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Covenant of Mayors for Climate and Energy: Greenhouse gas emission factors for local emission inventories

Covenant of Mayors collection - 2024 datasets

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Contents

Abstract

The Global Covenant of Mayors (GCoM) for Climate and Energy initiative brings together more than 13 000 local and regional administrative authorities fostering the design and implementation of effective climate change policies and strategies at the urban level. In the GCoM, signatories voluntarily commit to developing and implementing a Climate Action Plan (CAP), with measures to reduce energy-related greenhouse gas (GHG) emissions. The Joint Research Centre (JRC) provides scientific, methodological and technical support to the GCoM, in particular in assisting signatories with the preparation and implementation of their action plans through the development of methodological guidebooks and in supporting their scientific soundness. For signatories in EU Member States, it also ensures their alignment and coherence with EU climate and energy policies.

In this context, the JRC provides GHG emission factors (EFs) for local authorities to estimate emissions associated with their (i) local use of energy from a range of renewable and non-renewable energy sources and (ii) use of national grid electricity. These EFs are regularly published in two datasets available in the Covenant of Mayors (CoM) collection within the JRC Data Catalogue: the 'GHG emission factors for local energy use' dataset and the 'GHG emission factors for electricity consumption' dataset. This report updates these EFs and summarises the data and methodology used to calculate them. GHG EFs for electricity are updated to 2020/2021 for the EU Member States and 28 other countries in Europe, the eastern neighbourhood, the southern neighbourhood and central Asia.

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1. Introduction

The Global Covenant of Mayors (GCoM) for Climate and Energy initiative brings together more than 13 000 local and regional administrative authorities fostering the design and implementation of effective climate change policies and strategies at the urban level. Within the GCoM, regional/national Covenant of Mayors (CoM) for Climate & Energy are local-specific coalitions of cities that have made a commitment to take action tackling climate change, such as the CoM for Climate and Energy Europe (CoM EU), the CoM for Climate and Energy Eastern Partnership (CoM East) and the CoM Mediterranean (CoM Med, supported by the project Clima-MED[1]).

In the GCoM, signatories voluntarily commit to developing and implementing a Climate Action Plan (CAP), or a Sustainable Energy and Climate Action Plan (SECAP), which includes the compilation of greenhouse gas (GHG) emission inventories (Bertoldi et al., 2010; Bertoldi, 2018a; Bertoldi, 2018b). These emission inventories quantify potential GHG emissions associated with the geographical territory of the local authority. In brief, activity data (in energy units) is reported for a set of key urban sectors, and emission factors (EFs) are then applied to estimate the associated GHG emissions.

To support signatories and the scientific soundness of their SECAPs, the Joint Research Centre (JRC) provides GHG EFs for energy use, which can be applied in the compilation of CoM inventories. The CoM EFs were initially published in the CoM EU guidebook in 2010 (Bertoldi et al., 2010), and subsequently revised and updated in 2017 (Koffi et al., 2017) and in 2022 (Lo Vullo et al., 2022). This report updates the CoM EFs and summarises the data and methodology used to calculate them. GHG EFs for electricity are updated to 2020/2021 in the EU Member States and 28 other countries in Europe, the eastern neighbourhood, the southern neighbourhood and central Asia. The main methodological changes in this revision are related to:

— the update of energy data, using the Eurostat Energy Balances (April 2023 edition) and International Energy Agency (IEA) World Energy Balances (2022 edition) data;

— the update of global warming potentials (GWPs), using the sixth assessment report (AR6) of the International Panel on Climate Change (IPCC, 2021);

— the update of life-cycle inventory (LCI) data to account for supply chain emissions, using ecoinvent version 3.9.1;

— the accounting of international trade (imports and exports) in EFs for national electricity, for EU Member States, Iceland and Norway.

[1] https://www.climamed.eu/

2. Covenant of Mayors emission factor datasets

The CoM EFs are published in two datasets in the JRC Data Catalogue, under the CoM collection [2]:

- the 'GHG emission factors for local energy use' dataset, which provides EFs to account for GHG emissions associated with local use of energy from a wide range of non-renewable energy sources (NRES) and renewable energy sources (RES);
- the 'GHG emission factors for electricity consumption' dataset, which provides yearly EFs to account for indirect GHG emissions associated with the use of national grid electricity – that is, emissions associated with electricity generation and supply at the national level.

Both datasets include three types of EFs, based on two approach types:

- the activity-based approach provides EFs for CO_2 and GHG (CO_2, CH_4 and N_2O) emissions (in tonnes of CO_2/MWh and tonnes of CO_2-eq/MWh, respectively), building on EFs for stationary energy combustion and global warming potentials (GWPs) from the International Panel on Climate Change (IPCC);
- the life-cycle (LC) approach provides a single EF for GHG (CO_2, CH_4 and N_2O) emissions (in tonnes of CO_2-eq/MWh), which includes the emissions calculated with the activity-based approach, and adds emissions associated with the supply chain, for each type of energy source and/or technology.

All datasets provided in this report are based on the information available at the time of writing (January 2024) and are subject to updates. Readers are invited to check the online datasets in the CoM collection, to be considered prevailing in case of differences.

(2) https://data.jrc.ec.europa.eu/collection/id-00172

3. Covenant of Mayors emission factors for local energy use

As mentioned, CoM GHG EFs are calculated using both an activity-based approach and an LC approach. In brief, the activity-based approach builds on IPCC emission data for stationary combustion of the most commonly used energy sources and carriers. To this, the LC-based approach adds GHG emissions related to the supply of fuels and/or electricity.

This section summarises the data and methods used to update CoM EFs for local energy use and for local electricity generation. It details the main materials, modelling steps and assumptions considered in the calculations of GHG emissions associated with fossil and non-fossil energy sources, for the CoM activity-based EFs (Subsection 3.1) and for the additional emissions considered in the LC approach (Subsection 3.2). The materials and methods described here build on and are to be seen as complementary to the methodology developed previously to calculate CoM EFs, which is described in the guidebook (Bertoldi, 2018a, 2018b, 2018c) and in previous CoM EF updates (Koffi et al., 2017; Lo Vullo et al., 2022).

3.1. Activity-based approach

In the activity-based approach, CoM EFs for local energy use build on IPCC emission data on the stationary combustion of fuels. Two types of EFs are provided in this approach: one for only CO_2 emissions and the other including three GHGs, namely CO_2, CH_4 and N_2O, which are expressed in terms of CO_2-eq. For the GHG EFs, GWPs for a 100-year time horizon are combined with each of the single-gas EFs. The current update of EFs in the CoM activity-based approach uses CO_2, CH_4 and N_2O EFs from the 2006 IPCC Emission Factor Database (EFDB), Section 1.A.1 'Energy industries' (IPCC, 2006), and GWPs from the IPCC sixth Assessment Report (IPCC 2021) ([3]).

Box 1. Accounting for GHG emissions from bioenergy sources

Carbon balance

IPCC guidance recommends that biogenic CO_2 emissions from bioenergy (i.e. biofuels, biomass and/or biomass-based products used for energy purposes) are accounted for in the *Agriculture, Forestry, and Other Land Use* (AFOLU) sector (as changes in carbon stocks). These emissions should thus be excluded from the Energy and Waste sectoral inventories to avoid double counting, but they can be mentioned therein as an informative item (IPCC, 2019, Vol. 1, Chapter 1). CH_4 and N_2O emissions from the combustion of biomass and biomass-based products for energy purposes, however, should be accounted for.

Generally, the CoM GHG emission inventories do not include AFOLU, and thus double counting issues may not apply. Nonetheless, to ensure consistency and comparability with other GHG inventories at the urban, regional and national levels, the CoM EFs follow the IPCC guidelines and exclude CO_2 emissions associated with biomass and biomass-based products used for energy purposes, if these are harvested in a sustainable manner. The CoM framework assumes a 'carbon neutrality' principle – that is, a carbon balance between CO_2 emissions and carbon sequestration or removal by productive land (Lo Vullo et al., 2022). Biogenic CO_2 emissions can be provided as an informative item in the SECAP full document, complementary to the GHG inventory, to provide further insight into the overall emissions associated with energy generation and use at the urban level. If biofuels and biomass-based energy sources are not harvested in a sustainable manner and result in declining carbon stocks, an EF for CO_2 (higher than zero) should be applied in the inventory (Koffi et al., 2017).

([3]) The previous version of the CoM EFs (Lo Vullo et al., 2022) used the IPCC forth Assessment Report (AR) GWPs. GWPs in AR4, AR5 and AR6 are presented in Supporting Table 1 for a comparative overview.

GWP for methane emissions

Because this update of CoM EFs is based on the IPCC sixth Assessment Report (IPCC, 2021), differentiated GWPs for CH_4 emissions were considered for fossil and non-fossil sources. Several sources, such as sludge gas, might be associated with both biogenic and fossil-based emissions (Liu et al., 2021); however, each source was treated homogeneously as either fossil or non-fossil for simplicity ([4]).

