Emissions Estimation Techniques Manual

for

Aggregated Emissions from Fuel Combustion (Sub-Threshold)

September 1999

Environment Australia

Version 1.0 - First Published 1 September 1999

EMISSIONS ESTIMATION TECHNIQUE MANUAL:
AGGREGATED EMISSIONS FROM FUEL COMBUSTION
(SUB-THRESHOLD)

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1.0 Introduction

1.1 The NPI

The National Pollutant Inventory (NPI) was established under a National Environment Protection Measure (NEPM) made by the National Environment Protection Council (NEPC) under Commonwealth, State and Territory legislation on 27 February 1998. This Measure is to be implemented progressively through the laws and administrative arrangements of each of these participating jurisdictions (i.e. State and Territory Governments).

The NEPM and an associated Memorandum of Understanding for the NPI, which have been published as a single document by the NEPC, provide more details on the purpose and structure of the NPI, and the arrangements for implementation of the NEPM that have been agreed by the jurisdictions. Users of this Manual should read this publication if they are unfamiliar with the NEPM or the NPI.

1.2 Purpose and Scope of the Manual

The NPI will be developed as an internet database designed to provide information on the types and amounts of certain chemical substances being emitted to the air, land and water environments. If the NPI is to achieve its aim of communicating useful and reliable information to the community, industry and governments on pollutants present in our environment, the emissions estimation techniques (EETs) used to generate inputs to the NPI need to be consistent, and the process for developing these techniques needs to be transparent. This Manual has been developed, reviewed and finalised in this context.

The NEPM contains a list of substances for which emissions will be reported on an annual basis to the Commonwealth Government, which will then compile and publish the NPI. The aggregated emissions manuals, of which this is one, have been prepared to assist State and Territory Governments in preparing these submissions, and to facilitate consistent reporting between these jurisdictions.

State and Territory Governments will also be compiling and submitting emissions data based on annual inputs from reporting facilities. These facilities are primarily industrial enterprises which use (or handle, manufacture or process) more than specified amounts of certain polluting substances, burn more than specified amounts of fuel, or consume more than certain amounts of energy. These amounts or “thresholds” (which are clearly defined in the NEPM) govern whether an industrial facility is required to report and what substances it is required to report on, and industry handbooks are being developed to help industries to prepare the information for these reports.

The aggregated emissions manuals complement these handbooks, and are intended to enable Governments to estimate emissions from non-industrial activities (e.g. transportation, domestic and commercial activities) and emissions from industry which are not reported because the relevant thresholds are not exceeded.

Annual submissions are also to be prepared and submitted in conformance with the NPI Data Model and Data Transfer Protocol. For emissions to the air environment, this Protocol only requires jurisdictions to submit data on emissions into the particular airsheds that are listed in the Protocol, and not to the rest of each jurisdictional area. For example, in Victoria, emissions data are only required for the Port Phillip and Latrobe Valley Regions. In addition, emissions data are required to be submitted on a gridded basis, with each jurisdiction determining a grid domain and grid cell size appropriate to its needs and responsibilities (e.g. for air quality modelling purposes).

Therefore, in addition to recommending and providing details and examples of appropriate emissions estimation techniques (EETs) for the relevant NPI substances, this Manual provides guidance on the spatial allocation of emissions and the use of area-based surrogates for accurately distributing the activities or sources in question.

1.3 Application of the Manual

Each of the aggregated emissions manuals provides details of:

- the NPI substances that are expected to be emitted from the relevant aggregated source type;
- the origins or sources of the emissions, and the processes that may generate them;
- the impacts of any control equipment or procedures on those emissions;
- the broad approaches that may be employed in the estimation and spatial allocation of emissions;
- details of emission factors to be used in the estimation of emissions; and
- a series of illustrative sample calculations for each estimation technique.

Each of the manuals also contains a section on "Uncertainty Analysis", which provides information and guidance to users on the reliability of the various estimation techniques, problems and issues associated with their development and application, and recommendations for their improvement. In preparing the aggregated emissions manuals it has been recognised that some jurisdictions already undertake detailed emissions inventories on a regular basis, based on relatively sophisticated methodologies. For these jurisdictions the manuals offer techniques which represent commonly available best practice for emissions estimation in Australia (i.e. techniques of high quality which can be employed by larger or more experienced jurisdictions with an acceptable expenditure of time and effort). The most recent developments in inventory methodology in Australia and overseas have been considered in selecting and documenting these techniques.

Where a more simplified methodology for emissions estimation of acceptable quality is available, it is recommended in the manual for the use of those jurisdictions which may, for the time being at least, lack the data, resources or expertise to employ a more sophisticated approach, or not see the need for highly reliable estimates in that particular part of the inventory.

2.0 Emissions Covered by the Manual

This manual provides guidance on the estimation and spatial allocation of aggregated emissions from fuel burning at the following industrial and commercial facilities:

- facilities that do not burn 400 or more tonnes of fuel or waste in a year (i.e. facilities that do not trigger the NPI Category 2 thresholds); and

- facilities that trigger the NPI Category 2a and/or 2b thresholds, but fail to submit an annual report.

The overall contributions to an emissions inventory of emissions from the burning of solid, liquid and/or gaseous fuels at facilities that should report (but do not) could be quite significant, particularly if the number of these facilities is a significant fraction of the total number of facilities required to report.

2.1 NPI Substances

Emissions from the burning of various fuels at commercial and industrial premises include a large number of substances listed in Table 2 to Schedule A of the NEPM, which are listed in Table 1.

