REPORT

Electricity Maps emission factors methodology

Comparison and validation of the Electricity Maps emission factors dataset against the IEA Emission Factors

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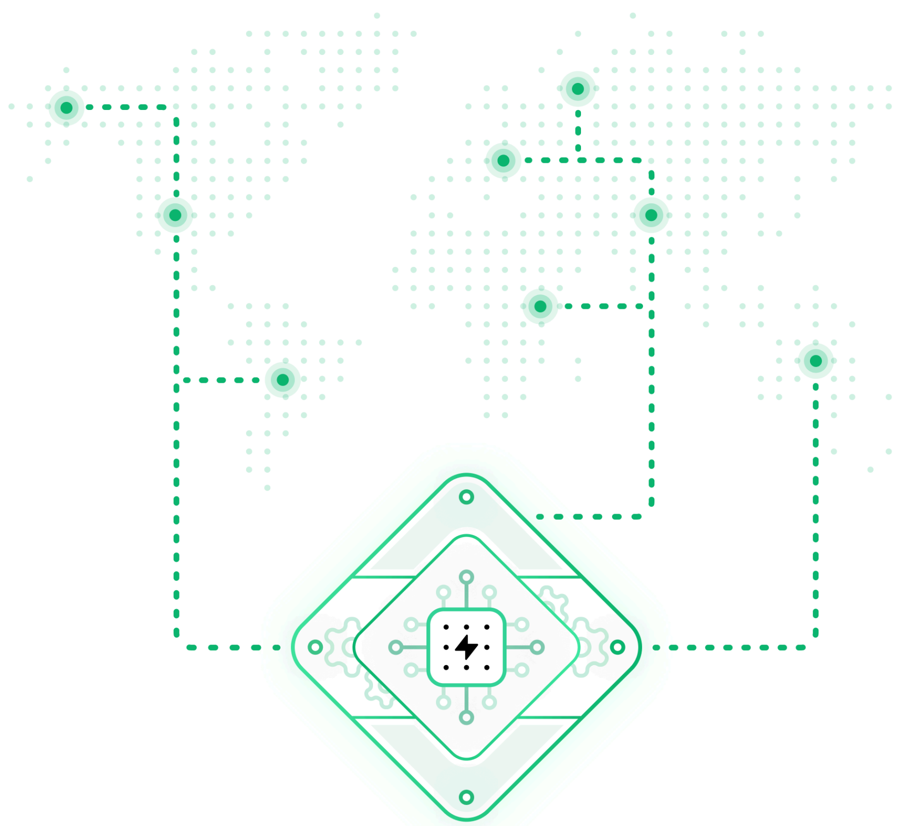

ELECTRICITY MAPS

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Executive Summary

From a single data source to regional-specific emission factors

The International Energy Agency (IEA) uses a single methodology to compute direct emission factors worldwide which relies on combustion emission factors from the International Panel on Climate Change (IPCC) 2006 Guidelines and World Energy Balances. In the past, Electricity Maps has also been using a single data source worldwide with IPCC 2014 emission factors for electricity production. This methodology is still used by default today but in 2022, Electricity Maps developed two advanced methodologies to increase its precision with regional emission factors in the United States (US) and the European Union (EU)[1].

The IEA methodology benefits from better CHP plant data while Electricity Maps leverages more granular and up-to-date data on power plant emissions

A comparison of the two methodologies showed that the IEA is allocating emissions of combined heat and power (CHP) plants with greater accuracy accounting for heat emissions by combining heat output with a fixed heat efficiency. Electricity Maps relies on a methodology for Europe which is more advanced but suffers from restricted data availability.

The Electricity Maps methodology proves to be more accurate than the IEA methodology when it comes to accounting for electricity trade and upstream emission factors, as well as benefiting from better time and spatial granularity.

Because it uses hourly data and applies an advanced flow-tracing algorithm, Electricity Maps can capture electricity flows and trades (and underlying emissions) much more accurately than the IEA does with annual numbers and electricity balances. The impact of electricity trade is significant as it highly impacts hourly variations in emissions from electricity consumption[2]. This impact most importantly should be considered with an hourly granularity.

The IEA uses a single adjustment factor to compute upstream emission factors for each electricity grid (even though this factor is computed by electricity source first and aggregated later). Electricity Maps, on the other hand, differentiates an upstream emission factor per electricity source which allows for greater accuracy when using hourly emissions data where the share of each electricity source in the total electricity consumed on the grid can significantly vary from one hour to the next.

By moving to regional emission factors for the EU and the US in 2022, Electricity Maps has not only increased the accuracy of its emission factors with higher spatial granularity but also with higher update frequency and more up-to-date data. The IEA uses Energy Balances from the most recent year, usually published with a delay of one to two years, but still relies on combustion emission factors from 2006. On the other hand, Electricity Maps leverages the availability of new data both for emissions and electricity production and calculates its emission factors with less than one year delayed data for both dimensions.

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[1] Electricity Maps | Regional Emission Factors
[2] Why emissions should be calculated with consumption data (electricitymaps.com)

The IEA includes an adjustment factor for T&D losses which is not included in the Electricity Maps methodology. However, if accounting for T&D losses is important, the adjustment factor given by the IEA could easily be combined with the Electricity Maps emission factors.

Emission Factors from Electricity Maps, the IEA, and the IPCC show differences worldwide but remain within the same order of magnitude

Electricity Maps uses the IPCC 2014 emission factors by default. These factors appear to be lower than the world-aggregated emission factors from the IEA. For the US and the EU however, values reported by Electricity Maps are overall higher than IEA values while remaining of the same order of magnitude. Values reported by both sources also remain of the same order of magnitude as the values documented by IPCC 2014 which serves as a reference for electricity emission factors.

For oil, the IPCC 2014 does not provide an emission factor. Electricity Maps uses the emission factor published by the UK Parliamentary Office of Science and Technology[3] as a default emission factor which seems to underestimate emissions compared to other emission factors (IEA and Electricity Maps regional emission factors). It adds to the overall uncertainty on the oil emission factor for both sources which does not have a significant impact given that oil is not among the most used electricity generation sources worldwide.

Electricity Maps offers higher granularity on the US emission factors while remaining close to the IEA values

In the US, Electricity Maps manages to have better spatial granularity thanks to its regional emission factor methodology. It provides an emission factor per balancing authority while the IEA uses country statistics and thus calculates an emission factor aggregated at the country level.

For coal and gas, values from both sources remain very close and slightly higher than the IPCC 2014 values. For oil, emission factors from Electricity Maps show a large variability between balancing authorities but the aggregated value is again close to the IEA value.

Greater differences are observed in the EU emission factors between both data sources

The differences observed between both methodologies mainly come from the differences in accounting for CHP plant emissions. The difference observed between the Electricity Maps dataset and the IEA dataset tends to be higher for the EU. In some European countries, emission factors between both sources can significantly differ, with a variation of almost 100% in some cases. In such cases, it has been observed that the Electricity Maps value is closer to values reported by national organizations of corresponding countries highlighting that the IEA dataset may contain some outlier data.

[3] UK Parliamentary Office of Science and Technology, Postnot number 268, Carbon footprint of electricity generation, https://researchbriefings.files.parliament.uk/documents/POST-PN-268/POST-PN-268.pdf

Introduction

Carbon intensity measures how clean the electricity consumption is in a zone at a given time. It represents how many grams of carbon dioxide (CO_2) are released into the atmosphere for each kilowatt hour (kWh) of electricity consumed. In other words, carbon intensity represents the greenhouse gas footprint of 1 kWh consumed inside that zone.

The carbon intensity of electricity generation in a zone is determined by the power production mix and their associated carbon intensity factors (or emission factors).

Updating the emission factors used to compute a grid's real-time carbon intensity is part of Electricity Maps' efforts to drive the transition towards a truly decarbonized electricity system. Accurate real-time data is necessary to enable our different users' actions to reduce the footprint of their electricity consumption.

Using the emission factors published in IPCC (2014)[4] is a good first step as this dataset serves as a global reference. These factors are computed for the whole world and are aggregated. They were also published in 2014 and power generation has gained in efficiency over the last decade, meaning that some plants may have lower emissions now than before. Additionally, new regulations have made more granular data accessible. In the United States (US), the reporting of indirect and direct emissions from Federal agencies was made mandatory in 2015. Following this new regulation, power production plants have started reporting their emissions to the Environment Protection Agency (EPA). In the European Union (EU), the Emission Trading Scheme (EU-ETS) began in 2005 to reduce greenhouse gas emissions. Emissions from thermal power plants are reported in the EU-ETS registry.

This highly granular information enables the computation of emission factors for the different zones in the two aforementioned regions. These emission factors are representative of the power mix of each zone and can vary depending on the technologies used and on carbon capture measures for instance. Electricity Maps collects emissions from the EU and US annually and computes the updated emission factors every year.

The resulting emission factors can be quite different from the values published by IPCC (2014). The International Energy Agency (IEA) also publishes emission factors from electricity generation on an annual basis and they also vary and differ from IPCC factors.

The purpose of this report is to compare and validate Electricity Maps' methodology to the IPCC and IEA methodology. This report can also be seen as documentation that can be used to understand Electricity Maps emission factors data.

4 Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change - Annex III https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf#page=7

Electricity Maps Methodology

Emission factors available in Electricity Maps' product offering

Life-Cycle emission factors

Our product includes emission factors taking into account the power plant's whole lifecycle. The lifecycle factors account for emissions arising from cradle to grave, or the equivalent steps. This can include raw material extraction, fuel production, manufacturing, operation, and decommissioning/disposal. Emissions resulting from the extraction of resources required to build up installed capacity, emissions from direct operations, and end-of-life-related emissions are all accounted for. An overview of the steps covered by the lifecycle emission factors is pictured in Figure 1.