3.2. Life-cycle approach

As mentioned, the CoM LC EFs for local energy use consist of the sum of (i) GHG emissions associated with the final use of energy in the territory, calculated using the activity-based approach (as described in Subsection 3.1), and (ii) GHG emissions associated with upstream processes, related to the supply of fuels and/or electricity. Generally, upstream processes include raw material extraction, transport and processing (Lo Vullo et al., 2022). GHG emissions associated with upstream processes were calculated using life-cycle inventory (LCI) data from ecoinvent (version 3.9.1). The LCI datasets used are presented in Table 1 for non-renewable energy sources (NRES), Table 2 for renewable energy sources (RES), and Table 3 for local electricity generation from wind, hydro and photovoltaics. In line with the activity-based approach, fossil GHG emissions were calculated for each of the datasets with GWPs for a 100-year time frame (IPCC, 2021).

Generally, market processes representative of an EU (or European) geographical scope were selected. Market processes represent a consumption mix – that is, they consider a mix of production technologies and/or regions of origin representative of a given consumption region and product, the transport of goods from the producer to the consumer and losses across those stages, when relevant. When there was no market process dataset available for Europe, either a dataset for a European country (e.g. Spain, Switzerland) or a global dataset was selected and assumed to be representative of the EU. Since supply chains and markets of fuels and electricity generation infrastructure tend to have a global or large international scale – for example, most wind turbine and photovoltaic panel components used in the EU come from China – the selection of a specific country dataset is not expected to have a large impact on the results. More variability, however, can be expected in the case of biofuels, where the selection of a dataset for a specific biofuel and origin can result in greater uncertainty.

The selected LCI datasets used a cut-off system model. The cut-off approach essentially considers that, when a material or product is used in more than one life cycle (e.g. if it is recycled), the environmental impacts associated with manufacturing that material or product stay with the primary product. At the end of its life, the material or product is considered burden-free for its subsequent uses, which consider only the impacts of recovering and recycling it. For more details on the ecoinvent LCI database, including market process and cut-off system modelling, see Wernet et al. (2016) and Weidema et al. (2013).

In the case of waste-to-energy processes, emissions associated with waste treatment (e.g. waste collection, transport and pre-treatment) were accounted for, in line with the CoM EF methodology and the IPCC guidelines. These recommend that all GHG emissions from waste-to-energy (waste used directly as a fuel or converted into a fuel) are estimated and reported under the energy sector (IPCC, 2006). Emissions associated with energy generation (e.g. power plant construction) were excluded from the LCIs for all NRES – the EFs account for the supply of the fuel (energy carrier). Emissions associated with land use change were excluded (Lo Vullo et al., 2022).

Some LCI datasets used mass- or volume-based process units (e.g. kg or m^3). These units were converted to energy units (e.g. MJ) and the datasets were adjusted accordingly. The CoM EFs built on IPCC's tier 1 type of EFs in the activity-based approach – that is, a default EF per unit amount of fuel combusted in the source category considering a net calorific basis (i.e. kg of GHG per TJ of fuel, on a net calorific basis) (IPCC, 2006). We used the net calorific values (NCVs) considered in the ecoinvent datasets or the default IPCC NCVs (IPCC, 2006, Vol. 2, Table 1.2), as indicated in Tables 1 and 2.

Biogenic CO_2 emissions and uptake associated with biofuel supply chains (production) were not considered in LC-based CoM EFs, to be consistent with the assumption of carbon balance, and with the exclusion of biogenic CO_2 emissions in the combustion stage for these fuels (see Subsection 3.1).

([4]) Supporting Table 2 presents IPCC energy sources and their classification as fossil or non-fossil energy sources, as used in the CoM EF calculations.

Table 1. LCI datasets used for non-renewable energy sources (NRES)

<table>
<tr><th colspan="2">Energy source</th><th rowspan="2">Dataset ([1])</th><th rowspan="2">Remarks ([2])</th><th rowspan="2">Geographical scope</th></tr>
<tr><th>SECAP category</th><th>IPCC category</th></tr>
<tr><td>Natural gas</td><td>Natural gas</td><td>Market group for natural gas, high pressure</td><td>Process unit (m^3) converted to MJ with NCV of 36.0 MJ/m^3 (from dataset)</td><td>Europe without Switzerland</td></tr>
<tr><td rowspan="2">Liquid gas</td><td>Liquefied petroleum gases</td><td>Market for liquefied petroleum gas</td><td>Process unit (kg) converted to MJ with NCV of 45.5 MJ/kg (from dataset)</td><td>Europe without Switzerland</td></tr>
<tr><td>Natural gas liquids</td><td>Market for natural gas liquids</td><td>Process unit (kg) converted to MJ with NCV of 24.6 MJ/kg (from dataset)</td><td>Global</td></tr>
<tr><td>Heating oil</td><td>Gas/diesel oil</td><td>Market for diesel</td><td>Process unit (kg) converted to MJ with NCV of 42.8 MJ/kg (from dataset).</td><td>Europe</td></tr>
<tr><td>Diesel</td><td>Gas/diesel oil</td><td>Market for diesel, low -sulphur</td><td>Process unit (kg) converted to MJ with NCV of 42.8 MJ/kg (from dataset)</td><td>Europe</td></tr>
<tr><td>Gasoline</td><td>Motor gasoline</td><td>Market for petrol, unleaded</td><td>Process unit (kg) converted to MJ with NCV of 43.2 MJ/kg (from dataset)</td><td>Europe</td></tr>
<tr><td>Lignite</td><td>Lignite</td><td>Market for lignite</td><td>Process unit (kg) converted to MJ with NCV of 8.8 MJ/kg (from dataset)</td><td>Europe</td></tr>
<tr><td rowspan="3">Coal</td><td>Anthracite</td><td>Market for hard coal</td><td>Process unit (kg) converted to MJ with NCV of 26.7 MJ/kg (from IPCC)</td><td>Europe without Russia and Türkiye</td></tr>
<tr><td>Other bituminous coal</td><td>Market for hard coal</td><td>Process unit (kg) converted to MJ with NCV of 25.8 MJ/kg (from IPCC)</td><td>Europe without Russia and Türkiye</td></tr>
<tr><td>Sub-bituminous coal</td><td>Market for hard coal</td><td>Process unit (kg) converted to MJ with NCV of 18.9 MJ/kg (from IPCC)</td><td>Europe without Russia and Türkiye</td></tr>
<tr><td rowspan="2">Other</td><td>Peat</td><td>Market for peat</td><td>Process unit (kg) converted to MJ with NCV of 9.76 MJ/kg (from IPCC)</td><td>Europe</td></tr>
<tr><td>Municipal waste</td><td>Treatment of municipal solid waste, incineration</td><td>Process unit (kg) converted to MJ with NCV of 10 MJ/kg (from IPCC); incineration emissions excluded</td><td>Switzerland</td></tr>
</table>

([1]) Datasets were selected from ecoinvent, version 3.9.1, with a cut-off system model.
([2]) We used the NCVs considered in the respective ecoinvent dataset or the default IPCC NCVs (IPCC, 2006, Vol. 2, Table 1.2).

Source: JRC analysis.

Table 2. Life-cycle inventory (LCI) datasets used for renewable energy sources (RES)

Energy source SECAP category	Energy source IPCC category	Dataset (1)	Remarks (2)	Geographical scope
Plant oil	Other liquid biofuels	Market for palm oil, refined	Process unit (kg) converted to MJ with NCV of 27.4 MJ/kg (from IPCC)	Global
Biofuel	Biogasoline	Market for ethanol, from fermentation, vehicle grade	Process unit (kg) converted to MJ with NCV of 27.0 MJ/kg (from IPCC)	Switzerland
	Biodiesel	Rape oil, crude, mill operation (adjusted with Market for rape oil, crude, for Switzerland)	Process unit (kg) converted to MJ with NCV of 27.0 MJ/kg (from IPCC)	Europe without Switzerland
Other biomass	Wood / wood waste	Market for cleft timber, measured as dry mass	Process unit (kg) converted to MJ with NCV of 15.6 MJ/kg (from IPCC)	Europe without Switzerland
	Municipal waste (biomass fraction)	Treatment of biowaste, municipal incineration with fly ash extraction	Process unit (kg) converted to MJ with NCV of 11.6 MJ/kg (from IPCC); incineration emissions excluded	Switzerland
	Other primary solid biomass	Market for wood chips, wet, measured as dry mass	Process unit (kg) converted to MJ with NCV of 10.8 MJ/kg (from dataset)	Europe without Switzerland
	Other biogas	Market for biogas	Process unit (m^3) converted to MJ with NCV of 22.7 MJ/m^3 (from dataset)	Switzerland
Solar thermal	—	Heat production, at hot water tank, solar + electric, flat plate	Process unit (MJ)	Switzerland
Geothermal	—	Central/small-scale heat production at heat pump 30 kW, exergy-based allocation	Process unit (MJ)	Europe without Switzerland

(1) Datasets were selected from ecoinvent, version 3.9.1, with a cut-off system model.
(2) We used the NCVs considered in the respective ecoinvent dataset or the default IPCC NCVs (IPCC, 2006, Vol. 2, Table 1.2).

