorying methods, and that the adjustment will effectively serve as a simple means for bridging these gaps. Three basic situations may arise; unknown emission factors, unknown activity levels, or a combination thereof. Consequently, adjustment approaches are potentially needed to address each of these situations.

- Before making any adjustments to account for a missing source category, checks should be performed to ensure that the missing source category has not inadvertently been aggregated with another category, and therefore, already been accounted by the inventory. This will become more of an issue as the reported level of disaggregation increases.

3.0 REVIEW OF IPCC METHODOLOGIES

This section provides a brief overview of the current inventorying methodological requirements of the Revised 1996 Guidelines (Section 1B) and the pending Good Practice Guidance as they pertain to fugitive emissions from fuels. Typical deficiencies that may arise in the application of these approaches, and for which an adjustment may be required, are identified and discussed in Section 5.0.

3.1 Solid Fuels

The specific emission rates from coal mining depend primarily on the relative contribution of surface and underground mining to the total production. Specific emissions are greater for the latter type of production and tend to increase with the depth of the underground mines. The emissions from coal handling are related to the type of mine from which the coal was produced.

It is good practice to estimate CH_4 emissions from underground coal mines using a Tier 3 approach if the mine-specific measurement data are available. Otherwise emissions from both underground and surface mining, and from post-mining are estimated based on the application of appropriate emission factors to national coal production statistics using an equation of the form:

$$\text{Emissions (Gg } CH_4) = [\text{Emission Factor } (m^3\ CH_4/\text{tonne})] \times [\text{Tonnes of Coal Produced}] \times [\text{Conversion Factor } (Gg/10^6\ m^3)]$$

Default emission factors are provided for each source category. The Tier 1 factors are presented as a range and it is the user’s responsibility to determine what value within each range is applicable to their situation. The Good Practice Guidance document provides guidelines for doing this where the depth of the individual mines is known. Two sets of factors are provided for post mining activities: one set for application to coal produced from underground mines and the other for application to coal from surface mines.

Where coal is upgraded, the amount of raw coal production is estimated by increasing the amount of saleable coal to reflect an initial 20 percent rejection rate.

3.2 Oil and Gas Systems

The amount of fugitive emissions from oil and gas activities tends to correlate poorly with production levels or system throughputs. It is more closely related to the amount, type, and age of process infrastructure, characteristics of the hydrocarbons being produced, processed or handled, and the industry design, operating and maintenance practices. Emissions from venting and flaring depend on the amount of process activity, operating practices, economic factors and the local regulatory environment.

The Tier-1 methodology delineated in the Revised 1996 IPCC Guidelines consists of applying aggregate production-based emission factors to national oil and gas statistics. Separate factors are presented by geographic region for each of the source categories shown in Table 1. The good practice guidance for this sector recommends a more disaggregated Tier-1 approach (see Table 2) coupled with the use of different emission indices (i.e., either system throughput or equipment counts) for each subcategory to provide more reliable estimates. A preliminary set of emission factors for this more refined approach is provided in the good practice document.

4.0 ADJUSTMENT METHODOLOGIES

The different methodological approaches that may be considered for making adjustments are delineated below according to the type of information available and the nature of the deficiency. Simple generalized options are considered as a first approach and problem-specific solutions are only provided where needed to address special situations. The need for an adjustment may occur at any level of disaggregation. For instance, it may be that a country has opted to take a Tier-3 approach for a given source category and has neglected to account for a specific subcategory. In these cases it is good practice to only apply an adjustment to correct the affected element rather than revert to a less disaggregated approach and thereby give up the refined estimates for the rest of the category.

The following sections provide an overview of each option in the order of decreasing preference. A decision tree for selecting the most appropriate option is presented in Figure 1. In all cases, it is assumed that the need for an adjustment is real and that prior efforts have been taken to ensure that any missing emission estimates have not already been accounted by an other source category.

4.1 Interpolation

If an emission estimate is invalid or missing for a specific category but is available for both preceding and subsequent years, then an adjustment may be made by interpolation between these two data sets with respect to time. A two-point linear interpolation may be applied for this purpose. It is given by the relation:

$$E_i = E_{i-1} + 0.5 \cdot (E_{i+1} - E_{i-1})$$

where,

E = emission rate for the target source category or subcategory,
i = the specific year of interest.

Provided there is a continuous and uniform emission trend, the maximum potential uncertainty in the result is half the absolute difference between the two interpolating points.

Ideally, the interpolation should be done using several points on either side of the target year to better model any trends, particularly if the time period on either side of the missing point is not uniform. The probable uncertainty in this approach would be approximately the same as average variability between years provided the missing year does not have atypical emissions.