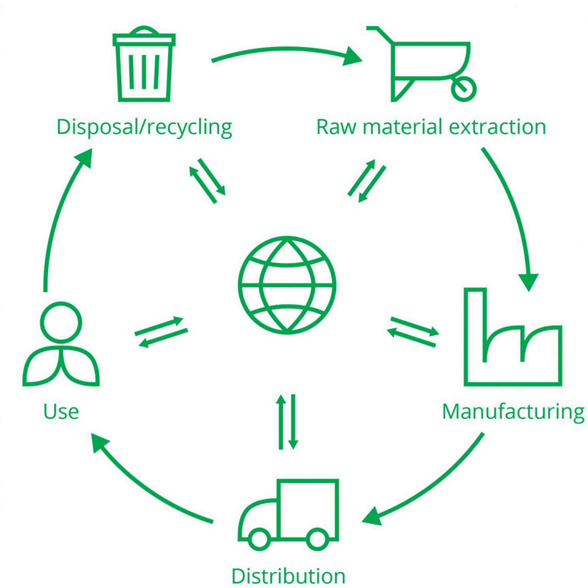

Figure 1. Life-Cycle emission factors overview

Direct emission factors

Direct emission factors only account for emissions that directly result from the operation of a given electricity source. For example, the combustion of gas in gas power plants directly releases greenhouse gasses into the atmosphere, while the photovoltaic effect that powers solar cells does not.

These values can vary largely from lifecycle emission factors which account for all emissions generated during the construction of power plants and during the extraction of these fuels. For some commercial purposes, we also support direct emission factors in our API.

Default emission factors

The main source used for emission factors is the IPCC (2014) Fifth Assessment Report[5]. This report contains carbon dioxide emission factors for electricity and heat. These factors are computed as the ratio of CO_2 emissions from fuel inputs of power plants relative to the electricity and heat generated. The fuel inputs are multiplied by the CO_2 emission factors defined in IPCC (2006).

The emission factors used for the majority of zones available in Electricity Maps' product offering are derived from Annex III of IPCC (2014)[6].

Annex III of IPCC (2014) does not include an emission factor for oil-fired generation. The default value used is published by the United Kingdom's Parliamentary Office for Science and Technology. We acknowledge this value could be refined as it is lower than the value published by the US Energy Information Administration (EIA)[7] or by the French transmission system operator (TSO) RTE[8]. Oil is however not among the most used electricity generation sources worldwide (9th generation source in the US for example behind coal, gas, nuclear, wind, solar, geothermal, biomass, and hydro) and the impact of this emission factor is limited.

The emission factor used for unknown power generation is an average of all thermal emission factors.

As a default, the discharge emission factors used are the annual mean carbon intensity of all Electricity Maps zones. These values are computed every year.

All default emission factors used by Electricity Maps are available in Appendix 1.

Regional operational emission factors

For some zones, specific emission factors are available. This is the case for the US and the EU where direct power plant emissions are publicly available. It is possible to match these emissions with power plant generation data and compute emission factors per power plant, which can later be aggregated at a zone level.

There are also some reputable sources, such as peer-reviewed scientific papers, or meta-analyses that offer direct emission factors with a precise geographical granularity. Using regional emission

[5] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change - Annex II https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-ii.pdf#page=16

[6] Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change - Annex III https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf#page=7

[7] EIA, FAQs How much carbon dioxide is produced per kilowatt hour of U.S. electricity generation?, https://www.eia.gov/tools/faqs/faq.php?id=74&t=11

[8] RTE, eCO2mix - CO2 emissions per kWh of electricity generated in France, https://www.rte-france.com/en/eco2mix/co2-emissions

factors increases the precision of our data and better reflects the specificities of a zone's electricity sector (such as different fuels, different technologies, different efficiencies, ...). In some cases, the format of the power production data is slightly different and the emission factors need to be updated to reflect the situation. This is the case in Chile, where all thermal production is aggregated as unknown. The unknown emission factor is therefore updated to accurately reflect the power mix in the zone.

US Emission factors

The US Environmental Protection Agency (EPA) publishes the Emissions & Generation Resource Integrated Database (eGRID) every year. The eGRID data contains electric power data at different levels of aggregation. The main focuses of this database are generation and emissions.

The dataset used to compute the emission factors contains production and emissions data for each power plant registered in the US. According to the eGRID documentation[9], the emissions reported in CO_2 equivalent are caused by electricity generation only. Emissions associated with useful thermal output, the amount of heat produced in a CHP facility for purposes other than power generation, are excluded from the adjusted emissions.

The full methodology is described in Appendix 2.

EU Emission factors

The methodology to compute the EU emission factors is similar to the one described above.

The European Union Emissions Trading System (EU-ETS) is a carbon emission trading scheme (or cap and trade scheme) intended to lower greenhouse gas emissions by the European Union countries. Cap and trade schemes limit emissions of specific pollutants over an area and allow companies to trade emissions rights within that area. The EU-ETS covers around 45% of the EU's greenhouse gas emissions.

ENTSO-E is an organization made up of European transmission system operators (TSO). ENTSO-E collects and publishes electricity generation, transmission, and consumption data at different levels of granularity. One of the datasets published is the Actual Generation Output per Generation Unit [16.1.A]. This dataset covers several generation units in different countries and is published with an hourly granularity.

Electricity Maps matches both datasets to calculate an emission factor per power plant which is later aggregated at the zonal level to derive an emission factor per zone and per technology. During this matching process, Electricity Maps has been able to match around 90% of all ENTSO-E power plants.

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[9] eGRID2021 Technical Guide, https://www.epa.gov/system/files/documents/2023-01/eGRID2021_technical_guide.pdf#page=26&zoom=100,117,432

The emissions published on the EU-ETS registry include both emissions from electricity generation and heat generation. For electricity power plants, these emissions are a result of electricity generation only. For CHP power plants, total verified emissions include emissions from heat generation and electricity generation. They need to be divided into electricity and heat emissions.

Heat emissions can be calculated from annual allocations. According to the following model[10], heat emissions are calculated as:

$$heat\_emissions \ = \ allocations \,/\, f(t)$$

where $f(t)$ is a function that depends on the heat benchmark[11] set by the European Commission, and carbon leakage.

The full methodology is described in Appendix 3.

Regional life-cycle emission factors

Depending on the production mode, the method to compute life-cycle emission factors is different. The process developed for coal, biomass, and solar is presented below. The process for other modes is available in Appendix 4.

Coal

To compute the upstream emissions linked with coal power generation, we used the methodology developed by Christopher Oberschelp et al. published in the Nature Sustainability review[12]. This methodology is used to compute upstream emissions from coal mining/transport. The database associated with the study includes power plants for the whole world. Only the EU and US plants are kept to compute the emission factors.

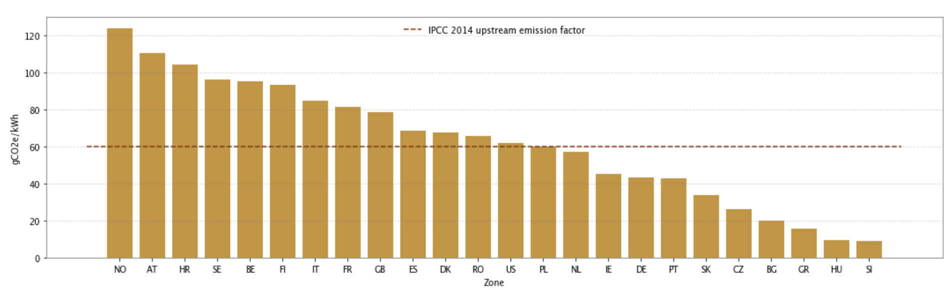

Figure 2. Coal upstream emission factors

[10] Jan Frederick Unnewehr, Anke Weidlich, Leonhard Gfüllner, Mirko Schäfer,
Open-data based carbon emission intensity signals for electricity generation in European countries – top down vs. bottom up approach,
https://www.sciencedirect.com/science/article/pii/S2772783122000176
[11] Update of benchmark values for the years 2021 – 2025 of phase 4 of the EU ETS,
https://climate.ec.europa.eu/system/files/2021-10/policy_ets_allowances_bm_curve_factsheets_en.pdf
[12] Oberschelp, C., Pfister, S., Raptis, C.E. *et al.* Global emission hotspots of coal power generation. *Nat Sustain* 2, 113–121 (2019). https://doi.org/10.1038/s41893-019-0221-6

Biomass

Direct biomass emissions are generally accounted as 0, as stated in Article 38 of Directive 2003/87/EC[13].

For US zones, we have therefore accounted for reported emissions from power plants as upstream emissions.

For EU zones, the sample of power plants used to generate emission factors is not significant and the factor used will be the IPCC (2014) biomass emission factor, at 230 gCO_2eq/kWh.

Solar

The upstream emission factors for solar were computed using the INCER-ACV[14] tool. Developed by the French Agency for Ecological Transition, it allows the computation of lifecycle (and thus upstream) emission factors for photovoltaic solar based on the average solar irradiance of a zone.

[13] Directive 2003/87/EC, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R2066&rid=1

[14] INCER-ACV - Intertitude Analyse de Cycle de Vie, https://viewer.webservice-energy.org/incer-acv/app/

International Energy Agency Methodology

Methodology for direct emission factors

The IEA calculates direct emission factors of electricity from the emission factors of fossil fuel combustion (coal, gas, oil, etc…) obtained from IPCC 2006 Guidelines[15] and energy figures from the IEA World Energy Balances[16].

For each fuel, the emission factor is calculated as follows:

$$EF_{elec,\, fuel} = \frac{Consumption_{fuel} * EF_{combustion,\, fuel}}{Ele_{inland,\, fuel}}$$

Where

- $EF_{elec,fuel}$ is the direct emission factor of electricity generation from the fuel $fuel$ expressed in $kgCO_2$ per kWh
- $Consumption_{fuel}$ is the total consumption of fuel $fuel$ expressed in energy units. It includes all fuel inputs in power plants including fuels consumed for the power plant self-consumption
- $EF_{combustion,\, fuel}$ is the combustion emission factor expressed in kg CO_2 per energy unit
- $Ele_{inland,\, fuel}$ is the domestic electricity production from fuel $fuel$ expressed in kWh

$EF_{combustion,\, fuel}$ is obtained from IPCC 2006 Guidelines, while $Consumption_{fuel}$ and $Ele_{inland,\, fuel}$ are obtained from the IEA World Energy Balances.