Source: JRC analysis.

Table 3. Life-cycle inventory (LCI) datasets used for local electricity generation from renewable energy sources (RES)

Electricity source SECAP category	Dataset (1)	Geographical scope
Wind	Electricity production, high voltage, wind turbine > 3 MW	Switzerland
Hydroelectric	Electricity production, high voltage, hydro, run-of-river	Switzerland
Photovoltaic	Electricity production, photovoltaic, 3 kWp slanted roof installation, multi-Si panel	Spain

(1) Datasets were selected from ecoinvent, version 3.9.1, with a cut-off system model.

Source: JRC analysis.

3.3. Datasets update

The updated CoM EFs for local energy use and electricity generation are presented in Tables 4 and 5, for local energy use from NRES and RES, respectively, and in Table 6 for local electricity generation from RES. The small difference between the two EFs in the activity-based approach – CO_2 and GHG – is associated with the fact that CO_2 accounts for a dominant share of energy-related direct GHG emissions.

In all tables of this report presenting updated CoM datasets, EFs are reported to three decimal places. If needed, readers can see the complete online datasets for additional significant digits.

Table 4. Updated CoM EFs for local energy use of non-renewable energy sources (NRES)

Energy source SECAP category	IPCC category	Activity-based approach		LC approach ([1])
		CO_2 (t CO_2/MWh)	GHG (t CO_2-eq/MWh)	GHG (t CO_2-eq/MWh)
Natural gas	Natural gas	0.202	0.202	0.261
Liquid gas	Liquefied petroleum gases	0.227	0.227	0.311
	Natural gas liquids	0.231	0.232	0.339
Heating oil	Gas/diesel oil	0.267	0.268	0.340
Diesel	Gas/diesel oil	0.267	0.268	0.349
Gasoline	Motor gasoline	0.249	0.250	0.333
Lignite	Lignite	0.364	0.365	0.373
Coal	Anthracite	0.354	0.355	0.404
	Other bituminous coal	0.341	0.342	0.392
	Sub-bituminous coal	0.346	0.348	0.416
Other	Peat	0.382	0.383	0.388
	Municipal waste (non-biomass fraction)	0.330	0.337	0.346

([1]) Life-cycle data on supply chain emissions can be considered representative of an EU/European geographical scope.

Source: JRC analysis.

Table 5. Updated CoM EFs for local energy use of renewable energy sources (RES)

Energy source SECAP category	IPCC category	Activity-based approach ([1])		LC approach ([2])
		CO_2 (t CO_2/MWh)	GHG (t CO_2-eq/MWh)	GHG (t CO_2-eq/MWh)
Plant oil	Other liquid biofuels	0.000 (0.287)	0.001 (0.287)	0.147
Biofuel	Biogasoline	0.000 (0.255)	0.001 (0.256)	0.057
	Biodiesel	0.000 (0.255)	0.001 (0.256)	0.264
Other biomass	Wood / wood waste	0.000 (0.403)	0.007 (0.410)	0.015
	Municipal waste (biomass fraction)	0.000 (0.360)	0.007 (0.367)	0.017
	Other primary solid biomass	0.000 (0.360)	0.007 (0.367)	0.022
	Other biogas	0.000 (0.197)	0.000 (0.197)	0.025
Solar thermal	—	0.000	0.000	0.020
Geothermal	—	0.000	0.000	0.083

([1]) Total CO_2 EFs, including fossil and non-fossil energy sources, are provided in brackets (activity-based approach). Following the principle of biogenic carbon balance and the IPCC guidance, CO_2 emissions of biomass/biofuels harvested in a sustainable manner can be considered neutral, and biogenic CO_2 may be mentioned as an informative item, in the context of CoM emission inventories. If biomass/biofuels are not harvested in a sustainable manner, CO_2 emissions from bioenergy sources should be reported in the CoM GHG emission inventories.

([2]) Life-cycle data on supply chain emissions can be considered representative of an EU/European geographical scope. In the case of biomass/biofuels, an LC EF is provided, assuming carbon balance and excluding biogenic emissions. This EF can be used when biomass/biofuels are harvested in a sustainable manner. If biomass/biofuels are not harvested in a sustainable manner, and the CoM inventory uses LC-based EFs, upstream and use-phase emissions should be modelled for the specific context/case.

Source: JRC analysis.

Table 6. Updated CoM EFs for local electricity generation from renewable energy sources (RES)

Energy source SECAP category	Activity-based approach		LC approach ([1])
	CO_2 (t CO_2/MWh)	GHG (t CO_2-eq/MWh)	GHG (t CO_2-eq/MWh)
Wind	0.000	0.000	0.036
Hydroelectric	0.000	0.000	0.004
Photovoltaic	0.000	0.000	0.063

([1]) LC data on supply chain emissions can be considered representative of an EU/European geographical scope.

Source: JRC analysis.

4. Covenant of Mayors emission factors for national electricity: European Union, Iceland and Norway

Yearly GHG EFs for electricity consumption, also referred to as National and European Emission Factors for Electricity (NEEFE), were calculated for end user electricity use, for all EU Member States, Iceland and Norway, from 1990 until 2021, considering that:

$$GHG_{electr.cons.} = GHG_{electr.gen.} + GHG_{imports} - GHG_{exports}$$

Where $GHG_{electr.cons.}$ are the GHG emissions associated with electricity consumption in the country, $GHG_{electr.gen.}$ are the GHG emissions associated with gross electricity generation in the country, $GHG_{imports}$ are the GHG emissions associated with the electricity imported to the country and $GHG_{exports}$ are the GHG emissions associated with the electricity exported from the country. GHG emissions in this equation can be expressed in tonnes of CO_2 or tonnes of CO_2-eq, depending on the approach selected (see Section 2). Considering that GHG emissions can be calculated by multiplying electricity consumption or generation by its EF, GHG emissions can be expressed as:

$$EF_{electr.cons.} \times E_{cons.} = EF_{electr.gen.} \times E_{gen.} + EF_{imports} \times E_{imports} - EF_{electr.gen.} \times E_{exports}$$

First, the EFs for electricity generation ($EF_{electr.gen.}$) were calculated for all countries. The annual energy inputs for electricity generation per energy source (in GWh) were calculated using the updated Eurostat Energy Balances data (nrg_bal_c_linear.csv; last updated in April 2023). Electricity generation in the Eurostat Energy Balances data is disaggregated into four types of power plant:

— main activity producer electricity only,

— main activity producer combined heat and power (CHP),

— autoproducer electricity only,

— autoproducer combined heat and power (CHP).

To estimate energy inputs for electricity in CHP generation, the current update followed the approach described by Lo Vullo et al. (2022). First, a fuel input for electricity coefficient was calculated, based on the input for electricity and the total fuel input:

$$Fuel\ input\ for\ electricty\ coefficient = \frac{fuel\ input\ for\ electricity}{total\ fuel\ input\ to\ CHP}$$

We retrieved the total fuel input to CHP (for main activity producer CHP and for autoproducer CHP) and calculated the fuel input for electricity, assuming a heat production efficiency of 0.90 (a default value, also used by the European Environment Agency (EEA) and the International Energy Agency (IEA), for example):

$$Fuel\ input\ for\ electricity = total\ fuel\ input\ to\ CHP - \frac{heat\ output}{0.90}$$

Then, EFs for local energy use by energy source (calculated as described in Section 3, and presented in Supporting Table 3) were applied to the annual energy inputs for electricity generation per energy source to estimate the overall yearly emissions associated with electricity generation in the country (both for CO_2 and for GHG emissions, using activity-based and LC-based approaches). Lastly, EFs for electricity generation were calculated as follows:

$$EF_{electr.gen.} = \frac{emissions\ from\ national\ electricity\ generation}{national\ electricity\ generation}$$

To estimate the GHG emissions associated with exports, the EFs calculated for electricity generation were multiplied by the volume of exports from the country, which assumes that all electricity exported by a country is generated in that country – that is, that all electricity imports to a country are consumed within the country and not exported ([5]). To estimate the GHG emissions associated with imports, EFs for the electricity generation of the countries of origin were applied to the corresponding volume of imports.

Yearly imports of electricity are provided by partner country (country of origin of the imports) (nrg_ti_eh_linear.csv). Since a share of these imports is reported under the category 'non-specified partner' (NSP), we complemented this data with data reported on exports (nrg_te_eh_linear.csv). In brief, to adjust (reduce) the relative share of the NSP category in the imports, we considered the highest value between (i) the imports to a country from a given partner in a given year and (ii) the exports reported by the partner to that country in the same year. In other words, we looked at the imports reported by country A from country B and at the exports reported by country B to country A – which should describe the same trade flow – and, if there was inconsistency, we used the higher value. This adjustment was carried out to calculate the coefficients of the overall imports for each country of origin. The overall volume of imports remained unchanged – that is, it remained the volume reported to Eurostat by the country importing the electricity.