If there are multiple years to be interpolated between the available data sets, an appropriate multipoint interpolating polynomial should be fitted to these data to better reflect the true emission trend. In these situations it is suggested that a classic algebraic polynomial of the following form be fitted to the data:

$$E(t) = a_0 + a_1 t + ... + a_n t^n$$

where,

t	=	time (in years),
a_0, a_1,... a_n	=	polynomial coefficients to be determined from the available emission estimates, and
n	=	a non-negative integer indicating the degree of the polynomial.

Table 1. Major categories and subcategories in the oil and gas industry based on the classification scheme presented in the Revised 1996 IPCC Guidelines.

Industry Segment	Sub-Categories
Oil and Gas Production	• Fugitive emissions from oil production. • Fugitive emissions from gas production. • Venting and flaring from oil and gas production.
Crude Oil Transportation, Storage and Refining	• Transportation. • Refining. • Storage tanks.
Natural Gas Processing, Transportation and Distribution	• All

Table 2. Major categories and subcategories in the oil and gas industry based on the classification scheme presented in the draft good practice guidance document.

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

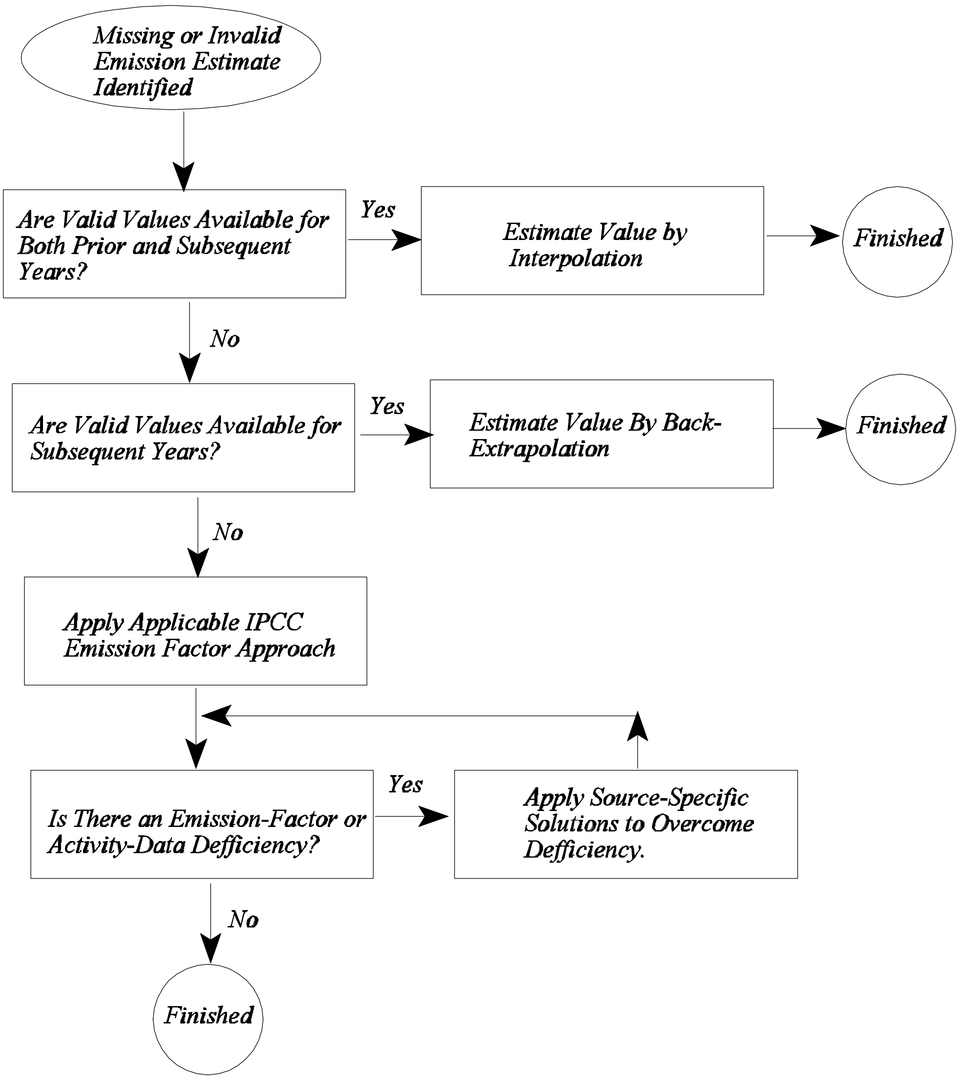

Figure 1. Adjustment Decision Tree

The maximum degree of the polynomial will be limited by the number of data points available for fitting the curve. The uncertainty of this approach increases with the interpolating interval, scatter in the data, and decreasing degree of the polynomial. Easy-to-use curve fitting algorithms are a standard feature of all current spreadsheet programs.

