Green Grid Compass

Methodology Report

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Methodology report on the project:
Green Grid Compass

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Brief summary

The Green Grid Compass (GGC), which is a combination of the "eco2grid" tool from 50Hertz and the "CO_2-Monitor" from TenneT and FfE, represents the next step towards the harmonization of temporally resolved emission intensities of electricity. The website developed has the necessary basic functionality to provide high-resolution greenhouse gas (GHG) emission factors of the electricity mix for the most important use cases. Stakeholders from various sectors were actively involved in the development phase as part of an implementation network through workshops. A core component of the GGC is the method developed as part of the CO_2-Monitor, which was incorporated into the GGC. The aim is to calculate emissions in the electricity grid in a transparent and comprehensible manner and to ensure conformity with the relevant parts of ISO standards 14040:2006, 14044:2006, 14067:2018 in conjunction with the Greenhouse Gas (GHG) Protocol Corporate Accounting and Reporting Standard. The calculation results are made available on a digital platform. The documentation of the method developed by FfE in cooperation with 50Hertz and TenneT and the underlying database for the calculation of hourly emission factors of the electricity mix is the subject of this method report.

Key messages

1. **The method is used to calculate hourly GHG intensities of the electricity mix for European bidding zones, which are broken down into Scope 2 and Scope 3 for reporting purposes.**

2. **The main objectives are to create a data basis for various use cases, to take into account the current state of the art, and to make the methodology and data basis comprehensible and transparent for users.**

3. **The core methodological elements are the consideration of electricity imports and exports using flow tracing and the inclusion of combined heat and power generation using the efficiency method. The generation data is scaled to statistical figures for the Germany-Luxembourg bidding zone.**

Report of changes

The following is a documentation of the changes made in comparison to the audited version 1 of the method report as of 31.01.2024, to which the inspection certificate in conjunction with the inspection report (InSp-ET-24-0042) refers.

The combination of the "eco2grid" tool from 50Hertz and the "CO_2-Monitor" from TenneT and FfE has resulted in changes compared to the audited methodology report. **The results presented have been expanded**. In addition to the hourly CO_2 intensity, its forecast and the share of renewable energies (RE) for the electricity mix consumed in Germany (as published by the CO_2-Monitor), the following data is provided in the GGC as results for European bidding zones for the generation and consumption mix:

- Absolute electricity generation and consumption by energy source (in MW)
- Share of renewable, nuclear and other energy sources (in %)
- Absolute greenhouse gas (GHG) emissions (t CO_2eq) and GHG intensity (g CO_2eq / kWh) , each broken down into operational (Scope 2), life cycle emissions with grid losses (Scope 3)
- Forecast of CO_2 intensity and RE share for the bidding zones Germany-Luxembourg and Belgium

The following general changes and adjustments have a fundamental impact on this methodology report:

- The methodology described is used in the harmonized tool, which is called Green Grid Compass (GGC). It replaces the CO_2-Monitor and eco2grid.
- The data is provided for European bidding zones. The countries Germany and Luxembourg are therefore combined in the calculation to form the Germany-Luxembourg bidding zone.
- In accordance with the review criteria, the methodology is adjusted to incorporate an improved database for the production type emission factors. Instead of the previous emission factors from the German Environment Agency (UBA) for Germany and the IPCC for other countries, an updated data source from the EU Commission is used. This enables a Europe-wide standardized calculation of country-specific emission factors per energy source as an input data basis. The CO_2-Monitor methodology is used for this, which also enables a uniform allocation for combined heat and power (CHP). (cf. chapter 2.3)
- For Germany-Luxembourg, the electricity generation data is scaled in the same way as in the CO_2-Monitor. This is not yet used for other bidding zones. (cf. chapter 2.2.2)
- As there is sometimes missing input data, the definition of missing data and how it is handled is disclosed transparently. In order to minimize the points in time with missing data, the forecast data is introduced as substitute values where available. (cf. chapter 2.5)

Furthermore, table Table 0-1 documents detailed changes in the document.

Table 0-1 Documentation of the changes made in the methodology report

Topic	Amendment	Chapter	Explanation / justification
Retrieval time of the input data	Retrieval of electricity data after three hours	2 Methodology and data basis	As necessary data is often still missing during real-time retrieval, the interval for retrieval has been extended to three hours.
Calculation of GHG intensity on an annual basis	No final recalculation at the end of the calendar year	2 Methodology and data basis	A freely selectable period is made available for download for the GHG intensity. This is an advantage for sustainability reporting, as a company's financial year does not have to be based on the calendar year.
Assumption on generation type-specific self-consumption	Assumption of the calculation of self-consumption per generation type based on German data for all bidding zones	2 Methodology and data basis; 2.3 Emission factors	This assumption must be made due to the lack of a Europe-wide database on power plant consumption. These are necessary for the conversion of gross to net electricity generation, which is required for the calculation of the emission factors per generation type at bidding zone level.
Time horizon for emission factors	Addition of the time horizon of the applied global warming potential (100 years)	2.1 System boundaries	The addition helps to improve the documentation.
Different geographical resolutions	Application of emission factors at country level to all bidding zones existing in a country	2.1 System boundaries	The exception here is the Germany-Luxembourg bidding zone, for which statistical data is aggregated before the calculation.
System boundary Scope 3.3 Emission factors	Addition of an info box on the wording of the emissions considered in Scope 3.3 according to the GHG Protocol in contrast to the GGC approach	2.1 System boundaries	Inclusion of plant construction in GGC emission factors, whereas in the exact wording only the upstream chains of fuel supply are taken into account. This represents a conservative approach in line with the principles of life cycle analysis.
Generation types	Expansion to include ENTSO-E generation types non-existent in Germany	2.2.1 Generation types Appendix A	Due to the broader geographical focus, it no longer makes sense to focus on German generation types.
Generation types "Other" and "Other renewable"	Addition and inclusion in calculation, conservative allocation of the maximum emission factor within a region	2.2.1 Generation types; 2.2.2 Scaling factors for Germany-Luxembourg; 2.3 Emission factors	Originally, these types of generation were not considered for Germany. Their inclusion is necessary due to the expanded data supply. For a conservative estimate, "Other" and "Other renewable" are each assigned the highest existing generation type-specific emission factor in a country.
Scaling factors outside Germany-Luxembourg	Supplementary explanation on the applicability of the scaling factor methodology to other European bidding zones	2.2.2 Scaling factors for Germany-Luxembourg	Not currently implemented, as a comprehensive individual assessment is required for each country.

Description of the new data source for emission factors	Reference and explanation of the emission factors from the new data source and the recalculation	2.3 Emission factors	Relevant information on the background, resolution, allocation, etc. of the emission factors is explained.
Designations in the Eurostat energy balances	Addition of explanations to Eurostat designations	2.3 Emission factors	The specification contributes to an improved comprehensibility of the documentation.
Data on allocation and emission factors for CHP	Removal of the table with constant values from 2021 for allocation and emission factors for CHP and non-CHP generation	Table 3 (originally)	Input data for the calculation that changes annually due to the calculation of statistical values is removed from the report due to it not being up to date.
Biogenic emissions	Additions to the data basis for the calculation	Digression 3	The calculation is based on values for Germany from 2021 according to the original methodology.
Calculation of absolute GHG emissions	Supplementary description of the calculation	2.4 Electricity imports and exports in the consumption mix	By displaying absolute emissions, the calculated GHG intensity is multiplied by the load.
Sensitivity analyses	Remove irrelevant sections	2.6 Sensitivity analyses	Due to the adjustments to the methodology, certain sensitivity analyses are no longer relevant.
Assumptions and limitations	Remove irrelevant sections	2.7 Assumptions and limitations	Due to the adjustments to the methodology, certain assumptions and limitations are no longer relevant.
Example of orientation towards test criteria	Swapping the example	2.8 Results	Example of data source for emission factors is no longer applicable, therefore swapped with assumptions for CHP.
Input data for the 2021 calculation	Removal of the tables with values for 2021 for emission factors, scaling factors and self-consumption	Appendix A, C, E (originally)	Input data for the calculation that changes annually due to the calculation of statistical values is removed from the report due to it not being up to date.
Assignment of generation types	Addition of allocation to AGEB, removal of UBA allocation	Appendix A	Due to the adjustments in the emission factor source, the allocation of the UBA generation types is irrelevant, but the AGEB generation types have been added.
Reference efficiencies	Update of the values for reference efficiencies	Appendix B	The values in the table have been updated due to the new publication of the reference efficiencies.
Bidding zones	Addition of the bidding zones taken into account in the calculation	Appendix D (new)	Due to the extension to Europe, a list of the bidding zones taken into account and which of these are considered to be the main zones is provided

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1 Background

The following section 1.1 the project context and in section 1.2 the use cases for electricity emission factors with a high temporal resolution based on the white paper on the CO_2-Monitor [1] predecessor project of the Green Grid Compass (GGC). Building on this, the objectives and criteria for the methodology and database are described in section 1.3 are derived from this. The detailed documentation of the method developed and the input data used is then provided in section 2.

1.1 Context of the Green Grid Compass

As in [1] the European Commission defines in the new version of the Renewable Energy Directive (RED III) that transmission system operators (TSOs) should verify the share of renewable energies (RE) and the greenhouse gas intensity of electricity in their market area as accurately as possible and in real time. Furthermore, the verification should be carried out at least on an hourly basis and, at best, also include forecasts.

A number of other requirements that go beyond the legal framework of RED III will lead to a sharp increase in demand for the reporting of high-resolution greenhouse gas (GHG) emissions in the electricity grid in the future: These include the Corporate Sustainability Reporting Directive (CSRD) [2] which states that up to 50,000 European companies will have to prepare a transparent sustainability report in the next few years. An important component of the Scope 2 and Scope 3 emissions to be reported there in accordance with the Greenhouse Gas Protocol Corporate Accounting and Reporting Standard (GHG Protocol for short) [3] are the GHG emissions from electricity procurement, including upstream and downstream emissions from plants and fuels. Currently, high-resolution emissions accounting in accordance with the GHG Protocol is still optional. However, in an energy system characterized by volatile RE, it will become increasingly important for the assessment of flexibility on the generation and consumption side in the future.