The IEA also calculates a total emission factor for electricity production as follows:

$$EF_{elec} = \frac{\sum_{fuel} Consumption_{fuel} * EF_{combustion,\, fuel}}{Ele_{inland}}$$

[15] Publications - IPCC-TFI (iges.or.jp)
[16] World Energy Balances - Data product - IEA

Methodologies for specific adjustments

Allocation of emissions for CHP plants

For combined heat power plants, the fuel consumption serves two purposes which are heat and power generation. In the case of the methodology used by the IEA for the direct emission factors calculation described above, the part of the fuel consumption dedicated to electricity production must be derived from the total power plant fuel consumption (which is known). To do so, the IEA adopts the fixed-heat-efficiency approach. In such an approach, the fuel consumption attributed to heat generation is calculated from the heat output and heat efficiency. Here, the IEA used an efficiency of 90% (η_{Heat}).

The fuel consumption attributed to electricity generation is calculated as follows:

$$Consumption_{fuel,\,plant} = Consumption_{fuel,\,heat} + Consumption_{fuel,\,elec}$$

$$Consumption_{fuel,\,heat} = \frac{Generation_{Heat}}{\eta_{Heat}}$$

$$Consumption_{fuel,\,elec} = Consumption_{fuel,\,plant} - \frac{Generation_{Heat}}{\eta_{Heat}}$$

In some cases, the IEA cannot use the fixed-heat-efficiency approach and thus adopted another approach called the proportionality approach where fuel consumption for heat and electricity are respectively considered proportional to the energy generation of the power plant for heat electricity.

Electricity Trade

The direct emission factors calculated by the IEA do not take into account any electricity trade between zones or countries as they both consider the fuel consumption and electricity generation of inland power plants. The IEA publishes both a direct emission factor calculated from the inland direct emission factor detailed above and a correction factor, which estimates carbon emissions of imported and exported electricity.

Carbon emissions from imported electricity are calculated from the total electricity imports at the end of the year and weighed by the yearly direct emission factor of the grid from which electricity is imported (calculated as detailed above).

Carbon emissions from exported electricity are calculated from the total electricity exports at the end of the year and weighed by the yearly direct emission factor of the grid taking into account both inland generation and imported electricity.

T&D Losses

The IEA calculates an adjustment emission factor for electricity transmission and distribution (T&D) losses. This factor is calculated from the direct emission factor calculated above and proportionally to the ratio of total transmission and distribution losses in the grid with the total electricity flowing in the country's transmission and distribution grid (electricity generation + imports - own use in power plants).

Upstream emission factors

The IEA uses a grid upstream emissions factor which is directly issued from the Life Cycle Upstream Emission Factors Database[17]. The methodology used to compute these factors leverages extensive fuel-specific and sometimes country-specific data sources. After computing a total upstream emission factor for all fuel categories, the IEA aggregates them all per grid. This aggregation does not allow the computation of hourly lifecycle emission factors as the aggregates would vary from one hour to another according to changes in the grid power breakdown while the IEA provides a fixed value.

[17] Life Cycle Upstream Emission Factors (Pilot Edition) - Data product - IEA

Comparison of the two methodologies

The two methodologies are compared in the following sections regarding differences in accounting for biomass emissions, allocating emissions of CHP plants, the update frequency, the spatial granularity, and the impact of electricity trade.

Biomass

Electricity Maps and the IEA both follow the IPCC guidelines for the biomass direct emission factor which state that direct emissions from biomass combustion at the power plant are positive and significant, but should be seen in connection with the CO_2 absorbed by growing plants. The IPCC guidelines[18] provide the simplifying assumption that the CO_2 emissions from the combustion of annual biomass are balanced by carbon capture of the growing crop so the net emission is zero.

The IEA publishes direct emission factors for biomass calculated following the methodology they also use for fossil fuels but does not include these factors in the grid emission factors.[19].

Allocation of emissions for CHP plants

The methodology used to account for CHP heat emissions in EU countries is limited as access to heat generation and heat emissions from CHP plants is not easily accessible. The data available in the EU is not as comprehensive as the data published by the EPA in the US and it is very difficult to estimate emissions from electricity generation in CHP power plants. We are working with our open-source community to come up with a more robust and sustainable solution. Isolating emissions from electricity generation for US CHP plants is done by the EPA in the eGRID database. They have access to fuel inputs for heat and electricity generation and emissions from heat and electricity generation for each power plant.

The IEA has access to fuel inputs for heat and electricity generation in the energy balances and can easily isolate emissions from electricity.

Therefore, the methodology used by the IEA and Electricity Maps are considered equivalent in terms of accuracy for emissions allocation of CHP plants in the US. However, in the EU, the methodology of the IEA is more robust for this allocation.

Update frequency

The update frequency of emission factors is important as various parameters can change with years which would ultimately affect direct emission factors. A non-exhaustive list of these parameters for power plants is:

[18] IPCC FAQ - Q2-10, https://www.ipcc-nggip.iges.or.jp/faq/faq.html
[19] IEA, Emission Factors 2023 Documentation, https://www.iea.org/data-and-statistics/data-product/emissions-factors-2023

- Fuel-to-electricity efficiency
- Combustion emission factor (if carbon capture measures are implemented)

The IEA uses fixed combustion factors from IPCC 2006 while they use yearly electricity production values from countries' energy balances. Changes in the first factor are reflected in the IEA emission factors but changes in the second factor are not. For default emission factors, Electricity Maps uses fixed emission factors from IPCC 2014 which do not capture any of these factors. However, for emission factors in the EU and in the US, Electricity Maps captures both these factors by considering emissions and electricity production reported by power plants in the last full calendar year. Emission factors used by Electricity Maps can thus be considered more up-to-date than emission factors published by the IEA.

Spatial granularity

In Europe, the IEA, and Electricity Maps have the same level of spatial granularity with country-level emission factors. In the US, the IEA uses a single emission factor for the whole country while Electricity Maps can compute a set of emission factors for each balancing authority[20]. As illustrated below in the comparison of emission factors, the differences between balancing authorities remain limited for gas and coal but can become significant for oil. The methodology used by Electricity Maps captures differences between balancing authorities on emission factors of the same generation technology while the IEA doesn't. These differences could come from differences in fuel type, differences in power plant technology, and efficiency...

Electricity trade

The methodology used by the IEA and Electricity Maps to take into account electricity trade differs in two main ways: Electricity Maps retraces all flows with an hourly granularity while the IEA only takes into account first-order exchanges with a yearly granularity.

Electricity Maps can capture the difference between the carbon intensity of electricity in times when electricity is imported or not, and exported or not. On the contrary, the IEA computes an adjustment factor from yearly exchange values. Their methodology does not capture how changes in carbon intensity may be correlated with changes in electricity flows (direction and magnitude of exchanges). With increasing renewables penetration, exchanges become more affected by hourly generation levels of renewables thus carbon intensity and capturing exchanges on an hourly granularity becomes more important. Today, we already observe grids exporting electricity when wind resources are abundant and importing electricity otherwise thus having exchanges highly correlated with carbon intensity.

Finally, the IEA does not trace back the origin of electricity using a flow-tracing algorithm and they only take first-rank imports when accounting for exchanges. Transit flows are not captured while these can have a significant impact on a zone's carbon intensity[21].

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[20] US Department of Energy, How it Works: The role of a Balancing Authority, https://www.energy.gov/sites/default/files/2023-08/Balancing%20Authority%20Backgrounder_2022-Formatted_041723_508.pdf

[21] How to trace back the origin of electricity (electricitymaps.com)

Electricity Maps methodology for electricity trade is more robust as it accounts for the electricity mix at the specific hour when this electricity is exchanged, and captures all flows on the system while the IEA calculates emission trade impact from yearly-aggregated values.

Comparison of direct emission factors values

A comparison of direct emission factors from Electricity Maps and the IEA is performed in this section for coal, gas, and oil (biomass has not been included following the IPCC guidelines). For each fuel, the emission factors of Electricity Maps and the IEA are compared for the seven European zones with the highest electricity consumption: Germany, France, Spain, Italy, Netherlands, Poland, and Great Britain, and the seven US RTOs: ERCOT, CAISO, SWPP, MISO, PJM, NYIS, ISNE. It should be noted that Great Britain is not part of the European Union and as such, Electricity Maps uses its default emission factors for this zone. Emission factors aggregated for the EU and US are also presented. Please note that the IEA only provides one single value for aggregated US and all subzones. These emission factors are also compared with the IPCC 2014 values used by Electricity Maps as default emission factors worldwide which serve as a reference.

Coal emission factors

For most zones selected here, the coal emission factor of Electricity Maps is higher than the coal emission factor of the IEA. Both values are also higher than the IPCC reference value. The aggregated value from Electricity Maps for the EU is 15% higher than the one of the IEA while for the US this value is only 4% higher.

For the rest of the world, Electricity Maps uses the emission factor from the IPCC which is 20% lower than the world-aggregated emission factor from the IEA.

Three zones stand out with great differences between values used by the IEA and Electricity Maps, we discuss them below together with Germany which is a country with significant electricity generation from coal where emission factors from Electricity Maps and the IEA also differ.

- The emission factor computed for France by the IEA is almost double the Electricity Maps emission factor of 869 gCO_2eq/kWh. According to the French TSO RTE, the direct emission factor for coal-fired power plants is 986 gCO_2eq/kWh[22]. Here the value provided by Electricity Maps is thus more consistent, given the IEA emission factor shows a more than 50% difference.
- The emission factor computed for Great Britain by the IEA is also more than double the Electricity Maps emission factor sourced from IPCC. According to the British TSO National Grid, the direct emission factor for coal is 937 gCO_2eq/kWh[23] which is closer to the Electricity Maps value. There were 3 coal power plants online at the end of 2022 and according to Elexon, the British market operator, all coal power production comes from the combustion of hard coal. Hard coal has a higher calorific value than lignite and is a less emitted fuel. The value provided by Electricity Maps is thus more consistent with the British power system.