Table 1: NPI Substances Typically Emitted from Fuel Combustion

Substance	Substance
Acetaldehyde	n-Hexane
Antimony and compounds	Hydrochloric acid
Arsenic and compounds	Lead and compounds
Benzene	Manganese and compounds
Beryllium and compounds	Mercury and compounds
Cadmium and compounds	Methyl ethyl ketone
Carbon disulphide	Methyl methacrylate
Carbon monoxide	Nickel and compounds
Chloroform	Oxides of nitrogen
Chromium (VI) compounds	Particulate matter $\leq 10\mu m$ (PM10)
Chromium (III) compounds	Phenol
Cobalt and compounds	Polycyclic aromatic hydrocarbons
Copper and compounds	Selenium and compounds
Cumene	Sulphur dioxide
Cyanide (inorganic) compounds	Styrene
Cyclohexane	Tetrachloroethylene
Dichloromethane	Toluene
Ethylbenzene	Total volatile organic compounds (VOCs)
Di-(2-Ethylhexyl) phthalate (DEHP)	Xylenes
Fluoride compounds	Zinc and compounds
Formaldehyde	

2.2 Emission Sources and Related Processes

As Table 1 indicates, the NPI substances emitted from fuel burning include carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), hydrogen chloride, hydrogen fluoride, particulate matter equal to or less than 10 microns (PM10), trace elements (e.g. arsenic, cadmium, lead and mercury) and organic compounds (e.g. formaldehyde, toluene, xylenes and polycyclic aromatic hydrocarbons).

A range of fossil fuels are burned in Australian airsheds and a wide variety of fuel-burning equipment such as boilers, dryers, furnaces, and process and space heaters are used. Since emissions vary considerably from one equipment and fuel type to another, information about fuel type and the type of combustion and pollution control equipment is desirable for emissions estimation. While this information is readily available for individual sites, overall or composite information for all facilities in an airshed is more difficult to assemble. Even with the best information available for these EETs, the estimates should only be considered accurate to an order of magnitude.

Black and brown coal and natural gas are the most commonly used fossil fuels in Australia. Black coal dominates the fuel mix in New South Wales and Queensland, and is used predominantly in the electricity generation sector. Brown coal dominates the fuel mix in Victoria, and is used exclusively for power generation (ABARE 1999).

In 1998/99 approximately 82% of black coal was used in boilers, 14% in coke ovens, and 2% in kilns in Australia (ABARE 1999), whereas brown coal is used exclusively in boilers. The sulphur content of Australian black coal does not vary greatly, ranging from 0.15% to 0.75% by weight (dry basis). The sulphur content of brown coal is in the range of 0.29% to 0.7% (Swaine 1990).

Natural gas is used in a wide variety of applications, including process and space heating, steam generation, and electricity generation. If crude oil and its derivatives used exclusively in petroleum refining are not taken into account, natural gas market share is 14% in NSW, 24% in Victoria, 8% in Queensland, 71% in Western Australia, 57% in South Australia, and 100% in the Northern Territory. ABARE (1999) reported that in 1998/99 in Australia, 33% of natural gas was used in boilers, 16% in stationary internal combustion engines, and 14% in gas distribution.

2.3 Emission Controls

Solid fuel-fired boilers in urban areas usually have particulate emission control devices, commonly simple mechanical collectors such as cyclones or scrubbers and occasionally electrostatic precipitators and fabric filters. It has been reported that no coal-fired combustion equipment has been licensed in NSW in the last 35 years without some control device for particulate emissions (EPAV1996).

Control of emissions from the majority of industrial and commercial oil-fired boilers is achieved by improved burner servicing and oil atomisation, and post-combustion controls are rarely employed.

Additional pollution control devices are also uncommon in small industrial and commercial boilers firing gaseous fuels such as natural gas, town gas and LPG.

3.0 Emissions Estimation Techniques

3.1 Approaches Employed

Although several types of EETs (e.g. direct measurement, mass balance, engineering calculations) can be used to estimate emissions from an individual facility, the use of emission factors is the only practical method for estimating aggregated emissions from fuel burning at sub-threshold facilities.

The information required for these EETs to calculate aggregated annual emissions in an airshed from fuel combustion at sub-threshold (including non-reporting) facilities is as follows:

- the total annual energy consumption (or amount) by sector (industrial and commercial) of each fuel type used in an airshed;
- the energy content of each fuel type used in the airshed;
- the total annual energy consumption (or amount) by sector of each fuel type used in the airshed at the facilities that report under the NPI; and
- emission factors for each type of fuel used in the airshed.

The annual aggregated emissions of NPI substances from fuel combustion at sub-threshold facilities in an airshed can be calculated using Equation 1.