4.2 Extrapolation

If valid emission estimates for the target category only exist on one side of the required year, the missing value(s) may be estimated by extrapolation provided the extrapolation is being made in a backward direction. If a forward extrapolation is required, it is better to either take a more rigorous problem-specific approach or wait until the value can be estimated by interpolation.

At least two, and preferably more, points should be used to make the extrapolation, particularly if there is a non-uniform or discontinuous emission trend. If only one data point is available, then a constant backward emission trend should be assumed. This will generally provide a conservative result for countries with increasing energy production and consumption rates.

The uncertainty of the estimate will increase with the size of the time step between the known and missing data points. Extrapolations over more than a few years should be avoided. In such cases it is more appropriate to either apply a problem-specific approach or, if the country has increasing energy activity levels for the target category, to assume a constant emission trend back from the last point as a conservative approximation.

4.3 Problem-Specific Approaches

The main advantage of interpolation and extrapolation approaches are that they offer a simple means for approximating a value without requiring any particular understanding of the source. Thus, they may be applied with minimal effort and without the need for a specialist. If these options are not appropriate (i.e., based on the constraints discussed in Sections 4.2 and 4.3) then a problem-specific approach should be taken. This involves applying a suitable emission-factor method to assess the emissions in accordance with the Revised 1996 IPCC Guidelines and the applicable good practice requirements. If insufficient data are available to apply the method, then problem-specific approximations are made to overcome these deficiencies.

It may be that problem-specific solutions will be used by review teams as suggestions to the affected country on how to solve an identified problem. In such cases, the results may not be considered an adjustment, but this is still to be discussed by the Parties.

4.3.1 Missing Activity Data

Missing activity data is perhaps the most probable type of deficiency that may occur since, collectively, the Revised 1996 IPCC Guidelines and pending Good Practice Guidance document provide Tier-1 emission factors for all major source categories pertaining to fugitive emissions from fuels, and for many of the subcategories.

If the required activity data are unavailable from an international agency, an effort should be made to identify and contact the applicable national agency. While some differences may exist in the data values reported by the different international sources of energy statistics, it is unlikely that they will have differing data gaps due to the good communication between these agencies.

If a specific activity value is not available for a country and it is known that the activity occurs during the period of interest, then interpolation and extrapolation methods should be applied (as described in Sections 4.1 and 4.2) to determined missing activity value. If neither of these two options is suitable, then an appropriate problem-specific approach should be applied as described in Section 5.

4.3.2 Missing Emission Factors

Missing emission factors should not be a problem at a Tier-1 level. The only potential difficulty might be in selecting an appropriate factor from an available range of values. The pending Good Practice Guidance document provides some direction in this regard. In the absence of a clear choice, the average value should be taken.

4.4 Other Options

Other potential options for making adjustments include:

- Estimation of emissions based on averages over countries included in Annex B of the Kyoto Protocol. The average emission rate would be applied to an emission driver such as GDP, population, energy statistics, etc.

- Estimation of emissions of one gas or source category based on the linkage to emissions of another source or source category.

Neither of these approaches is recommended for estimation of fugitive emissions from fuels. For solid fuels it is better to simply apply a Tier-1 IPCC approach since the above methods require comparable or greater effort and are less reliable. For oil and gas activities, the amount of fugitive emissions is too dependent on a range of factors that may vary dramatically between countries (e.g., design and operating practices, types of oil and gas activity, age of the industry, economic drivers, and regulatory environment) and are not properly considered by either of the above options.

5.0 ESTIMATION DEFICIENCIES

The following sections identify source-specific data gaps that may occur in applying a standard emission factor approach to estimate fugitive emissions from fuels, and provides recommended procedures for overcoming these deficiencies.

5.1 Activity Data

Coal, oil and gas production statistics are available for most countries from the Energy Information Administration (EIA), United Nations Statistics Department (UNSD), and International Energy Agency (IEA), as well as from the respective national agencies. Additional data is available from international surveys conducted by Oil and Gas Journal. Refer to Annex 1 for details of these international databases. The available energy indices for Annex B Parties to the Kyoto Protocol are summarized in Annex 2 of this paper.

The source-specific data issues to be considered are delineated in the subsections below. The following are data issues common to both source categories (i.e., solid fuels and oil and gas activities):

- Data from the international reporting agencies are less current than data from national agencies and are deemed to be less reliable; however, they are more readily available and convenient to use.

- EIA reports data using imperial units of measure while the other sources report in metric units. As well, the calorific basis (i.e, net or gross) may differ between statistical agencies. Consequently, it may be necessary to apply conversion factors before using these data.