EFs for electricity generation for all countries covered in the Eurostat Energy Balances database ([6]) were calculated as described above (for the EU Member States) for all years from 1990 to 2021. A few countries had no generation EFs in certain years (mostly eastern European countries, such as Montenegro, which did not report to Eurostat in the early 1990s). The imports from these countries for these years were added to the NSP imports, resulting in an overall volume of imports for which no EF could be calculated. When the share of imports to a country for which we had no EF was higher than 40%, an alternative calculation was performed to estimate the EF of imports in that year, using an average coefficient between the yearly imports and the country's own generation EF for the available years (between 1990 and 2021).

Imports also came from five countries not included in the Eurostat Energy Balances data: Belarus, Switzerland, Morocco, Russia and Andorra. For the first four countries, yearly generation EFs were calculated using data from the IEA World Energy Balances database. Because the data in this case was only available until 2020, imports from these countries in 2021 were estimated using the generation EF of 2020. This simplification is not expected to significantly affect the results. Given the limited data and significance, imports from Andorra were considered negligible and excluded.

Box 2. Addressing international trade in the CoM EFs for national electricity

The previous CoM NEEFE methodology calculated the overall GHG emissions of national electricity generation and associated them to the electricity consumed in the country. This simplification may be adequate for a closed system (i.e. a country without imports or exports); however, it can affect countries differently, depending on whether they are net importers or exporters of electricity. In practice, imported electricity was included in electricity consumption without accounting for its associated GHG emissions, while emissions associated with exports remained allocated to the national electricity consumption. As a result, net exporters of electricity were likely to have higher NEEFEs than the actual EF for electricity supply (and consumption) in the country, while net importers were likely to have lower NEEFEs. This depends, naturally, on the relative volume of imports and exports, and on their associated emissions.

([5]) Ideally, exported electricity should consist of a mix of both generated and imported electricity, which could be modelled with a set of recurrence equations for national emission factors, solved by iteration (see, for example, Scarlat et al., 2022). Nevertheless, for the sake of simplicity and reproducibility, it was decided to adopt the more direct approach described. Similarly, the share of electricity imported and directly exported (transit flows) was assumed to be zero, partly due to the limited availability of reliable data.

([6]) In principle, the annual data collection of the Eurostat Energy Balances dataset covers the EU Member States, the European Free Trade Association, EU candidate countries and potential candidate countries.

4.1. Datasets update

The CoM GHG EFs for national electricity consumption in EU Member States, Iceland and Norway are presented for activity-based (IPCC) CO_2 emissions (Table 7), activity-based (IPCC) GHG emissions (Table 8) and LC-based GHG emissions (Table 9) for a selection of years. The complete dataset for 1990–2021 is available in the CoM collection.

Table 7. CoM activity-based (IPCC) CO_2 EFs for national electricity consumption (also referred to as NEEFEs) of EU Member States, Iceland and Norway, for selected years (tonnes of CO_2/MWh)

Country	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
BE	0.408	0.401	0.317	0.307	0.260	0.270	0.216	0.216	0.226	0.188	0.188	0.169
BG	0.640	0.779	0.732	0.718	0.749	0.648	0.609	0.657	0.568	0.542	0.475	0.505
CZ	1.064	1.040	0.929	0.871	0.786	0.717	0.708	0.657	0.634	0.580	0.513	0.544
DK	0.508	0.626	0.414	0.270	0.375	0.134	0.193	0.138	0.165	0.131	0.085	0.103
DE	0.745	0.682	0.617	0.568	0.530	0.507	0.508	0.473	0.452	0.385	0.342	0.382
EE	1.336	2.081	1.585	1.414	1.256	0.595	0.859	1.026	0.889	0.510	0.228	0.249
IE	0.906	0.878	0.768	0.668	0.527	0.463	0.459	0.422	0.363	0.318	0.291	0.347
EL	1.245	1.089	1.022	0.957	0.833	0.688	0.572	0.614	0.636	0.560	0.453	0.411
ES	0.522	0.548	0.512	0.471	0.279	0.348	0.294	0.337	0.302	0.232	0.183	0.174
FR	0.142	0.096	0.091	0.103	0.099	0.068	0.077	0.087	0.069	0.068	0.066	0.068
HR	0.235	0.207	0.264	0.193	0.092	0.480	0.511	0.417	0.482	0.345	0.318	0.376
IT	0.583	0.551	0.511	0.497	0.421	0.334	0.329	0.326	0.303	0.283	0.269	0.284
CY	0.944	0.944	0.963	0.890	0.789	0.735	0.742	0.720	0.709	0.686	0.684	0.660
LV	0.043	0.283	0.365	0.368	0.506	0.586	0.471	0.367	0.465	0.332	0.216	0.301
LT	0.242	0.210	0.197	0.159	0.166	0.123	0.096	0.070	0.102	0.068	0.061	0.078
LU	0.851	0.688	0.523	0.515	0.529	0.489	0.472	0.435	0.396	0.314	0.283	0.285
HU	0.796	0.729	0.635	0.490	0.434	0.345	0.343	0.281	0.294	0.245	0.224	0.220
MT	1.935	1.265	1.024	1.063	1.022	0.569	0.496	0.423	0.372	0.373	0.393	0.356
NL	0.640	0.600	0.539	0.535	0.467	0.521	0.499	0.464	0.447	0.390	0.317	0.329
AT	0.354	0.307	0.313	0.377	0.332	0.337	0.301	0.314	0.288	0.252	0.220	0.243
PL	1.280	1.357	1.206	1.132	1.035	0.902	0.876	0.864	0.843	0.773	0.725	0.776
PT	0.633	0.684	0.565	0.576	0.291	0.402	0.335	0.422	0.346	0.271	0.213	0.179
RO	0.940	1.011	0.761	0.643	0.561	0.465	0.444	0.470	0.452	0.457	0.379	0.377
SI	0.526	0.448	0.336	0.372	0.312	0.250	0.252	0.234	0.218	0.218	0.213	0.203
SK	0.546	0.511	0.458	0.443	0.359	0.457	0.411	0.427	0.369	0.358	0.340	0.352
FI	0.181	0.228	0.166	0.147	0.236	0.089	0.101	0.097	0.108	0.078	0.055	0.057
SE	0.012	0.021	0.024	0.033	0.055	0.013	0.021	0.016	0.020	0.016	0.012	0.014
IS	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO	0.001	0.005	0.002	0.005	0.038	0.014	0.015	0.015	0.016	0.018	0.008	0.012
UK	0.808	0.638	0.558	0.569	0.529	0.411	0.326	0.289	0.264	0.241	—	—

NB: Country codes and lists of countries are provided in Supporting Table 4.

Source: JRC analysis.

Table 8. CoM activity-based (IPCC) GHG EFs for national electricity consumption (also referred to as NEEFEs) of EU Member States, Iceland and Norway, for selected years (tonnes of CO_2-eq/MWh)

Country	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
BE	0.410	0.402	0.318	0.308	0.261	0.272	0.217	0.217	0.227	0.189	0.190	0.170
BG	0.642	0.781	0.734	0.720	0.751	0.650	0.610	0.658	0.570	0.544	0.477	0.508
CZ	1.067	1.043	0.932	0.874	0.788	0.719	0.710	0.660	0.636	0.582	0.515	0.546
DK	0.510	0.628	0.416	0.272	0.378	0.136	0.195	0.141	0.167	0.134	0.086	0.105
DE	0.747	0.684	0.618	0.570	0.532	0.510	0.510	0.475	0.454	0.387	0.344	0.383
EE	1.343	2.092	1.593	1.421	1.263	0.599	0.864	1.032	0.896	0.516	0.232	0.253
IE	0.908	0.880	0.769	0.669	0.528	0.464	0.460	0.423	0.364	0.319	0.292	0.348
EL	1.248	1.093	1.025	0.959	0.836	0.690	0.573	0.615	0.638	0.562	0.454	0.412
ES	0.523	0.550	0.514	0.472	0.280	0.349	0.296	0.338	0.303	0.233	0.184	0.175
FR	0.142	0.096	0.092	0.103	0.100	0.069	0.078	0.087	0.069	0.069	0.066	0.068
HR	0.235	0.207	0.264	0.194	0.092	0.482	0.512	0.419	0.484	0.346	0.319	0.378
IT	0.585	0.553	0.512	0.498	0.423	0.336	0.330	0.328	0.305	0.284	0.271	0.285
CY	0.947	0.947	0.966	0.894	0.792	0.738	0.745	0.722	0.712	0.689	0.686	0.663
LV	0.043	0.284	0.367	0.369	0.509	0.590	0.474	0.370	0.469	0.336	0.219	0.305
LT	0.242	0.210	0.197	0.159	0.166	0.124	0.097	0.071	0.104	0.069	0.063	0.079
LU	0.853	0.690	0.525	0.517	0.531	0.491	0.474	0.437	0.398	0.316	0.285	0.287
HU	0.798	0.731	0.637	0.492	0.436	0.347	0.345	0.282	0.296	0.247	0.226	0.222
MT	1.941	1.269	1.027	1.067	1.026	0.571	0.498	0.424	0.372	0.374	0.394	0.356
NL	0.642	0.602	0.540	0.537	0.469	0.523	0.502	0.466	0.449	0.392	0.319	0.331
AT	0.355	0.308	0.314	0.379	0.334	0.339	0.303	0.316	0.290	0.254	0.221	0.244
PL	1.284	1.360	1.209	1.136	1.038	0.906	0.879	0.868	0.846	0.776	0.728	0.779
PT	0.635	0.686	0.567	0.578	0.293	0.404	0.337	0.423	0.347	0.273	0.215	0.181
RO	0.942	1.013	0.763	0.644	0.562	0.466	0.445	0.471	0.453	0.458	0.380	0.378
SI	0.527	0.450	0.337	0.373	0.313	0.251	0.253	0.236	0.219	0.219	0.214	0.205
SK	0.547	0.512	0.459	0.445	0.361	0.459	0.413	0.429	0.371	0.360	0.342	0.354
FI	0.182	0.230	0.168	0.149	0.238	0.091	0.103	0.098	0.110	0.080	0.057	0.059
SE	0.012	0.022	0.024	0.033	0.056	0.014	0.022	0.017	0.021	0.018	0.013	0.015
IS	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO	0.001	0.005	0.002	0.005	0.038	0.014	0.015	0.015	0.016	0.018	0.008	0.012
UK	0.810	0.640	0.559	0.570	0.530	0.413	0.328	0.290	0.266	0.243	—	—