Equation 1: Calculation of annual emissions of an NPI substance in an airshed

$$E_{jk} = \sum_{i} EF_{ij} \times (B_{ik} - D_{ik})$$

where

E_{jk} = Annual emissions of substance j from consumption of fuels by facilities in sector k in the airshed, kg yr^{-1}

EF_{ij} = Emission factor for substance j from consumption of fuel i, kg $tonne^{-1}$ for solid fuels, kg kL^{-1} for liquid fuels and kg 10^{-6} m^{-3} for gaseous fuels

B_{ik} = Total annual consumption of fuel i by facilities in sector k in the airshed, tonne yr^{-1} for solid fuels, kL yr^{-1} for liquid fuels and 10^6 m^3 yr^{-1} for gaseous fuels

D_{ik} = Total annual consumption of fuel i by facilities in sector k that report under the NPI, tonne yr^{-1} for solid fuels, kL yr^{-1} for liquid fuels and 10^6 m^3 yr^{-1} for gaseous fuels

Total airshed emissions of a particular substance can be derived by summing the emissions estimates for each fuel type. However, the emissions from fuel combustion at industrial sector facilities must be calculated separately from the commercial sector emissions because there are differences in the preferred methods of spatially allocating the emissions from these two sectors. While the majority of manufacturing plants are located in industrial zones, commercial facilities are usually located near residential areas, so a different approach to allocation is used for each sector.

3.1.1 Total Fuel Consumption

Consumption data for each of the major fuels used in an airshed is required for this EET. The primary holders of this information are local fuel suppliers, which are either private companies or Government agencies. However, fuel retailing is a very competitive business and some suppliers may not be willing to disclose sales information.

If consumption data are not available from fuel suppliers, airshed consumption can be calculated from energy or fuel consumption in the jurisdiction and other data (e.g. information on population or employee numbers). However, deriving airshed consumption from consumption data for the jurisdiction is more complex and less reliable than using information obtained directly from fuel suppliers.

Data on consumption in each jurisdiction are available from the Australian Bureau of Agriculture and Resource Economics (ABARE), including information on equipment type (e.g. boiler, industrial dryer, kiln, oven) and fuel type. Annual reports prepared by the Australian Gas Association (AGA) are a valuable source of data on the consumption, characteristics and the distribution network for gaseous fuels. Consumption data and characteristics for coal fuels can be obtained from the Australian Coal Association.

ABARE collects information on energy consumption by industry and fuel type. The Australian Energy Report (ABARE 1999) provides energy consumption data by the following sectors:

- agriculture, forestry and fishing (Division A);
- mining (Division B);
- manufacturing (Division C);
- electricity, gas and water supply (Division D);
- construction (Division E);
- transport and storage (Division I);
- commercial and services (total of Divisions F, G, H, J, K, L, M, N, O, P and Q); and
- residential (Division R).

The energy consumption data reported for commercial facilities and services should be used to estimate consumption by the commercial sector. Fuel combustion in the residential sector is considered in the EET Manuals for Aggregated Emissions (AE) from Domestic Solid Fuel Burning, Domestic Gaseous Fuel Burning, and Barbeques.

To estimate the total annual consumption of each fuel by the industrial sector in a jurisdiction, consumption by the commercial, residential and transport sectors should be excluded from the total for the jurisdiction.

Sub-regional variations in fuel usage should also be accounted for during the estimation of airshed consumption. Sometimes a particular fuel type is not used across an entire jurisdiction. For example, although reticulated natural gas is provided to the capital cities of Victoria, NSW and Queensland, it is not provided to all regional centres in these jurisdictions. Local fuel suppliers should be able to provide a list of regional centres and towns served by the gas distribution network, even if they are reluctant to provide sales data. Distribution information can also be obtained from the AGA or ABARE.

There are also clear differences between jurisdictions in the type of fuel used in the electricity generation sector and in manufacturing facilities. As mentioned above, black coal is predominantly used in the electricity generation sector in New South Wales and Queensland, while brown coal is the only coal used for electricity generation in Victoria. Mining facilities and some other industrial plants in locations near coal mines may also use coal.

Industrial Sector

The manufacturing and electricity generation industries are the main fuel consumers in urban airsheds when the consumption of the residential and commercial sectors is excluded. All power station operators will exceed the NPI thresholds and re expected to report under the NPI. This leaves manufacturing industry as the principal source of aggregated emissions from fuel combustion in the industrial sector to be accounted for in this EET.

If fuel suppliers are unwilling to provide airshed consumption data, employment data can be used to calculate the energy consumption of manufacturing industry in an airshed, using ABARE data at jurisdiction level.

Equation 2: Estimation of total energy consumption for the various fuel types used by the industrial sector in an airshed

$$C_{ia} = C_{ij} * N_a / N$$

where

C_{ia} = Annual consumption by manufacturing industry of fuel i in an airshed, PJ yr^{-1}

C_{ij} = Annual consumption by manufacturing industry of fuel i in the jurisdiction, PJ yr^{-1}

N_a = Number of manufacturing sector employees in the airshed

N_j = Number of manufacturing sector employees in the jurisdiction

This approach has a number of limitations. Energy consumption depends on both the type of manufacturing process and the size of the facility, so there may be no strong correlation between the amount of fuel used at a facility and the number of employees. Also, there are difficulties associated with the collection and reporting by ABARE of small amounts of fuel. Further, it is expected that some industry reports may contain incorrect consumption data. Finally, while the market share of fuels as a percentage of total consumption in a jurisdiction can be provided by ABARE, the market share of fuels used in an airshed within that jurisdiction may be quite different, as discussed above

Because of these limitations, it is recommended that airshed consumption estimates should only be made on the basis of employment figures for fuels with a significant market share (say, at least 10%) in the jurisdiction and airshed. Consumption figures for fuels with small market shares are likely to be smaller that the *errors* in consumption figures for fuels that are more widely used, so it makes little sense to make a rough estimate of the small consumption level of a fuel. Of course, if actual airshed consumption data are available for small volume fuels, then these data can and should be used.