[22] RTE, eCO2mix - CO2 emissions per kWh of electricity generated in France, https://www.rte-france.com/en/eco2mix/co2-emissions

[23] National Grid ESO, Carbon intensity dashboard, https://www.nationalgrideso.com/future-energy/our-progress-towards-net-zero/carbon-intensity-dashboard

- The emission factor computed for CAISO by Electricity Maps is 525 gCO_2eq/kWh and is more than 40% lower than the IEA factor and 30% lower than the IPCC 2014. There is only one coal CHP power plant in CAISO and the calculated electric allocation factor with the Electricity Maps methodology is 11%. It means only 11% of emissions of this power plant have been allocated to electricity which is likely underestimating emissions. Coal-fired generation however only represented 0.01% of electricity production in US-CAL-CISO in 2023 and the emission factor used for coal there has a limited impact on the grid emissions calculations.

- The emission factor for Germany computed by the IEA is 15% lower than the one computed by Electricity Maps. According to Agora Energiewende, coal production in 2022 was 65% from lignite-fired plants and 35% from hard coal power plants. The average of the Agora Energiewende emission factors[24] weighed by coal-fired generation for 2022 is 999 gCO_2eq/kWh. Both the IEA and Electricity Maps are less than 10% different compared to the Agora Energiewende value.

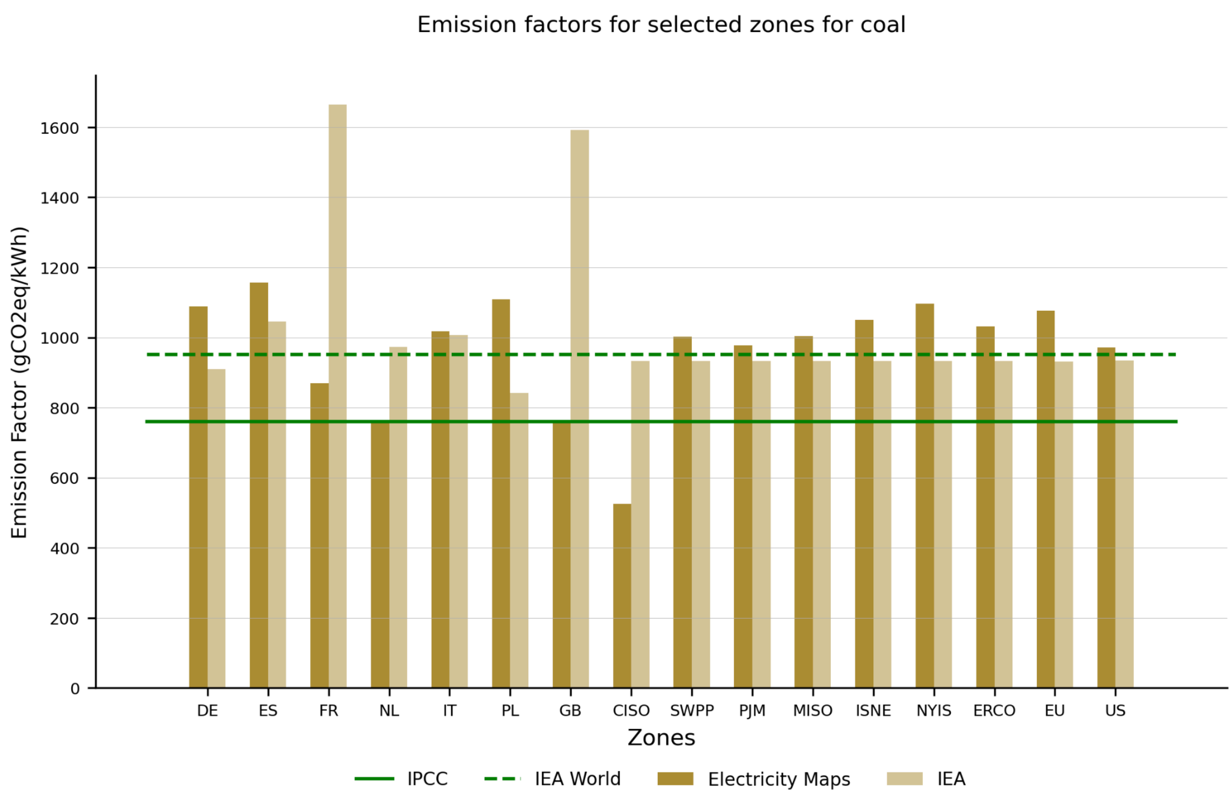

Figure 13. Coal direct emission factor for selected zones

[24] Agora Energiwende, Agorameter Documentation, https://www.agora-energiewende.org/fileadmin/Projekte/Agorameter/2023-10-01_Hintergrunddokumentation_Agorameter_v13_EN.pdf#page=10

Gas emission factors

As for coal-fired electricity generation, the gas emission factor of Electricity Maps is higher than the coal emission factor of the IEA for most zones investigated here. Unlike coal-fired electricity generation, the value used by the IEA is lower than the IPCC value for the EU. Again, the emission factors of Electricity Maps and the IEA remain close for the US (less than 10% difference for aggregated US) while showing greater differences for the EU (30% difference for aggregated EU). This difference is most likely due to the difference in the methodology to allocate CHP emissions.

For the rest of the world, Electricity Maps uses the emission factor from the IPCC which is 13% lower than the world-aggregated emission factor from the IEA.

The difference in gas emission factors is discussed below for France and Germany:

- Electricity Maps uses a gas emission factor of 452 gCO_2eq/kWh in Germany while the IEA uses an emission factor that is 25% lower. Similar to the comparison performed for coal above, we compare these values to the emission factor given by Agora Energiewende[25] which is 390gCO_2eq/kWh. Electricity Maps' emission factor is thus 15% higher while the IEA emission factor is 15% lower.
- In France, the TSO uses a value of 429 gCO_2eq/kWh[26] for the gas emission factor. The value used by Electricity Maps is 10% lower while the value used by the IEA is 25% lower. Here, the IEA is likely underestimating emissions from gas-fired electricity generation in France.
- The gas emission factor computed for SWPP by Electricity Maps is slightly above the US average and other main US regions. The reason for this is that most gas power plants in SWPP are electricity-only plants. Out of 165 plants registered, only 19 are CHP plants. Electricity-only plants have a lower fuel efficiency and emit more greenhouse gasses than CHP plants.

[25] Agora Energiewende, Agorameter Documentation, https://www.agora-energiewende.org/fileadmin/Projekte/Agorameter/2023-10-01_Hintergrunddokumentation_Agorameter_v13_EN.pdf#page=10
[26] RTE, eCO2mix - CO2 emissions per kWh of electricity generated in France, https://www.rte-france.com/en/eco2mix/co2-emissions

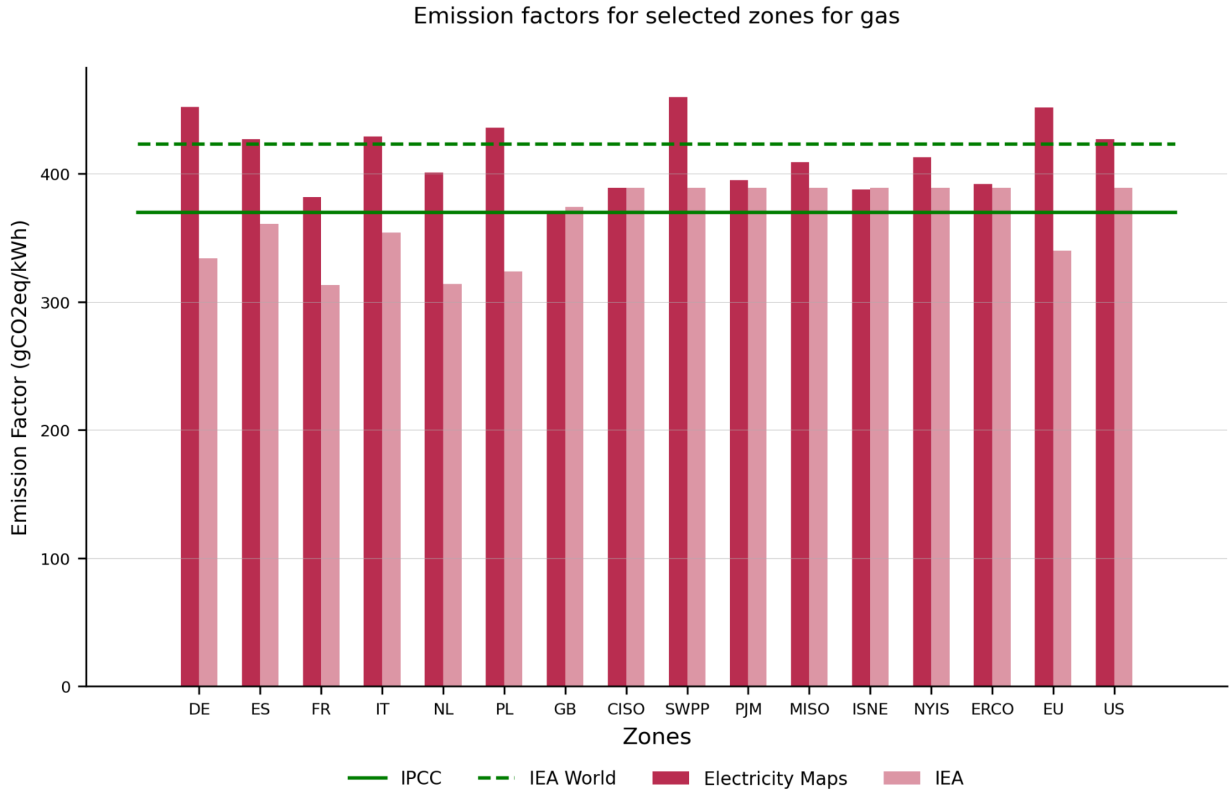

Figure 14. Gas direct emission factor for selected zones

Oil emission factors

The ENTSO-E generation per unit data set does not cover a lot of oil power plants. It is not possible to compute an emission factor for all countries that have oil-fired capacity. The emission factor used for most EU countries is the average of all oil emission factors computed in the EU.