In addition to regulatory requirements, the focus is also shifting to the reporting of GHG emissions from electricity, as many companies are increasingly offering their customers the option of purchasing electricity based on emissions intensity in order to reduce their personal GHG footprint. In this context, high temporal resolution emission factors for load optimization will play an important role in the future. This results in an increasing need for transparent, time-resolved data from all directions for the verification and prediction of the GHG emission factor of electricity, taking into account the entire life cycle.

With the GGC, a platform has been created that has the necessary basic functionality to cover the most important use cases for time-resolved GHG emission factors for electricity (see section 1.2). The special feature is the balancing methodology developed in the former CO_2-Monitor, which was approved by TÜV SÜD, the applicability for important use cases and the mapping of future developments. Actors from various sectors were actively involved in a comprehensive stakeholder dialog via corresponding workshops and bilateral discussions as early as the development phase.

A core component of the GGC is the adoption and improvement of the method and database developed for the CO_2 monitor in order to calculate emissions from the electricity mix at bidding zone level in Europe in a transparent and comprehensible manner and to ensure conformity with the relevant parts of ISO standards 14040:2006, 14044:2006, 14067:2018 [4-6] in conjunction with the GHG Protocol [3] to ensure compliance. Based on the eco2grid platform, data on GHG intensity and the share of renewable energies in the European electricity grid are reported. A forecast based on artificial intelligence also provides forecasts for Germany-Luxembourg and Belgium that can be used, for example, to optimize flexible systems. Via a browser-based user interface [7] is used to visualize currently available data and show how it can be used for possible use cases.

1.2 Use cases "Verification and reporting"

A large number of use cases were identified during the stakeholder dialogs. These can be assigned to the categories "Verification and reporting", "Flexibilization and GHG reduction" and "Future-oriented GHG balance sheet" (see White Paper [1]). The use cases identified in the area of "verification and reporting" are explained below, as they are of particular relevance for the ex-post assessment and therefore the methodology and database described in this document.

Background

As described in section 1.1 section, regulations such as RED III and the CSRD will soon require more and more companies to provide evidence of the GHG emissions directly or indirectly associated with their economic activities. For many companies, especially in the case of energy-intensive processes, the GHG intensity of the purchased electricity is crucial for the GHG footprint to be reported. In view of the increasing electrification that is necessary to achieve the climate targets, the GHG balance of electricity will also play an increasingly central role in assessing the footprint of companies in the future. This applies not only to the electricity purchased directly by the company, but also to the upstream and downstream processes in which electricity will also be increasingly used in the future. This can be done either directly or indirectly (e.g. in the form of hydrogen).

Various norms and standards exist for assessing the GHG emissions of products and organizations, taking the entire life cycle into account. ISO standards 14040:2006 and 14044:2006 set standards for life cycle analysis at product level. These are specified in ISO 14067:2018 for the carbon footprint. At the organizational level, there is the ISO standard ISO14064-1:2018 [8]. These standards are closely linked to the GHG Protocol [3] which also provides guidelines for recording GHG emissions at product and organizational level. Both the above-mentioned ISO standards and the GHG Protocol are methodologically based on the principle of holistic mapping of GHG emissions, i.e. including upstream and downstream GHG emissions, or over the entire product life cycle. The methods and data sets used are therefore similar in the calculation of GHG emission intensity [9].

In practice, the GHG Protocol and the corresponding ISO standard are used to calculate the corporate carbon footprint and are therefore also used in the new regulatory framework. The GHG Protocol distinguishes between Scope 1 (direct emissions on site), Scope 2 (emissions from energy procurement) and Scope 3 (upstream and downstream emissions). The emissions for electricity procurement are essentially combustion-related emissions, which are assigned to Scope 2. The upstream emissions from the plants and fuels as well as emissions from electricity losses are assigned to Scope 3, subcategory 3 (cf. Figure 1: Overview of the scopes of the Greenhouse Gas Protocol (own illustration based on [3])).

For the assessment of GHG emissions from electricity, the GHG Protocol [10] distinguishes between location-based and market-based accounting. While location-based accounting, i.e. the use of an emission factor for the public electricity mix of the respective region, is mandatory, a company can also use market-based reporting. This means that a company uses product- or supplier-specific emission factors for its

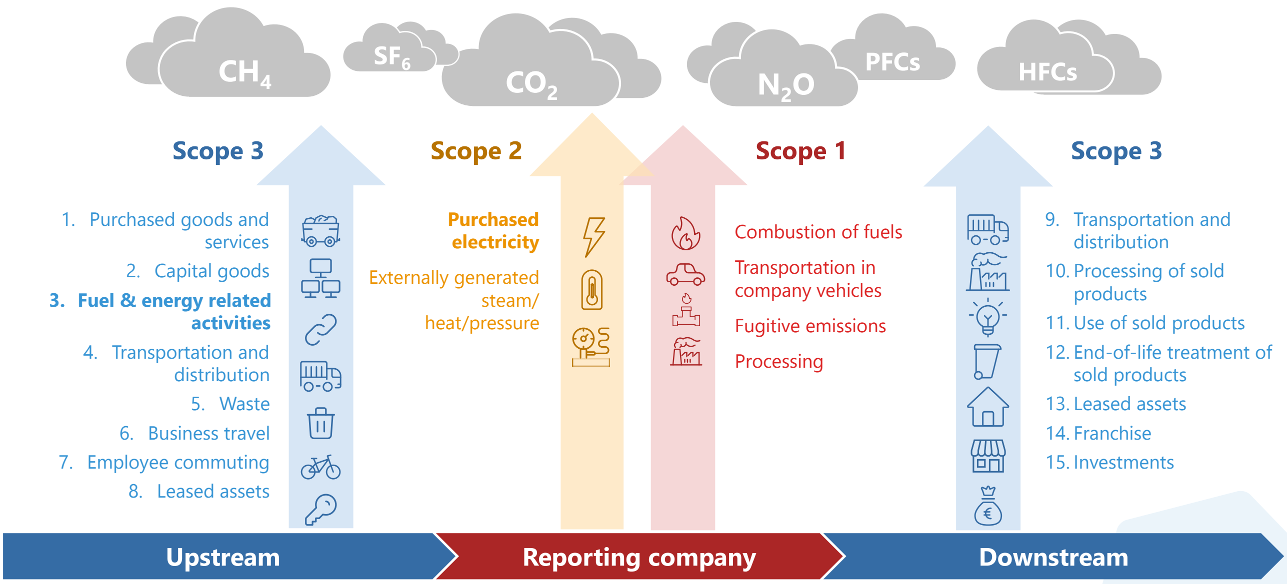

Figure 1: Overview of the scopes of the Greenhouse Gas Protocol (own illustration based on [3])

electricity procurement, which means that green electricity products are taken into account, for example.

Currently, the GHG emissions associated with electricity consumption are usually calculated using an average emission factor of the electricity mix for a year and multiplied by the annual electricity consumption. If, on the other hand, GHG emission intensities with a high temporal resolution are used and offset against equally high-resolution load profiles, a more accurate picture emerges: the calculated GHG emissions better reflect the GHG emissions caused by the company's electricity consumption, as the time of electricity consumption is taken into account. A higher temporal resolution is therefore also required as part of the current revision of the GHG Protocol [11].

Use Cases

The disclosure of key sustainability figures creates transparency and thus the basis for the following use cases identified in a stakeholder workshop:

- Sustainability reporting, in particular CSRD and SFDR - Sustainable Finance Disclosure Regulation (companies in all sectors)
- Proof of savings through load flexibilization, e.g. in the CSRD (companies in all sectors)
- Proof of emission intensity in the electricity grid for RED III (grid operators)
- Verification of reported GHG balances and GHG savings (verification bodies, auditing firms)
- Monitoring of GHG savings to achieve set GHG targets (policy, companies in all sectors)
- Proof of the GHG footprint of electricity-based downstream products such as green hydrogen from electrolysis (companies from all sectors)
- Creating awareness through transparency (society, customers, private individuals)

Example

The following figure shows the temporal variation of the emission factor of electricity using a summer week (calendar week 24, 2023) as an example. A clear deviation of the hourly emission factor from the load-weighted weekly average can be seen. For example, the hourly emission factor is below the average at midday when photovoltaic (PV) feed-in is high and above the average weekly emission factor at night when the share of renewable energy is low.

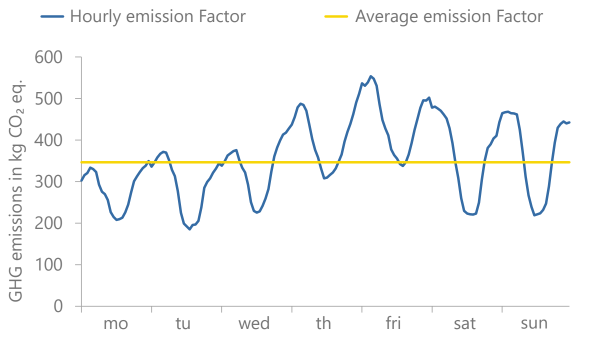

Figure 2: Difference between hourly and average emission factors (incl. life cycle perspective) using the example of a summer week

The influence that the use of time-resolved emission factors can have on the GHG balance for different load profiles is illustrated below using various sectors. For each sector, a type load profile based on [12] which is normalized to 1 GWh per year and reflects the different characteristics of the sectors. These load profiles are then compared with the hourly GHG emission factor from the CO_2 monitor for calendar week 24 in 2023 (see Figure 2) to determine the GHG emissions over the course of the week:

While the GHG emissions in the example week for all sectors amount to 6,660 kg CO_2 equivalents (eq.) when using the average emission factor, a deviation of -8 % (quarrying, other mining) to +2 % (basic chemicals) can be observed when using the hourly emission factors, depending on the sector. It is therefore clear that the use of hourly emission factors is particularly relevant for load profiles that correlate strongly with the hours of high RE shares and therefore low emission factors.

