FfE Research Center for Energy Economics

EU Displacement Mix

A Simplified Marginal Method to Determine Environmental Factors for Technologies Coupling Heat and Power in the European Union

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1 Executive Summary

The European Union is building the European Energy Union /EC-01 15/ to ensure that Europe is supplied by secure, affordable and climate-friendly energy. In this context, energy efficiency and reduction of CO_2-emissions are prioritised at the EU level as key to realise EU's energy and climate objectives /EC-02 18/. Correctly measuring efficiency gains and CO_2 emission reductions is indispensable to reach the Energy Union objectives and will play an important role in ensuring a level playing field that fairly recognises contributions of all energy solutions accurately. As Europe's energy transition currently brings especially renewable electricity into the energy supply system, electricity is expected to play a great role in helping different sectors decrease their CO_2 emissions.

While security of energy supply and energy costs remain a concern, accurately assessing the environmental impacts of technologies in the energy system is essential to ensure a sound and proportionate EU energy and climate change regulatory framework. The Primary Energy Factor (PEF) for electricity is one of the instruments used by policymakers to assess the efficiency of the electricity. The need for science-based and fit-for-purpose energy efficiency and carbon reduction policies is becoming increasingly relevant to allow a cost-effective energy transition, e.g. for sectors subject to electrification such as the transport sector and heat sector.

In order to estimate the PEF and CO_2 Equivalent Emission Factor (CEEF) of cogeneration units in /FFE-27 09/ the "Replacement Mix" approach was introduced and developed further in /FFE-21 12/. It can be considered a simplified marginal approach, assessing the environmental effects of additional (marginal) electricity generation. In this study the approach is developed further, especially considering the employed data set, accounting of electricity imports and the inclusion of grid losses as well as the upstream chain. This now called displacement mix can also be seen as the mix which would be required to meet additional electricity demand in sectors subject to electrification. The actual mix for additional electricity consumption is highly dependent on the type of load management used for electricity consumers. Studies indicate that system adapted load management of electricity consumers has the potential to reduce their negative effect on the energy supply system by shifting load to times of higher RES infeed /FFE-02 17/, /FFE-07 17/, /FFE-16 17/. In some cases load shifting can even allow further integration of renewable energies into the energy supply system /FFE-50 17/. Also the exclusion of cogeneration plants in the displacement mix can be seen as debatable for its application to evaluate additional electricity consuming units. An inclusion of renewables and cogeneration plants would decrease PEF and CEEF.

In this study, PEF and CEEF values are calculated for each EU-28 country based on the displacement mix, an electricity generation mix that excludes the priority of dispatch generation, e.g. non-dispatchable renewable electricity. Because electricity generation from non-dispatchable renewable energies such as wind, solar and run-of-river has the lowest variable costs, these feed-in as much electricity as they generate If the residual load is positive (electricity demand is higher than generation from priority of dispatch units), these units will not be available to cover any additional electricity demand. Also cogeneration plants are excluded as it is assumed, that they would not be displaced by new cogeneration plants. All further plants are selected in the order of appearance in the merit order curve depending on the residual load (electricity demand minus electricity supply from non-dispatchable renewable energies).In the displacement mix also electricity imports from other EU or non-EU countries are considered.

The study also provides a sensitivity analysis on the effect of in- or excluding nuclear power plants in the category of must-run generation. Aggregated EU-28 PEF and CEEF (hereinafter EU PEF and EU CEEF respectively) are calculated based on the national PEFs and CEEFs, by weighted average with respect to the country's electricity consumption.

Key findings

- The electricity mix displaced by additional generation or used to cover additional electricity demand differs from the yearly average. A "marginal" approach, which more realistically reflects the composition of relevant electricity generation units, more accurately estimates the PEF and CEEF of this specific electricity mixes.
- An average PEF, as proposed by the European Commission in the ongoing Energy Efficiency Directive review, and specific CEEF based on a yearly average electricity generation mix, are not suitable for evaluating the efficiency or carbon intensity of additionally produced or consumed electricity. Using an average approach will overestimate the renewable electricity in the displacement respectively consumption mix. Meanwhile, the marginal approach will more accurately estimate the environmental impact on the electricity system due to additional generation and consumption, signalling more adequately to both policymakers and consumers the environmental impacts of appliances generating or using or this electricity.
- The marginal PEF for the displacement mix excluding the upstream chain, excluding nuclear power plants and including grid losses of 5 % is 2.81 in the EU-28. At national level, the corresponding displacement mix PEFs range from 2.3 to 3.75. Including conversion factors from lower to higher heating value into the calculation, increases the average PEF to 3.26 including nuclear energy and 2.99 excluding nuclear energy.
- The marginal CEEF for the displacement mix is determined including the upstream chain and including grid losses of 5 %. Excluding nuclear power plants this results in a CEEF 986 gCO_2/kWh_{el}.
- A separate analysis was carried out on the potential implications of including nuclear power plants, under the assumption that in some countries nuclear power plants may not act as must-run. Including nuclear power plants in the displacement mix results in a higher EU PEF (of 3.17) and a lower EU CEEF (446 gCO_2/kWh_{el})
- Depending on the calculation method used, the PEF for electricity will be impacted differently by an increasing share of renewable electricity. While the PEF of the average generation mix will decrease at a rate reflecting the increase in renewable electricity generation, the decrease of the marginal PEF will be more gradual than the increasing share of renewable electricity. This is because most of the times the residual load (the difference between electricity demand and the supply of wind and sun electricity) in most countries is still positive in the short term. In the medium to long term the development highly depends on the increase in renewable energy

capacity and the employed load management of additional electricity generation and consumption units.

- The use of PEF and CEEF in climate and energy policymaking is complementary. Both the PEF and CEEF are needed to assess the two-dimensional characteristics in environmental impact (energy savings and reduction of CO_2 emissions). PEF and CEER should be determined correctly and include impacts on the energy system transparently. It may be up to the policymaker to favour one of these factors, depending on the priorities at a certain time. Even in an energy system 100 % free of fossil fuels, the PEF is still needed to improve the overall system efficiency, while the CEEF may lose its relevance.

2 Background and Motivation

The most relevant factors for the assessment of the environmental impact of energy consumption are the primary energy demand for energy supply and the resulting emissions as CO_2-equivalent. In this study the focus are the assessment of the primary energy demand per supplied energy, called the Primary Energy Factor (PEF), and the specific emissions of greenhouse gases, e.g. CO_2, for energy supply, namely the CO_2 Equivalent Emission Factor (CEEF).