NB: Country codes and lists of countries are provided in Supporting Table 4.

Source: JRC analysis.

Table 9. CoM life-cycle (LC) GHG EFs for national electricity consumption (also referred to as NEEFEs) of EU Member States, Iceland and Norway, for selected years (tonnes of CO_2-eq/MWh)

Country	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
BE	0.472	0.462	0.366	0.361	0.314	0.325	0.260	0.261	0.275	0.230	0.237	0.208
BG	0.709	0.849	0.782	0.774	0.801	0.681	0.642	0.691	0.599	0.574	0.508	0.540
CZ	1.120	1.095	0.986	0.928	0.837	0.774	0.764	0.709	0.680	0.624	0.558	0.590
DK	0.589	0.730	0.494	0.327	0.446	0.171	0.237	0.176	0.206	0.171	0.118	0.138
DE	0.814	0.746	0.676	0.627	0.590	0.567	0.570	0.532	0.510	0.442	0.400	0.438
EE	1.850	2.889	2.200	1.968	1.747	0.820	1.192	1.438	1.243	0.725	0.327	0.351
IE	1.042	1.020	0.912	0.796	0.641	0.556	0.555	0.515	0.448	0.401	0.376	0.442
EL	1.321	1.160	1.099	1.032	0.903	0.759	0.645	0.695	0.720	0.651	0.546	0.502
ES	0.594	0.633	0.598	0.563	0.353	0.428	0.367	0.417	0.375	0.301	0.245	0.236
FR	0.161	0.109	0.105	0.120	0.119	0.084	0.096	0.108	0.085	0.086	0.085	0.087
HR	0.289	0.256	0.321	0.233	0.111	0.517	0.550	0.461	0.516	0.386	0.360	0.416
IT	0.718	0.684	0.641	0.619	0.533	0.437	0.433	0.432	0.403	0.382	0.368	0.383
CY	1.154	1.155	1.179	1.089	0.973	0.909	0.921	0.899	0.886	0.859	0.864	0.833
LV	0.055	0.372	0.490	0.506	0.699	0.826	0.658	0.518	0.655	0.477	0.317	0.437
LT	0.305	0.261	0.250	0.204	0.215	0.164	0.123	0.090	0.129	0.089	0.083	0.100
LU	0.918	0.754	0.580	0.581	0.600	0.551	0.533	0.494	0.451	0.363	0.336	0.334
HU	0.891	0.818	0.711	0.563	0.498	0.388	0.388	0.324	0.338	0.289	0.267	0.266
MT	2.316	1.542	1.264	1.307	1.262	0.716	0.633	0.551	0.489	0.492	0.519	0.470
NL	0.758	0.713	0.638	0.638	0.564	0.610	0.590	0.552	0.533	0.476	0.398	0.406
AT	0.405	0.358	0.355	0.429	0.381	0.381	0.343	0.359	0.330	0.293	0.258	0.281
PL	1.414	1.500	1.338	1.258	1.156	1.007	0.980	0.967	0.945	0.873	0.822	0.877
PT	0.749	0.808	0.672	0.692	0.367	0.494	0.415	0.522	0.432	0.353	0.286	0.248
RO	1.102	1.136	0.842	0.700	0.601	0.508	0.488	0.518	0.499	0.503	0.424	0.418
SI	0.565	0.476	0.366	0.426	0.355	0.286	0.287	0.270	0.249	0.250	0.242	0.235
SK	0.602	0.575	0.505	0.488	0.398	0.503	0.455	0.470	0.409	0.397	0.381	0.396
FI	0.209	0.260	0.191	0.169	0.275	0.106	0.120	0.117	0.129	0.095	0.071	0.073
SE	0.017	0.028	0.030	0.040	0.068	0.023	0.032	0.026	0.030	0.027	0.024	0.027
IS	0.166	0.137	0.174	0.143	0.179	0.159	0.134	0.150	0.170	0.170	0.169	0.153
NO	0.006	0.010	0.007	0.010	0.051	0.023	0.024	0.024	0.025	0.028	0.017	0.022
UK	0.934	0.749	0.666	0.678	0.640	0.499	0.409	0.367	0.340	0.315	—	—

NB: Country codes and lists of countries are provided in Supporting Table 4.

Source: JRC analysis.

5. Covenant of Mayors emission factors for national electricity: other countries

CoM EFs for national electricity were calculated for a further 26 countries (in addition to the EU Member States, Iceland and Norway, presented in Section 4), using IEA World Energy Balances data. For these countries, due to limited international trade data availability and completeness, the methodology of the previous CoM update was used (Lo Vullo et al., 2022). Therefore, the EFs for national electricity were calculated as follows:

$$EF_{electr.cons.} = \frac{emissions\ from\ national\ electricity\ generation}{national\ electricity\ consumption}$$

The CoM EFs for national electricity consumption are presented for these countries and selected years, using the activity-based (IPCC) approach for CO_2 (Table 10) and for GHG emissions (Table 11). Table 12 presents the CoM EFs for national electricity using the LC-based approach. The complete dataset for 1990–2020 is available in the CoM collection.

5.1. Datasets update

Table 10. CoM activity-based (IPCC) CO_2 EFs for national electricity consumption (also referred to as NEEFEs) of other countries, for selected years (tonnes of CO_2/MWh)

Country	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
CoM East countries											
AM	0.551	0.388	0.396	0.201	0.129	0.236	0.220	0.220	0.274	0.232	0.241
AZ	0.816	0.923	0.967	0.684	0.663	0.683	0.678	0.694	0.648	0.613	0.597
GE	0.588	0.634	0.268	0.118	0.096	0.127	0.101	0.098	0.085	0.112	0.106
MD	1.142	0.716	0.656	0.436	0.685	0.619	0.630	0.478	0.505	0.544	0.595
UA	0.966	0.779	0.614	0.612	0.585	0.536	0.583	0.468	0.500	0.473	0.430
Clima-MED countries											
DZ	0.830	0.865	0.852	0.775	0.748	0.730	0.689	0.665	0.660	0.630	0.638
EG	0.618	0.523	0.419	0.565	0.500	0.552	0.555	0.581	0.544	0.512	0.480
IL	0.965	0.913	0.862	0.904	0.840	0.722	0.681	0.668	0.592	0.579	0.554
JO	0.986	0.941	1.039	0.789	0.669	0.691	0.580	0.569	0.517	0.460	0.428
LB	2.076	0.764	0.744	0.656	0.746	0.838	0.838	0.803	0.808	0.796	0.788
MA	0.936	1.071	0.847	0.921	0.694	0.722	0.696	0.694	0.714	0.861	0.862
TN	0.774	0.690	0.682	0.531	0.583	0.597	0.553	0.547	0.545	0.539	0.557
Western Balkans and Türkiye											
AL	0.295	0.122	0.059	0.028	0.003	0.000	0.000	0.000	0.000	0.000	0.000
BA	1.046	0.220	1.496	1.326	1.220	1.077	1.242	1.236	1.218	1.159	1.345
ME	—	—	—	0.298	0.539	0.580	0.469	0.451	0.520	0.500	0.564
MK	1.109	1.104	1.057	0.898	0.745	0.582	0.556	0.655	0.569	0.672	0.545
RS	1.194	1.394	1.125	1.107	0.971	1.046	1.026	1.023	0.963	0.972	1.017
TR	0.745	0.692	0.699	0.559	0.578	0.541	0.555	0.555	0.553	0.514	0.485
XK	—	—	1.746	1.602	1.653	1.393	1.740	1.303	1.370	1.336	1.310
Other European countries											
CH	0.025	0.026	0.028	0.029	0.027	0.028	0.029	0.029	0.030	0.029	0.030
UK	0.800	0.598	0.546	0.569	0.522	0.387	0.312	0.275	0.254	0.230	0.214
Other countries											
KG	0.264	0.157	0.150	0.114	0.062	0.094	0.084	0.062	0.061	0.063	0.064
KZ	0.586	0.766	1.079	0.682	0.620	0.651	0.854	0.862	0.848	0.984	0.947
TJ	0.070	0.027	0.028	0.024	0.001	0.009	0.027	0.057	0.085	0.100	0.095
TM	1.306	1.835	1.478	1.510	1.737	1.262	1.262	1.262	1.262	1.262	1.262
UZ	0.836	0.692	0.747	0.761	0.774	0.830	0.835	0.821	0.543	0.583	0.594

NB: Country codes and lists of countries are provided in Supporting Table 4.