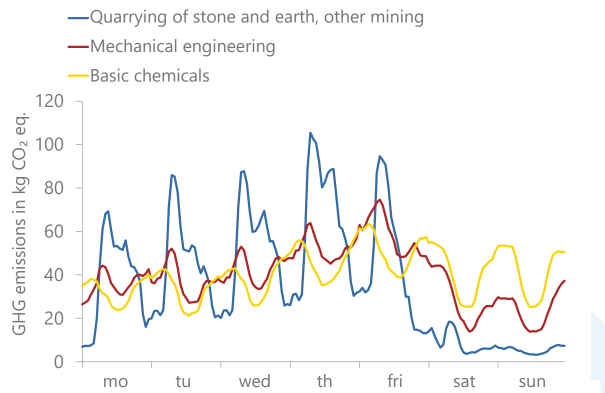

Figure 3: Hourly GHG balance of selected sectors for an exemplary summer week

The previous example illustrates not only the relevance of an hourly resolution of GHG emission factors for electricity, but also the basic procedure for applying the data for the use cases mentioned above. The following procedure can be defined for all use cases:

- Recording electricity consumption
  - → for the desired period (e.g. certain days, weeks or the entire calendar year)
  - → in the required time resolution (either load profile in hourly resolution or annual consumption)
- Download or direct integration of the GHG emission factors of the electricity mix via the GGC platform [7]:
  - → for the desired period (consistent with electricity consumption, e.g. specific periods or complete calendar year)
  - → in the required time resolution (consistent with electricity consumption, either hourly or annual average)
  - → for the scope considered (Scope 2, Scope 3 or entire life cycle)
  - → in the desired format (see section 2.8)
- Multiplication of the electricity consumption by the emission factors in the respective hour or year
- If necessary, add up the calculated emissions of the individual hours over the period under consideration

Derived requirements
For the use cases from the "Verification and reporting" category, the following requirements for GHG date were developed in the course of the stakeholder dialog (see White Paper [1]):

- Applicability for the GHG Protocol
  - → Location-based: Electricity mix
  - → Breakdown by Scope 2 and 3
- Consideration of energy industry correlations
  - → Electricity exchange between countries
  - → Combined heat and power generation
- High temporal resolution
  - → At least 1 h, better 15 min.
- Ex-post observation
  - → For previous calendar year(s)
- Updatability
  - → Regularly updated input data
  - → Regular recalculation
- Transparency and traceability
  - → Public, recognized sources if possible
  - → Documentation of the database and methodology
  - → Comprehensible calculation approaches
  - → External audit of the methodology

1.3 Resulting objectives and criteria

It is clear that the requirements arising from the use cases in the area of CO_2 monitoring are diverse and are also particularly relevant to the calculation method and database. The following three objectives were therefore defined for the GGC as part of the project, which the methodology should fulfill: Firstly, the applicability of the data for high-resolution CO_2 monitoring over time should be ensured for the use cases described above. In addition, the aim is to select a science-based approach that takes into account the current "state of the art", i.e. existing established approaches, and ensures that the input data is up to date. Furthermore, the GGC aims to be transparent, comprehensible and understandable. Based on these overarching objectives and the requirements resulting from the use cases, the following criteria were derived for the methodology and database:

1.3.1 Applicability for relevant use cases

The first objective is usability for relevant use cases. As explained above, the methodology presented in this document only refers to current or historical emission factors (ex-post consideration). Therefore, the focus below is on the reporting use cases (see section 1.2). This results in the criterion that the method is used to present the GHG emission intensity in the electricity mix in high temporal resolution (at least hourly). For ease of use, this data is made available to users in various formats (visualized, downloadable, automatically machine-readable).

The objective of usability for reporting also means that the emission factors calculated by the method follow the principles of location-based accounting in the GHG Protocol. This is because the GHG Protocol is an established standard for determining GHG emissions, which is required in the CSRD, among other things. This requires the provision of emission factors separated by scope: while scope 2 emission factors show the direct GHG emissions of the electricity mix, the scope 3 emission factors reflect the GHG emissions from upstream and downstream processes [10]. The applicability for the GHG Protocol, as well as the conformity of the method with the relevant parts of ISO 14040:2006, 14044:2006 and 14067:2018 (see section 1.2), is an important criterion and has an influence on many other methodological decisions.

It should be noted that, although the applicability of the data provided for the purposes described in section 1.2, the conformity of the subsequent use in the individual use cases is not the subject of the audit. This is because this depends on the specific application of the input data provided by the GGC (e.g. the use of the emission factors for the downstream preparation of the CSRD report) and therefore on the individual case in question.

In summary, this results in the following verification criteria:

- The method is used to calculate the GHG emissions intensity of the electricity mix on an hourly basis to provide location-based Scope 2 and Scope 3 emissions in the electricity grid for application to the GHG Protocol.
- The application of the data for different use cases is shown as an example in order to demonstrate to users the possibilities for applying the data and the associated added value.
- Additional information is provided on the proportion of electricity from renewable sources.

1.3.2 State-of-the-art and topicality

Another aim is to develop a science-based methodology that draws on already established approaches. This results in the following criteria: Firstly, in order to calculate Scope 3 emission factors, it is necessary to consider the GHG emissions of the entire life cycle. An established method for this is the life cycle assessment (LCA) according to ISO 14040:2006 and 14044:2006 or the carbon footprint of products specified in ISO 14067:2018 [4-6]. Therefore, one criterion is that the method developed is based on the relevant principles of life cycle assessment. Furthermore, the aim is to enable consumption-based accounting, which requires the inclusion of electricity imports and exports. The exchange of electricity between different countries is included using the scientifically established "flow tracing" approach established. It is also relevant to take into account the fact that electricity is also generated in the power plant park with the help of combined heat and power (CHP) plants. As two co-products are created here, GHG emissions must be allocated to heat and electricity in accordance with ISO 14067:2018.

Another important principle is the timeliness of the data. This means that the source from the last available year is always used, provided that all other requirements are met. The necessary requirements include applicability for the relevant use cases (see inspection criteria in section 1.3.1) and the transparency of the source (see inspection criteria in section 1.3.3). If all the necessary criteria are met, the extent to which the source fulfills further, preferred requirements is then checked. These include the completeness of the data records and their regular updating. This results in the two further inspection criteria that secondary data from current sources is used and workflows are defined to ensure that the database is up to date.

Table 1 Overview of the three main objectives and the associated criteria

Applicability for relevant use cases
- GHG emission intensity of the electricity mix in hourly resolution
- Scope 2 and Scope 3 emission factors for location-based accounting in accordance with the GHG Protocol
- Demonstrating the application of the data for relevant use cases

State-of-the-art and up-to-date
- Methodical application of life cycle assessment (LCA) aspects in accordance with ISO 14040:2006, 14044:2006 and 14067:2018
- Inclusion of electricity imports and exports using a flow-tracing approach
- Inclusion of combined heat and power (CHP) through allocation in accordance with ISO 14067:2018
- Secondary data from current sources
- Ensuring that the data is up to date

Transparency and traceability
- Use of freely available data sources (open source)
- Secondary data from recognized sources
- Transparent documentation of the calculation for external parties (e.g. users and examiners)

In summary, the following inspection criteria result:

- The method takes into account relevant parts of the ISO standards on the carbon footprint of products (14067:2018) and the life cycle assessment (14040:2006 and 14044:2006).
- The method takes into account the current state of the art for the inclusion of electricity imports and exports using a flow-tracing approach.
- The method defines the inclusion of combined heat and power generation in the calculation in order to ensure a transparent representation of this in the emissions intensity of the electricity mix.
- The method uses secondary data from current sources.
- Workflows are defined to ensure that the database is up to date.

1.3.3 Transparency, traceability, comprehensibility

Ultimately, the goal of transparency, traceability and comprehensibility is derived from the aforementioned objectives. This is because in order to be used in corresponding use cases, users of the data as well as assessors must be able to view and understand the calculation methodology. In order to enable a broad application of the GGC data, simple, comprehensible methodological approaches are therefore preferred over more complex and therefore less transparent approaches.

This results in various criteria that significantly influence methodological decisions. In order to guarantee traceability, one criterion is the use of freely available data sources. This allows the input data to be traced and results to be reproduced. In addition to free availability, another criterion is the reliability of the secondary data sources. Where possible, statistical data and data from recognized institutions should be used to ensure the credibility of the database.

Ultimately, traceability can only be guaranteed if comprehensive documentation is available. The methodology used and the underlying database for calculating the GHG emission intensity of the electricity mix in European bidding zones are therefore explained in detail in this methodology report.

Against the background of making the calculation basis comprehensible for external parties (users and examiners) and the results of different platforms comparable, the following inspection criteria are thus summarized:

- The method uses freely available (open source) data sources.
- The method uses secondary data from recognized sources.
- Transparent documentation (in the form of a methodology report, white papers and text modules on the platform) makes it easier to understand and interpret the data, especially for users with little previous experience.

2 Methodology and data basis

While the explanation of possible use cases including application examples for hourly GHG emission factors of the electricity mix is described in detail in chapter 1, the white paper [1] and on the platform [7], the underlying calculation logic and the data sources used are described below. It should be noted that decisions with regard to the methodology must always be made against the background of the criteria described in section 1.3.

The aim of the methodology is to calculate the GHG intensity of the electricity mix in European bidding zones on an hourly basis in order to create a data basis for various use cases. A central use case is non-financial reporting in accordance with the CSRD. This includes GHG emissions resulting from electricity consumption as part of Scope 2 and Scope 3 emissions in accordance with the GHG Protocol [3] must be reported.

Even if no hourly resolution has been specified in the GHG Protocol to date, this is required as part of the current revision of the GHG Protocol [11]. The focus of the GGC is therefore on the provision of hourly emission factors.

In addition, the share of renewable generation in the electricity mix is provided. This share is calculated by first adding up the net electricity generation of all plants operated with renewable energy sources per hour and then determining their share of total generation. The net electricity generation required for the calculation comes directly from the Transparency Platform of the European Network of Transmission System Operators for Electricity (ENTSO-E) [13] which is a recognized and freely accessible data source in the EU.