As part of the ongoing review of the EU Energy Efficiency Directive, the European Union PEF for Electricity (EU PEF) is being revised. The European Commission has proposed to calculate the EU PEF from the average yearly composition of the European electricity generation mix. The Commission has calculated that the increasing share of electricity from renewable energies results in a lower EU PEF compared to the current value, from 2.5 to 2.0 (further information see chapter 6). In addition, the Commission has indicated its intention to use this updated average EU PEF in the context of the Eco-design and Energy Labelling regulations 811/2013 and 813/2013, to estimate the efficiency of different electricity consuming as well as generating devices.

Yet, for technologies which couple the heat and electricity sector, such as electricity generators like combined heat and power (CHP) and electricity-consuming space heaters, the actual PEF of the electricity produced or consumed may vary strongly from the average electricity generation mix. This is caused by the seasonality of heat demand and the corresponding composition of the electricity mix at times of demand. Furthermore, additional loads and generators affect the daily dispatch of power plants, which is executed according to the Merit Order curve. Additional generation displaces the latest plant chosen from the Merit Order curve and extra consumption is supplied by this plant (explanation see chapter 3.2). Therefore, the PEF and the CEEF of a yearly average generation mix of electricity supply is not suitable to evaluate additional electricity generation or consumption units.

In this study, different approaches to determine environmental factors such as CEEF and PEF are first described and compared. Then country specific and EU-28 PEFs and CEEFs of electricity generation resulting from the displacement mix methodology are calculated. Furthermore dependencies of PEF and CEEF on electricity generation composition are assessed focussing on the in- and exclusion of nuclear energy in the generation mix. Moreover, the results from the average approach used by the European Commission are compared with the results of this study and implications are discussed. From this, conclusions regarding the adequacy of using the average and displacement mix approach in the context of EED review are derived as well as the applicability of the PEF and CEEF in other contexts.

3 Approaches to Determine Environmental Indicators for Sector-Coupling Technologies

Several approaches exist to determine the PEF and CEEF of electricity used or generated by sector coupling technologies. In cogeneration heat and electricity are generated simultaneously. Consequently, it is debateable how to allocate the primary energy input, emissions or operating costs to either of these energy outputs. To address this problem, different allocation methods have been developed. In chapter 3.1 several frequently used approaches are briefly described and the power bonus method is explained in more detail. For the power bonus method it is necessary to determine the environmental indicators of the electricity displaced due to additional generation, e.g. in the case of cogeneration. This electricity mix can also be determined via different methods (see chapter 3.2). The same methods can be considered relevant for the determination of the environmental factors of additional electricity consumption.

3.1 Fuel Allocation Methods in Cogeneration

Here the only method to be explained in detail is the power bonus method, which is included in the Energy Performance of Buildings Directive /EC-06 10/. Other methods for the allocation of input energy in coupled production are the heat bonus, alternative generation, Carnot and electricity loss method. While further information can be found in /EC-05 17/ and /FFE-75 10/, here some basic differences are highlighted:

1. Heat bonus method: The electricity receives a bonus from the heat side, according to the heat source which is replaced.
2. Alternative generation method: The reference efficiencies of single-output and CHP plants are given. The fuel demand of the CHP is allocated to heat and power generation according the ratio of the efficiency of the CHP conversion relative to the efficiency of the reference technology.
3. Carnot method: This method uses the equivalence of heat and power that can be transformed into each other according to Carnot’s efficiency. Therefore only CHP plant data is needed but no external references are used.
4. Electricity loss method: In CHP plants with a variable power-to-heat ratio, the reduction of electricity generation is compared to the additional generation of heat. An example for application are extraction steam turbines.

Figure 3-1 illustrates how the power bonus method is applied assuming an annual electrical efficiency of 30 % and a thermal efficiency of 50 %. Therefore the CHP plant would generate 30 units of electricity out of 100 units of primary energy. While this only includes the fuel energy which directly enters the CHP plant, further energy input is required to cover the losses of the upstream (mainly fuel preparation and transport). In the example of Figure 3-1 an exemplary amount of 10 additional primary energy units has been chosen as upstream primary energy demand. Generally, the determination of the primary energy demand for the upstream chain is rather complicated.

In order to quantify the primary energy input needed for electricity generation, the electricity output is multiplied with the primary energy factor for electricity (see formula (1)). This primary energy factor for electricity is in our case predetermined by legislation and in the illustrated example is set to 2.5 in accordance with the currently valid value for the European Union /EC-01 12/.

$$E_{PE,el,in} = E_{el,out} \cdot f_{PE,el,mix} \tag{1}$$

$E_{PE,el,in}$ $in\ TWh$:	Primary energy input allocated to electricity generation
$f_{PE,el,mix}$:	Primary energy factor of electricity based on the generation mix
$E_{el,out}$ $in\ TWh$:	Electricity output

Consequently, the primary energy input for the heat generation can be derived according to formula (2):

$$E_{PE,th,in} = E_{PE,in} - E_{PE,el,in} \tag{2}$$

$E_{PE,th,in}$ $in\ TWh$:	Primary energy input allocated to heat generation
$E_{PE,in}$$in\ TWh$:	Total primary energy input
$E_{PE,el,in}$ $in\ TWh$:	Primary energy input for electricity generation

Then the resulting primary energy factor for heat from cogeneration can calculated from formula (3), for the chosen example it is 0.7.

$$f_{PE,th} = \frac{E_{PE,th,in}}{E_{th,out}} \tag{3}$$

$f_{PE,th}$:	Primary energy factor of CHP heat
$E_{PE,th,in}$ $in\ TWh$:	Primary energy input allocated to heat generation
$E_{th,out}$ $in\ TWh$:	Heat output

