IEA emission factors: Methodology

This document contains a description of the complementary files distributed together with the 2017 edition of the CO2 data package. These files include a set of indicators complementing the IEA carbon emission factors for electricity and electricity/heat generation (available in the file World_CO2kWh.ivt of the IEA *CO_2 emissions from fuel combustion* online services). The new factors are described below:

- Provisional emission factors for electricity and electricity/heat generation for the most recent year (2016), based on provisional electricity generation data (for OECD countries);
- Emission factors for electricity and electricity/heat generation from non-renewable wastes;
- Emission factors for electricity and electricity/heat generation from biofuels;
- Adjustments to emission factors from electricity generation for indirect emissions induced by electricity trade between countries (for OECD countries);
- Adjustment to emission factors from electricity generation for emissions associated to transmission and distribution losses of electricity in the grid (for countries with available data);
- CH_4 and N_2O emission factors for electricity generated (based on default IPCC factors);
- Emission factors from direct combustion of fuels in other sectors than electricity and heat production.

1. Overall description of the carbon emission factors

1.1. Data source

The estimates of CO_2 emissions in this publication are based on the *2006 IPCC Guidelines* and the IEA *World Energy Balances* data; they represent the total emissions from fuel combustion.

For OECD Member countries, these figures are derived based on information provided in the five annual OECD questionnaires completed by the national administrations. For the member countries of the Economic Commission for Europe of the United Nations (UNECE) and a few others, the data shown are mostly based on information provided by the national administrations through the same annual questionnaires. The commodity balances for all other countries are based on national energy data of heterogeneous nature, converted and adapted to fit the IEA format and methodology.

Considerable effort has been made to ensure that the data presented adhere to the IEA definitions reported in the section on Methodological notes in the general documentation[1]. These definitions, based on the *United Nations International Recommendations on Energy Statistics*[2], are used by most of the international organisations that collect energy statistics.

Nevertheless, energy statistics at the national level are often collected using criteria and definitions which differ, sometimes considerably, from those of international organisations. This is especially true for non-OECD countries, which are submitting data to the IEA on a voluntary basis. The IEA secretariat has identified most of these differences and, where possible, adjusted the data to meet international definitions.

1. http://wds.iea.org/wds/pdf/WorldCO2_documentation.pdf
2. http://unstats.un.org/unsd/energy/ires/IRES_Whitecover.pdf.

1.2. The indicator: definition

In the **total** CO_2 emissions per kWh, for electricity or for electricity and heat generation, the numerator presents the CO_2 emissions from fossil fuels consumed for electricity generation, while the denominator presents the total electricity generated, coming from fossil fuels, but also from nuclear, hydro, geothermal, solar, biofuels, etc. As a result, the emissions per kWh vary a lot across countries and from year to year, depending on the generation mix.

In the CO_2 emissions per kWh **by fuel** the numerator and denominator only refer to the electricity generation from a given fuel:

- Coal includes primary and secondary coal, and coal gases. Peat and oil shale have also been aggregated with coal, where applicable.
- Oil includes oil products (and crude oil for some countries).
- Gas represents natural gas.
- Non-renewable wastes includes industrial waste and non-renewable municipal waste.
- Biofuels includes both biofuels and renewable wastes. Note that these emission factors are included for information, as CO_2 emissions from biofuel are not accounted for in the total CO_2 emissions of the energy sector according to the IPCC guidelines.

Note: Emissions per kWh should be used with caution due to data quality problems relating to electricity efficiencies for some countries.

1.3 Electricity-only carbon emission factors: allocation of emissions from CHP plants

Calculating emission factors for electricity-only generation from the IEA energy balances require specific assumptions, as for combined heat and power (CHP) plants only data for a combined input are available.

The IEA adopts the **fixed-heat-efficiency approach,** which consist in fixing the efficiency of heat generation to compute the input to heat, and calculating the input to electricity as a residual from the total input. The standard heat efficiency was set to that of a typical heat boiler, 90%.

The **proportionality approach** would conversely allocate inputs based on the proportion of electricity and heat in the output. This is equivalent to fixing the efficiency of electricity and heat to be equal. With the advantage of simplicity and transparency, the proportionality approach however tends to overstate electricity efficiency and to understate heat efficiency. For example, for CHP generation in OECD countries, total efficiency is around 60%. However, total electricity-only plant efficiency is around 41% in OECD countries. Similarly, 60% is quite low for heat generation (given typical heat-only plant efficiencies of 80-95%).