- The international data sources do not provide statistics for all the countries of interest. For example, none of the international energy statistics currently provide data for Monaco or Liechtenstein. Additionally, the European Community is not summarized explicitly in the international data bases. It must be characterized by aggregating the data for the member countries.

- Data for the eastern block countries and the former Soviet Union generally are not available for periods prior to 1992. The only practicable means for establishing values for prior years is by extrapolation.

- The data bases do not distinguish between zero values and cases where no data are available. In both situations a zero entry is reported. This makes it difficult to assess whether an adjustment even needs to be made. For example, if non-zero entries are only provided for years after a certain date, it is not clear if the data were not available in prior years, or if the specified activity did not exist in prior years.

- Countries that both import and export fuels do not necessarily have any fuel production. Conversely, countries that have fuel production do not necessarily have any fuel imports or exports.

- There is generally good communication and sharing of raw data between the different international data sources. Consequently, it is expected that any data gaps will be common to all such databases. For example, UNSD and IEA share the same questionnaire and exchange their data in order to minimize duplication. Notwithstanding this, each statistical office conducts their own quality control procedures on the data and present the results in

a slightly different way. Consequently, reported values may not agree between the agencies. If the required activity data are not available from an international source, some effort should be made to contact the applicable national agency to obtain this information before attempting to apply any estimation techniques.

5.1.1 Coal Statistics

Unless otherwise noted, coal statistics usually include both primary (including hard coal and lignite) and derived fuels (including patent fuel, coke oven coke, gas coke, BKB, coke oven gas and blast furnace gas). Peat is also included in this category. The statistics typically summarize total coal consumption, production, reserves, trade, and average heat content. Breakdowns are also given by type of coal produced (i.e., anthracite, bituminous or lignite). At the international level; however, no information is provided regarding the method of mining (i.e., surface/strip or underground) or the depth of the mines. In the absence of any information on the type of mining, a conservative first approximation is to assume that all lignite coal is surface mined and all bituminous and anthracite coal is produced from underground mines. This will tend to overstate emissions since substantial amounts of bitumous coal and lesser amounts of anthracite coal are produced from surface mining operations. Worldwide, it is reported that some 60 percent of all coal production is from surface mining.

If coal production statistics are not available for a country and it is known that some coal production does occur during the period of interest, the following options, presented in the order of decreasing preference, may be considered to estimate the amount of production:

- Interpolation,
- Extrapolation, and
- Application of Regional Energy Indices .

Details on interpolation and extrapolation techniques are provided in Section 4. If no production data exists to allow the use of these two approaches then the value for the target year should be estimated based on per capita consumption rates for the general region (see Annex 2). This approach contains substantial uncertainty since the availability and utilization/exploitation of coal deposits may vary dramatically between countries and geographic regions. The results could easily be in error by several orders of magnitude. Nonetheless, it provides a fair and transparent means of estimating the amount of production activity.

Once estimated, the production value should be corrected, as may be applicable to account for any net imports or exports. It is possible that import and export data may be available for a country while production data are not; however, it is unlikely that the opposite would be true.

5.1.2 Oil and Gas Statistics

Despite any uncertainties due to differences in methodologies and data quality, there are potentially substantial real difference between countries in terms of specific fugitive emissions from oil and natural gas systems. The main reason for these differences include relative differences in:

- infrastructure intensities,
- design, operating and maintenance practices,
- age of equipment,
- quality of components,
- processing requirements,
- gathering and transport distances, and
- economic and environmental drivers for gas conservation and emissions control.

These factors are not always well accounted by inferring emissions based on the available oil and gas statistics. The following sections delineate the limitations of the different data types and discuss options for bridging potential data gaps. A summary of the available international databases is provided in Annex 1.

Production Statistics

Oil and gas production statistics are susceptible to misapplication due to potential confusion regarding the terminology, classification schemes and reporting basis. Production data reported by international sources are expressed on a net basis (i.e., after shrinkage, losses, and reinjected, vented and flared volumes). When data are expressed on an energy basis, UNDS and IEA apply the net calorific values while EIA uses the gross calorific value (the convention varies between national reporting agencies). Crude oil normally includes all hydrocarbons liquids produced from oil wells and lease condensate (separator liquids) recovered at natural gas facilities. It may also include synthetic crude oil production from oilsands and shale oil operations. Total oil includes crude oil, natural gas plant liquids, synthetic crude oils, and refinery processing gain. Natural gas includes gas originating from gas wells, conserved gas produced in association with crude oil, and methane recovered from coal mines (colliery gas).

In the absence of any oil and gas production statistics it is recommended that the same approach applied to coal production be used (see Section 4.1.1). This involves estimating the amount of production by interpolation, extrapolation or based on per capita consumption rates for the general region (see Annex 2).