Source: *JRC analysis.*

Table 11. CoM activity-based (IPCC) GHG EFs for national electricity consumption (also referred to as NEEFEs) of other countries, for selected years (tonnes of CO_2-eq/MWh)

Country	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
CoM East countries											
AM	0.553	0.388	0.396	0.201	0.129	0.236	0.220	0.220	0.274	0.232	0.241
AZ	0.817	0.925	0.970	0.685	0.663	0.684	0.679	0.695	0.648	0.614	0.597
GE	0.589	0.636	0.268	0.118	0.096	0.127	0.101	0.098	0.085	0.112	0.106
MD	1.144	0.717	0.656	0.436	0.685	0.619	0.630	0.478	0.505	0.544	0.595
UA	0.969	0.781	0.616	0.614	0.586	0.537	0.585	0.469	0.502	0.475	0.431
Clima-MED countries											
DZ	0.831	0.866	0.853	0.776	0.749	0.731	0.689	0.666	0.660	0.631	0.639
EG	0.620	0.524	0.420	0.566	0.501	0.553	0.556	0.582	0.545	0.513	0.480
IL	0.969	0.916	0.865	0.907	0.843	0.724	0.683	0.670	0.593	0.581	0.556
JO	0.989	0.944	1.043	0.791	0.671	0.692	0.581	0.569	0.518	0.460	0.428
LB	2.083	0.766	0.747	0.659	0.748	0.841	0.841	0.805	0.811	0.799	0.791
MA	0.939	1.075	0.851	0.925	0.697	0.725	0.698	0.697	0.717	0.865	0.866
TN	0.775	0.691	0.683	0.531	0.584	0.598	0.554	0.548	0.545	0.540	0.557
Western Balkans and Türkiye											
AL	0.296	0.122	0.059	0.028	0.003	0.000	0.000	0.000	0.000	0.000	0.000
BA	1.048	0.220	1.503	1.332	1.226	1.080	1.245	1.239	1.221	1.162	1.349
ME	—	—	—	0.299	0.540	0.582	0.470	0.453	0.522	0.502	0.565
MK	1.112	1.107	1.060	0.900	0.747	0.584	0.558	0.657	0.571	0.674	0.546
RS	1.197	1.398	1.128	1.110	0.973	1.049	1.029	1.026	0.966	0.974	1.019
TR	0.746	0.694	0.700	0.560	0.579	0.542	0.556	0.556	0.554	0.516	0.486
XK	—	—	1.751	1.607	1.657	1.397	1.745	1.306	1.374	1.340	1.314
Other European countries											
CH	0.026	0.027	0.029	0.030	0.028	0.029	0.030	0.030	0.031	0.030	0.031
UK	0.802	0.599	0.547	0.570	0.523	0.389	0.314	0.276	0.256	0.232	0.216
Other countries											
KG	0.327	0.199	0.190	0.145	0.081	0.113	0.100	0.075	0.072	0.075	0.077
KZ	0.694	0.906	1.280	0.808	0.730	0.776	1.017	1.027	1.010	1.172	1.128
TJ	0.092	0.038	0.040	0.036	0.006	0.017	0.038	0.073	0.106	0.124	0.118
TM	1.644	2.311	1.861	1.901	2.187	1.589	1.589	1.589	1.589	1.589	1.589
UZ	0.999	0.851	0.919	0.937	0.959	1.026	1.032	1.013	0.666	0.715	0.726

NB: Country codes and lists of countries are provided in Supporting Table 4.

Source: JRC analysis.

Table 12. CoM life-cycle (LC) GHG EFs for national electricity consumption (also referred to as NEEFEs) of other countries, for selected years (tonnes of CO_2-eq/MWh)

Country	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
CoM East countries											
AM	0.687	0.500	0.513	0.261	0.169	0.307	0.286	0.286	0.357	0.301	0.315
AZ	1.027	1.139	1.195	0.865	0.858	0.877	0.868	0.892	0.837	0.792	0.770
GE	0.720	0.785	0.343	0.155	0.130	0.168	0.133	0.128	0.112	0.147	0.141
MD	1.390	0.888	0.842	0.564	0.885	0.800	0.814	0.617	0.653	0.704	0.769
UA	1.141	0.916	0.727	0.711	0.678	0.620	0.673	0.541	0.581	0.551	0.505
Clima-MED countries											
DZ	1.049	1.092	1.075	0.977	0.943	0.921	0.869	0.839	0.832	0.795	0.805
EG	0.763	0.651	0.524	0.706	0.625	0.688	0.694	0.728	0.685	0.647	0.606
IL	1.155	1.089	1.026	1.077	1.008	0.873	0.828	0.815	0.721	0.707	0.680
JO	1.208	1.152	1.264	0.983	0.833	0.861	0.729	0.716	0.657	0.588	0.552
LB	2.513	0.927	0.935	0.836	0.951	1.074	1.073	1.023	1.031	1.018	1.008
MA	1.126	1.281	1.004	1.092	0.829	0.862	0.832	0.829	0.853	1.027	1.027
TN	0.957	0.861	0.853	0.668	0.735	0.751	0.698	0.690	0.688	0.681	0.704
Western Balkans and Türkiye											
AL	0.367	0.157	0.078	0.038	0.009	0.004	0.006	0.003	0.006	0.004	0.004
BA	1.093	0.234	1.723	1.519	1.392	1.107	1.276	1.269	1.252	1.192	1.386
ME	—	—	—	0.307	0.556	0.597	0.483	0.465	0.538	0.518	0.584
MK	1.142	1.133	1.097	0.921	0.767	0.604	0.584	0.689	0.599	0.708	0.581
RS	1.240	1.434	1.159	1.141	1.000	1.074	1.054	1.052	0.991	1.001	1.046
TR	0.816	0.764	0.788	0.648	0.671	0.641	0.655	0.662	0.658	0.613	0.590
XK	—	—	1.791	1.644	1.695	1.429	1.785	1.336	1.405	1.371	1.344
Other European countries											
CH	0.032	0.033	0.035	0.035	0.034	0.035	0.037	0.037	0.038	0.038	0.039
UK	0.925	0.702	0.652	0.678	0.633	0.471	0.392	0.351	0.327	0.301	0.282
Other countries											
KG	0.327	0.199	0.190	0.145	0.081	0.113	0.100	0.075	0.072	0.075	0.077
KZ	0.694	0.906	1.280	0.808	0.730	0.776	1.017	1.027	1.010	1.172	1.128
TJ	0.092	0.038	0.040	0.036	0.006	0.017	0.038	0.073	0.106	0.124	0.118
TM	1.644	2.311	1.861	1.901	2.187	1.589	1.589	1.589	1.589	1.589	1.589
UZ	0.999	0.851	0.919	0.937	0.959	1.026	1.032	1.013	0.666	0.715	0.726

NB: Country codes and lists of countries are provided in Supporting Table 4.

Source: JRC analysis.

In the LC approach, EFs used LCI data for the same processes and with the same adjustments as presented in Tables 1, 2 and 3 but for a global (GLO) or rest of the world (RoW) scope, instead of (only) a European one, as far as possible considering the available data. The source of energy data and geographical scope of the LCIs selected for each country and/or region are presented in Supporting Table 4.