As observed in the graph below, emission factors for oil can significantly vary both in Electricity Maps and the IEA dataset from one zone to another. This is due to major differences in technology and fuel used between zones as well as the limited number of power plants per zone as highlighted above which increases the volatility of results. As oil is not among the most used electricity sources worldwide, the overall impact of this emission factor remains low.

For oil, the IPCC 2014 does not provide an emission factor. Here Electricity Maps uses the emission factor of GB as a default emission factor which seems to underestimate emissions compared to other emission factors (IEA and Electricity Maps regional emission factors).

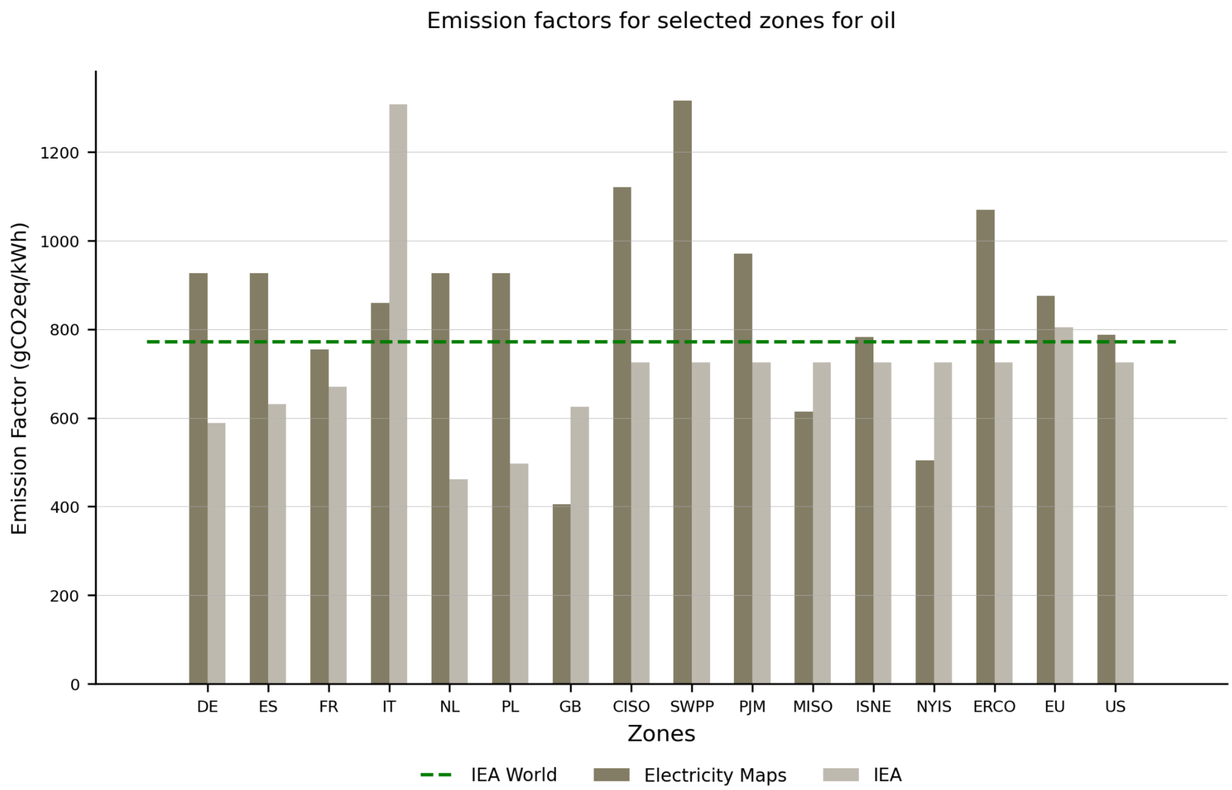

Figure 15. Oil direct emission factor for selected zones

Conclusion

A comparison of the two methodologies showed that the IEA is allocating emissions of CHP plants with greater accuracy while Electricity Maps' methodology proves to be more accurate than the IEA when it comes to accounting for electricity trade, upstream emission factors, as well as time and spatial granularity.

Because it uses hourly data and applies an advanced flow-tracing algorithm, Electricity Maps can capture electricity flows and trades (and underlying emissions) much more accurately than the IEA does with annual numbers. Additionally, by moving to regional emission factors for the EU and the US in 2022, Electricity Maps has not only increased the accuracy of its emission factors with higher spatial granularity but also with higher update frequency and more up-to-date data.

For direct emission factors, the values from Electricity Maps and the IEA show some differences but remain overall of the same magnitude order being close but higher than IPCC values.

In the US, Electricity Maps manages to have better spatial granularity by providing an emission factor per US balancing authority according to the granularity of available data while the IEA uses country statistics and can thus only calculate an emission factor aggregated at the country level.

In the EU, some emission factors from the IEA may be outliers while emission factors from both datasets show greater differences than in the US and the rest of the world.

Appendix

Appendix 1. Default emission factor used at Electricity Maps

Mode	Life-cycle emission factor (gCO2eq/kWh)	Operational emission factor (gCO2eq/kWh)	Category	Source
battery discharge	TBD	TBD	Renewable (default)	World average intensity by Electricity Maps
biomass	230	0	Renewable	IPCC 2014
coal	820	760	Fossil	IPCC 2014
gas	490	370	Fossil	IPCC 2014
geothermal	38	0	Renewable	IPCC 2014
hydro	24	0	Renewable	IPCC 2014
hydro discharge	TBD	TBD	Renewable (default)	World average intensity by Electricity Maps
nuclear	12	0	Low-carbon	IPCC 2014
oil	650	406	Fossil	UK Parliamentary Office of Science and Technology
solar	45	0	Renewable	IPCC 2014
unknown	700	575	Fossil	Assumes thermal (coal, gas, oil)
wind	11	0	Renewable	IPCC 2014

Appendix 2. US emission factors methodology

The dataset used to compute the emission factors contains data for each power plant registered in the US. This dataset provides information about:

- Whether the plant only produces electricity or is a combined heat and power plant (CHP),
- Whether the plant only burns one fuel or burns multiple fuels,
- Whether the plant produces electricity solely from combustible fuels or not,
- The annual generation from different modes in MWh,
- The adjusted emissions for all greenhouse gasses caused by the production of electricity.

The emissions published in eGRID are in imperial units and need to be converted to metric units before the emission factors are generated.

To compute regional emission factors for the US, each power plant in the eGRID dataset was matched to the corresponding Electricity Maps zone. Power plants with an installed capacity below 20 MW or an annual production below 1000 MWh are excluded from the sample as their output is not significant.

In some cases where the inputs include multiple fuels, the primary fuel is relabelled. Some power plants are registered with coal as a primary power source but the input fuel is made up of more than 50% biomass. In this specific case, the primary power source is reallocated to biomass.

In 2021, the sample of power plants used to generate thermal emission factors was made up of:

- 1205 gas power plants,
- 260 coal power plants,
- 186 biomass power plants,
- 107 oil power plants.

The four figures below represent the thermal emission factors computed per zone in 2021. The variation in biomass emission factor is caused by the different input fuels. Overall, larger emission factors are observed in zones where production is dominated by municipal waste incinerators and other unspecified types of biomass. The variations for the other fuels are mainly due to the type of power plants. CHP plants with a lower electric allocation factor will generate less emissions from electricity generation and have a lower associated emission factor than electricity-only plants.