In general, the fixed-heat-efficiency approach attributes larger emissions to electricity than the proportionality approach, with values much closer to those of electricity-only plants. While the fixed-heat-efficiency approach has proven to provide sensible results in most cases, implementation problems arise in two cases:

i) When the observed efficiency is over 100% (i.e. there are problems in data quality).
ii) When the observed efficiency is between 90% and 100% (the total efficiency may be correct or it may be overstated).

In both cases, it is not possible to use the fixed-heat-efficiency approach and, by default, the proportionality approach is used to allocate the inputs based on the output shares.

1.4 Calculation of the carbon emission factor

CO_2kWh for electricity and heat generation =

$$\frac{\sum_{fuels} \langle \left(Input_{Electricity\ plants} + Input_{CHP\ plants} + Input_{Heat\ plants} + Own\ use_{Plants} \right) \times EF_{fuel} \rangle}{Ele_{Inland} + Heat_{Inland}}$$

Where:

- CO_2kWh : Carbon factors (in CO_2/kWh) calculated at the generation point

- $\sum_{fuels}$: Sum over the fuels.
- $Input_{plants}$: Fuel input into the plants (both main activity and autoproducer) expressed in energy unit.
- EF_{fuel} : Default emission factors as provided in the *2006 IPCC Guidelines*.
- $Ele_{Inland} + Heat_{Inland}$:
    - For the total emission factor: includes the generation from all sources (i.e. as well the non-emitting sources).
    - For the emission factors by fuel (oil, coal, gas, non-renewable waste and Memo: biofuels): includes only the electricity generated by the corresponding fuel.

$$CO_2kWh \text{ for electricity generation} = \frac{\sum_{fuels} \langle (Input_{Electricity\ plants} + Input_{CHP\ plants/Ele} + Own\ use_{Plants/Ele}) \times EF_{fuel} \rangle}{Ele_{Inland}}$$

Where:

- CO_2kWh : Carbon factors (in CO_2/kWh) calculated at the generation point
- $\sum_{fuels}$: Sum over the fuels.
- $Input_{plants}$: Fuel input into the plants (both main activity and autoproducer) expressed in energy unit.
- $Input_{CHP\ plants/Ele} = Input_{CHP\ plants} - \frac{Heat\ output}{\eta_{heat}}$
- η_{heat} efficiency of heat generation - assumed to be 0.9 (*i.e.* 90%) except when the observed efficiency of CHP generation is higher than 90%, in which case emissions are allocated using the proportionality approach ($EFF_{HEAT} = EFF_{ELEC} = EFF_{CHP}$).
- $Own\ use_{Plants/Ele} = Own\ use_{Plants} \times \frac{Total\ electricity\ output}{Total\ electricity\ output + Total\ heat\ output}$
- EF_{fuel} : default emission factors as provided in the *2006 IPCC Guidelines.*
- Ele_{Inland} :
    - For the total emission factor: includes the generation from all sources (i.e. as well the non-emitting sources).
    - For the emission factors by fuel (oil, coal, gas, non-renewable waste and Memo: biofuels): includes only the electricity generated by the corresponding fuel.

Note that in some cases, when the output of electricity is very small for a given fuel, rounding effects can cause the corresponding emission factor to appear very high. It is advised to disregard these emission factors which are clearly out of the range.

1.5 Comparison between electricity-only and combined electricity and heat ratios

For the majority of OECD countries, the electricity-only indicator is not significantly different from the combined electricity and heat indicator, shown in previous editions of this publication and in the online database. For the OECD total in 2014, the electricity-only indicator is 4% higher, while 19 of the OECD's 34 countries saw a difference of 5% or less. Of the 15 countries with differences of more than 5%, 7 countries had large amounts of non-emitting electricity generation, giving them a small ratio to begin with (thus more prone to change). In addition, non-emitting generation is generally electricity-only, and so when the heat-only and heat CHP emissions are removed from the calculation, greater weight is attached to the non-emitting generation, with a lower level for the final indicator.