The Australian Bureau of Statistics (ABS) annually collects manufacturing employment data by Statistical Division (SD) and industry type. For example, the ABS (1997) has reported that around 70% of New South Wales manufacturing activity took place in the Sydney SD in 1993-94, with the largest non-metropolitan SDs (Illawarra and Hunter) each having about 9% of NSW manufacturing activity. Approximately 76% of South Australian manufacturing activity in 1993-94 took place in the Adelaide SD, giving South Australia the most centralised manufacturing operations of all states. Similar information for other jurisdictions can be found in ABS publications.

Manufacturing employment statistics at 30 June 1996 for all jurisdictions are shown in Table 2. The latest ABS statistics should be used in future years.

Table 2: Manufacturing Sector Employment

Jurisdiction	Employment [a] (* 10^3 persons)
New South Wales	298
Victoria	292
Queensland	134
South Australia	86
Western Australia	69
Tasmania	22
Northern Territory	4
Australian Capital Territory	4
Australian	908

[a] ABS (1997).

Particular care should be taken in using Equation 2 if a particular fuel is available only in some regions of a jurisdiction. In these cases it may be necessary to use the number of employees (or manufacturing establishments) for only that part of the jurisdiction where the fuel is available.

Where available, reticulated natural gas will be by far the prevalent fossil fuel burnt, because it is clean and easy to handle. Other types of fuel would be rarely used by industrial and commercial facilities (possibly only at some old sites) in regions where gas is available. It would not always be appropriate or accurate to assume that the amount of fuel used (other than gas) is proportional to the number of establishments or employees in these airsheds.

While the manufacturing and electricity generation sectors are the major industrial fuel consumers in urban airsheds, the mining sector may be a major fuel consumer in some other airsheds. Employment statistics for the mining sector at jurisdiction and airshed levels are available from the ABS. These data can be used to calculate airshed consumption using Equation 2, with all references to manufacturing changed to mining.

Since consumption data provided by ABARE is generally in the form of energy equivalence (i.e. in PJ yr^{-1}), it needs to be converted into the appropriate form for use with emission factors (i.e. units of mass for solid fuels, and units of volume for liquid and gaseous fuels), using the typical energy contents of Australian fuels. The values in Table 3 should be considered indicative, because fuel quality varies with many factors (e.g. extraction location, ambient air pressure and fuel temperature).

Table 3: Typical Energy Content of Fuels

Type of Fuel	Gross Calorific Value [a]	Unit
Solid fuels		
Black Coal (NSW, washed steaming)	27.0	GJ $tonne^{-1}$
Black Coal (NSW, unwashed	23.9	GJ $tonne^{-1}$
Black Coal (QLD)	23.0	GJ $tonne^{-1}$
Black Coal (SA)	13.5	GJ $tonne^{-1}$
Black Coal (WA)	19.7	GJ $tonne^{-1}$
Black Coal (TAS)	22.8	GJ $tonne^{-1}$
Brown Coal (Victoria)	9.7	GJ $tonne^{-1}$
Brown Coal (Victoria, briquettes)	22.1	GJ $tonne^{-1}$
Liquid fuels		
Industrial Diesel Fuel	39.6	GJ kL^{-1}
Fuel Oil (low sulphur)	39.7	GJ kL^{-1}
Fuel Oil (high sulphur)	40.8	GJ kL^{-1}
Gaseous fuels		
Natural Gas (Victoria)	38.8	MJ m^{-3}
Natural Gas (Queensland)	38.5	MJ m^{-3}
Natural Gas (South Australia)	38.9	MJ m^{-3}
Natural Gas (New South Wales)	38.9	MJ m^{-3}
Natural Gas (Western Australia)	39.6	MJ m^{-3}
Natural Gas (Northern Territory)	40.7	MJ m^{-3}
Town Gas (Synthetic Natural Gas)	39.0	MJ m^{-3}

Town Gas (Reformed Gas)	20.0	$MJ\ m^{-3}$
Town Gas (Tempered LPG[b])	25.0	$MJ\ m^{-3}$
Town Gas (Tempered Natural Gas)	25.0	$MJ\ m^{-3}$

[a] ABARE (1999)
[b] Tempered LPG is supplied via a reticulation system in a gaseous form and should not be confused with bottled LPG, which is supplied in a liquid form.

The amounts of different fuel types (e.g. black coal, fuel oil, or natural gas) used by the industrial sector in an airshed can be calculated from Equations 3, 4 and 5.

Equation 3: Calculation of the mass of solid fuel used annually by the industrial sector in an airshed

$$A_{ia} = C_{ia} * 10^6 / Q_i$$

where

A_{ia} = Annual amount of solid fuel i used in the airshed, $t\ yr^{-1}$
C_{ia} = Energy consumption of solid fuel i in the airshed, $PJ\ yr^{-1}$
Q_i = Energy content of solid fuel i used in the airshed, $GJ\ tonne^{-1}$

Equation 4: Calculation of the volume of liquid fuel used annually by the industrial sector in an airshed

$$A_{ia} = C_{ia} * 10^6 / Q_i$$

where

A_{ia} = Annual amount of liquid fuel i used in the airshed, $kL\ yr^{-1}$
C_{ia} = Energy consumption of liquid fuel i in the airshed, $PJ\ yr^{-1}$
Q_i = Energy content of liquid fuel i used in the airshed, $GJ\ kL^{-1}$

Equation 5: Calculation of the volume of gaseous fuel used annually by the industrial sector in an airshed

$$A_{ia} = C_{ia} * 10^3 / Q_i$$

where

A_{ia} = Annual amount of gaseous fuel i used in the airshed, $10^6\ m^3\ yr^{-1}$
C_{ia} = Energy consumption of gaseous fuel i in the airshed, $PJ\ yr^{-1}$
Q_i = Energy content of gaseous fuel i used in the airshed, $MJ\ m^{-3}$

Commercial Sector

The preferred sources of information on fuel consumption by commercial facilities in the airshed are local or centralised fuel suppliers. Alternatively, the amount of energy consumed for each fuel by commercial facilities in an airshed can be derived by scaling consumption data at the jurisdiction level according to population. ABARE can provide commercial consumption data for each jurisdiction.