6. Application of Covenant of Mayors emission factors

The development of default emission factors (EFs) is inherently associated with choices and assumptions that should be discussed and considered to ensure their adequate interpretation and transparent application. First, CoM EFs have been proposed for commonly used energy carriers and sources in the main CoM energy sectors and categories. The EFs presented in this report are intended to be representative of European emission patterns. Their potential application to other contexts should be considered with caution. Second, these factors build on emissions from stationary energy sources. While these emissions are similar for CO_2 across different sectors, for GHG emissions associated with transportation, for example, these factors can be higher (higher non-CO_2 emissions per unit of energy) (Koffi et al., 2017). Third, the CoM guidebook recommends using the same EFs for local use of fossil and renewable energy sources applied in the baseline emission inventory (BEI) during the monitoring phase (in the monitoring emission inventory, MEI), as methodological and statistical data updates could affect the understanding, interpretation and monitoring of CO_2 and GHG emission inventory changes. However, if a measure adopted in the SECAP can result in an actual change of emissions associated with the same energy use, this can be taken into consideration. For example, if there is a change in the supply of an energy source that results in lower emissions along the supply chain (e.g. associated to a change in the origin of biomass or biofuels), this change can be accounted for by updating the corresponding LC-based EF.

In the case of electricity, EFs can vary significantly from city to city, and from year to year, due to technological evolution and changes in the energy mix. Moreover, the current revision considers international trade (imports and exports) for the first time, which can result in significant differences from previous data in some cases. The revised and updated EFs considering imports and exports (for EU Member States, Iceland and Norway) are expected to better represent emissions associated with electricity use for countries with significant relative shares of trade (both imports and exports).

For further guidance on the application of EFs and on the development of local GHG emission inventories in the context of the CoM, please refer to the CoM guidebook and its most recent updates, and to the CoM collection in the JRC Data Catalogue.

7. Conclusions

In the framework of the Global Covenant of Mayors (GCoM), the Joint Research Centre (JRC) provides emission factors (EFs) that can be used by local authorities to calculate their local greenhouse gas (GHG) emission inventories. These EFs include activity-based and life-cycle (LC) EFs that can be used to estimate emissions of CO_2 (in tonnes of CO_2/MWh) or of GHGs (CO_2, CH_4 and N_2O, in tonnes of CO_2-eq/MWh) associated with the local use of a wide range of renewable and non-renewable energy sources (RES and NRES), and of national grid electricity.

This report provides a revision and update of the Covenant of Mayors (CoM) EFs for the EU Member States and 28 other countries in Europe, the eastern neighbourhood, the southern neighbourhood and central Asia. It presents the data, methodologies and main assumptions considered in the EFs' calculation and considerations of their application. The main updates and changes in this revision are related to data updates, namely (i) the use of more recent IPCC global warming potentials (GWPs) and life-cycle inventory (LCI) data to account for supply chain emissions and (ii) the introduction of international trade (imports and exports) in the case of EFs for national electricity for EU Member States, Iceland and Norway. The revised and updated EFs are expected to better represent GHG emissions associated with energy use and to enable a more accurate and sound estimation of emissions in CoM local emission inventories.

References

Bertoldi, P. (ed.) (2018a), *Guidebook 'How to develop a sustainable energy and climate action plan (SECAP)' – Part 1 – The SECAP process, step-by-step towards low carbon and climate resilient cities by 2030*, Publications Office of the European Union, Luxembourg, JRC112986, doi:10.2760/68327.

Bertoldi, P. (ed.) (2018b), *Guidebook 'How to develop a sustainable energy and climate action plan (SECAP)' – Part 3 – Policies, key actions, good practices for mitigation and adaptation to climate change and financing SECAP(s)*, Publications Office of the European Union, Luxembourg, JRC112986, doi:10.2760/58898.

Bertoldi, P. (ed.) (2018c), *Guidebook 'How to develop a sustainable energy and climate action plan (SECAP)' – Part 2 – Baseline emission inventory (BEI) and risk and vulnerability assessment (RVA)*, Publications Office of the European Union, Luxembourg, JRC112986, doi:10.2760/118857.

Bertoldi, P., Bornas Cayuela, D., Monni, S. and Piers De Raveschoot, R. (2010), *Guidebook 'How to develop a sustainable energy action plan (SEAP)'*, Publications Office of the European Union, Luxembourg, JRC57789, doi:10.2790/20638.

IPCC (2006), *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, national greenhouse gas inventories programme, Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (eds), Institute for Global Environmental Strategies, Kanagawa.

IPCC (2007), *Climate Change 2007: The physical science basis – Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change*, Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L. (eds), Cambridge University Press, Cambridge, United Kingdom, and New York, United States.

IPCC (2013), *Climate Change 2013: The physical science basis – Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change*, Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P. M. (eds), Cambridge University Press, Cambridge, United Kingdom, and New York, United States.

IPCC (2019), *2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories*, Calvo Buendia, E., Tanabe, K., Kranjc, A., Jamsranjav, B., Fukuda, M., Ngarize S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. (eds), IPCC, Geneva.

IPCC (2021), *Climate Change 2021: The physical science basis – Contribution of Working Group I to the sixth assessment report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O. and Yu, R. (eds), Cambridge University Press, Cambridge, United Kingdom, and New York, United States, doi:10.1017/9781009157896.

Koffi, B., Cerutti, A., Duerr, M., Iancu, A., Kona, A. and Janssens-Maenhout, G. (2017), *Covenant of Mayors for Climate and Energy: Default emission factors for local emission inventories – Version 2017*, Publications Office of the European Union, Luxembourg, JRC107518, doi:10.2760/290197.

Liu, C., Oshita, K., Takaoka, M. and Fukutani. S. (2021), 'Behaviour of fossil and biogenic carbon in sewage sludge treatment processes and their impacts on greenhouse gas emissions', *Chemical Engineering Transactions*, Vol. 89, pp. 97–102, doi:10.3303/CET2189017.

Lo Vullo, E., Monforti-Ferrario, F., Palermo, V. and Bertoldi, P. (2022), *Greenhouse gases emission factors for local emission inventories*, Publications Office of the European Union, Luxembourg, JRC129433, doi:10.2760/776442.

Scarlat, N., Prussi, M. and Padella, M. (2022) 'Quantification of the carbon intensity of electricity produced and used in Europe', *Applied Energy*, Vol. 305, 117901, doi:10.1016/j.apenergy.2021.117901.

Weidema, B. P., Bauer, C., Hischier, R., Mutel, C., Nemecek, T., Reinhard, J., Vadenbo, C. O. and Wernet, G. (2013), *Overview and Methodology – Data quality guideline for the ecoinvent Database version 3*, ecoinvent report No 1 (v3), ecoinvent Centre, St. Gallen.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E. and Weidema, B. (2016), 'The ecoinvent Database version 3 (part I): Overview and methodology', *International Journal of Life Cycle Assessment,* Vol. 21, No 9, pp. 1218–1230, doi:10.1007/s11367-016-1087-8.

Abbreviations

AFOLU	agriculture, forestry and other land use
AR	assessment report
CAP	climate action plan
CHP	combined heat and power
CO_2-eq	carbon dioxide equivalent
CoM	Covenant of Mayors
CoM East	Covenant of Mayors for Climate and Energy Eastern partnership
CoM EU	Covenant of Mayors for Climate and Energy Europe
CoM Med	Covenant of Mayors Mediterranean (supported by the Clima-MED project)
EF	emission factor
GCoM	Global Covenant of Mayors
GHG	greenhouse gas
GWP	global warming potential
IEA	International Energy Agency
IPCC	International Panel on Climate Change
JRC	Joint Research Centre
LC	life-cycle
LCI	life-cycle inventory
NCV	net calorific value
NEEFE	national and European emission factors for electricity
NRES	non-renewable energy source
NSP	non-specified partner (in international trade data)
RES	renewable energy source
SECAP	sustainable energy and climate action plan

Country codes are provided in Supporting Table 4.

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Annex – Supporting tables

Supporting Table 1. Global Warming Potentials (GWPs) in the IPCC Assessment Reports – AR4, AR5 and AR6

GHG	AR4 (IPCC, 2007)	AR5 (IPCC, 2013) (1)	AR6 (IPCC, 2021) (2)	
CO_2	1	1	1	1
CH_4	25	34	29.8	27
N_2O	298	298	273	273

(1) For AR5, the GWP with the inclusion of climate–carbon feedbacks was considered.
(2) For AR6, CH_4 from fossil fuel sources (GWP = 29.8) is separated from CH_4 from non-fossil sources (GWP = 27.0).

Source: JRC analysis based on IPCC reports (IPCC, 2007, p. 33; IPCC, 2013, p. 714; IPCC, 2021, p. 1017).