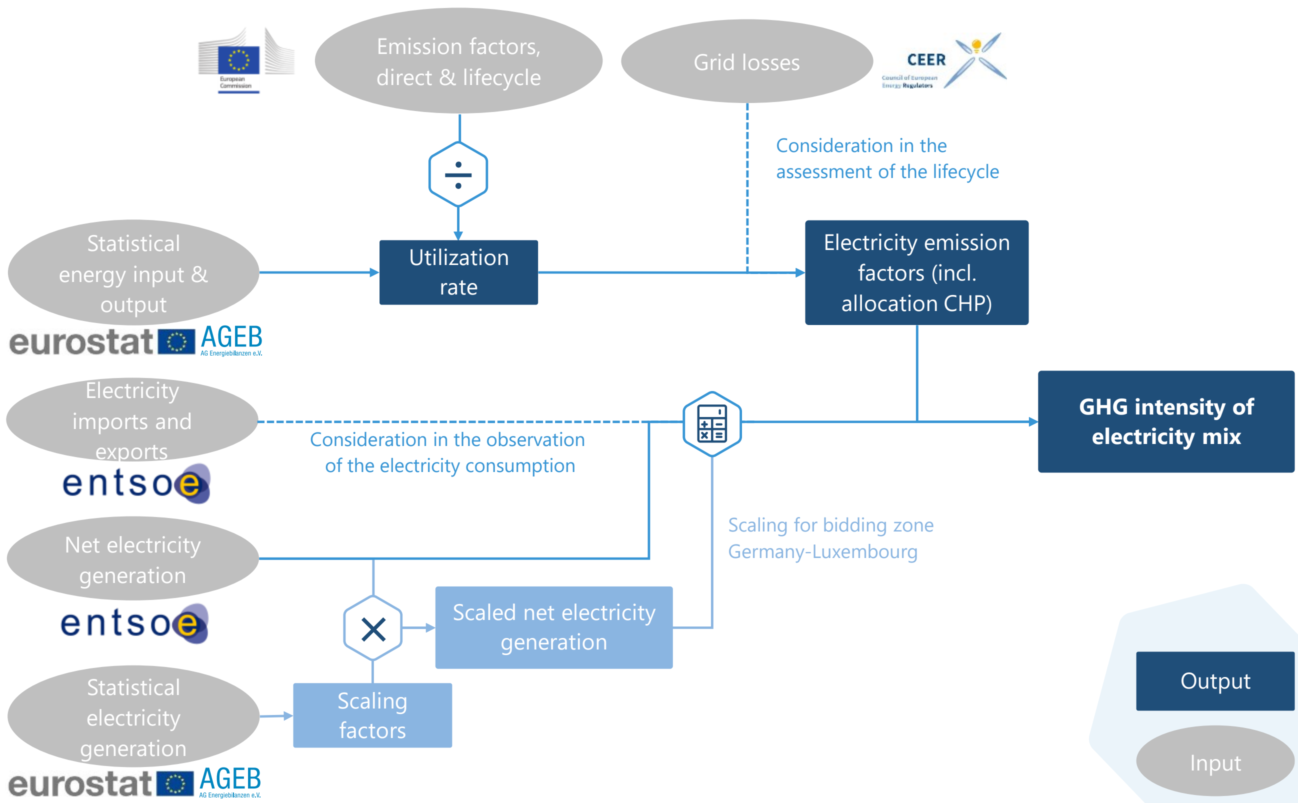

Figure 4: Overview of the methodology for calculating the hourly GHG intensity of the electricity mix

Figure 4 schematically illustrates the calculation logic used to calculate the hourly GHG intensity of the electricity mix. The starting point is the data on electricity generation from the ENTSO-E Transparency Platform [13]. Here, data from the transmission system operators on net electricity generation by generation type[1] and on electricity imports and- exports[2] are provided on an hourly basis.

In addition to the generation data for the generation mix, the methodology also includes electricity imports and exports to calculate the consumption mix. The flow tracing approach [14, 15] is used to track the energy source-specific electricity flows, which allows the influence of electricity trading to be taken into account.

Combined with energy source-specific emission factors, the average GHG intensity of the electricity mix can thus be calculated on an hourly basis. The data on GHG emission factors from the European Commission [16] is primary energy-related. The energy carrier-specific efficiencies can be calculated from energy input and output using Eurostat data [17] can be calculated. With the help of the calculated own consumption per energy source from data from the Working Group on Energy Balances (AGEB) [18], gross electricity generation is converted into net electricity generation. The net efficiencies are necessary to convert the primary energy-related emission factors into electricity-related emission factors. In this step, the efficiency method according to the GHG Protocol [19] is also used to allocate GHG emissions to heat and electricity generation in combined heat and power (CHP) plants. Grid losses are also relevant for the calculation of Scope 3 emissions, where percentage grid losses [20] are taken into account.

A special feature for the Germany-Luxembourg bidding zone is the scaling of the ENTSO-E values. Due to differences between the annual totals of the ENTSO-E generation data and other statistical data, the ENTSO-E generation data is scaled to Eurostat figures. This makes it possible to use the high temporal resolution of the data on the ENTSO-E Transparency Platform while at the same time complying with statistically recorded annual totals. The scaling factors are calculated from the statistical electricity generation per generation type in a historical year according to Eurostat [17] which, if required, can be supplemented by AGEB's own consumption [18] are converted into net electricity generation. This statistical net electricity generation is then set in relation to the net electricity generation reported to ENTSO-E in the same year.

Table 2 provides an overview of the secondary data sources and a brief description of these. When selecting the data basis, care was taken to ensure that freely available, comprehensible and as up-to-date as possible data was used for the calculation (see section 1.3). In addition, the year to which the data in this report relates and the expected frequency of updating are indicated for each source.

The ENTSO-E data on high-resolution electricity generation by generation type and electricity trading are published hourly or quarter-hourly, depending on the data provision by transmission system operators in each bidding zone. In order to be able to show a value for the GHG emission intensity of the electricity mix on the GGC platform promptly while at the same time minimizing missing values for the electricity data, these are retrieved with a three-hour delay and the calculations are then triggered directly. However, the data on electricity trading and generation on the ENTSO-E platform is updated retrospectively - partly systematically and partly due to irregular errors. Therefore, if data is missing for the respective hour, the retrieval of updated data is checked for up to three days and the GHG intensity of the electricity mix in the respective hour is recalculated in the event of subsequent reporting. This interval was defined in order to include any short-term data updates in the calculation.

When using the data on the emissions intensity of the electricity mix in reporting, it is important that the data is up-to-date, but also that it is transparent and traceable. As a company's financial year does not necessarily correspond to the calendar year, a new feature in the GGC compared to the CO_2-Monitor is the customizable selection of the period for which the emissions intensity of the electricity mix is to be downloaded. This ensures that the latest data from ENTSO-E at that time is included in the calculation. For other input data, such as data from statistical sources, the latest published status must be included. This means that the emission factors for reporting are always calculated using data from the previous year, as the data for the reporting year is not yet available in an updated form at the time of reporting. This applies, for example, to the determination of the scaling factors.

[1] Actual Generation per Production Type [16.1.B&C]

[2] Physical Flows [12.1.G]

Table 2 Overview of secondary data sources for calculating GHG intensity and share of renewables

Indicator	Source	Region	Year[3]	Update	Description
Net electricity generation	ENTSO-E [13]	ENTSO-E member countries	-	(quarter-) hourly[4]	• (Quarter-) hourly data on net electricity generation by production type (Actual Generation per Production Type [16.1.B&C])
Imports & exports	ENTSO-E [13]	ENTSO-E member countries	-	(quarter-) hourly[4]	• Hourly flows across national borders (Physical Flows [12.1.G])
Emission factors	EU Commission [16]	ENTSO-E member countries	2024	irregular [5]	• Primary energy related to gross electricity generation according to Eurostat generation types • Direct and life cycle within the EU • If not available: IPCC value [21]
Efficiency reference values	EU Commission [22]	EN	2024	irregular[5]	• Generation type-specific efficiencies for reference power plants for electricity and heat generation (necessary for allocation for CHP plants)
Energy balances	Eurostat [17]	EN	2023	yearly[5]	Data by energy source (SIEC): • Gross electricity generation (output) without own consumption (*GEP_MAPE, GEP_MAPCHP)* • Gross heat generation CHP without own consumption (*GHP_MAPCHP*) • Fuel input (*TI_EHG_MAPE, TI_EHG_MAPCHP*)
Monthly electricity generation	Eurostat [23]	EN	2024	monthly [6]	• Net electricity generation for solar, onshore wind, offshore wind and geothermal generation types
Power plant own consumption	AGEB [18]	EN	2023	yearly[5]	• Calculation from generation type-specific gross & net electricity generation • Assumption of unavailability for fossil fuel power plant types: 10%
Network losses	CEER [20]	ENTSO-E member countries	2018	irregular[5]	• Factor for total losses (transmission and distribution) • If not available: last existing value for country (before 2018), otherwise average across all countries

The method summarized above is described again in detail below. For this purpose, section 2.1 first defines the system boundaries. Subsequently, sections 2.2 to 2.5 the individual components of the calculation and corresponding methodological decisions are explained in more detail. Based on the sensitivity analyses in section 2.6, section 2.7 a discusses the assumptions and limitations. Finally, section 2.8 presents the results of the GGC.

[3] The value refers to the year for which the source is available as of the date of the method report.

[4] Data retrieval is automated via the ENTSO-E Transparency Platform and is checked once a month.

[5] The availability of updated data is checked at the beginning of each quarter and incorporated promptly (by the end of the quarter at the latest).

[6] Monthly data on electricity generation is updated when statistical data is available in annual resolution.

2.1 System boundaries

The GHG emission intensity of the electricity mix is determined on an hourly basis for bidding zones within the ENTSO-E area. In accordance with the life cycle approach (see ISO 14040:2006, ISO 14044:2006, ISO 14067:2018 in conjunction with the GHG Protocol), both combustion-related emissions (Scope 2) and other emissions from upstream processes and grid losses (Scope 3.3) are taken into account. The sum of these two emission factors results in the total GHG emission factor for the life cycle (LC).