ABS collects population data by Collection District (CD). If a fuel type is available across an entire jurisdiction, its airshed consumption can be calculated from Equation 6.

Equation 6: Estimation of total energy consumption for the various fuel types used by the commercial sector in an airshed

$$C_{ia} = C_{ij} * P_a / P_j$$

where

C_{ia}	=	Annual consumption by the commercial sector of fuel i in an airshed, PJ yr^{-1}
C_{ij}	=	Annual consumption by the commercial sector of fuel i in the jurisdiction, PJ yr^{-1}
P_a	=	Population of the airshed
P_j	=	Population of the jurisdiction

Care should be taken in applying Equation 6 if a particular fuel type is available only in some areas of the jurisdiction. In this case, the figures used in Equation 6 should be adjusted to relate only to those areas of the airshed and jurisdiction where the fuel is available.

As an alternative but less preferred option, airshed consumption can be estimated from ABARE data for the jurisdiction by using ABS data on commercial sector employment (i.e. using the ratio of *employment numbers* in the airshed and jurisdiction, instead of the population ratio, in Equation 6 to scale the ABARE consumption figures).

As with the industrial sector, energy consumption data for the commercial sector need to be converted into the appropriate forms (mass or volume usage) using typical energy contents (see Table 3 and Equations 3 to 5).

3.1.2 Fuel Consumption Reported by Individual Facilities

Emissions from the combustion of fuels or other thermal processes at facilities that burn 400 tonnes or more of fuel in a year, or one or more tonne in an hour, must be estimated and reported by these facilities to the Commonwealth. Many of these facilities may also provide information on their consumption of each fuel, and they should be strongly encouraged to do so. However, since provision of this information is not mandatory, in some cases only emissions data will be provided. In these cases it will be necessary to either contact the facilities to obtain the fuel consumption data, or apply emission factors to calculate fuel consumption from the emissions data.

Total consumption of different fuel types at facilities reporting under the NPI should be calculated separately for the industrial and commercial sectors because of the different techniques used for spatial distribution of their emissions. These consumption figures should then be subtracted from the estimates of total airshed consumption for each fuel (from Equations 2 and 6), and used with the relevant emission factors (from Table 4 below) in Equation 1 to derive estimates of the total annual airshed emissions of each NPI substance.

3.2 Spatial Surrogates and Spatial Allocation

Emissions from the burning of fuels at sub-threshold industrial and commercial facilities usually occur at different types of locations. Most manufacturing plants are located in industrial zones, while the majority of commercial facilities are usually located near residential areas. The spatial allocations of emissions from the two sectors (industrial and commercial) are therefore treated separately.

3.2.1 Industrial Sector

The preferred spatial surrogate for allocating emissions from sub-threshold industrial facilities is the industrial zone. This method allocates the total emissions from industrial sector facilities in proportion to the area of industrial zones in each grid cell (see Equation 7).

Equation 7: Allocation of emissions of an NPI substance from sub-threshold industrial facilities to a grid cell

$$E_{ij} = E_i * Z_j / Z_a$$

where

E_{ij} = Annual emissions of substance i from industrial sector facilities in grid cell j, kg yr^{-1}

E_i = Total annual emissions of substance i from industrial sector facilities in the airshed, kg yr^{-1}

Z_j = Area of industrial zoning in grid cell j, ha

Z_a = Area of industrial zoning in the airshed, ha

Land use information is available from the planning departments and agencies of local and jurisdiction level Governments. GIS-based information should be available for the capital cities in all jurisdictions. The size of these areas in each grid can be easily calculated with a GIS. If GIS-based information is unavailable for smaller airsheds, these areas may need to be estimated from the boundaries of major industrial areas illustrated in the relevant land use planning maps.

An alternative method for allocation of emissions is to distribute these emissions equally to locations of those facilities that reported under the NPI. This simple but less accurate approach is based on the assumption that the locations of reporting facilities can be used as a surrogate for industrial zoning in the airshed.

3.2.2 Commercial Sector

Emissions from fuel combustion at sub-threshold commercial facilities should be spatially disaggregated according to the population distribution within the airshed. ABS population data by CDs can be converted to population by grid cells using a program or GIS. Emissions in a grid cell can then be estimated using Equation 8.

Equation 8: Allocation of emissions of an NPI substance from sub-threshold commercial facilities to a grid cell

$$E_{ij} = E_i * P_j / P_a$$

where

E_{ij} = Annual emissions of substance i from commercial sector facilities in grid cell j, kg yr^{-1}

E_i = Total annual emissions of substance i from commercial sector facilities in the airshed, kg yr^{-1}

P_j = Population of grid cell j

P_a = Population of the airshed

If some fuels are not available across the entire airshed, emissions from combustion of these fuels should be allocated only to the relevant areas. It is expected that GIS-based coverages of the regions with reticulated fuel will be available for some airsheds. If GIS-based information is unavailable, the boundaries of the regions with reticulated fuel can be derived from the fuel reticulation network maps or from lists of postal codes of these regions that are normally available from local fuel suppliers.