Vented and Flared Volumes

Venting and flaring is potentially a major source of GHG emissions from the oil and gas industry; however, of the 29 Annex B Parties for which either crude oil production or gas consumption statistics are available, less than one third (i.e., only 9) report any venting or flaring. To have oil production or any form of gas system without at least some venting or flaring is simply not attainable. Moreover, where data are provided, they are highly suspect since they are usually only

estimates and often are incomplete (normally there is no metering on vent or flare systems, especially on emergency relief systems). Even in advanced countries with highly regulated oil and gas industries, it is not uncommon for many operating facilities to incorrectly report zero vented and flared volumes. In other cases, the reported vented and flared volume is used as a balancing term to reconcile production accounting reports, and therefore, may contain significant uncertainties due both to metering errors and the fact substantial venting and flaring may occur upstream of any metering. This latter point is of particularly of issue in countries where the industry is effectively monopolized by a single national petroleum company since, in such cases, there is often only metering at the final sales points (i.e., due to reduced ownership and royalty issues).

An additional issue is that neither the Revised 1996 IPCC Guidelines or the pending Good Practice Guidance document provide a clear definition of venting emissions. Venting emissions should comprise all intentional and emergency discharges of natural gas to the atmosphere. These releases may occur on either a continuous or intermittent basis and may comprise the following:

- use of natural gas as the supply medium for gas operated devices (e.g., chemical injection pumps, starter motors on compressor engines and instrument control loops),
- pressure relief and disposal of off-specification product during process upsets,
- purging and blowdown events related to maintenance and tie-in activities,
- disposal of off-gas streams from gas treatment units (e.g., still-column off-gas from glycol dehydrators, emulsion treater overheads and stabilizer overheads),
- separator off-gas disposal at oil facilities where there is no gas conservation or reinjection,
- gas releases from pigging and well-testing activities,
- disposal of casing-head gas,
- solution gas emissions from storage tanks, and
- biogenic gas formation and evaporation losses from process sewers, API separators, dissolved air flotation units, tailings ponds and storage tanks.

Some countries currently classify several of these activities as fugitive emission sources, and in other cases it is not clear whether they are accounted at all.

Also, where vented and flared statistics are provided, they are reported as a combined value rather than being separated into vented and flared fractions. The actual split has a significant impact on the total CO_2-equivalent emissions from these activities since unburned methane contributes approximately 7.7 times more radiative forcing on a 100-year time horizon than fully combusted methane. If the waste gas is high in non-methane hydrocarbons, the opposite effect may occur.

Typically, waste gas is flared if it contains hydrogen sulphide or if it is in a populated area and there is an odour potential; otherwise, it is vented since this can be done safely and is a more economical option. This general rule may be used to infer disposal practices at oil and gas facilities, but usually requires an intimate knowledge of the industry. In the absence of such knowledge it should be assumed, as a conservative first approximation, that all waste gas is vented . Venting rather than flaring is common practice at gas transmission and storage facilities, but may be in error at other types of facilities.

It should also be noted that the international venting and flaring statistics do not differentiate between acid-gas flaring and other waste-gas flaring. Acid gas streams are a bi-product of the sweetening process at sour gas processing plants and refineries, and may contain large amounts of raw CO_2 extracted from the process gas. The rest of the acid gas is mostly H_2S. The amount of acid gas production is usually metered and the CO_2 content, although not normally tracked by regulatory agencies, is known by the facility operators. Depending on the raw CO_2 content, the net emissions of CO_2 per unit volume of acid gas flared may be appreciably less than for typical waste gas streams. If the acid gas is processed by a sulphur recovery unit rather than being flared, the raw CO_2 passes through the process and is discharged out the final tail gas incinerator and not reported in the available statistics as either vented or flared gas.

Surprisingly, of 5 national GHG emission inventories checked (i.e., Canada, France, New Zealand, United Kingdom and United States of America), none explicitly accounted for any methane venting in the venting and flaring field (i.e., other than a small amount attributable to incomplete combustion). Thus, it is not clear from the information provided whether these countries assumed vented emissions to be flared or if they broke out the vented fraction and included it in fugitive emissions from oil systems and gas systems. A detailed examination of the data for Canada showed the latter situation to be true, but this may not be the case for all other countries. Additionally, a carbon balance on the CH_4 and CO_2 entries for vented and flared emissions shows apparent combustion efficiencies of 99 percent or higher for all 5 countries. Under ideal conditions a combustion efficiency of 98 percent may be achieved (U.S. EPA, 1995). For high-velocity flaring events, strong cross-winds, flame stability problems, or flaring of rich/condensing streams such as associated and solution gas, the efficiencies could be appreciably less (ARC, 1996). The high apparent combustion efficiencies would imply that at least half of the CO_2 emissions accounted under venting and flaring is due to the release of raw CO_2 extracted from the produced gas streams, the flared waste gas contained substantial concentrations of heavier-than-methane hydrocarbons, or some combination thereof. These factors may differ greatly between oil and gas fields, and consequently, between countries.