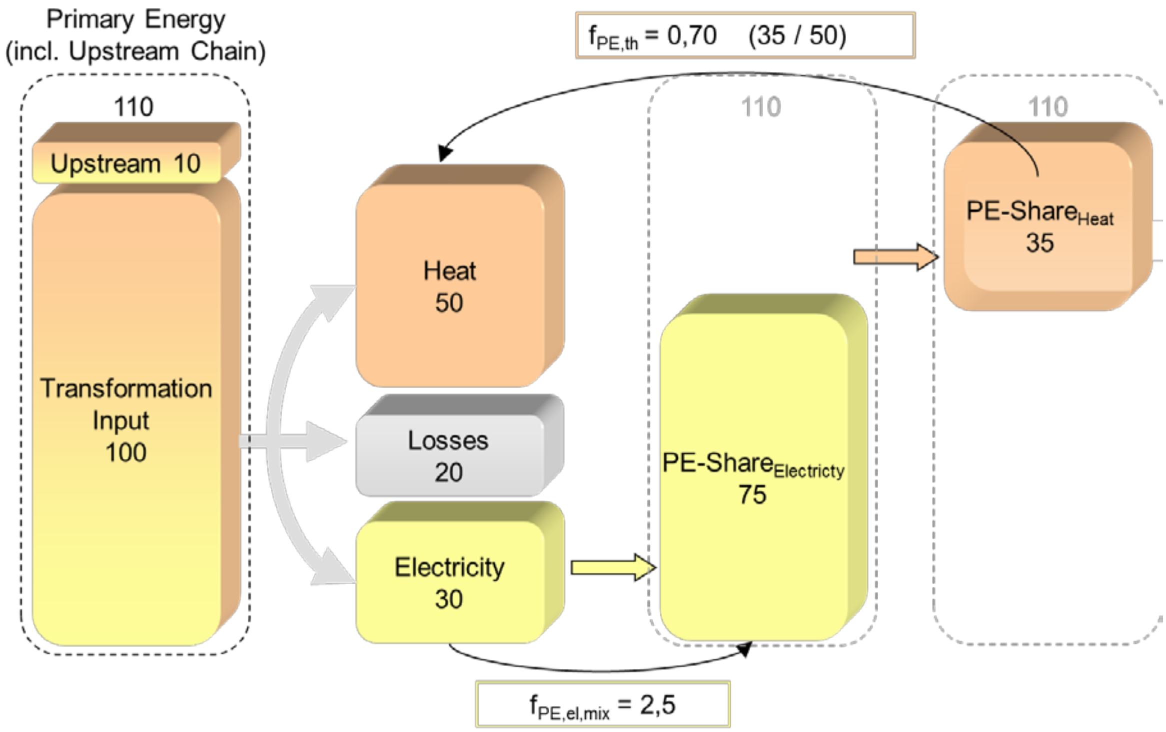

Figure 3-1: *Calculation example for the energetic allocation of CHP via the power bonus method including the upstream chain /FFE-27 09/*

Figure 3-2 illustrates the possible difference caused by the exclusion of the upstream chain for this allocation method, assuming an accordingly smaller PEF for electricity of 2.3. Consequently, the resulting PEF for district heat from CHP is also slightly smaller if the upstream chain is excluded.

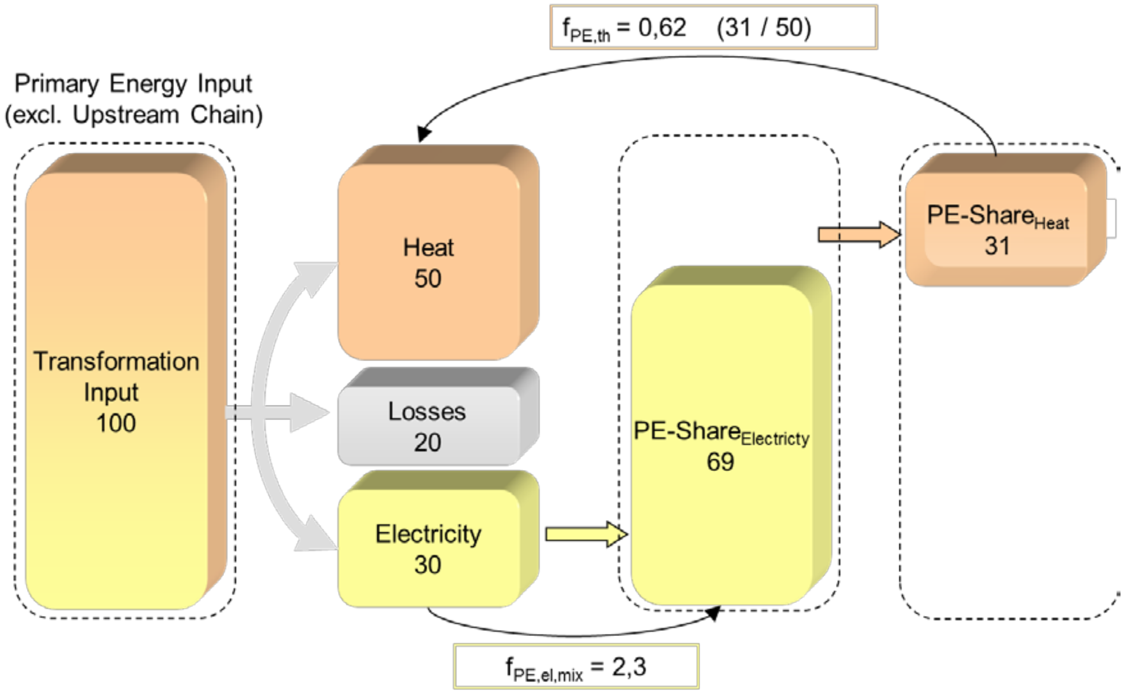

Figure 3-2: *Calculation example for the energetic allocation of CHP via the power bonus method excluding the upstream chain /FFE-27 09/*

3.2 Determination of the Environmental Factors for Electricity

In the previous chapter the PEF for the electricity mix was taken from regulation. In order to determine the PEF and the CEEF of electricity, several approaches are in use which can be classified as yearly average approach, hourly average approach, marginal approach and scenario-based analysis (/ETG-01 17/, /ISI-103 16/). Additionally, in /FFE-21 12/ the replacement mix approach was introduced. Here, the different approaches are briefly described and their inherent advantages as well as disadvantages are listed. The focus is on the criteria accessibility of data and realistic depiction of the actual electricity supply system.

For understanding the relevance of time resolution the principle generation-follows-consumption is highly relevant. This means that the electricity demand must at any time be covered by running generation units. The type of generation units selected for the supply of the electricity can be derived from the merit order of electricity generation. In the merit order curve all available plants for electricity generation are sorted price-ascending (see Figure 3-3). Because electricity generation from non-dispatchable renewable energies such as wind, solar and run-of-river has the lowest variable costs these feed-in as much electricity as they generate. All further plants are selected in the order of appearance in the merit order curve depending on the residual load (electricity demand minus electricity supply from non-dispatchable renewable energies).