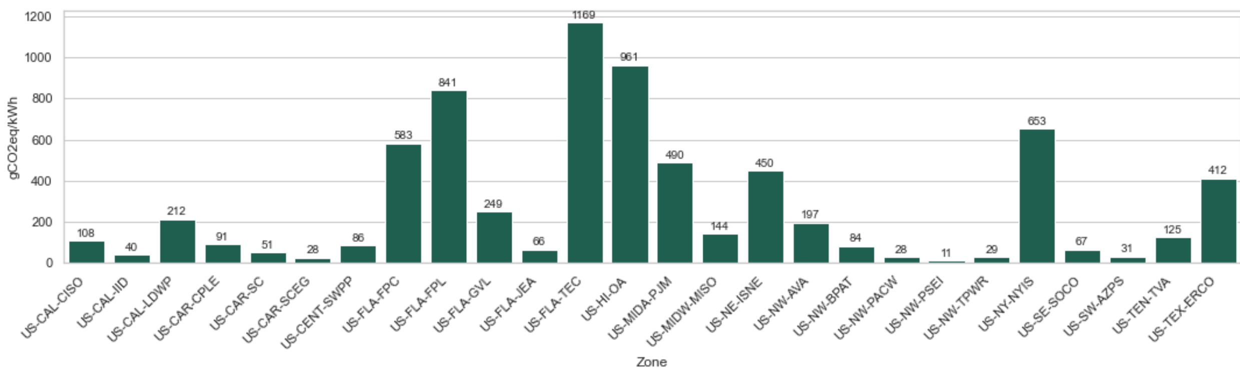

Figure 2. Biomass emission factors generated for US zones in 2021

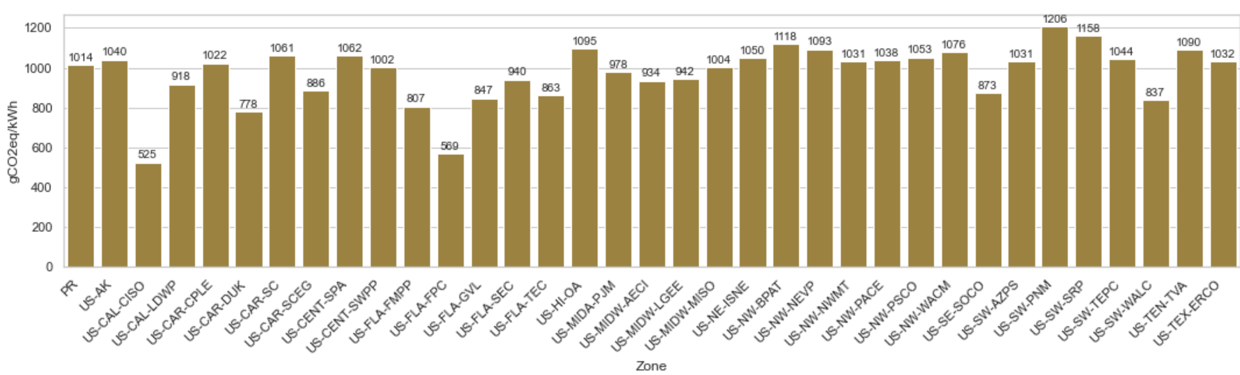

Figure 3. Coal emission factors generated for US zones in 2021

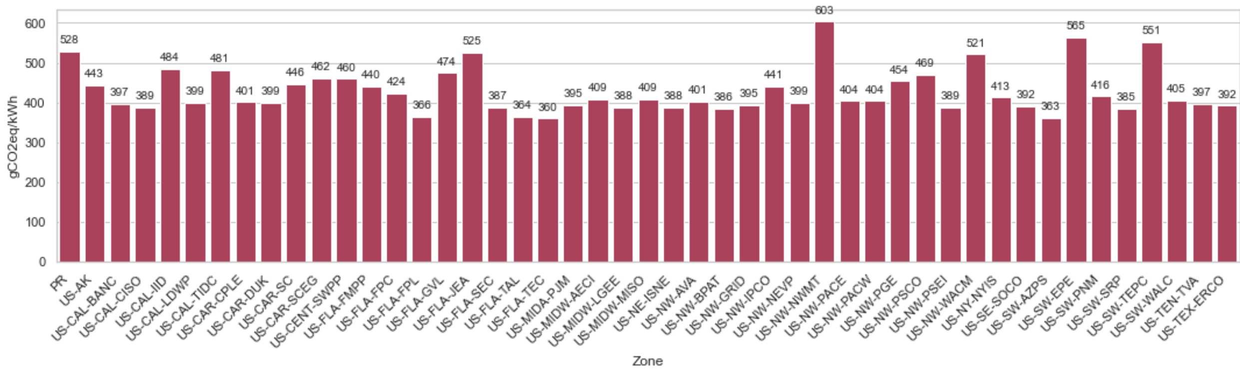

Figure 4. Gas emission factors generated for US zones in 2021

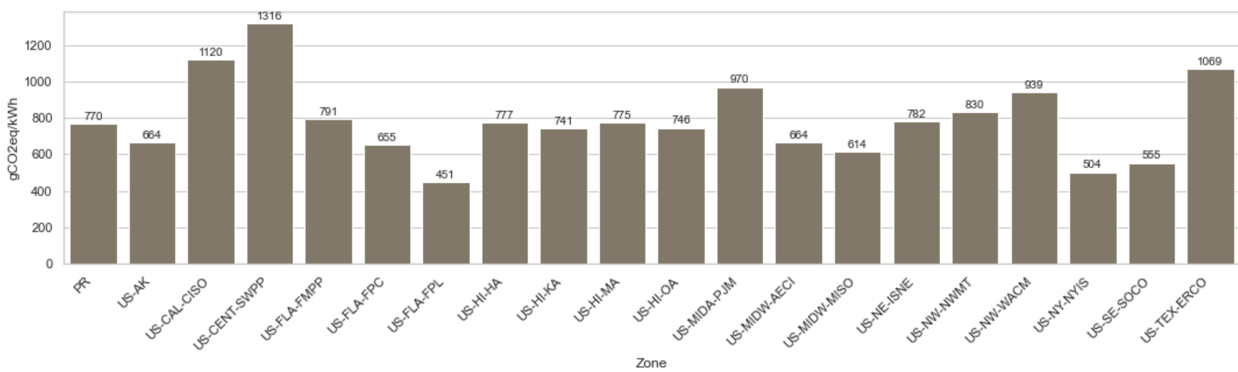

Figure 5. Oil emission factors generated for US zones in 2021

Appendix 3. EU emission factors methodology

Under this framework, the EU publishes the Union registry. This registry is a database containing information about all emitting installations in the EU. Each installation is reported under a specific activity code. Power plants are labeled as:

- 1: Combustion installations with a rated thermal input exceeding 20 MW.
- 20: Combustion of fuels.

The dataset is further filtered by removing installations that are excluded or have "-1" verified emissions for the chosen year. All closed accounts are also filtered out. For 2022, 5146 out of 14517 installations were selected.

This data can be aggregated at the yearly level and by power plant. A power plant is usually made up of several generation units. As for the US, only the power plants with an annual output exceeding 1000 MWh are considered. Each row in the set corresponds to the average generation for a power plant in a zone for a selected year. As the EU-ETS registry only includes power plants generating direct emissions, only combustible fuel-fired power plants are kept in the dataset. The dataset should only have biomass, coal, gas, and oil power plants. Power plants that burn multiple fuels are excluded from the sample as the EU-ETS registry only has one entry per power plant and it is not possible to split the total emissions between the different fuels with the information available.

Once this aggregation is done, the power plants need to be matched to the EU-ETS registry. This plant mapping is necessary to get the emissions and generation data used to compute the plant's carbon intensity.

Unfortunately, the naming conventions used to refer to the power plants on ENTSO-E are not the same as the ones used for the EU-ETS installations. The plant mapping is therefore done in two steps. The first step is to match the data entries automatically using word recognition. This automatic matching process covers approximately 80% of the ENTSO-E power plants. The remaining power plants are mapped manually by comparing the entries in both datasets. This manual mapping covers about 150 plants. After both steps are completed, approximately 90% of ENTSO-E power plants have a matching EU-ETS installation.

Heat emissions can be calculated from annual allocations. According to the following model[27], heat emissions are calculated as:

$$heat\_emissions \ = \ allocations \ / \ f(t)$$

where $f(t)$ is a function that depends on the heat benchmark[28] set by the European Commission, and carbon leakage. The carbon leakage coefficient defines the proportion of energy provided to carbon-emitting activities that could be moved outside of the EU boundaries. For example, steel production would be considered an activity that is sensitive to carbon leakage as steel production could be exported outside of EU boundaries if the carbon prices would increase too much. Residential heating is on the other hand not sensitive to carbon leakage. We assume that carbon leakage is 40% for all production modes and will use the corresponding heat emission factor.

Emissions are not reported for the power plants in Bulgaria and it was not possible to match the gas power plant in Latvia to any record in the EU-ETS dataset. It is not possible to compute regional emission factors for the following countries:

- Bulgaria,
- Cyprus
- Croatia
- Luxembourg
- Latvia
- Malta

[27] Model developed with the help of Mirko Schäfer: https://docs.google.com/spreadsheets/d/1y27Ro5T1FeGoV9Bf8pPF52Tw4U0MX08zpJbtk9Gz7b8/edit?usp=sharing

[28] Update of benchmark values for the years 2021 – 2025 of phase 4 of the EU ETS, https://climate.ec.europa.eu/system/files/2021-10/policy_ets_allowances_bm_curve_factsheets_en.pdf

For the other countries, the sample of power plants that have been matched to the EU-ETS installations is presented in the figure below.

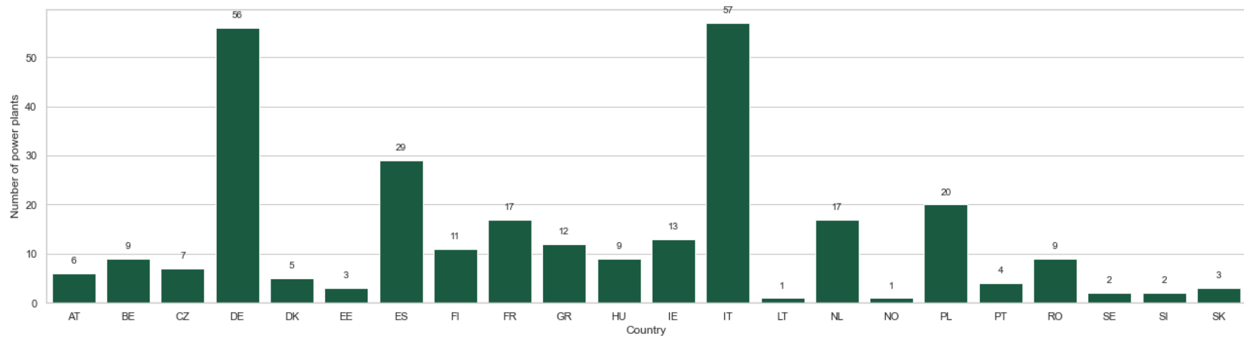

Figure 6. Sample of power plants used to compute emission factors in Europe in 2022

The emission factors are then computed as the average of the adjusted emissions divided by annual generation for all power plants. Before computing the final average for a country, outliers are removed from the dataset. These outliers are typically emission factors above 2000 gCO_2eq/kWh for coal or 1000 gCO_2eq/kWh for gas.