Scope 3.3 according to GHG Protocol
In the exact wording of the GHG Protocol [9] the "extraction, production and transportation of fuels, [...] [such as] the mining of coal, refining of fuels, extraction of natural gas, etc." are taken into account in the upstream chain emissions of electricity. This does not include plant construction, which makes the life cycle emission factor zero, especially for renewable energies.
As this is not compatible with the life cycle analysis methodology and is unusual in the corporate context, plant construction is also considered in the GGC, which can be seen as a conservative approach for Scope 3.3 emissions.

When using statistical data, the Eurostat energy balances [17] are used, which are available at national level. When using statistical data, the calculation must therefore be carried out for countries. Each bidding zone is therefore assigned the superordinate country-specific value. The exception is the Germany-Luxembourg bidding zone, which consists of two countries. Here, the Eurostat data is aggregated before it is included in the calculation. Appendix D shows the countries and associated bidding zones that are included in the calculation.

The functional unit is one kilowatt hour of electricity in the electricity mix based on the data reported by ENTSO-E. For the Germany-Luxembourg bidding zone, the scaling to statistical data limits the functional unit to the public grid without industrial own generation (cf. digression 1 in section 0). It is therefore a location-based balancing, which according to the GHG Protocol for the Scope 2 calculation [10] is mandatory. In order to take account of the polluter pays principle, electricity imports and exports are included in the production mix for the consumption mix (cf. 2.4).

In addition to CO_2, the GHG emission intensity also includes other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O). These are converted into CO_2 equivalents based on their global warming potential (GWP) over a time horizon of 100 years [16].

2.2 Power generation

In order to determine the hourly GHG emission intensity of the electricity mix, generation type-specific, high-resolution data on electricity generation is required. In Europe, the ENTSO-E Transparency Platform [13] a widespread data source that is used as standard in the industry and therefore forms the basis for the methodology presented here.

ENTSO-E provides data on net electricity generation by different generation types for each country in at least hourly resolution. As the statistical data relates to gross electricity generation, the power plant consumption for individual generation types must be determined in order to convert gross to net electricity generation. These can be determined from the data published annually by AGEB on gross and net electricity generation in Germany a proportionate own consumption depending on the type of generation [18]. A self-consumption of 0% is assumed for renewables, with the exception of biomass[7]. The self-consumption calculated for Germany is assumed for all countries, as there is no comprehensive Europe-wide database. The allocation of generation types from different sources (ENTSO-E, Eurostat, AGEB, IPCC, EU Commission) can be found in Annex A.

2.2.1 Generation types

The categorization of the generation types of the GGC follows the ENTSO-E generation types (see Annex A). The ENTSO-E distinguishes a total of 21 different generation types. The following generation types are divided into non-renewable and renewable power plant types according to [24] as follows.

- Non-renewable:
  - → Fossil Brown coal/Lignite
  - → Fossil Hard coal
  - → Fossil Oil
  - → Nuclear
  - → Hydro Pumped storage

[7] There is no electricity generation in Germany for the fossil generation types "Fossil coald-derived gas", "Fossil oil shale" and "Fossil peat", so no self-consumption can be derived from AGEB data. For these types of generation, a self-consumption of 10% is assumed across the board.

- → Energy storage[8]
- → Fossil gas
- → Waste
- → Fossil peat
- → Fossil coal-derived gas
- → Fossil Oil shale
- → Other
- Renewable:
  - → Biomass
  - → Geothermal
  - → Hydro
  - → Solar
  - → Wind Offshore
  - → Wind Onshore
  - → Marine
  - → Other renewable

The ENTSO-E generation types are used to calculate the GGC emission factors and generation by type is provided via the API. Individual generation types are summarized on the user interface for better understanding. This summary, as well as a detailed overview of the allocation of generation types according to ENTSO-E and the statistical sources used (Eurostat, AGEB) can be found in Appendix A.

2.2.2 Scaling factors for Germany-Luxembourg

The ENTSO-E generation data is reported to the platform by the transmission system operators. In addition to short-term problems with data availability, such as the late delivery of data, there are also systematic limitations with the data source. One methodological approach to compensate for these is to scale the input data.

As the focus of the method development was originally on the German electricity mix, the described scaling was initially only created for the Germany-Luxembourg bidding zone. In principle, the methodological approach can also be rolled out to other European countries, but the quality of the necessary data differs greatly, meaning that a case-by-case analysis would be necessary for each country.

In [24] shows the degree of coverage of the reported data, which is not complete for some generation types. This applies in particular to natural gas, which is partly based on measured and schedule values as well as extrapolations. Deviations from statistical data also occur for other energy sources, as already shown by Hirth et al. [26] found.

In order to methodically map the systematic deviation of electricity generation from statistical data, so-called scaling factors are formed for the Germany-Luxembourg bidding zone from the last available year. This means that the data on net electricity generation from ENTSO-E is scaled to the values from the Eurostat energy balances[9] using a generation type-specific factor. As the electricity mix is to be assessed without industrial own generation, electricity from autoproducers is excluded (see digression 1).

In general, an annual scaling factor is applied here, as a monthly correction is not possible for all generation types due to the limited availability of monthly data. The statistical annual values refer to gross electricity generation, which is why these are calculated with the help of the own consumption calculated from AGEB [18] are converted into net electricity generation. As monthly values for net electricity generation are available for renewable electricity generation and there are seasonal differences in generation, monthly scaling factors are determined for volatile renewable generation from solar and wind.

Digression 1: Autoproducers

Power plants can be categorized according to the purpose of generation. For energy companies, the conversion of primary energy into e.g. electricity or heat is the underlying business model (main activity producers, MAP). Autoproducers (AP) are industrial companies that produce electricity and/or heat for their own use and do not sell it.

Hence, electricity from autoproducers is not included due to the consideration of the public electricity grid. As statistical data, such as Eurostat, distinguishes between main and autoproducers [25] the underlying database makes it possible to exclude self-generation from industrial power plants through the scaling factors.

[8] The "Energy Storage" generation type was newly introduced by ENTSO-E in 2024. As no data is currently reported for this generation type, it is not taken into account in the current calculation methodology and is integrated into relevance

[9] GEP_MAPE and GEP_MAPECHP (see section 2.3)

Exceptions: Geothermal and hydro
In the case of geothermal energy, we deviate from the procedure just described, as an analysis of the data for Germany shows that the annual gross electricity generation in the Eurostat energy balances, even after conversion to net electricity generation, significantly exceeds the aggregated monthly net electricity generation in Eurostat. The latter, however, corresponds approximately to the generation reported in Germany by ENTSO-E. It can therefore be assumed here that the self-consumption of geothermal power plants is determined differently. The monthly net electricity generation is therefore used directly. As irregularities occur in the scaling factor in the case of monthly scaling factors, the annual total of the monthly values is used instead.

Generation from hydropower is another exception. In Eurostat's annual energy balances, there is no distinction between different types of generation for hydropower in gross electricity generation[10]. However, pumped storage power plants are a special type of power plant because - unlike run-of-river power, for example - they do not generate electricity, but only store it. This means that, unlike other power plants, the stored electricity cannot automatically be categorized as renewable (see section 2.2.1). However, as it is not possible to scale the individual hydropower generation types with the available database, the generation from hydropower as a whole (including pumped storage) is scaled to the annual generation according to Eurostat. For reasons of data availability, it is therefore assumed that both conventional hydropower and pumped storage power plants must be adjusted to the statistical base figures in the same way. However, this only applies to the scaling factors. Otherwise, conventional hydropower plants and pumped storage power plants continue to be considered as separate generation types and therefore also receive different emission factors.

There is no scaling for generation in the "Other" and "Other renewable" categories, as it is not clear which generation types are reported here. This simplification can be explained by the low share of these two generation types in the electricity mix in Germany-Luxembourg.

2.3 Emission factors

In addition to the data on electricity generation, generation-type-specific emission factors are also required to determine the emission intensity of the electricity mix.

In order to calculate hourly Scope 2 and Scope 3 emission factors for the electricity mix, combustion-related emission factors and emission factors over the life cycle are required for the various generation types. The emission factors for Europe provided by the EU Commission are used for this purpose [16]. These show emission factors for generation types according to the Eurostat SIEC classification.

Both operational and combustion-related emission factors as well as life cycle-based emission factors that take the upstream chain into account are provided. The operational emission factors are based on the IPCC database [27]. Other greenhouse gases are converted using the GWP100 values from the sixth IPCC Assessment Report [28]. To provide the life cycle emission factors, the upstream chain of energy sources based on the database ecoinvent (version 3.9.1., cut-off model) is taken into account. The selected ecoinvent processes are representative for the EU and the European region.

From the data shown in [16] country-specific emission factors can be derived with the help of Eurostat energy balances [17]. As the Eurostat generation types are available in a more detailed breakdown than ENTSO-E generation types, the matching shown in Annex A is applied. For generation types for which several Eurostat generation types are available, the emission factor is determined using the average value weighted according to electricity generation. The primary energy-related emission factors refer to the energy input of the respective generation type. In order to bring this into line with the selected functional unit

$$EMF_{electricity} = share_{eo} \times \frac{EMF_{primary\ energy}}{\left(\frac{net\ electricity\ output_{eo}}{fuel\ input_{eo}}\right)} + share_{chp} \times \left(\frac{EMF_{primary\ energy}}{\left(\frac{net\ electricity\ output_{chp}}{fuel\ input_{chp}\ \times A_p}\right)}\right)$$

[10] In the monthly data on net electricity generation, hydropower is divided into the categories "pumped storage", "pure hydro" and "mixed hydro", but these cannot be meaningfully matched with the ENTSO-E generation types for hydropower. Data analyses show that the generation from pumped storage power plants reported in ENTSO-E exceeds the generation from pumped storage and the sum of pumped storage and mixed hydro. This indicates a different allocation of the power plants.

(see section 2.1), a conversion is made into electricity-related emission factors using the degree of utilization. This is done using the energy inputs and outputs reported in the Eurostat energy balances.

In addition to the data used, the designations from Eurostat are given in brackets below to improve comprehensibility. In principle, the electricity output (*GEP_MAPE*[11] and *GEP_MAPCHP*[12]) is divided by the fuel input (*TI_EHG_MAPE*[13] *and TI_EHG_MAPCHP*[14]) for each generation type. The electricity generation is converted into net electricity generation using the power plant's own consumption calculated using AGEB data. The German values are assumed for all European countries due to a lack of data sources. For the renewable generation types of solar, wind, hydropower and geothermal energy, the following is used according to [29] a degree of utilization of 100% is assumed.