3.3 Emission Factors

Since the larger industrial and commercial facilities are expected to report their emissions from fuel combustion to the NPI, this manual is primarily aimed at estimating emissions from small to medium-sized facilities. The following discussion explains some of the considerations that have influenced the selection of appropriate emission factors (EFs) for this manual.

Brown coal emission factors are not provided because brown coal is used almost exclusively in the electricity generation sector, and it is expected that all power stations will report under the NPI arrangements.

It is also expected that emissions from black coal consumed in electricity generation sector would be reported directly. For black coal in other applications, it is assumed that the coal is burnt in spreader stokers where mechanical or pneumatic feeders distribute coal uniformly over the surface of a moving grate.

Some coal-fired combustion equipment used in cities and larger towns may have particulate emission control devices fitted. Since the control efficiency of such devices varies widely from 50 to 98%, a figure of 80% has been adopted as an indicative efficiency for this EET.

It is assumed that fuel oil used at industrial facilities not reporting under the NPI is burnt in industrial category boilers with more than 3MW of heat input. Similarly, for the commercial sector, fuel oil is assumed to be burnt in commercial category boilers with less than 3MW of heat input.

It is expected that the balance of natural gas and town gas burnt at facilities that do not report to the NPI is consumed in uncontrolled wall-fired boilers with less than 2.9 MW of heat input.

Emission factors for major fuel and equipment types for both the industrial and commercial sectors are given in Table 4. Relevant sections of the USEPA AP-42 publication (USEPA 1998) or the NPI EET Manual for Combustion in Boilers (EA 1999) should be consulted if it is necessary to apply emission factors for other fuels that are considered significant in a particular airshed.

Table 4: Emission Factors for Fuel Combustion

NPI Substance	Emission Factors [a]		
	Black Coal ($kg\ tonne^{-1}$)	**Fuel Oil ($kg\ kL^{-1}$)**	**Natural Gas ($kg\ 10^{-6}\ m^{-3}$)**
Acetaldehyde	2.9×10^{-4}		
Antimony and compounds	9.0×10^{-6}	6.3×10^{-4}	
Arsenic and compounds	2.1×10^{-4}	1.6×10^{-4}	3.2×10^{-3}
Benzene	6.5×10^{-4}	2.6×10^{-5}	3.4×10^{-2}
Beryllium and compounds	1.1×10^{-5}	3.3×10^{-6}	1.9×10^{-4}
Cadmium and compounds	2.6×10^{-5}	4.8×10^{-5}	1.8×10^{-2}
Carbon disulphide	6.5×10^{-5}		
Carbon monoxide	2.5	6.0×10^{-1}	1.3×10^{3}
Chloroform (trichloromethane)	3.0×10^{-5}		
Chromium (VI) compounds	4.0×10^{-5}	3.0×10^{-5}	6.6×10^{-3} [b]
Chromium (III) compounds	9.0×10^{-5}	7.0×10^{-5}	1.5×10^{-2} [b]
Cobalt and compounds	5.0×10^{-5}	7.2×10^{-4}	1.3×10^{-3}
Copper and compounds		2.1×10^{-4}	1.4×10^{-2}

Cumene (1-methylethylbenzene)	2.7×10^{-6}		
Cyanide (inorganic) compounds	1.3×10^{-3}		
Cyclohexane			1.4 [c]
Dichloromethane	1.5×10^{-4}		
Ethylbenzene	4.7×10^{-5}	7.6×10^{-6}	
Di-(2-Ethylhexyl) phthalate (DEHP)	3.7×10^{-5}		
Fluoride compounds	7.5×10^{-2}	4.5×10^{-3}	
Formaldehyde	1.2×10^{-4}	4.0×10^{-3}	1.2
n-Hexane	3.4×10^{-5}	8.5×10^{-3} [c]	2.9×10^{1}
Hydrochloric acid	6.0×10^{-1}	4.2×10^{-2}	
Lead and compounds	2.1×10^{-4}	1.8×10^{-4}	8.0×10^{-3}
Manganese and compounds	2.5×10^{-4}	3.6×10^{-4}	6.1×10^{-3}
Mercury and compounds	4.2×10^{-5}	1.4×10^{-5}	4.2×10^{-3}
Methyl ethyl ketone	2.0×10^{-4}		
Methyl methacrylate	1.0×10^{-5}		
Nickel and compounds	1.4×10^{-4}	1.0×10^{-2}	3.4×10^{-2}
Oxides of nitrogen	5.5	6.6	1.6×10^{3}
Particulate matter ≤10µm (PM10)	4.4 [d]	0.86 (1.12S+0.37) [e]	1.2×10^{2}
Phenol	8.0×10^{-6}		
Polycyclic aromatic hydrocarbons	1.1×10^{-5}	1.4×10^{-4}	1.1×10^{-2}
Selenium and compounds	6.5×10^{-4}	8.2×10^{-5}	3.8×10^{-4}
Sulphur dioxide	19 S [f]	19 S [e]	2.1 S [g]
Styrene	1.3×10^{-5}		
Tetrachloroethylene	2.2×10^{-5}		
Toluene	1.2×10^{-4}	7.4×10^{-4}	5.4×10^{-2}
Total volatile organic compounds (VOCs)	2.5×10^{-2}	3.4×10^{-2} [h]	8.8×10^{1}
Xylenes	1.9×10^{-5}	1.3×10^{-5} [i]	
Zinc and compounds		3.5×10^{-3}	4.6×10^{-1}