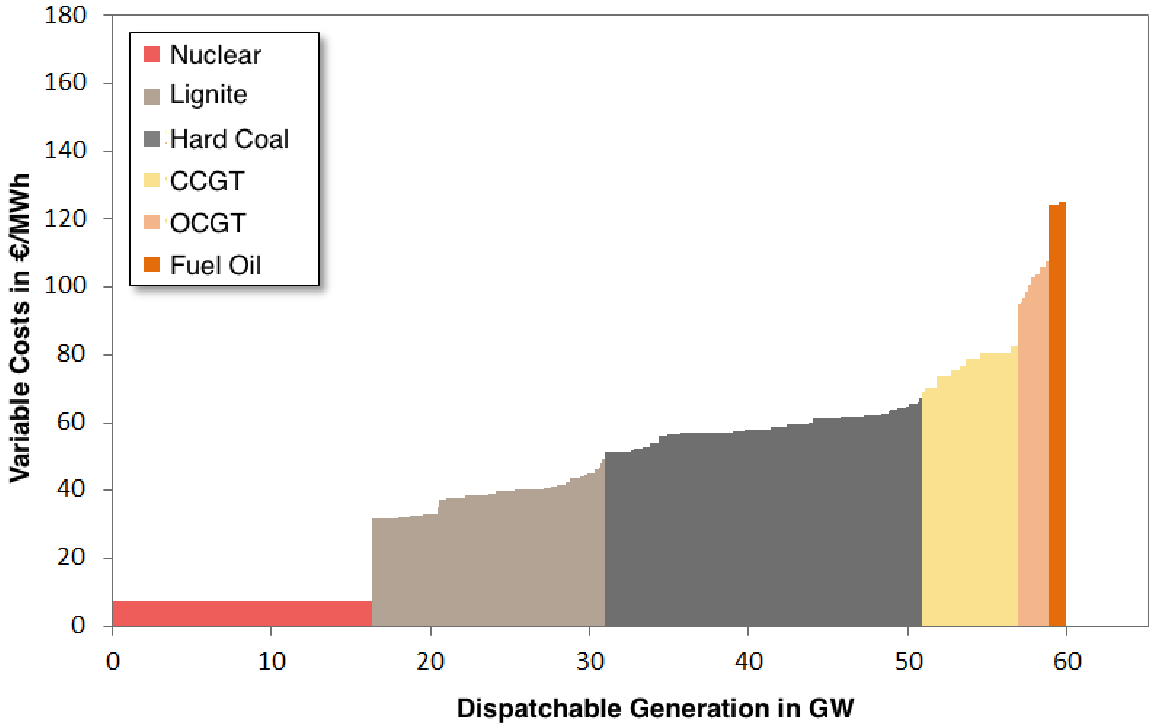

Figure 3-3: *Exemplary Merit Order curve for electricity generation*

For example at an electricity demand of 50 GW and an electricity generation from renewable energies of 10 GW, the residual load is 40 GW. Taking into consideration the merit order curve in Figure 3-3 all nuclear and lignite plants and a part of the hard coal plants will be dispatched to supply electricity

According to their position in the merit order curve and the resulting full load hours, the different generation plant can be divided into base load (approx. over 6,000 full load hours), medium load (approx. between 2,000 and 6,000 full load hours) and peak load (approx. under 2,000 full load hours). While nuclear power plants for example mainly run in base load due to low variable prices, fuel oil plants run at times of peak load.

Figure 3-4 exemplarily shows the development of the active power plants in two weeks of January. High yields from wind energy in the first week reduced the residual load noticeably so that even the base load plants reduced power. Additional generation would therefore displace not only gas and hard coal but also base load power. In the second week from Wednesday to Friday there was a period of low RES-E generation. Here, the marginal plant affected by additional generation would be a peak load plant.

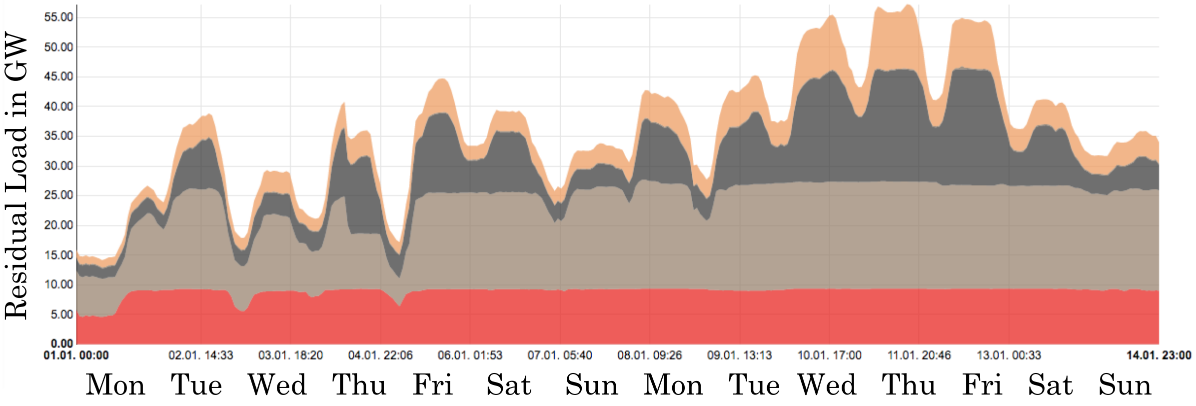

Figure 3-4: *Example of time series of residual load (14 days) with peak (orange) medium (dark grey) and base load plants (brown & red) /ISE-03 18/*

Yearly average approach

The overall yearly primary energy demand for electricity generation is divided by the yearly electricity generation. Due to this neither seasonal nor within-day fluctuation of the composition in electricity generation units are reflected. Furthermore, the assumption is false that every additional unit of electricity demand will be covered by the same composition of electricity generating units as the already existing electricity mix. Especially renewable energies will make up a significantly lower share in the electricity mix. Also electricity generation units newly added to the system will not displace the average electricity generation mix. The main advantage of the approach is the availability of the required data.

Hourly average approach

For every hour of the year the primary energy demand for electricity generation is divided by the appropriate electricity generation in that hour. Due to the change in electricity generation composition throughout the year, the results for the environmental factors differ strongly over the year. The applicability of this method is mainly limited to the availability of data. Furthermore, the same limitation regarding additional electricity generation and consumption compared to the generation mix applies.