The countries in the OECD with larger differences are generally coal-intensive countries with large amounts of heat generation. As mentioned, in general, heat plants are more efficient than electricity-only or CHP plants; therefore, excluding heat plants from the calculation increases CO_2 intensity. The same is true if we allocate a high efficiency to the heat part of CHP generation; this decreases the efficiency of the electricity part and thus increases electricity's carbon intensity. Further, CHP and heat plants are more likely to be powered by CO_2-light natural gas while electricity-only plants tend to be powered by CO_2-heavy coal, making the new ratio more CO_2 intensive for these countries.

2. Description of the set of additional indicators

2.1 Provisional carbon emission factors

The carbon factor for the latest year (Y) is only available for OECD countries. The available data for the year Y only include the breakdown of electricity generated by fuel, but not the fuel input to plant. Therefore, the assumption required is that there was no change in the efficiency of plants, and in the energy content of the input products compared to the year Y-1.

With these assumptions, the factor was derived as follows:

$$CO_2kWh\,(Y) = \frac{\sum_{fuels}\left(CO_2kWh_{\,fuel}(Y-1) \times Ele_{Inland_{fuel}}\,(Y)\right)}{Ele_{Inland}\,(Y)}$$

Only the total carbon emission factor is included for the provisional year.

2.2: Adjustments due to trade

Part of the electricity consumed in one country may have been generated in another one. Similarly, part of the electricity generated in one country can be exported to other countries. Therefore, adjustments may be done to the emission factors calculated above to account for electricity trade. Such adjustments are based on the share of electricity that is imported or exported compared to the domestic supply. The data needed to calculate such adjustment (i.e. the breakdown of electricity import by trade partner) are only available for OECD countries. This adjustment can be positive or negative, and is calculated as follows:

$$\mathrm{CO_2kWh}_{trade} = \frac{C_{Indigenous} + C_{Imported} - C_{Exported}}{Net\ electricity} - \ CO_2kWh$$

With

$$C_{Indigenous} = Ele_{Inland} * CO_2kWh$$

And

$$C_{Imported} = \sum_{partner} Ele_{Imports_{partner}} * \ CO_2kWh_{partner}$$

And

$$C_{Exported} = Ele_{Exports} * \frac{C_{Indigenous} + C_{Imported}}{Ele_{Inland} + Ele_{Imports}}$$

Where

- $\mathrm{CO_2kWh}_{trade}$: Adjustment of the carbon factor (in CO_2/kWh) for emissions induced by the trade of electricity with partner countries.
- $\mathrm{CO_2kWh}_{partner}$: Carbon emission factor for electricity generation of the partner country.
- $Net\ electricity$: $Ele_{Inland} + Ele_{Imports} - \ Ele_{Exports}$

Note that for a given country, trade data are those reported by the country for which the factor is calculated, which in some cases can differ from those reported from trade partners. Also, since the emission factors from trading partners are used, the quality of this adjustment depends not only on the quality of the data reported by the country, but also on the quality of the data reported by the trading partners. Moreover, in some cases, country report imports from non-specified countries. In such cases, assumptions were made based on transmission grid and data reported by potential partners.

This adjustment does not take into account geographically localized connections between countries. For example, Luxembourg reports trade from Germany, which is mostly related to electricity from the Vianden hydro plant; however the trade adjustment would be calculated using the nationally averaged carbon emission factor for Germany. As this case was known, the figure was set as “not available”. But other similar issue may occur.

2.3 Adjustments due to losses

As electricity is transmitted through a grid from the generation point to the consumption point, losses can occur for different reasons - they usually represent between 5 and 15% of the energy transmitted, mainly depending on the distance of the lines. Basically, for each kWh being consumed, a higher amount had to be generated.

The adjustment due to losses was calculated as follows:

$$\mathrm{CO_2kWh}_{loss} = CO_2 kWh \times loss\ factor$$

Where

- $\mathrm{CO_2kWh}_{loss}$: Adjustment (in CO_2/kWh) for emission induced by the losses of electricity in transmission and distribution.
- $loss\ factor = \frac{Losses}{Total\ grid}$

  Where
  - $Losses$: Total transmission and distribution losses in the grid.
  - $Total\ grid$: Total amount of electricity transiting through the country electricity grid, calculated as gross electricity generation – own use in plant + imports.