Inclusion of CHP generation
In order to better reflect the power plant fleet, a distinction is made between power plants that generate electricity exclusively and CHP plants. For main activity producer electricity only *(MAPE*) power plants, the degree of utilization and thus the emission factor is calculated as described above by dividing by the degree of utilization. In the case of CHP plants, the GHG emissions must be allocated to the co-products using an allocation method due to the combined provision of electricity and heat, which is reflected in the resulting emission factor. The calculation for CHP plants and the subsequent calculation of the weighted emission factor for each generation type are explained below.

The allocation of GHG emissions to electricity and heat production is crucial, as this can lead to different emission factors depending on the methodology. Due to the orientation towards the reporting use cases (see section 1.2), the decision here is made in favor of the GHG Protocol [19] preferred allocation methodology, the efficiency method described in section 2. Here, the allocation factor is calculated using efficiencies for reference power plants. The European Commission publishes harmonized efficiency reference values for electricity and heat generation for individual generation types [22]. The reference values used are listed in Annex B. Using these reference efficiencies, the electricity output (*GEP_MAPCHP*) and the heat output (*GHP_MAPCHP*), the allocation factor can be calculated as described in Digression 2.

After determining the allocation factor for CHP plants A_p an aggregated electricity-related emission factor is then calculated for the $EMF_{electricity}$ of the respective generation type is then calculated. This is done, as shown in the following formula, by forming an average of CHP and non-CHP plants weighted by electricity generation. This approach is applied to both the combustion-related emission factors and the emission factors with upstream chain.

As annual values from Eurostat are used for the calculation, this approach implies an even distribution of electricity and heat generation from CHP plants across all hours of the year. However, the operation of CHP plants is also based on heat demand, so there is a temperature dependency. In warm hours, when there is little demand for heat, the emissions intensity of electricity production from energy sources with a relevant CHP share is therefore underestimated, as the CHP input is lower than the annual average. In turn, the emissions intensity is overestimated in cold hours. The chosen approach is due to data gaps on the heat side, which could only be closed by complex and therefore difficult to understand modeling approaches. As soon as the required input data is available in the corresponding statistics for heat generation in a higher temporal resolution, it can be integrated into the methodology presented here at any time.

For the generation types "Other" and "Other renewable", the challenge is that there is no information on the composition of this generation type and this can vary by bidding zone. Therefore, no unique emission factor can be assigned. As a conservative approach, the highest emission factor is applied for the renewable and non-renewable generation types occurring in a country for "Other" and "Other renewable".

[11] GEP_MAPE: gross electricity production main activity producer electricity only

[12] GEP_MAPCHP: gross electricity production main activity producer electricity

[13] TI_EHG_MAPE_E:_ transformation input electricity and heat generation main activity producers electricity only

[14] TI_EHG_MAPCHP:_ transformation input electricity and heat generation main activity producers combined heat and power

Digression 2: Efficiency method according to the GHG Protocol

The efficiency method takes into account the different efficiencies of heat and electricity generation. This is done by including the efficiencies of reference power plants for pure heat and electricity production.

The allocation factor for electricity A_P is then calculated as follows from the electricity output P (GEP_MAPCHP) and the heat output H (GHP_MAPCHP) and the efficiencies of the reference power plants for pure electricity and heat generation (e_P and e_H):

$$A_p = \frac{(P \div e_P)}{(P \div e_P) + (H \div e_H)}$$

Consideration of grid losses

In addition to the upstream emissions from electricity generation, downstream losses in the electricity grid are also taken into account when calculating the Scope 3 emission factor. Grid losses are specified as a relative loss factor (see Appendix C). The Scope 3 emission factor EMF_{S3} is therefore calculated as follows:

$$EMF_{S3} = \frac{EMF_{upstream}}{1 - grid\ losses} - EMF_{operation}$$

The emission factor with upstream chain, which includes both the direct emissions and the upstream chain, is first divided by a grid loss term. This takes into account the fact that the amount of electricity that reaches the consumer is less than the amount of electricity generated. Due to the grid losses, the emission factor with upstream chain increases accordingly. The direct emission factor is then subtracted from the resulting emission factor including grid losses. This is because only the difference is allocated to Scope 3, while the direct emissions are counted as Scope 2 emissions.

As can be seen from the formula, data on grid losses is required to calculate the Scope 3 emission factors. For this purpose, data from the CEER (Council of European Energy Regulators) [20] are used. The data is based on national measurements and/or estimates. The total grid losses are given relative to the electricity fed into the grid. For countries where no value is provided for 2018, the last available grid loss factor since 2010 is used. Countries for which no specific data exists are assigned the mean value from all available grid losses as the grid loss. The grid losses used are listed in Annex C.

Digression 3: Biogenic emissions

Biogenic GHG emissions arise from the combustion of biogenic carbon contained in biomass. Since biomass, as a renewable raw material, binds CO_2 from the air during growth, biogenic emissions are treated separately. ISO 14067:2018 [6] provides for separate reporting of fossil and biogenic GHG emissions. In addition to the source of carbon (fossil or biogenic), a distinction should also be made between emitted and removed GHG quantities.

In the context of the GGC, it is only possible to report biogenic emissions to a limited extent due to the data. Biogenic emissions can be approximated via electricity generation from biomass. However, biogenic emissions can occur in the upstream chain for all types of generation, for which no separate information is available. As GHG emissions from the upstream chain only account for a small proportion overall, the order of magnitude of biogenic GHG emissions can be estimated using the biomass generation type.

The emission factors originally used for Germany by the UBA [29] for biomass only include GHG emissions resulting from the provision of biomass and combustion-related emissions of greenhouse gases other than CO_2, such as methane. The same applies to the new emission factors [16, Box 1]. The biogenic CO_2 emissions resulting from combustion are not included here, as they have already been removed from the atmosphere. In contrast, the emission factors in the National German GHG Inventory Report [30] include all CO_2 emissions generated during combustion. This can be used to approximately determine the biogenic CO_2 emissions for biomass, which are not included in the emission factor. If the biogenic CO_2 emissions from combustion are included, the result is 978 g CO_2eq. per kWh, which is a significantly higher direct emission factor for the biomass production type than the one based on [29] which is 95 g CO_2eq. per kWh.

In order to estimate the scale of biogenic GHG emissions Figure 5 shows the load-weighted average emissions intensity of the German electricity mix for the entire life cycle including biogenic emissions - as suggested in [6]. The biogenic emissions include the biogenic CO_2 produced during combustion as well as other direct GHG emissions apart from CO_2. As the biogenic CO_2 was previously bound in the biomass,

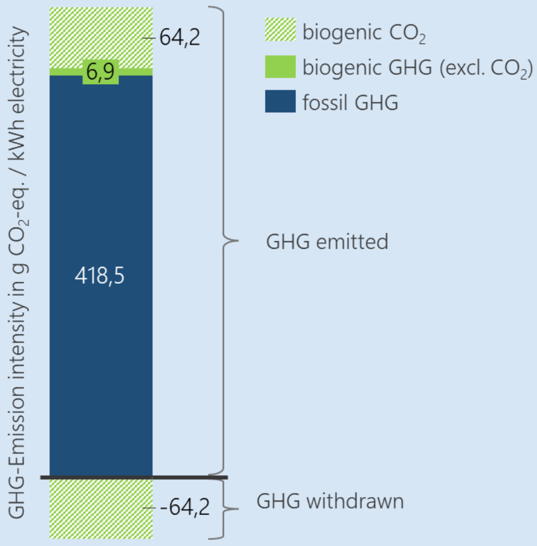

Figure 5: Illustration of the load-weighted electricity emission factor (life cycle) for Germany for 2021 broken down into emitted and removed GHG quantities[15]

these emissions are also taken into account as removed GHG quantities.

It can be seen that biogenic emissions make up a relevant share of the total GHG emissions. This is largely due to the biogenic CO_2 emitted, while other combustion-related GHG emissions make up a small proportion of the emissions intensity of the electricity mix. Nevertheless, biogenic emissions are not initially reported separately in the GGC, as the database is only sufficient for an estimate and not for a detailed balance. In addition, due to the absorption of CO_2 by biomass, the impact on the resulting overall emission factor is low. For sustainability reporting in accordance with the GHG Protocol [10] it is permissible not to report biogenic GHG emissions separately for the location-based accounting of Scope 2 emissions due to the lack of data. If an improved database for the accounting of biogenic emissions becomes available, the aim is to integrate it into the GGC.

[15] Calculation based on the database and methodology described in version 1

2.4 Electricity imports and exports in the consumption mix

In consumption-based emissions accounting, electricity trading between countries is mapped using the flow-tracing methodology. The methodology described below is therefore used to determine the consumption mix. The basic idea of flow tracing is to follow energy flows through the energy system.
ENTSO-E data [13] on electricity imports and exports between the regions under consideration enable the tracing of electricity flows in Europe (see Appendix D). The method used here and outlined below is based on [14] and [15] which provide a more detailed description of the flow tracing approach.

Emission balances provide the mathematical basis for calculating the emission factors in the energy system. Taking into account the energy flows, the emissions balance can be represented as a linear system of equations at any time under consideration:

$$A \cdot x = b$$

matrix A describes all energy flows in the energy system at the time under consideration. Matrix A is made up of the electrical load in the region under consideration and the electricity trade with other regions under consideration. The electrical load of a region $Load_{el}(reg)$ is calculated from generation processes Genimports Imp into the region, exports Exp from the region as well as injection processes $P_{in,sto}$ and withdrawal processes $P_{out,sto}$:

$$Load_{el}(reg) = Gen(reg) + Imp(reg) + P_{out,sto}(reg) - Exp(reg) - P_{in,sto}(reg)$$

All emissions occurring in the energy system are described by the vector b vector. Depending on the scope to be calculated, these are made up of the direct emissions of the supply processes and/or the upstream chain emissions. For each generation process, the net electricity generation at the time under consideration is multiplied by the corresponding emission factor. The regions under consideration are linked via their imports and exports and the associated emissions.