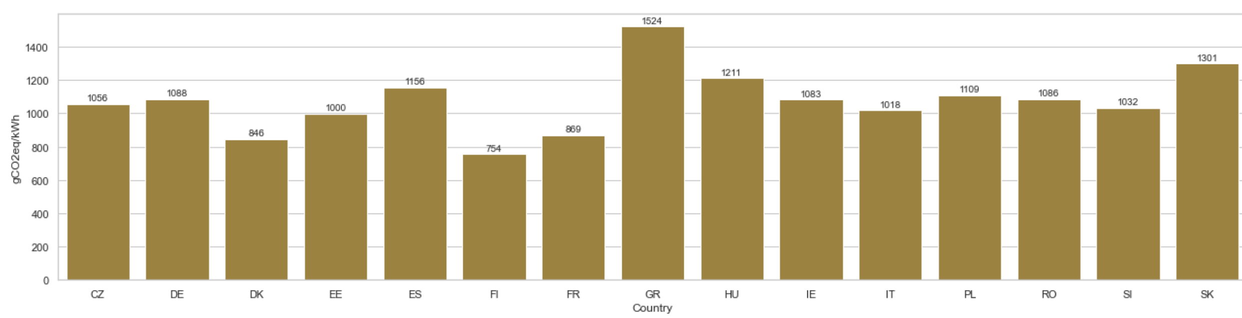

Figure 7. Coal emission factors in Europe in 2022

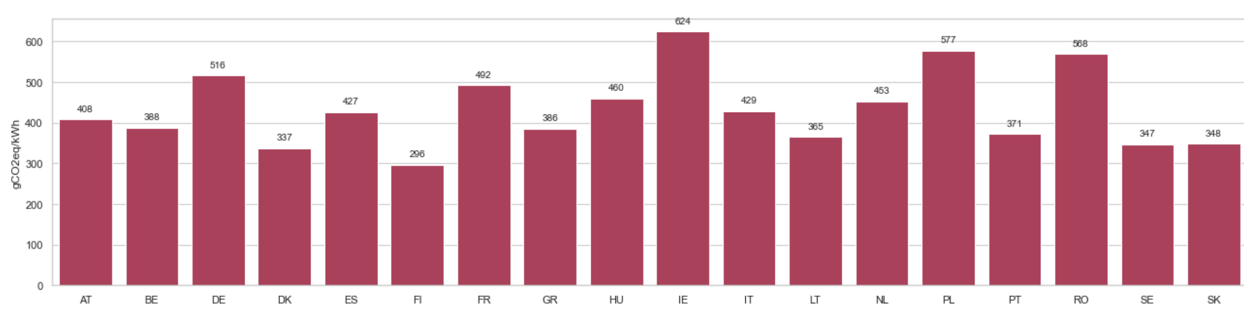

Figure 8. Gas emission factors in Europe in 2022

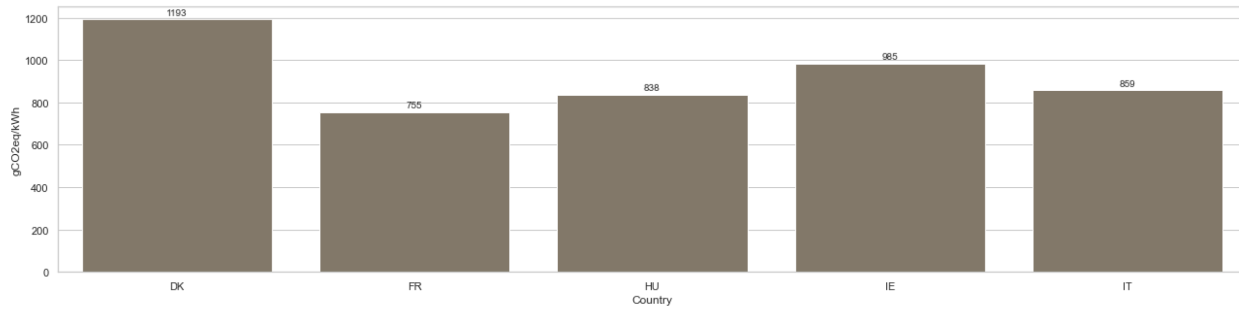

Figure 9. Oil emission factors in Europe in 2022

The average emission factor for the entire dataset is also computed and will be used as the default value for the EU zones where the emission factors are missing.

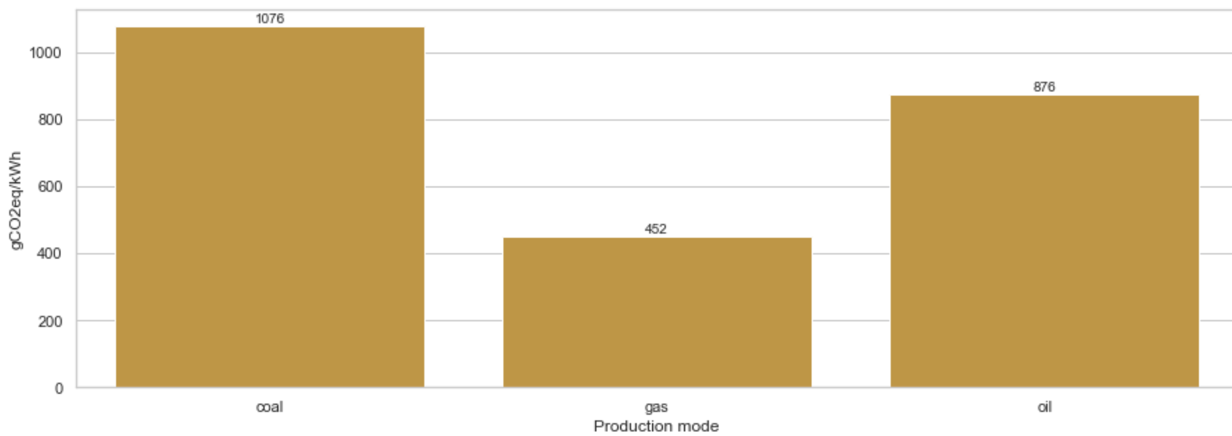

Figure 10. Average emission factors in Europe in 2022

Appendix 4. Calculation of life-cycle emission factors

Nuclear

For the US zones, the IPCC (2014) factor is used.

For EU zones, the life-cycle emission factor is taken from the United Nations Economic Commission for Europe (UNECE) report on the life-cycle assessment of electricity sources[29]. The value for nuclear power is 5.13 gCO_2eq/kWh.

[29] UNECE, Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, 2022, https://unece.org/sites/default/files/2022-04/LCA_3_FINAL%20March%202022.pdf

Wind

For the US zones, the IPCC (2014) factor is used.

For EU zones, the life-cycle emission factor is taken from the UNECE report on the life-cycle assessment of electricity sources. The value for nuclear power is 12.4 gCO_2eq/kWh.

Hydro

For the US zones, the IPCC (2014) factor is used.

For EU zones, the life-cycle emission factor is taken from the UNECE report on the life-cycle assessment of electricity sources. The value for nuclear power is 10.7 gCO_2eq/kWh.

Other combustible fuels

For gas and oil, upstream emission factors are computed as the difference between the life-cycle emission factor and the direct emission factor published in IPCC (2014)[30].

Appendix 5. Electricity Maps direct emission factors for the US

Zone	Date	Production mode	Emission factor type	Emission factor
US-AK	2021-01-01	coal	direct	1040
US-AK	2021-01-01	gas	direct	443
US-AK	2021-01-01	oil	direct	664
US-CAL-BANC	2021-01-01	gas	direct	397
US-CAL-CISO	2021-01-01	coal	direct	525
US-CAL-CISO	2021-01-01	gas	direct	389
US-CAL-CISO	2021-01-01	oil	direct	1120
US-CAL-CISO	2021-01-01	biomass	direct	0
US-CAL-IID	2021-01-01	gas	direct	484
US-CAL-IID	2021-01-01	biomass	direct	0
US-CAL-LDWP	2021-01-01	coal	direct	918
US-CAL-LDWP	2021-01-01	gas	direct	399
US-CAL-LDWP	2021-01-01	biomass	direct	0
US-CAL-TIDC	2021-01-01	gas	direct	481
US-CAR-CPLE	2021-01-01	coal	direct	1022
US-CAR-CPLE	2021-01-01	gas	direct	401
US-CAR-CPLE	2021-01-01	biomass	direct	0

[30] Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change - Annex III https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf#page=7

US-CAR-DUK	2021-01-01	coal	direct	778
US-CAR-DUK	2021-01-01	gas	direct	399
US-CAR-SC	2021-01-01	coal	direct	1061
US-CAR-SC	2021-01-01	gas	direct	446
US-CAR-SC	2021-01-01	biomass	direct	0
US-CAR-SCEG	2021-01-01	coal	direct	886
US-CAR-SCEG	2021-01-01	gas	direct	462
US-CAR-SCEG	2021-01-01	biomass	direct	0
US-CENT-SPA	2021-01-01	coal	direct	1062
US-CENT-SWPP	2021-01-01	coal	direct	1002
US-CENT-SWPP	2021-01-01	gas	direct	460
US-CENT-SWPP	2021-01-01	oil	direct	1316
US-CENT-SWPP	2021-01-01	biomass	direct	0
US-FLA-FMPP	2021-01-01	coal	direct	807
US-FLA-FMPP	2021-01-01	gas	direct	440
US-FLA-FMPP	2021-01-01	oil	direct	791
US-FLA-FPC	2021-01-01	coal	direct	569
US-FLA-FPC	2021-01-01	gas	direct	424
US-FLA-FPC	2021-01-01	oil	direct	655
US-FLA-FPC	2021-01-01	biomass	direct	0
US-FLA-FPL	2021-01-01	gas	direct	366
US-FLA-FPL	2021-01-01	oil	direct	451
US-FLA-FPL	2021-01-01	biomass	direct	0
US-FLA-GVL	2021-01-01	coal	direct	847
US-FLA-GVL	2021-01-01	gas	direct	474
US-FLA-GVL	2021-01-01	biomass	direct	0
US-FLA-JEA	2021-01-01	gas	direct	525
US-FLA-JEA	2021-01-01	biomass	direct	0
US-FLA-SEC	2021-01-01	coal	direct	940
US-FLA-SEC	2021-01-01	gas	direct	387
US-FLA-TAL	2021-01-01	gas	direct	364
US-FLA-TEC	2021-01-01	coal	direct	863
US-FLA-TEC	2021-01-01	gas	direct	360
US-FLA-TEC	2021-01-01	biomass	direct	0
US-HI-HA	2021-01-01	oil	direct	777
US-HI-KA	2021-01-01	oil	direct	741
US-HI-MA	2021-01-01	oil	direct	775
US-HI-OA	2021-01-01	coal	direct	1095
US-HI-OA	2021-01-01	oil	direct	746