For the evaluation of heat coupled units the heat profile can serve as weighting factor of the hourly conventional power plant mix. For every country these profiles can be derived from weather data combined with further assumptions or by gas consumption profiles.

Marginal approach

The marginal approach considers that additional electricity generation will not displace the average electricity generation mix, but only plants which can decrease their generation (dispatchable medium or peak load units). Similarly, additional demand for electricity is supplied not by the current generation mix, but by those power plants, which are running in part load or are not operating and can therefore increase their electricity generation. These are usually plants from the peak and medium load sector.

In order to determine the power plants that will de- or increase their generation, respectively, two possibilities exist: the average of marginal power plants approach and the last power plant approach. The average of marginal power plants approach considers a mix of all dispatchable power plants. In the last power plant approach, only the power plant with the highest generation costs from the currently activated plants is relevant. This plant is used to cover the last kWh of demand and is also called a marginal plant.

The employment of the marginal approach is suitable for a realistic estimation of the supply system effect of additional generation or consumption. Unfortunately, for assessments of diverse electricity markets such as the market of the EU vast and temporally resolved data collection is necessary (e.g. electricity generation composition, country-specific merit order curves).

Displacement mix

Because of the time restriction of this study a highly time-resolved precise quantification of the share of power plants that are replaced by additional electricity generation in each EU member state is not feasible: Therefore, a simplified estimation of a comprehensible displacement mix has been derived. Similar to the marginal approach, this concept is based on the assumption that each additional unit of electricity produced in a cogeneration plant does not replace the entire fuel mix but only certain fuels, which are represented by a displacement mix. This displacement mix mainly excludes the electricity generation from renewable energy sources and must-run units such as waste combustion. The methodology and results for the PEF as well as CEEF are in detail explained in chapter 4.

The same reasoning applies to each additional unit of electricity demand. Yet intelligent load management of electricity consuming devices may change the validity of applying the same approach to additional electricity consumers.

Scenario-based analysis

The most suitable way to investigate the effect of additional electricity demand or supply is to carry out a dispatch simulation with and without the deployment of the relevant technologies. Then their effect can be deduced from a comparison of the simulation results. This approach gives the most accurate results, but requires suitable simulation tools and assumptions on hourly data. Overall the approach is more time-intensive to implement than the other approaches. Still, according to /EC-06 14/ and /EC-02 11/ the relevant data should be available as well as simulation models of the energy system

/FFE-04 16/. Moreover, studies using models of the energy system in different EU-countries, in order to calculate possible benefits from micro-CHP, have already been executed /ICL-04 17/.

Applicability of approaches for technologies coupling heat and power
Technologies, which couple the sectors heat and electricity, are predominantly heat driven. The heat demand strongly differs seasonally and during the course of the day. Hence in order to calculate the environmental factors of these technologies realistically temporally resolved heat profiles can be combined with resolved data on electricity generation composition. Therefore, only approaches including the analysis of temporally resolved data are suitable to realistically evaluate these technologies.

4 Determination of Displacement Mix, Primary Energy Factors and CO_2 Equivalent Emission Factors

In this chapter, firstly general assumptions and relevant parameters for the sensitivity analysis are derived (4.1). Then, the two relevant data sets displacement mix (4.2) and country net electrical efficiency (4.3) are calculated from adequate primary data. From the combination of these data sets, the country-specific values and the EU-28 average of the PEF (4.4) as well as CEEF (4.5) are calculated. A discussion of the results and exemplary peculiarities of the countries Denmark and France are qualitatively outlined in 4.6.

4.1 General Assumptions and Sensitivities

While grid losses are included all of the final results, a sensitivity analysis in- and excluding the electricity generation from nuclear power plants is done.

Grid losses through locally generated electricity
Losses in electric power networks are dependent on the length of transmissions lines as well as necessary voltage transformations. These losses differ between the cases (a) electricity generation in the transmission grid connected to consumption in distribution grids and (b) generation as well as consumption in the distribution grid. Therefore, in the final results for PEF and CEEF a bottom limit estimate of grid losses of 5 % /IEA-10 14/ are included.

Inclusion of nuclear power in the displacement mix
The calculations in the methodology include the generation of electricity from nuclear power, which due to their very low variable costs could be seen as priority of dispatch unit and would therefore not be replaced by CHP. As a sensitivity analysis the electricity generation from nuclear power plants is neglected in the calculation of the displacement mix and the resulting PEF and CEEF are determined.

4.2 Displacement Mix

In order to determine the displacement mix by country at first the electricity generation by country is calculated, then modifications due to electricity imports are derived to obtain the electricity consumption.

Electricity generation by country

In order to calculate the simplified displacement mix for each member state of the EU-28, the electricity generation mix for each member state as well as for the adjoining countries exporting to the EU-28 has to be determined. The share of electricity production by fuel type for 2015 is taken from the Eurostat data series "Supply, transformation, consumption - electricity - annual data (nrg_105a)" /EPP-07 16/. In the primary data the following generation types are available:

1. gross electricity generation autoproducer CHP plants,
2. gross electricity generation autoproducer electricity only,
3. gross electricity generation main activity CHP plants and
4. gross electricity generation main activity electricity only.

For this study the electricity generation from autoproducers and main activity CHP are excluded. Additional electricity generation from large CHP plants on the electricity market will not displace autoproduction. Moreover, it is assumed that CHP plants do not replace CHP plants. Hence, the only relevant dataset is gross electricity generation main activity electricity only.

Electricity imports

For the calculation of a displacement mix in each member state it has to be considered that CHP can also replace electricity imported from a neighboring country. While in the previous displacement mix study from 2012 the imports were only determined for the countries with a net electricity import over 10 % of the own generation, in this study the country specific net electricity exchange is calculated for each country from /EPP-08 16/ and /EPP-09 16/ (e.g. net electricity exchange of Germany with Denmark, France and Sweden). From these balances the actual electricity consumption of each country is determined. This is seen as highly relevant as nearly all EU-28 countries exchange relevant amounts of electricity and the PEF and CEEF therefore differ between a country‘s electricity generation and consumption.

A weighted average based on the country-of-origin-composition of the electricity supplied for consumption is used to newly calculate for all importing countries the:

- electricity generation mix by fuel,
- PEF of electricity generation by primary energy,
- CEEF per primary energy.