Accordingly, it is difficult to infer the amount of venting and flaring based on values in other countries due to the high uncertainty in the available data, possible inconsistencies in the reporting basis, and the potential for substantial differences in specific venting and flaring rates between countries. A more direct approach is therefore warranted. For oil systems, the amount of venting and flaring is approximately equal to the gross amount of associated-gas production less any volumes conserved (i.e., produced into a gas gathering system), reinjected or utilized for fuel. The gross associated-gas production volume may be determined by applying a typical gas-to-oil ratio for the region to the amount of oil production using the relation:

[Gross Associated Gas Production] = GOR x [Crude Oil Production]

Typical GOR ranges for several types of oil production are presented in Table 3; however, a more refined summary by geographic area is warranted.

Table 3. Typical ranges of gas-to-oil ratios for different types of production[1].

Type of Crude Oil Production	Typical GOR Range (m^3/m^3)
Conventional Oil	200 to 2000+ [2]
Primary Heavy Oil	0 to 325+ [3]
Thermal Heavy Oil	0 to 90
Crude Bitumen	0 to 20

1 Based on unpublished data for a selection of wells in North America.
2 Appreciably high GORs may occur but these wells are normally either classified as gas wells or there is a significant gas cap present and the gas would be reinjected until all the recoverable oil had been produced.
3 Values as high as 7160 m^3/m^3 have been observed for some wells where there is a significant gas cap present. Gas reinjection is not done in these applications. The gas is either conserved or vented and flared.

In the absence of any gas conservation, reinjection or utilization data, it is perhaps reasonable to assume that all associated gas is disposed by venting and flaring.

The amount of venting and flaring on gas systems is, for the most part, independent of system throughput and more closely related to the number of facilities and the amount of maintenance and construction activity. This type of activity data is unavailable from international sources.

Infrastructure Data

Infrastructure data is more difficult to obtain than production statistics, and use of consistent terminology and clear definitions is critical in developing proper equipment counts. Information concerning the numbers and types of major facilities, the types of processes used at these facilities, numbers and types of active wells, numbers of wells drilled, and the lengths of pipeline are typically only available from national agencies, if available at all. Information on minor facilities (e.g., numbers of field dehydrators and field compressors) usually is not available, even from the actual oil and gas companies.

The only infrastructure data potentially required for application of IPCC Tier-1 approaches are well counts and the lengths of pipeline systems. Facility information is currently only required for IPCC Tier-3 methods.

Possible options for estimation of infrastructure data are as follows:

- Take the length of transmission pipeline to be the same as the largest dimension of the country.

- Estimate the amount of distribution pipeline based on per capita values for other comparable countries. In Canada, where the population is widely dispersed over a large geographic area, there is 7.0 m of distribution main per capita for provinces in which gas service is provided. The average for the entire United States is 5.6 m per capita. These values would be expected to provide an upper limit on the length of distribution main per capita.

5.2 Emission Factors

The potential for missing emission factors will increase with the level of disaggregation used in the inventory. Nonetheless, the Revised 1996 Guidelines and pending Good Practice Guidance document provide factors for all simpler approaches, while factors for many of the more refined approaches are readily available in the open literature.

6.0 CONCLUSIONS

Various options have been considered for adjusting estimates of fugitive emissions from fuels (this sector comprises coal mining and handling, and oil and gas exploration, production, processing/refining, transmission and distribution activities). While the aim was to devise simple generic approaches that could be applied regardless of the type of problem, it is concluded that such options have limited applicability, and that some problem-specific solutions also are required to achieve meaningful results. National energy indices can be used to interpolate or make moderate extrapolations from valid data already available for a given country; however, the amount of fugitive emissions from fuels does not correlate well enough with national indices to allow extrapolations or interpolations between countries. The oil and gas industry, in particular, is simply too complex, and the potential differences between countries too great for high-level problem-independent approaches to be generally applied.

The recommended approaches detailed herein attempt to provide a reasonable balance between ease-of-use and reliability of the results, while also maintaining transparency and objectivity. A proposed decision tree for working through the adjustment process is provided (see Figure 1). Where interpolation and extrapolation methods are not appropriate, an IPCC emission-factor approach is taken and problem-specific procedures are presented for bridging the different types of data gaps or deficiencies that may occur. Potential sources of energy statistics for use in these efforts are identified and discussed.