US-HI-OA	2021-01-01	biomass	direct	0
US-MIDA-PJM	2021-01-01	coal	direct	978
US-MIDA-PJM	2021-01-01	gas	direct	395
US-MIDA-PJM	2021-01-01	oil	direct	970
US-MIDA-PJM	2021-01-01	biomass	direct	0
US-MIDW-AECI	2021-01-01	coal	direct	934
US-MIDW-AECI	2021-01-01	gas	direct	409
US-MIDW-AECI	2021-01-01	oil	direct	664
US-MIDW-LGEE	2021-01-01	coal	direct	942
US-MIDW-LGEE	2021-01-01	gas	direct	388
US-MIDW-MISO	2021-01-01	coal	direct	1004
US-MIDW-MISO	2021-01-01	gas	direct	409
US-MIDW-MISO	2021-01-01	oil	direct	614
US-MIDW-MISO	2021-01-01	biomass	direct	0
US-NE-ISNE	2021-01-01	coal	direct	1050
US-NE-ISNE	2021-01-01	gas	direct	388
US-NE-ISNE	2021-01-01	oil	direct	782
US-NE-ISNE	2021-01-01	biomass	direct	0
US-NW-AVA	2021-01-01	gas	direct	401
US-NW-AVA	2021-01-01	biomass	direct	0
US-NW-BPAT	2021-01-01	coal	direct	1118
US-NW-BPAT	2021-01-01	gas	direct	386
US-NW-BPAT	2021-01-01	biomass	direct	0
US-NW-GRID	2021-01-01	gas	direct	395
US-NW-IPCO	2021-01-01	gas	direct	441
US-NW-NEVP	2021-01-01	coal	direct	1093
US-NW-NEVP	2021-01-01	gas	direct	400
US-NW-NWMT	2021-01-01	coal	direct	1031
US-NW-NWMT	2021-01-01	gas	direct	603
US-NW-NWMT	2021-01-01	oil	direct	830
US-NW-PACE	2021-01-01	coal	direct	1038
US-NW-PACE	2021-01-01	gas	direct	404
US-NW-PACW	2021-01-01	gas	direct	404
US-NW-PACW	2021-01-01	biomass	direct	0
US-NW-PGE	2020-01-01	coal	direct	1041
US-NW-PGE	2021-01-01	gas	direct	454
US-NW-PSCO	2021-01-01	coal	direct	1053
US-NW-PSCO	2021-01-01	gas	direct	469
US-NW-PSEI	2021-01-01	gas	direct	389

US-NW-PSEI	2021-01-01	biomass	direct	0
US-NW-TPWR	2021-01-01	biomass	direct	0
US-NW-WACM	2021-01-01	coal	direct	1076
US-NW-WACM	2021-01-01	gas	direct	521
US-NW-WACM	2021-01-01	oil	direct	939
US-NY-NYIS	2020-01-01	coal	direct	1096
US-NY-NYIS	2021-01-01	gas	direct	413
US-NY-NYIS	2021-01-01	oil	direct	504
US-NY-NYIS	2021-01-01	biomass	direct	0
US-SE-SOCO	2021-01-01	coal	direct	873
US-SE-SOCO	2021-01-01	gas	direct	392
US-SE-SOCO	2021-01-01	oil	direct	555
US-SE-SOCO	2021-01-01	biomass	direct	0
US-SW-AZPS	2021-01-01	coal	direct	1031
US-SW-AZPS	2021-01-01	gas	direct	363
US-SW-AZPS	2021-01-01	biomass	direct	0
US-SW-EPE	2021-01-01	gas	direct	565
US-SW-PNM	2021-01-01	coal	direct	1206
US-SW-PNM	2021-01-01	gas	direct	416
US-SW-SRP	2021-01-01	coal	direct	1158
US-SW-SRP	2021-01-01	gas	direct	385
US-SW-TEPC	2021-01-01	coal	direct	1044
US-SW-TEPC	2021-01-01	gas	direct	551
US-SW-WALC	2021-01-01	coal	direct	837
US-SW-WALC	2021-01-01	gas	direct	405
US-TEN-TVA	2021-01-01	coal	direct	1090
US-TEN-TVA	2021-01-01	gas	direct	397
US-TEN-TVA	2020-01-01	oil	direct	473
US-TEN-TVA	2021-01-01	biomass	direct	0
US-TEX-ERCO	2021-01-01	coal	direct	1032
US-TEX-ERCO	2021-01-01	gas	direct	392
US-TEX-ERCO	2021-01-01	oil	direct	1069
US-TEX-ERCO	2021-01-01	biomass	direct	0

Appendix 6. Electricity Maps direct emission factors for the EU

Zone	Date	Production mode	Emission factor type	Emission factor

AT	2022-01-01	coal	direct	1076
AT	2022-01-01	gas	direct	408
AT	2022-01-01	oil	direct	926
AT	2021-01-01	biomass	direct	0
BE	2022-01-01	coal	direct	1076
BE	2022-01-01	gas	direct	388
BE	2022-01-01	oil	direct	926
BE	2021-01-01	biomass	direct	0
BG	2022-01-01	coal	direct	1076
BG	2022-01-01	gas	direct	412
BG	2022-01-01	oil	direct	926
BG	2021-01-01	biomass	direct	0
CY	2022-01-01	coal	direct	1076
CY	2022-01-01	gas	direct	412
CY	2022-01-01	oil	direct	926
CY	2021-01-01	biomass	direct	0
CZ	2022-01-01	coal	direct	1056
CZ	2022-01-01	gas	direct	412
CZ	2022-01-01	oil	direct	926
CZ	2021-01-01	biomass	direct	0
DE	2022-01-01	coal	direct	1088
DE	2022-01-01	gas	direct	452
DE	2022-01-01	oil	direct	926
DE	2021-01-01	biomass	direct	0
DK	2022-01-01	coal	direct	846
DK	2022-01-01	gas	direct	337
DK	2022-01-01	oil	direct	1193
DK	2021-01-01	biomass	direct	0
EE	2022-01-01	coal	direct	1000
EE	2022-01-01	gas	direct	412
EE	2022-01-01	oil	direct	926
EE	2021-01-01	biomass	direct	0
ES	2022-01-01	coal	direct	1156
ES	2022-01-01	gas	direct	427
ES	2022-01-01	oil	direct	926
ES	2021-01-01	biomass	direct	0
FI	2022-01-01	coal	direct	754
FI	2022-01-01	gas	direct	296
FI	2022-01-01	oil	direct	926

FI	2021-01-01	biomass	direct	0
FR	2022-01-01	coal	direct	869
FR	2022-01-01	gas	direct	382
FR	2022-01-01	oil	direct	755
FR	2021-01-01	biomass	direct	0
GR	2022-01-01	coal	direct	1524
GR	2022-01-01	gas	direct	386
GR	2022-01-01	oil	direct	926
GR	2021-01-01	biomass	direct	0
HR	2022-01-01	coal	direct	1076
HR	2022-01-01	gas	direct	412
HR	2022-01-01	oil	direct	926
HR	2021-01-01	biomass	direct	0
HU	2022-01-01	coal	direct	1211
HU	2022-01-01	gas	direct	460
HU	2022-01-01	oil	direct	838
HU	2021-01-01	biomass	direct	0
IE	2022-01-01	coal	direct	1083
IE	2022-01-01	gas	direct	412
IE	2022-01-01	oil	direct	985
IE	2021-01-01	biomass	direct	0
IT	2022-01-01	coal	direct	1018
IT	2022-01-01	gas	direct	429
IT	2022-01-01	oil	direct	859
IT	2021-01-01	biomass	direct	0
LT	2022-01-01	coal	direct	1076
LT	2022-01-01	gas	direct	365
LT	2022-01-01	oil	direct	926
LT	2021-01-01	biomass	direct	0
LU	2022-01-01	coal	direct	1076
LU	2022-01-01	gas	direct	412
LU	2022-01-01	oil	direct	926
LU	2021-01-01	biomass	direct	0
LV	2022-01-01	coal	direct	1076
LV	2022-01-01	gas	direct	412
LV	2022-01-01	oil	direct	926
LV	2021-01-01	biomass	direct	0
MT	2022-01-01	coal	direct	1076
MT	2022-01-01	gas	direct	412

MT	2022-01-01	oil	direct	926
MT	2021-01-01	biomass	direct	0
NL	2022-01-01	gas	direct	401
NL	2022-01-01	oil	direct	926
NL	2021-01-01	biomass	direct	0
PL	2022-01-01	coal	direct	1109
PL	2022-01-01	gas	direct	436
PL	2022-01-01	oil	direct	926
PL	2021-01-01	biomass	direct	0
PT	2022-01-01	coal	direct	1076
PT	2022-01-01	gas	direct	371
PT	2022-01-01	oil	direct	926
PT	2021-01-01	biomass	direct	0
RO	2022-01-01	coal	direct	1086
RO	2022-01-01	gas	direct	568
RO	2022-01-01	oil	direct	926
RO	2021-01-01	biomass	direct	0
SE	2022-01-01	coal	direct	1076
SE	2022-01-01	gas	direct	347
SE	2022-01-01	oil	direct	926
SE	2021-01-01	biomass	direct	0
SI	2022-01-01	coal	direct	1032
SI	2022-01-01	gas	direct	412
SI	2022-01-01	oil	direct	926
SI	2021-01-01	biomass	direct	0
SK	2022-01-01	coal	direct	1301
SK	2022-01-01	gas	direct	348
SK	2022-01-01	oil	direct	926
SK	2021-01-01	biomass	direct	0