The target vector x is calculated by solving the linear system of equations. The target vector describes the emission factors of the domestic electricity consumption of the regions under consideration at the time under consideration. In this case, the hourly GHG emission factor for electricity consumption can be determined. In order to calculate the absolute emissions of a bidding zone based on the hourly GHG emission factors calculated in this way, the electrical load $Load_{el}(reg)$ is multiplied by the corresponding emission factor.

The detailed description of the energy system in Matrix A makes it possible to trace (flow-trace) the emissions occurring in the energy system from the emitting region to the region whose consumption causes the emissions. Flow tracing thus enables the extension from the producer to the polluter pays principle. Missing values are taken into account as described in section 3.5.

In addition to electricity trading, the consideration of storage systems also plays a special role in the context of the GGC. Due to the limited availability of data for smaller storage systems, only pumped storage power plants (PSPPs) are taken into account as a storage technology in the GGC. PSPPs are included in the emissions balance in two places: When electricity is withdrawn from PSPPs, they act like a conventional power plant and provide electricity ($P_{out,sto}$). As with the other generation types, in this case the PSPP receives a specific emission factor at the time of withdrawal. This includes the emissions from the upstream chain of the power plant. The emissions associated with injection during operation, on the other hand, are taken into account at the time of injection via the generation Gen of the power plants running at that time. However, the emissions from the injection process are not shifted to the time of consumption.

1.3If load data or more than one cross-border flow is not available in a main zone (see Annex D) at a given time, flow tracing is not carried out and therefore no consumption-based emission intensity is calculated for this bidding zone.

2.5 Replacement values

In order for the data provided on CO_2 intensity and the share of renewables to be integrated into use cases, a consistent provision of data is required. As data gaps regularly occur in the input data for electricity generation, provisional data is applied for the bidding zones Germany-Luxembourg and Belgium. These replacement values are marked accordingly. The available forecast values from the already calculated previous-day forecast are used as replacement values.

2.6 Sensitivity analyses

Sensitivity analyses are used to examine the influence of methodological decisions and uncertainties on the results. The aspects summarized below were analyzed as part of the GGC.

Scaling factors
The scaling factors scale the electricity generation of each generation type to historical statistical data for the Germany-Luxembourg bidding zone (cf. section 2.2.2). The scaling factors for the years 2019 to 2021 were determined and compared as part of a sensitivity analysis. There are no significant deviations in the monthly scaling factors, which indicates a systematic underestimation in the ENTSO-E data. In the case of the annual scaling factors, there are some fluctuations between the years, depending on the generation type. In principle, it can be assumed - both for ENTSO-E and for Eurostat - that the recording of electricity generation will continue to develop and improve over the years. The scaling factor is therefore calculated using the data from the most recent historically available year.

CHP generation
In a CHP plant, heat is generated as a second product in addition to electricity. In the production of co-products, there is the fundamental question of how the resulting GHG emissions should be distributed. An allocation method must be selected for this. This allocation method has a major influence on the emission factor for electricity and heat generation, as has already been shown in various studies (e.g. [31-33]). Depending on the allocation method selected, there is a wide range for the generation type-specific GHG emission factor for electricity. Here, the allocation method only affects the GHG intensity of generation types for which CHP plants account for a significant share of electricity generation. In Germany-Luxembourg, for example, CHP accounts for more than two thirds of generation for the generation types "fossil gas" and "biomass". The emission factors for these types of generation are therefore more strongly influenced by the choice of allocation method. As no specific allocation method is prescribed in the ISO standards for life cycle analysis, the efficiency method is used here (see section 2.3) to ensure conformity with the GHG Protocol [19].

Electricity imports and exports
Electricity trading is taken into account as explained in section 2.4. In this context, a main zone (see Annex D) was defined based on the relevance of the ENTSO-E bidding zones for emission intensity in the Germany-Luxembourg and Belgium bidding zones. If load data or more than one cross-border electricity flow is not available in a bidding zone of the main zone at a given time, no consumption-based emission intensity is calculated for this bidding zone. If no generation data is available either, no production-based emission intensity is calculated.

2.7 Assumptions and limitations

Generally speaking, the system boundaries as defined in section 2.1 apply. The emission factors provided using this methodology are therefore only applicable for location-based balancing of electricity procurement.

In the following, limitations of the developed method are presented and their influence on the results is classified.

Actuality of the data
In principle, the method developed aims to use input data that is as up-to-date as possible (see section 1.3.2). As shown in Table 2 there are, however, individual data sources that are not regularly updated. This applies, among other things, to data on grid losses. These sources are used until suitable data sources are available that meet the other test criteria. The availability of new data sources is checked at quarterly intervals.

A further limitation results from the fact that only ENTSO-E data is updated continuously. This means, for example, that statistical data for scaling and calculating emission factors is published at the earliest in the course of the following year or with an even greater delay. As reporting must be carried out promptly after the end of the financial year, current ENTSO-E data for this period is offset against input data based on the previous year. For example, to determine the GHG emission intensity, electricity generation from 2022 is calculated with scaling factors and emission factors from 2021, as no data is yet available for 2022. As described in section 2.88, a further calculation for use in other use cases will therefore be initiated in the course of the year as soon as the statistical data for the previous year is available.

Emission factors
As there is no emission factor for the "nuclear" and "marine" generation types in [16] is listed, the value from the IPCC report [21] is used here. No clear emission factor can be provided for other ENTSO-E generation types ("Other" and "Other renewable"). The conservative approach of assigning the highest emission factor in a country to each of these types is therefore chosen. The highest value within the renewable generation types is selected for "Other renewable" .

Scaling factors for Germany-Luxembourg
For bidding zones other than Germany-Luxembourg, a simplified approach without scaling the input data is used. This would require an individual analysis of the ENTSO- E and statistical data supplied in other countries. Depending on the data quality, additional sources would have to be consulted if necessary. Therefore, due to the transparency criterion (see section 1.3.3), a simplified approach is initially pursued.

A further limitation with regard to the generation types is that, in the case of geothermal and hydropower, these only match the reported electricity generation in the statistical data to a limited extent. For this reason, an adapted approach is used to calculate the scaling factors for these generation types, which is described in detail in Chapter 2.2.2 is explained in detail. If the sources and associated documentation are updated, the assumptions made and approaches derived are checked and adjusted if necessary.

In addition, for other types of generation, such as "waste", there is the limitation that it is not clearly documented for the ENTSO-E data whether it is waste from renewable or non-renewable sources. For Germany, a comparison with statistical data was also unable to clarify this unequivocally, but suggests that electricity generation from renewable waste is not included. It is therefore assumed that the reported electricity generation in ENTSO-E consists purely of non-renewable waste and that renewable waste is included in biomass.

Temporal resolution of data
The goal of providing high-resolution data on the emissions intensity of the electricity mix is limited by the availability of data. Implementation to date has therefore been limited to hourly emission intensity, even though a quarter-hourly resolution is being sought in the future. However, the data required for this is not yet available across the board for all ENTSO-E countries.

A higher temporal resolution is also desirable for other input data. This applies, for example, to the scaling factors, for which the highest temporal resolution currently provided by Eurostat is monthly electricity generation. However, this is not available for all generation types, meaning that it can currently only be used for selected generation types (see section 2.2.2). To improve the accuracy of the scaling, this can also be carried out in future for other generation types at a higher temporal resolution as soon as the required data is available.

Furthermore, there is a lack of publicly available, high-resolution data on CHP generation. Due to the lack of data availability and in order to ensure the desired transparency, an annual allocation factor is determined to allocate the emissions to electricity and heat generation. Due to the temperature dependency of heat generation, this leads to an over- or underestimation of the emission factor for CHP plants depending on the month (see section 2.3). As soon as the data situation on the heat side improves, the allocation is to be carried out in future with a higher temporal resolution in order to take this temperature dependency into account.

Life cycle analysis method
Further assumptions are also necessary when applying the life cycle analysis. One is the determination of an allocation method for CHP plants, the effects of which are described in section 06 is discussed. In the GGC, the allocation of emissions to electricity and heat is based on the efficiency method, which is described in the GHG Protocol [19] is recommended. In addition to the data on electricity and heat generation, the assumption of reference efficiencies is necessary (see section 2.3), based on data from the EU Commission. No temperature-specific adjustment is made.

The ISO 14067:2018 [6] requires a subdivision of the GHG footprint into fossil and biogenic GHG emissions. Due to the limited data basis, which is also described in the GHG Protocol [10] explicitly for the location-based accounting of Scope 2 emissions, biogenic GHG emissions are not reported separately in the GGC. For reasons of transparency, however, these are estimated and discussed for a historical year for Germany (see digression 3).

A lack of data also leads to the restriction that GHG emissions in connection with direct and indirect land use changes cannot be mapped. This is not mandatory for the reporting of GHG emissions from electricity generation in accordance with the GHG Protocol [3, 10]. As soon as a better data basis exists for these areas, mapping in the GGC will be reviewed.

Electricity trading and storage
The approach to balancing electricity consumption integrates electricity imports and exports using a flow tracing approach. For methodological reasons, the GHG intensity in transit countries with relatively low domestic generation is mainly determined by the transiting electricity flows. In addition to electricity trading, storage facilities are also taken into account. However, these are initially limited to pumped storage power plants due to the limited availability of data for smaller storage systems. If electricity storage is reported by ENTSO-E, it will be taken into account in the methodology. Pumped storage power plants are currently mapped using the approach described in section 2.4. For reasons of transparency, no temporal shift of emissions from the injection process to the time of consumption is taken into account, as this would require more complex and difficult to understand modeling approaches.

2.8 Results

Finally, the data sets resulting from the method are explained and the extent to which the results described in section 1.3 are fulfilled.

Data records provided
Using the methodology and database described above, GHG emission intensities can be generated for the electricity mix per bidding zone in hourly resolution and for the annual mix and published on the GGC platform [7] can be provided. As described on the platform the results are available to users via an automatic machine-readable interface (API) or via download in csv format. On the user interface and when retrieving data using the API, users can select the desired time period (individual days, weeks, months or subsequently the entire calendar year) and the required scope (Scope 2 or the entire life cycle - LC).