This calculation procedure is based on the assumption that the composition of the electricity exports of a country is equal to the entire fuel mix of that country.

The fuel share in the displacement mix for each member state is calculated by excluding both the electricity generation from renewable energy sources (RES) and “other fuels” according to formula (4):

$$\mathrm{\rho'}_{\mathrm{PE}} = \mathrm{\rho}_{\mathrm{PE}} \cdot \frac{\sum_{\mathrm{PE}} \mathrm{E}_{\mathrm{el,PE}}}{\sum_{\mathrm{PE}\notin\mathrm{ren}} \mathrm{E}_{\mathrm{el,PE}}} \tag{4}$$

ρ'_{PE} in %:	Share of primary energy in the displacement mix
$\mathrm{\rho}_{\mathrm{PE}}$ in %:	Share of primary enery in the overall generation mix
$\mathrm{E}_{\mathrm{el,PE}}$ $in\ TWh$:	Annual gross electricity generation by primary energy
$\mathrm{PE} \notin \mathrm{ren}$ $[-]$:	Non-renewable primary energy of the PE mix (excluding both RES and “other fuels”)

4.3 Average Annual Net Electrical Efficiency

The primary energy input for electricity generation strongly depends on the electrical efficiency of a power plant. Therefore, the average annual gross electrical efficiency for each member state of the EU-28, as well as countries from which relevant amounts of electricity are imported, have to be determined. The International Energy Agency (IEA) publishes data regarding the annual electricity generation by fuel and the associated fuel input. From this the average annual gross electrical efficiency by primary energy carrier and country is calculated according to formula (5).

$$\eta_{el,PE,gr} = \frac{E_{el,PE,out}}{E_{PE,in}} \cdot 100 \tag{5}$$

$\eta_{el,PE,gr}$ in %:	Average annual gross electrical efficiency
$E_{el,PE,out}$ $in\ TWh$:	Annual electricity generation by primary energy
$E_{PE,in}$ $in\ TWh$:	Fuel input for electricity generation by primary energy carrier

As stated by the IEA, a gross electrical efficiency for nuclear energy of 33 % can be assumed for all member states representing the average efficiency for nuclear power plants in Europe /IEA-03 11/.

Unfortunately, it is not possible to calculate the average annual gross electrical efficiency for each fuel of the displacement mix for each member state based on the IEA data. The reasons for the partial incompleteness are:

- The IEA energy balances do not distinguish brown coal, lignite and peat from hard coal, therefore, only a summarized gross efficiency for coal can be determined.
- If the electricity generated by a fossil fuel is only generated in CHP plants in a certain country in the considered year, no precise allocation of the fuel input for the electricity generation in CHP plants was done. Hence, the average annual gross electrical efficiency cannot be calculated for the electricity generation from non-CHP plants.
- For some countries, the energy balances are either incomplete or inconsistent.

To address these problems, the following assumptions and simplifications are applied, if no average annual gross electrical efficiency can be calculated:

- If the efficiency of the generation units cannot be derived from the available data an average gross efficiency by fuel based on the evaluation of all member states can be applied resulting in only a minor discrepancy.
- Several efficiencies cannot be calculated and are also not required. For example in Latvia electricity is almost solely generated in CHP plants. Therefore, it is not possible to determine the average annual gross electrical efficiency based on the IEA data, but it is also not needed to calculate the value for this analysis.

The resulting average annual gross electrical efficiencies are summarized in Table 4-1.

Table 4-1: *Resulting average annual gross electrical efficiencies referring to lower heating value (LHV) based on the IEA Energy Balances /IEA–03 11/ and /IEA-04 11/ (Green: No efficiency factor required; Pink: No efficiency factor available, average of other countries used; Blue: Calculated efficiency factor not suitable, average of other countries used; Brown: Calculated efficiency factor from 2009 data not suitable, 2008 data used)*

	Coal & Peat	**Oil**	**Gas**	**Nuclear**
	kWh_{el}/kWh_{LHV}	kWh_{el}/kWh_{LHV}	kWh_{el}/kWh_{LHV}	kWh_{el}/kWh_{LHV}
Austria	42 %	40 %	53 %	33 %
Belgium	37 %	34 %	49 %	33 %
Bulgaria	33 %	37 %	32 %	33 %
Croatia	38 %	38 %	34 %	33 %
Cyprus	-	37 %	-	33 %
Czech Republic	36 %	34 %	34 %	33 %
Denmark	-	37 %	-	33 %
Estonia	31 %	34 %	47 %	33 %
Finland	41 %	38 %	49 %	33 %
France	41 %	37 %	37 %	33 %
Germany	38 %	41 %	59 %	33 %
Greece	36 %	37 %	51 %	33 %
Hungary	33 %	39 %	40 %	33 %
Ireland	40 %	36 %	50 %	33 %
Italy	37 %	33 %	52 %	33 %
Latvia	-	-	-	33 %
Lithuania	-	-	-	33 %
Luxembourg	-	-	54 %	33 %
Malta	-	32 %	-	33 %
Netherlands	42 %	-	54 %	33 %
Poland	37 %	-	-	33 %
Portugal	39 %	37 %	56 %	33 %
Romania	30 %	30 %	38 %	33 %
Slovakia	30 %	-	41 %	33 %
Slovenia	36 %	37 %	47 %	33 %
Spain	37 %	38 %	54 %	33 %
Sweden	-	46 %	-	33 %
United Kingdom	37 %	37 %	52 %	33 %
Non-EU-countries				
Serbia	34 %	37 %	47 %	33 %
Bosnia and Herzegovina	-	-	-	33 %
Norway	52 %	37 %	56 %	33 %
Turkey	36 %	34 %	53 %	33 %

For the net electrical efficiency the self-consumption, , i.e. the consumption of auxiliaries in power plants needed for internal processes has to be considered. This aspect is merely a technical issue and it is therefore assumed that there are no major differences in own consumptions between member states. Based on this assumption, the average fractions for own consumption for Germany are used to calculate the average annual net electrical efficiency for each power plant type in the EU and relevant countries exporting to the EU.