[a] USEPA (1998), unless otherwise stated.
[b] Cr(VI) and Cr(III) emission factors are calculated from the USEPA emission factor for total chromium, assuming the Cr(VI) contribution is 30%.
[c] CARB (1991).
[d] Controlled by multiple cyclones without fly-ash re-injection, for which assumed control efficiency is 80%.
[e] EF_{PM10} = 0.86 (1.12S+0.37) for industrial boilers and 0.62 (1.12S+0.37) for commercial boilers, where S is % sulphur content (by weight) of fuel oil. If no information is available, it should be assumed that S = 3.0.
[f] S is % sulphur content (by weight) of black coal (as fired). If no information is available, assume that S = 0.75.
[g] S is the sulphur concentration of natural gas. For Victoria, S = 4 mg m^{-3} and for NSW 12mg m^{-3}.
[h] EF_{VOC} = 3.4×10^{-2} for industrial boilers and 1.4×10^{-1} for commercial boilers.
[i] Only o-xylene is reported.

3.4 Sample Calculations

The following information for a notional jurisdiction W is used in sample calculations for aggregated emissions of carbon monoxide from combustion of natural gas at sub-threshold facilities in an airshed covering regional centre Y:

1) It is reported by ABARE that natural gas and black coal are the major fuels used in the jurisdiction.

2) ABARE also reports that natural gas is supplied only to capital city X and two regional centres Y and Z in jurisdiction w, and was used in electricity generation, manufacturing, commercial and residential sectors.

3) It is assumed that all power stations using natural gas in jurisdiction W report their combustion emissions for the NPI.

4) No information about natural gas consumption in regional centre Y is available from gas suppliers.

5) According to ABARE, total natural gas consumption in jurisdiction W by manufacturing and commercial facilities is 50 and 15 PJ yr^{-1} respectively.

6) ABS reports that 65% of the manufacturing activity in jurisdiction W occurs in capital city X, while the regional centres Y and Z account for about 8% each of this activity.

7) Also according to ABS, the populations of city X, centres Y and Z and grid cell G are 1,500,000, 110,000, 100,000 and 1,600 respectively.

8) It is assumed that consumption of 58 and 7 million m^3 of natural gas is reported by manufacturing and commercial facilities respectively.

9) The industrial areas in the airshed covering regional centre Y and grid cell G in that airshed are calculated by GIS as 8,500 and 200 ha respectively.

Example 1: Estimation of total airshed energy consumption of natural gas by manufacturing facilities

Manufacturing industry gas consumption in the airshed covering regional centre Y is calculated from consumption data at jurisdiction level by using Equation 2 with the manufacturing industry activity data (substituting the activity data for employment numbers). The level of manufacturing activity in the three regions supplied (X, Y and Z) with natural gas is 81% (the sum of 65%, 8% and 8% from information point 6 above).

$$C_{industry,\ naturalgas,airshed} = 50 * 8 / 81$$
$$= 4.9 \text{ PJ } yr^{-1}$$

Example 2: Estimation of total airshed energy consumption of natural gas by commercial facilities

Commercial sector gas consumption in the airshed is calculated from the consumption data at jurisdiction level by using population statistics (as per Equation 6). The population in the three regions supplied with natural gas (X, Y and Z) is 1,710,000 (the sum of 1,500,000, 110,000 and 100,000 from information point 7 above).

$$C_{commercial,\ naturalgas,airshed} = 15 * 1.1 * 10^5 / (1.71 * 10^6) = 0.96 \text{ PJ yr}^{-1}$$

Example 3: Calculation of the volume of natural gas used in an airshed

The volumes of natural gas consumed by manufacturing and commercial facilities in the airshed are calculated using Equation 5 and the results of Examples 1 and 2, assuming a calorific value of 38.8 MJ m^{-3}.

$$A_{industry,\ naturalgas,airshed} = 10^3 * 4.9 / 38.8 = 126 * 10^6 \text{ m}^3 \text{ yr}^{-1}$$

$$A_{commercial,\ naturalgas,airshed} = 10^3 * 0.96 / 38.8 = 25 * 10^6 \text{ m}^3 \text{ yr}^{-1}$$

Example 4: Calculation of annual CO emissions in the airshed

Annual emissions of carbon monoxide in the airshed are calculated using Equation 1 and the CO emission factor for natural gas (from Table 4). Natural gas burnt by sub-threshold facilities (and facilities that failed to report) is the difference between the estimates of total amounts consumed by each sector (i.e. the results from Example 3) and the amounts reported by the facilities in those sectors (the figures in information point 8 above).

$$E_{CO,industry,airshed} = 1.3 *10^3 * (126 - 58) = 8.9 *10^4 \text{ kg yr}^{-1}$$

$$E_{CO,commercial,airshed} = 1.3 *10^3 * (25 - 7) = 2.3 *10^4 \text{ kg yr}^{-1}$$

Example 5: Allocation of annual airshed emissions of CO to a grid cell

The CO emissions in grid cell G can be estimated separately for industrial and commercial sector facilities using Equations 7 and 8 with the results from Example 4, and the grid cell data from information points 7 and 9 above.