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ANNEX 1 - Sources of International Energy Statistics

The following provides a brief summary of various potentially-useful international sources of energy statistics.

- **Energy Information Administration (EIA)** (www.eia.doe.gov) - is a statistical agency in the U.S. Department of Energy. EIA regularly reports data about the supply, consumption, distribution, and price of energy in the United States and internationally. The statistics cover petroleum, natural gas, coal, electricity, and various forms of renewable energy (solar, wood, wind, etc.). Energy information is available at four geographic levels -- States, regions, the nation, and foreign countries. The key databases are delineated below:
    - Petroleum - consumption (or demand), production (or supply), reserves, trade (imports and exports), inventories (stock), refinery capacity (including number and through-put of refineries), rotary rigs in operation, and gross heat content.
    - Natural Gas - consumption (demand), production (supply), vented and flared, reinjected and marketed production, natural gas trade (imports and exports), reserves and resources, liquefied natural gas (LNG), and gross heat content.
    - Coal - consumption, production, reserves, trade, heat content, etc.
    - Gross Domestic Product (GDP) and Population - GDP at market exchange rates, population and conversion factors.

  When presented on an energy or energy-equivalent basis, all statistics are based on the gross calorific values of the fuels.

- **International Energy Agency (IEA)** (www.iea.org) - is the energy forum for 25 Member countries. All but one of these are Annex B parties. IEA Member governments are committed to taking joint measures to meet oil supply emergencies. They have agreed to share energy information, to co-ordinate their energy policies and to co-operate in the development of rational energy programmes. In addition, IEA compiles international statistics and reports key indicators for most countries (i.e., populations, total primary energy supply, total electricity consumption, GDP, and the percentage contribution of each form of energy to total primary energy supply [TPES]). When presented on an energy or energy-equivalent basis, all statistics are based on the net calorific values of the fuels.

- **United Nations Statistics Department** (www.un.org/Depts/unsd) - publishes an internationally comparable series on commercial energy for more than 215 countries and areas. The current report contains data in original and common units for the years 1993-1996. Annual data are presented on the production, trade and consumption (including per capita) of solid, liquid and gaseous fuels and electricity. When presented on an energy or energy-equivalent basis, all statistics are based on the net calorific values of the fuels.

- **Oil and Gas Journal** (http://ogj.pennwellnet.com) - publishes statistics on oilfield production, gas processing facilities, and petroleum refineries as well as other information based on its own international surveys of industry. These databases are summarized below. The facilities data would only be potentially useful where countries are applying a Tier-3 approach for estimating fugitive emissions. While the facilities data are known to be very complete and reliable for North America, the quality of the data likely varies significantly for different countries.

    - **Worldwide Oil Field Production Survey** - This Oil & Gas Journal survey provides oil production data by field for the most current year available for more than 80 producing countries outside the U.S., including the Former Soviet Union. Data include country; company; field name; field type (onshore or offshore); discovery date; depth; number of producing wells; oil production for 1997 in b/d; and API gravity. Updated annually in January. Lotus 123 and Excel formats. Sample available.

    - **Worldwide Gas Processing Survey -** Information on over 1,500 operating gas plants worldwide based on Oil & Gas Journal's annual survey is presented. Data include country; state; company; plant; location; gas capacity; gas throughput; process method and production of ethane, propane, isobutane, normal butane, LP-gas mix, raw NGL mix, debutanized natural gasoline and other products. Also, Oil & Gas Journal's annual worldwide survey of sulfur production and capacity by plant is presented. Data include country, company, location, source, design capacity and sulfur production. Updated annually in June. Lotus 123 and Excel Formats.

    - **Worldwide Refinery Survey** - Data for more than 530 foreign and 170 domestic refineries is presented from Oil & Gas Journal's annual Worldwide Refining Report. Both surveys include: number of plants; crude capacities (b/cd); charge capacity (b/cd)for vacuum distillation, thermal operations, catalytic cracking, catalytic reforming, catalytic hydrocracking, catalytic hydrorefining, catalytic hydrotreating; production capacity (b/cd) for alkylation, polymerization, aromatics, isomerization, lubes, oxygenates, asphalt, hydrogen (MMcfd), coke (t/d), sulfur (t/d). Categories include country, location, city and state. Also includes a worksheet on inactive refineries since 1980. Updated annually in December. Lotus 123 and Excel formats.

ANNEX 2 - Summary of Available Energy Indices for Annex B Parties

Table 4 summarizes the available energy indices for Annex B Parties to the Kyoto Protocol for the year 1997. The source of these data is the statistics section of IEA’s Web site.

Table 4. Summary of national indices for Annex B Parties to the Kyoto Protocol (adapted from data provided on the IEA Web site for the year 1997).