Table 4-2: *Own consumption for electricity generation in Germany in % /FFE-27 09/*

	2003	2004	2005	2006	2007	Average
Hard Coal	7.8 %	7.8 %	8.0 %	7.8 %	7.7 %	7.8 %
Natural and Derived Gas	3.8 %	3.6 %	3.4 %	3.3 %	3.1 %	3.4 %
Oil	8.3 %	8.2 %	7.2 %	8.4 %	8.4 %	8.1 %
Brown Coal, Lignite, Peat	7.8 %	7.7 %	8.0 %	8.2 %	8.1 %	7.9 %
Nuclear	5.2 %	5.2 %	5.2 %	5.1 %	5.2 %	5.2 %

The annual net electrical efficiency is calculated by formula (6).

$$\eta_{el,PE,net} = \eta_{el,PE,gr} \cdot (1 - f_{PE,own-cons}) \tag{6}$$

$\eta_{el,PE,net}$ in %:	Average annual net electrical efficiency by primary energy carrier
$\eta_{el,PE,gr}$ in %:	Average annual gross electricity generation by primary energy carrier
$f_{PE,own-cons}$$in$ %:	Fraction of own consumption for electricity generation by primary energy carrier

4.4 Calculation of EU-28 Primary Energy Factors

For the PEF calculation of the displacement mix the PEF per primary energy carrier and country are relevant. These can be calculated as the reciprocal of the net electrical efficiencies determined in chapter 4.3. The resulting primary energy factors are summarized in Table 4-3.

Table 4-3: *Primary Energy Factor by country and energy carrier calculated from net electrical efficiency*

	Coal & Peat	Oil	Gas	Nuclear
	[-]	[-]	[-]	[-]
Austria	2.61	2.71	1.96	3.20
Belgium	2.91	3.16	2.11	3.20
Bulgaria	3.30	2.96	3.28	3.20
Croatia	2.86	2.86	3.05	3.20
Cyprus	-	2.97	-	3.20
Czech Republic	3.03	3.16	3.01	3.20
Denmark	2.95	2.96	-	3.20
Estonia	3.50	3.16	2.19	3.20
Finland	2.63	2.88	2.13	3.20
France	2.67	2.91	2.80	3.20
Germany	2.85	2.63	1.76	3.20
Greece	3.05	2.95	2.02	3.20
Hungary	3.26	2.78	2.60	3.20
Ireland	2.72	2.99	2.07	3.20
Italy	2.93	3.34	1.99	3.20
Latvia	-	-	-	3.20
Lithuania	-	-	-	3.20
Luxembourg	-	-	1.92	3.20
Malta	-	3.38	-	3.20
Netherlands	2.58	-	1.93	3.20
Poland	2.95	-	-	3.20
Portugal	2.77	2.95	1.86	3.20
Romania	3.58	3.61	2.70	3.20
Slovakia	3.65	-	2.54	3.20
Slovenia	3.02	2.96	2.19	3.20
Spain	2.90	2.89	1.93	3.20
Sweden	-	2.37	-	3.20
United Kingdom	2.90	2.96	2.01	3.20
Non-EU-countries				
Serbia	3.19	2.96	2.19	3.20
Bosnia and Herzegovina	-	-	-	3.20
Norway	-	2.96	1.85	3.20
Turkey	3.02	3.20	1.95	3.20

Taking into account the share of each fuel in the displacement mix and the associated PEF, the PEF of the displacement mix can be calculated for each member state as:

$$f'_{PE,el,MS} = \sum_{PE} \left(\frac{\rho'_{PE,MS}}{\eta_{el,PE,net,MS}} \right) \tag{7}$$

$f'_{PE,el,MS}$: Primary energy factor for electricity of the displacement mix per member state

$\rho'_{PE,MS}$ in %: Share of primary energy in the displacement mix per member state

$\eta_{el,PE,net,MS}$ in %: Average annual net electrical efficiency by primary energy and member state

For nearly all member states an import fuel mix (see chapter 4.2) was calculated. Therefore, in contrast to the results in the predecessor study also countries without own non-CHP fossil electricity generation units have a PEF and CEEF for all fuels. The results are given in Figure 4-1.

The EU-28 average PEF is calculated from the country specific PEFs as the weighted average regarding the country's electricity consumption. The resulting average PEF for the CHP displacement mix of the EU-28 is 3.17 including nuclear energy or 2.81 excluding nuclear energy, respectively.

As the electric efficiencies were based on net calorific value, also the PEF is here stated for the net calorific value. From /ANL-01 08/ average conversion values for the different fossil fuel types can be derived: 0.95 (coal), 0.90 (gas) and 0.93 (oil). Including these conversion factors into the calculation, increases the average value to 3.26 including nuclear energy and 2.99 excluding nuclear energy.