$$E_{CO,industry,cell} = 8.9 *10^4 * (2 * 10^2) / (8.5 * 10^3) = 2.1 *10^3 \text{ kg yr}^{-1}$$

$$E_{CO,commercial,cell} = 2.3 *10^4 * 1.6 * 10^3 / (1.1 * 10^5)$$

$$= 3.3 * 10^{2} \text{ kg yr}^{-1}$$

then

$$E_{CO,cell} = E_{CO,industry,cell} + E_{CO,commercial,cell}$$
$$= 2.1 * 10^{3} + 3.3 * 10^{2}$$
$$= 2.4 * 10^{3} \text{ kg yr}^{-1}$$

It is expected that coal consumption by sub-threshold facilities in this airshed would be quite small because of the availability of natural gas. If no information on coal consumption is available from suppliers, it would be inadvisable to calculate airshed consumption from ABARE data because of the likely errors in calculations and the relatively small market share for coal.

If coal consumption data is provided by local coal suppliers, this data can be used together with information on data reported by facilities to calculate the amount of coal unaccounted for. Aggregated emissions from coal combustion (sub-threshold facilities) can then be calculated using Equation 1 and EFs for from Table 4 (as illustrated above for natural gas).

4.0 Uncertainty Analysis

In the following discussion, reliability is classified into 3 levels of confidence: high (uncertainty of 20% or less), medium (uncertainty of between 20% and 80%) and low (uncertainty of greater than 80%).

4.1 Data Reliability

Fuel consumption data obtained from centralised and local fuel distributors and from reporting facilities is considered to be of high reliability.

ABARE and Australian Gas Association fuel consumption data and ABS population and employment statistics are also considered to be highly reliable. ABARE fuel characteristics are considered to be of medium reliability.

The derivation of the airshed consumption data by scaling jurisdictional consumption figures with population or employment statistics considerably reduces the reliability of the fuel consumption data to a rating of low to medium.

4.2 Reliability of Emission Factors

The estimation of aggregated emission estimates requires assumptions to be made about commonly used combustion and pollution control equipment in the airshed. It is obviously not possible to use a different set of emission factors suitable for every application, even using the best information on types of equipment employed locally. Although the majority of the emission factors used in this manual are of high quality, their application to aggregated emissions estimation significantly reduces their reliability.

4.2.1 Black Coal Emission Factors

All emission factors for black coal combustion are based on USEPA AP-42 data for controlled burning of bituminous coal in a spreader stoker boiler. The emission factors for benzene, carbon monoxide, formaldehyde and toluene, and for all trace elements apart from chromium are considered to be of high reliability.

The remaining factors are considered to have low reliability, with the exception of factors for acetaldehyde, fluoride compounds, hydrochloric acid, oxides of nitrogen, PM10, sulphur dioxide, total volatile organic compounds and xylenes, which are considered to be of medium reliability.

4.2.2 Fuel Oil Emission Factors

The majority of the emission factors for fuel oil combustion are based on USEPA AP-42 data for uncontrolled burning of fuel oil in an industrial boiler. The emission factors for carbon monoxide, oxides of nitrogen, sulphur dioxide and total volatile organic are considered to be highly reliable.

The remaining factors are considered to be of medium reliability, with the exception of factors for antimony, chromium, ethylbenzene, fluoride compounds, hydrochloric acid, PM10, polycyclic aromatic hydrocarbons, toluene, xylenes and zinc, which are considered low reliability.

The factor for n-hexane is sourced from CARB (1991) and is also considered to be of low reliability.

4.2.3 Natural Gas Emission Factors

The majority of the emission factors for natural gas combustion are based on USEPA AP-42 data for gas burning in uncontrolled wall-fired boilers. Only one emission factor (for sulphur dioxide) is considered to be of high reliability.

The remaining factors are considered to have low reliability, with the exception of factors for benzene, carbon monoxide, copper, formaldehyde, nickel, oxides of nitrogen, toluene and total VOCs, which are considered to be of medium reliability.

The factor for cyclohexane is sourced from CARB (1991) and is considered to be of low reliability. The emission factors for chromium VI and chromium III are derived from the USEPA emission factor for total chromium, and are also considered as having low reliability.

4.3 Problems and Issues Encountered

Fuel consumption data availability for an airshed is the primary problem that will limit the accuracy of results using the EETs in this manual.

Although the majority of industrial and commercial combustion equipment is manufactured overseas (mainly in the US), local fuels differ from those used in the US. Since the emission factors used in this manual are primarily based on USEPA data, they may not accurately reflect the situation in Australia.

4.4 Recommendations for Further Work

Further investigation and development of emission factors for Australian fuels would improve the accuracy of emissions estimates. In addition, some effort should be directed towards further development of GIS-based land use information, which would allow better spatial allocation of emissions.

5.0 Glossary of Terms and Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
AE	Aggregated emissions
AGA	Australian Gas Association
CARB	California Air Resources Board
CD	Collection District
CO	Carbon monoxide
EA	Environment Australia
EET	Emissions estimation technique
EF	Emission factor
EPAV	Environment Protection Authority of Victoria
GIS	Geographic information system
LPG	Liquefied petroleum gas
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NO_x	Oxides of nitrogen
NPI	National Pollutant Inventory
NSW	New South Wales
PM10	Particulate matter equal to or less than 10 μm
SD	Statistical Division
SO_2	Sulphur dioxide
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compound

6.0 References

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