Note that data quality for electricity transmission and distribution losses may be very variable across countries.

2.4 CH_4 and N_2O emissions for electricity generation

If CO_2 represent a large majority in term of greenhouse gas emissions from fuel combustion, it is not the only one.

Emission factors for CH_4 and N_2O were calculated using the same methodology as for the CO_2 per kWh, using the Tier 1 methodology and the default emission factors of the *2006 IPCC Guidelines*, including also emissions from biofuels in this case (as opposed to CO_2 only emissions).

The emission factors are converted from gCH_4 and gN_2O to gCO_2eq using the 100-year Global Warming Potential (GWP) given below. For the purpose of comparability with international data submission guidelines, the factors from the 4th Assessment of the IPCC are used.

Designation or Name	**Chemical formula**	**100-Year GWP**
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298

Note that the uncertainty associated with CH_4 and N_2O emissions factors is very large, therefore these emission factors are provided as an indication when no better information is available. Please see the *2006 IPCC guidelines*[3] for more information about the uncertainty associated to emission factors.

2.5 Use of the adjustment indicators

In order to allow more flexibility for the users depending on their reporting needs, the CO_2 emission factors are presented in a disaggregated manner. Since the CO_2 emission per kWh represents the emissions at the generation point, this factor can be completed by adding the transmission and distribution losses factor, and the correction for electricity trade. By adding these figures one can obtain a closer figure to the CO2 per kWh at the final user point. Please note that in order to calculate completely the scope 3 emissions, the losses from Well to Tank (WTT) would have to be included as well, and these figures are not provided here.

This factor can also be completed with the CH_4 and N_2O figures to obtain a more complete greenhouse gas per kWh indicator. As stipulated above, these figures are to be taken with caution due to the uncertainty

[3] http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

associated with the corresponding IPCC emission factors. The CH_4 and N_2O adjustment for trade and losses are not provided here due to the negligible impact compared to the uncertainty associated with the figure.

2.6 Implied emission factors from direct combustion of fuels

In most cases fuels are combusted directly for other purposes than electricity generation. The direct emissions factors (IEF) vary according to the fuel used, and are computed as weighted average of the consumption across all sectors excluding electricity generation, as follows:

$$IEF = \frac{E_{Industry} + E_{Transport} + E_{Others}}{FC_{Industry} + FC_{Transport} + FC_{Others}}$$

Where:

- IEF : Implied emission factors for fuel combustion other than for electricity and heat generation, in kg CO_2 / kg of fuel
- $E_{Industry}$: Total CO_2 emissions from fuel combustion in the *Industry* sector plus emission in the *Energy* sector except electricity and CHP plants in kg CO_2.
- $E_{Transport}$: Total CO_2 emissions from fuel combustion in the *Transport* sector in kg CO_2.
- E_{Others} : Total CO_2 emissions from fuel combustion in the *Residential*, *Commercial and Public services*, *Agriculture/Forestry*, *Fishing* and *Other non-specified* sectors in kg CO_2.
- FC_{sector} : Total fuel consumption in the respective sector, expressed in kg.

Which is equivalent to:

$$DEF = \frac{\left(FC_{Industry} \times NCV_{Industry} + FC_{Transport} \times NCV_{Transport} + FC_{Others} \times NCV_{Others}\right) \times EF_{fuel}}{FC_{Industry} + FC_{Transport} + FC_{Others}}$$

Where:

- NCV_{Sector}: Net Calorific Value, which is product-, country-, sector- and time-specific.

These emission factors are presented for individual and for some average fuels described below:

- For coal: individual primary products (anthracite, coking coal, other bituminous coal, sub-bituminous coal and lignite); as well as the weighted average coal mix;
- For oil: individual secondary products (refinery gas, ethane, LPG, motor gasoline excl. biofuels, aviation gasoline, gasoline type jet fuel, kerosene type jet fuel excl. biofuels, kerosene, gas/diesel oil excl. biofuels, fuel oil, naphtha, white spirit, bitumen, petroleum coke and non-specified oil products); as well as the weighted average oil product mix.

When no data is reported for a fuel and year, the data is marked as X: Not applicable.