Country	Population (millions)	GDP (billion 1990 $US)	TPES (million tons of oil equivalent)	TPES/cap (tons oil equivalent per capita)	Electricity Consumption (kWh per capita)	Energy Share of TPES						
						Coal	Oil	Gas	Nuclear	Hydro	Combustible Renewables and Waste	Other (inlcudes geothermal, solar, wind, etc.)
Australia	18.53	364.1	101.63	5.48	9249	41.7	35	16.6		1.4	5.2	0.1
Austria	8.07	183.27	27.76	3.44	6553	13	43.4	23.5		11.1	8.9	
Belgium	10.18	218.25	57.12	5.61	7703	14.9	42.5	19.8	21.7		1	
Bulgaria	8.31	15.18	20.62	2.48	3999	34.8	22.5	17.7	22.1	0.7	1.1	
Canada	30.29	647.38	237.98	7.86	16973	11.4	33.5	29.3	8.9	12.5	4.3	
Croatia	4.77	9.49	7.65	1.61	2477	3.5	55.1	30.7		6.2	4.4	
Czech Republic	10.3	27.17	40.58	3.94	5660	51.9	19.5	18.8	8	0.4	1.3	0.1
Denmark	5.28	160.69	21.11	4	6623	30.3	44	17.8			7.1	0.8
Estonia	1.46	5.32	5.56	3.81	4619	57.2	22.4	11			10.5	
European Community	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Finland	5.14	143.99	33.07	6.43	14454	21.1	31.7	9	16.8	3.2	18.1	
France	58.6	1307.35	247.53	4.22	6992	5.8	34.8	12.4	40.7	2.1	4.2	0.1
Germany	82.05	1833.12	347.27	4.23	6426	24.8	40.1	20.7	12.8	0.4	1.1	0.1
Greece	10.49	93.17	25.56	2.44	4003	33.3	60.4	0.7		1.3	3.8	0.5
Hungary	10.16	33.64	25.31	2.49	3231	17.3	27.8	38.6	14.5	0.1	1.8	
Iceland	0.27	7.12	2.33	8.6	18967	2.4	34			19.2	0.1	44.3
Ireland	3.66	73.4	12.49	3.42	5002	23.7	52.4	22.2		0.5	1.3	
Italy	57.52	1181.92	163.32	2.84	4739	7.1	58.5	29.7		2.2	1	1.6
Japan	126.17	3343.73	514.9	4.08	7933	16.8	52.7	10.7	16.1	1.5	1.4	0.7
Latvia	2.46	6.82	4.46	1.81	2028	3.7	40.5	24.7		5.9	25.1	
Liechtenstein	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lithuania	3.71	8.51	8.81	2.38	2631	1.5	35.4	22	35.1	0.3	5.7	
Luxembourg	0.42	14.41	3.39	8.04	15045	10.6	66.7	21.2		0.2	1.3	
Monaco	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Netherlands	15.61	336.46	74.91	4.8	6122	12.5	37.4	47.8	0.9		1.3	0.1
New Zealand	3.76	52.56	16.68	4.43	8694	8.1	37.7	28.2		12	4.1	9.9
Norway	4.41	150.96	24.23	5.5	24297	4.3	34.9	16.4		39.5	4.9	
Poland	38.65	74.58	105.15	2.72	3206	67.7	18.3	8.9		0.2	4.9	
Portugal	9.95	80.68	20.4	2.05	3401	17.5	70.6	0.4		5.6	5.6	0.3
Romania	22.55	33.33	44.14	1.96	2252	20.8	28.8	36.1	3.2	3.4	7.6	
Russian Federation	147.31	349.89	591.98	4.02	4976	16.4	21.5	52.2	4.8	2.3	2.9	
Slovakia	5.38	15.13	17.22	3.2	4931	27.8	19.5	34.4	16.7	2.1	0.5	

Slovenia	1.99	24.82	6.38	3.21	5430	19.4	42.5	11	20	4.1	4	
Spain	39.32	557.57	107.33	2.73	4243	16.9	53.1	10.5	13.4	2.8	3.3	0.1
Sweden	8.85	242.39	51.93	5.87	15348	4.8	30.9	1.4	34.9	11.4	15.9	0.7
Switzerland	7.11	231.53	26.22	3.69	7347	0.4	50	8.6	24.8	10.9	5.3	0.1
Ukraine	50.7	65.23	150.06	2.96	2948	29	12.3	44.2	13.8	0.6	0.2	
United Kingdom of Great Britain and Northern Ireland	59.01	1100.51	227.98	3.86	5704	17.7	36.4	33.7	11.3	0.2	0.7	
USA	266.79	6629.5	2162.19	8.1	13132	23.8	38.6	23.5	8	1.3	3.1	0.6