Supporting Table 2. Classification of IPCC 2006 fuel categories as fossil or non-fossil energy sources applied in the CoM EFs

IPCC 2006 fuel category	Classification
Crude oil	Fossil
Orimulsion	Fossil
Natural gas liquids (NGLs)	Fossil
Motor gasoline	Fossil
Aviation gasoline	Fossil
Jet gasoline	Fossil
Jet kerosene	Fossil
Other kerosene	Fossil
Shale oil	Fossil
Gas oil	Fossil
Diesel oil	Fossil
Residual fuel oil	Fossil
Liquefied petroleum gases	Fossil
Ethane	Fossil
Naphtha	Fossil
Bitumen	Fossil
Lubricants	Fossil
Petroleum coke	Fossil
Refinery feedstocks	Fossil
Refinery gas	Fossil
Waxes	Fossil
White spirit and SBP	Fossil
Other petroleum products	Fossil
Anthracite	Fossil
Coking coal	Fossil
Other bituminous coal	Fossil
Sub-bituminous coal	Fossil
Lignite	Fossil
Oil shale and tar sands	Fossil
Brown coal briquettes	Fossil
Patent fuel	Fossil
Coke oven coke and lignite coke	Fossil
Gas coke	Fossil
Coal tar	Fossil
Gas works gas	Fossil
Coke oven gas	Fossil

Blast furnace gas	Fossil
Oxygen steel furnace gas	Fossil
Natural gas	Fossil
Municipal wastes (non-biomass fraction)	Fossil
Industrial wastes	Fossil
Waste oils	Fossil
Peat	Fossil
Wood / wood waste	Non-fossil
Sulphite lyes (black liquor)	Non-fossil
Other primary solid biomass	Non-fossil
Charcoal	Non-fossil
Biogasoline	Non-fossil
Biodiesels	Non-fossil
Other liquid biofuels	Non-fossil
Landfill gas	Non-fossil
Sludge gas	Non-fossil
Other biogas	Non-fossil
Municipal wastes (biomass fraction)	Non-fossil

NB: SBP, special boiling point industrial spirit.

Source: JRC analysis

Supporting Table 3. EFs considered in the CoM EFs for national electricity use in EU Member States, Iceland and Norway calculations, including correspondence between Eurostat and IPCC stationary energy (fuel) categories and IPCC-based EFs

Energy source/carrier categories		Activity-based approach		LC approach (Europe)	LC approach (global)
Eurostat Energy Balances (1)	IPCC 2006	CO_2 (t CO_2/MWh)	GHG (t CO_2 eq/MWh)	GHG (t CO_2 eq/MWh)	GHG (t CO_2 eq/MWh)
Non-renewable energy					
Additives & oxygenates (excl. biofuel portion)	Refinery feedstocks	0.264	0.265	0.313	0.310
Anthracite	Anthracite	0.354	0.355	0.404	0.410
Aviation gasoline	Aviation gasoline	0.252	0.253	0.325	0.321
Bitumen	Bitumen	0.291	0.291	0.340	0.337
Blast furnace gas	Blast furnace gas	0.936	0.936	0.936	0.936
Brown coal briquettes	Brown coal briquettes	0.351	0.353	0.441	0.432
Coal tar	Coal tar	0.291	0.292	0.364	0.391
Coke oven coke	Coke oven coke and lignite coke	0.385	0.387	0.449	0.474
Coke oven gas	Coke oven gas	0.160	0.160	0.315	0.371
Coking coal	Coking coal	0.341	0.342	0.392	0.395
Crude oil	Crude oil	0.264	0.265	0.313	0.310
Ethane	Ethane	0.222	0.222	0.307	0.307
Fuel oil	Residual fuel oil	0.279	0.280	0.341	0.337
Gas coke	Gas coke	0.385	0.385	0.447	0.472
Gas oil and diesel oil (excl. biofuel portion)	Gas oil	0.267	0.268	0.349	0.351
Gas works gas	Gas works gas	0.160	0.160	0.315	0.371
Gasoline-type jet fuel	Jet gasoline	0.252	0.253	0.325	0.321
Industrial waste (non-renewable)	Industrial wastes	0.515	0.522	0.522	0.522

Kerosene-type jet fuel (excluding biofuel portion)	Jet kerosene	0.257	0.258	0.330	0.327
Lignite	Lignite	0.364	0.365	0.373	0.376
Liquefied petroleum gases	Liquefied petroleum gases	0.227	0.227	0.311	0.308
Lubricants	Lubricants	0.264	0.265	0.403	0.415
Motor gasoline (excl. biofuel portion)	Motor gasoline	0.249	0.250	0.333	0.338
Naphtha	Naphtha	0.264	0.265	0.324	0.321
Natural gas	Natural gas	0.202	0.202	0.261	0.254
Natural gas liquids	Natural gas liquids (NGLs)	0.231	0.232	0.339	0.339
Non-renewable municipal waste	Municipal wastes (non-biomass fraction)	0.330	0.337	0.346	0.349
Oil shale and oil sands	Oil shale and tar sands	0.385	0.387	0.534	0.534
Other bituminous coal	Other bituminous coal	0.341	0.342	0.392	0.401
Other hydrocarbons	Refinery feedstocks	0.264	0.265	0.313	0.310
Other kerosene	Other kerosene	0.259	0.260	0.332	0.328
Other oil products	Refinery feedstocks	0.264	0.265	0.313	0.310
Other recovered gases	Gas works gas	0.160	0.160	0.315	0.371
Paraffin waxes	Waxes	0.264	0.265	0.323	0.327
Patent fuel	Patent fuel	0.351	0.353	0.415	0.426
Peat	Peat	0.382	0.383	0.388	0.393
Peat products	Peat	0.382	0.383	0.388	0.393
Petroleum coke	Petroleum coke	0.351	0.352	0.416	0.412
Refinery feedstocks	Refinery feedstocks	0.264	0.265	0.313	0.310
Refinery gas	Refinery gas	0.207	0.208	0.281	0.277
Sub-bituminous coal	Sub-bituminous coal	0.346	0.348	0.416	0.427
White spirit & special boiling point industrial spirits	White spirit and SBP	0.264	0.265	0.352	0.361
Renewable energy					
Biogases	Other biogas	0	0.000	0.025	0.055
Blended bio jet kerosene	Other liquid biofuels	0	0.001	0.147	0.147
Blended biodiesels	Other liquid biofuels	0	0.001	0.147	0.147
Blended biogasoline	Other liquid biofuels	0	0.001	0.147	0.147
Geothermal	—	0	0	0.083	0.178
Hydro	—	0	0	0.004	0.005
Other liquid biofuels	Other liquid biofuels	0	0.001	0.147	0.147
Primary solid biofuels	Wood / wood waste	0	0.007	0.015	0.028
Pure bio jet kerosene	Other liquid biofuels	0	0.001	0.147	0.147
Pure biodiesels	Other liquid biofuels	0	0.001	0.147	0.147
Pure biogasoline	Other liquid biofuels	0	0.001	0.147	0.147
Renewable municipal waste	Municipal wastes (biomass fraction)	0	0.007	0.017	0.018
Solar photovoltaic	—	0	0	0.063	0.078
Solar thermal	—	0	0	0.020	0.020
Wind	—	0	0	0.036	0.036

([1]) The following Eurostat categories were excluded because they aggregate other existing categories: solid fossil fuels, manufactured gases, peat & peat products, oil & petroleum products, renewables & biofuels, non-renewable waste, fossil energy and bioenergy.

NB: SBP, special boiling point industrial spirit. EFs assume carbon neutrality (i.e. exclude biogenic CO_2 emissions and uptake).

Source: JRC analysis.

Supporting Table 4. Countries covered in the CoM Emission Factor datasets, energy data sources used per region and LCI geographical scope

Region	Country		Energy data source	LCI geographical scope
CoM EU, Iceland and Norway			*Eurostat*	*Europe*
	BE	Belgium		
	BG	Bulgaria		
	CZ	Czechia		
	DK	Denmark		
	DE	Germany		
	EE	Estonia		
	IE	Ireland		
	EL	Greece		
	ES	Spain		
	FR	France		
	HR	Croatia		
	IT	Italy		
	CY	Cyprus		
	LV	Latvia		
	LT	Lithuania		
	LU	Luxembourg		
	HU	Hungary		
	MT	Malta		
	NL	Netherlands		
	AT	Austria		
	PL	Poland		
	PT	Portugal		
	RO	Romania		
	SI	Slovenia		
	SK	Slovakia		
	FI	Finland		
	SE	Sweden		
	IS	Iceland		
	NO	Norway		
	UK	United Kingdom (1990–2019)		
CoM EAST countries			*IEA*	*Europe*
	AM	Armenia		
	AZ	Azerbaijan		
	GE	Georgia		
	MD	Moldova		
	UA	Ukraine		
Clima-MED countries			*IEA*	*Global*
	DZ	Algeria		
	EG	Egypt		
	IL	Israel		
	JO	Jordan		
	LB	Lebanon		
	MA	Morocco		
	TN	Tunisia		

Western Balkans and Türkiye		*IEA*	*Europe*
AL	Albania		
BA	Bosnia and Herzegovina		
ME	Montenegro		
MK	North Macedonia		
RS	Serbia		
TR	Türkiye		
XK	Kosovo*		
Other European countries		*IEA*	*Europe*
CH	Switzerland		
UK	United Kingdom		
Other countries		*IEA*	*Global*
KG	Kyrgyzstan		
KZ	Kazakhstan		
TJ	Tajikistan		
TM	Turkmenistan		
UZ	Uzbekistan		

* This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

Source: *JRC analysis.*