Possible use cases for the emission factors provided are described for potential users both on the platform and in the white paper [1]. Different time resolutions and different time periods (selected days, weeks, months or entire calendar year) are relevant for the use cases.

Input data from ENTSO-E, which form the basis of the GHG intensity calculation, are reworked and improved over time by the data provider. As a result, the calculation of the GHG intensity on the GGC platform is carried out repeatedly if missing data points are subsequently supplied. The calculation of the hourly GHG intensity with a time offset of three hours primarily serves to ensure the short-term availability of data for GHG monitoring on the platform.

Fulfillment of the test criteria
With a view to the information presented in section 1.3 all the objectives set were achieved. *Applicability for relevant use cases* is ensured by calculating and providing the GHG emission intensity of the electricity mix in the German electricity grid in hourly resolution, broken down by Scope 2 and 3. This complies with the principles of location-based accounting in accordance with the GHG Protocol. In addition, the platform and the supplementary documents show how the data is used for relevant use cases.

At the same time, it is ensured that the methodology corresponds to the current *state of the art* and that the database is *up to date*. To this end, particular attention was paid to ensuring that methodological principles of life cycle analysis in accordance with ISO 14040:2006, 14044:2006 and 14067:2018. Furthermore, electricity imports and exports are included in the calculation using the scientifically recognized flow-tracing approach and combined heat and power generation using an allocation method. When using secondary data, sources that are as up-to-date as possible are used, provided they fulfill the other criteria listed in section 1.3.

To ensure the *transparency and traceability* of the calculation, freely available data sources and secondary data from recognized sources are used. In addition, the methodology and database are documented transparently in this document and are therefore comprehensible for users and examiners.

The biggest challenge in meeting the test criteria was the necessary trade-offs between the various criteria. One example of this is the consideration of CHP generation in the emission factor, as separate modeling of heat generation would be necessary for an hourly analysis. In this case, a simple approach was chosen, as this ensures the transparency and traceability of the calculations as an important premise.

3 Summary and outlook

As part of the CO_2-Monitor project, FfE and TenneT developed a method for calculating high-resolution GHG emission factors of the German electricity mix, which was adapted and improved as part of the harmonization with the 50Hertz eco2grid tool. The data is freely accessible on the Green Grid Compass (GGC) platform [7]. The objectives of the method are applicability for the most important use cases, consideration of the current state of science and the greatest possible transparency and traceability for users. This is reflected in certain criteria that the methodology must fulfill, such as the separate calculation of Scope 2 and Scope 3 emission factors. Core methodological elements are the treatment of electricity imports and exports using the flow-tracing approach and the inclusion of combined heat and power generation through allocation according to the efficiency method. In addition, the generation data for the Germany-Luxembourg bidding zone is scaled to statistical figures.

In future, the method will also serve as a basis for short-term forecasts - in addition to the "verification and reporting" use cases - and can potentially even be applied to long-term scenarios. The other use cases described in the white paper [1] from the areas of "Flexibilization and GHG reduction" and "Future-oriented GHG balance" can be developed step by step. Based on the knowledge gained in the course of developing the methodology and the identified use cases, there is a need for further development of the methodology in the future. There are various starting points here, such as

- An application of scaling factors to other European countries
- A more detailed illustration of heat production from CHP
- Integration of further electricity-to-electricity storage systems and sector coupling technologies
- A higher temporal resolution (quarter-hourly)
- The (further) development of methodological approaches to
  - → market-based reporting
  - → higher spatial resolution (regionalization)
  - → Forecast of emission intensities
  - → Integration of future scenarios

However, the feasibility of these approaches depends heavily on the available database and applicability in use cases in practice. The incomplete database and lack of standardization currently pose fundamental challenges for time-resolved CO_2 monitoring. However, standardization makes sense for many use cases in order to ensure a certain degree of comparability. The publication of the GGC, including the available documentation of the methodology and database, should therefore also contribute to the development of an industry standard. Such a jointly developed standard can ensure that the methodology and database of different providers/platforms meet the same requirements. This can facilitate applicability for certain use cases and increase comparability. This can only happen within the framework of a comprehensive stakeholder dialog, which is to be continued in follow-up projects with the relevant actors.

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List of figures and tables

Appendix

The following appendices provide detailed information on the input data used in the method, which remains constant over the years.

A Generation types

To merge the different data sources, it is necessary to match generation types. The following table shows which generation types from the data sources used are assigned to which generation type in the GGC. Cells with a gray background show a possible matching, which, however, is not used in the calculation method.

GGC	ENTSO-E [13]	Eurostat SIEC [16, 17]	EU Commission [22]	AGEB[16] [18]	IPCC [21]
	Non-renewable				
Biomass	Biomass	R5110-5150_W6000RI, R5160, R5210P, R5220B, R5230P, R5230B, R5290, R5300, W6210	S4	Biomass	Biomass - dedicated
Waste[21]	Waste	W6100, W6220	S6	Industrial waste, household waste	-
Fossil Brown coal/Lignite	Fossil Brown coal/Lignite	C0210	S2	Lignite	-
Fossil hard coal	Fossil Hard coal	C0110, C0121, C0129	S1	Hard coal	Coal - PC
Fossil Oil	Fossil Oil	O4000XBIO	L7	Mineral oil	-
Pumped storage	Hydro Pumped Storage	RA100	-	Pumped storage	Hydropower
Fossil gas	Fossil gas	G3000	G10	Natural gas	Gas - Combined Cycle

[16] For renewable generation types, self-consumption is assumed to be 0%. In the absence of self-consumption, 10% self-consumption is assumed for non-renewable power plants.

Nuclear	Nuclear	N900H	O15	Nuclear energy	Nuclear
Fossil coal-derived gas[17]	Fossil coal-derived gas	C0350, C0371, C0379, C0360	G13	-	-
Fossil Oil shale[21]	Fossil Oil Shale	S2000	O18	-	-
Fossil Peat[21]	Fossil Peat	P1000	S3	-	-
Other[21]	Other	-	O18	-	-
	Renewable				
Geothermal	Geothermal	RA200	O17	Geothermal energy	Geothermal
Hydro power	Hydro Run-of-river and poundage	RA100	-	Hydropower	Hydropower
	Hydro Water Reservoir	RA100	-	Hydropower	Hydropower
Solar	Solar	RA420	O16	Photovoltaics	Solar PV - utility
Wind offshore	Wind offshore	RA320 (RA310)[18]	-	Wind offshore	Wind offshore
Wind onshore	Wind Onshore	RA310	-	Wind onshore	Wind onshore
Marine	Marine	RA500	-	-	Ocean
Other renewables	Other renewable	-	-	-	-

[17] On the user interface, these generation types are summarized as "Other conventional" for simplified display.

[18] No differentiation in [16]

B Reference efficiencies

In 2024, the EU Commission presented an update of the harmonized efficiency reference values for the separate generation of electricity and heat, which are used for the allocation according to the efficiency method [22]. The values are for power plants from 2016 onwards. No country-specific adjustments are made.

Generation type	Electricity Reference efficiency in %	Heat Reference efficiency in %	Category of generation types
Biomass	37.0	86	S4
Waste	25.0	80	G12
Lignite	41.8	86	S2
Hard coal	44.2	88	S1
Mineral oil	44.2	85	L7
Natural gas	53.0	92	G10
Nuclear power	33.0	92	O15
Photovoltaics	30.0	92	O16
Geothermal	19.5	92	O17
Oil shale	30.0	92	O18
Peat	39.0	86	S3
Industrial gases	41.8	80	G13

C Grid losses

The grid losses relate to 2018 and are derived from CEER data [20]. If no value is available for 2018, the last available value is used. For countries for which there is no information on grid losses, the average from all countries is used.

	Grid losses in %		Grid losses in %
Bosnia and Herzegovina	6.41	**Romania**[19]	6.78
Belgium	4.58	**Montenegro**	7.87
Bulgaria[19]	6.78	**Netherlands**	2.60
Denmark	4.48	**Norway**	5.42
Germany	4.46	**Austria**	3.48
Estonia	5.26	**Poland**	5.71
Finland[20]	4.00	**Portugal**	8.09
France	6.41	**Sweden**	4.46
Greece nd[20]	9.79	**Switzerland**[19]	6.78
Italy[20]	7.09	**Serbia**	10.96
Croatia	7.32	**Slovakia**	4.27
Latvia	4.49	**Slovenia**	3.75
Lithuania	2.52	**Spain**	8.93
Luxembourg	3.68	**Czech republic**	5.05
Malta[19]	6.78	**Hungary**	6.95
Macedonia	10.35		

[19] No value available, therefore average value (6.78 %) applied.

[20] No value available for 2018, therefore last historical value applied.

D Bidding zones

The bidding zones are classified for the calculation. The designation in brackets is the ENTSO-E designation for the corresponding bidding zone. The following bidding zones are taken into account, with the **main zones** marked in bold:

- Germany-Luxembourg (**DE_LU)**
- Belgium (**BE**)
- Austria (**AT**)
- Bosnia and Herzegovina (BA)
- Bulgaria (BE)
- Switzerland (CH)
- Czech Republic (**CZ**)
- Denmark (**DK_1, DK_2**)
- Estonia (EE)
- Spain (**ES**)
- Finland (FI)
- France (**FR**)
- Greece (GR)
- Croatia (HR)
- Hungary (HU)
- Italy (IT_BRNN, IT_CALA, IT_CNOR, IT_CSUD, **IT_NORD**, IT_ROSN, IT_SARD, IT_SICI, IT_SUD)
- Lithuania (LT)
- Latvia (LV)
- Montenegro (ME)
- Macedonia (MK)
- Malta (MT)
- Netherlands (**NL**)
- Norway (NO_1, **NO_2**, NO_3, NO_4, NO_5)
- Poland (PL)
- Portugal (PT)
- Romania (RO)
- Serbia (RS)
- Sweden (SE_1, SE_2, SE_3, **SE_4**)
- Slovenia (SI)
- Slovakia (SK)

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