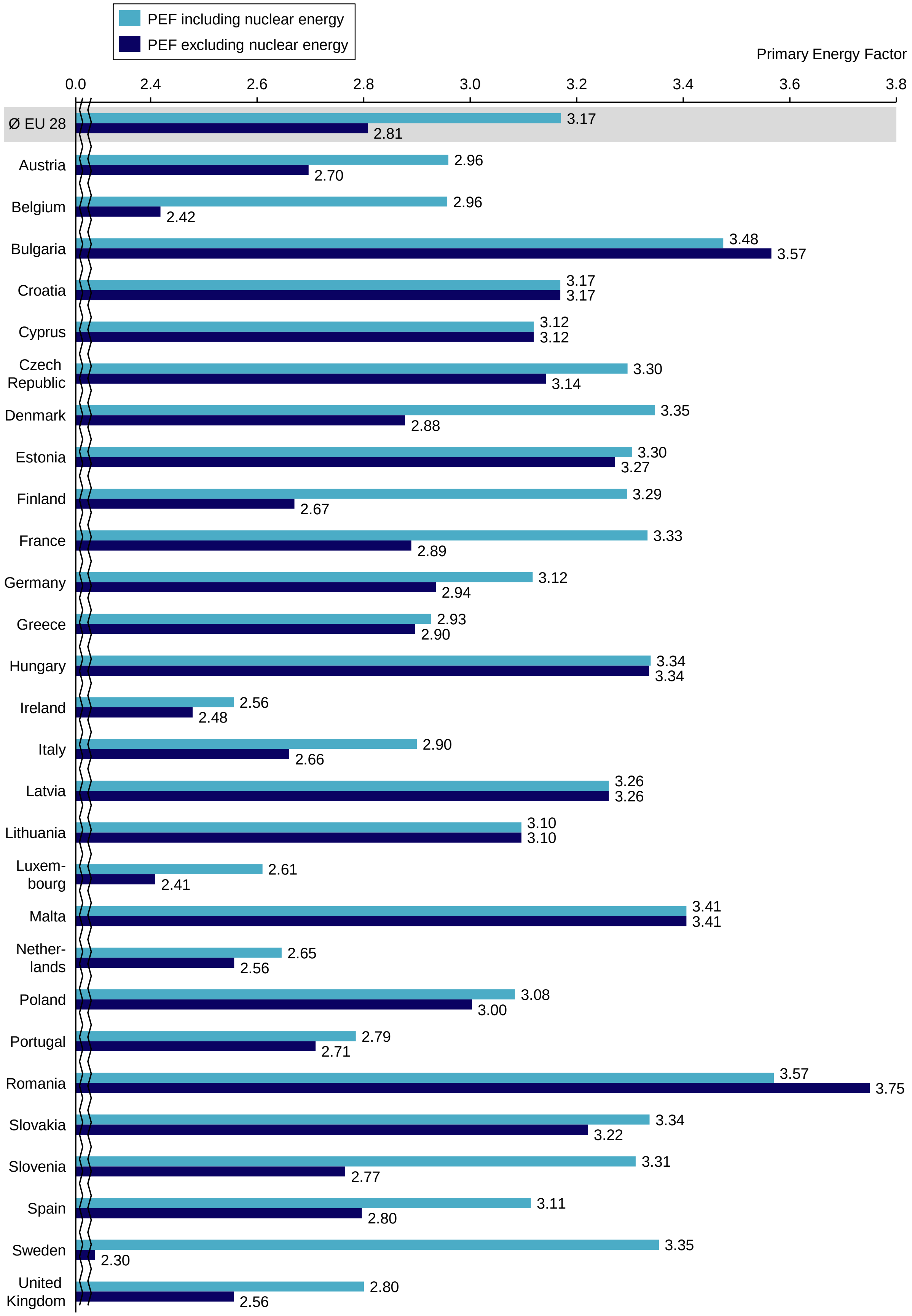

Figure 4-1: *Resulting Primary Energy Factors for electricity of the EU-28 including grid losses according to displacement mix methodology based on lower heating value*

4.5 Calculation of EU-28 CO_2 Equivalent Emission Factor

Because the primary data gives information for electricity generation from primary energy carrier sub-types (e.g. gas includes blast furnace gas, coke oven gas, etc.), a weighted average for energy carrier specific CO_2-emissions is calculated employing the emission coefficient of energy carriers from /IGES-01 06/.

The specific emission factor for blast furnace gas was adapted according to the following logic. Overall, the CO_2-emissions of blast furnace gas can be separated in two parts. The one part of the CO_2 emission freight accumulates inevitably due to the pig iron production by deoxidation of iron ore with coke in the furnace stack. It has been subtracted from total CO_2 emissions. Accordingly only the CO content of burnable gas and uCEEFul fuel is accounted for in the CO_2 balance, neglecting a hydrogen content of 2 – 4 %. Following this approach, the specific emission factor of blast furnace gas in the energy sector is 573 gCO_2/kWh (equal to 159 tCO_2/TJ).

In contrast to the methodology of the previous study, the upstream chain of energy carriers is included in the calculations, here no differentiation between the countries was considered. Data for the additional CO_2 emissions due to the upstream chain is taken from /ECOINV-01 17/, for the evaluation here the data from IPCC 2001 - GWP for 100 years was chosen. The country specific emission factors for the combination of direct emissions and upstream chain by energy carriers are given in Table 4-4.

It shall be underlined that only the upstream chain of the energy carriers is included here, especially for nuclear fuel the final disposal would be of even more importance.

The CEEF of the displacement mix by country is calculated according to formula (8). Results by country are visualized in Figure 4-2.

$$f_{CO_2,el,MS} = \sum_{PE} \left(\rho'_{\mathrm{PE,MS}} \cdot \frac{f_{CO_2,PE}}{\eta_{el,PE,net,MS}} \right) \tag{8}$$

$f_{CO_2,el,MS}\ in\ \frac{g}{kWh}$:	Specific CO_2 emission factor related to electricity output in each member state
$\rho'_{PE,State}\ in\ \%$:	Share of primary energy in the displacement mix and per member state
$f_{CO_2,PE}\ \ in\ \frac{g}{kWh}$:	Specific CO_2 emission factor by primary energy carrier
$\eta_{el,PE,net,MS}$	Average annual net electrical efficiency by primary energy and member state

The difference between an inclusion and exclusion of nuclear power in the displacement mix shows that the CEEF strongly depends on the assumed boundary conditions. The average CEEF in EU-28 is calculated from the country specific results as the weighted average regarding the country's electricity consumption. The resulting average CEEF for the CHP displacement mix is 446 gCO_2/kWh_{el} including nuclear energy or 986 gCO_2/kWh_{el} excluding nuclear energy.

Table 4-4: *Country and energy carrier specific CO_2 emissions referring to lower heating value (LHV) derived from composition of energy carrier subtypes and their specific CO_2 emissions according to /IGES-01 06/ with upstream emissions from /ECOINV-01 17/ (net calorific values for nuclear fuel elements /NIEDER-01 14/, peat /BEV-01 02/, others from /AGEB-01 18/)*

	Hard Coal	Brown Coal. Lignite. Peat	Oil	Gas	Nuclear
	$gCO_2/$ kWh_{LHV}	$gCO_2/$ kWh_{LHV}	$gCO_2/$ kWh_{LHV}	$gCO_2/$ kWh_{LHV}	$gCO_2/$ kWh_{LHV}
Austria	388	-	320	239	-
Belgium	388	-	304	292	3
Bulgaria	388	372	315	239	3
Croatia	388	-	318	239	-
Cyprus	-	-	319	-	-
Czech Republic	-	371	320	239	3
Denmark	-	-	309	-	-
Estonia	-	388	425	197	-
Finland	388	388	319	573	3
France	388	-	315	289	3
Germany	389	371	310	244	3
Greece	-	371	318	239	-
Hungary	394	371	317	240	-
Ireland	388	388	316	239	-
Italy	389	-	318	239	-
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Luxembourg	-	-	-	239	-
Malta	-	-	319	-	-
Netherlands	388	-	-	273	3
Poland	-	371	308	-	-
Portugal	388	-	319	239	-
Romania	-	371	-	239	3
Slovakia	-	-	-	239	3
Slovenia	-	-	308	239	3
Spain	390	-	327	254	3
Sweden	-	-	314	-	3
United Kingdom	388	-	324	239	3

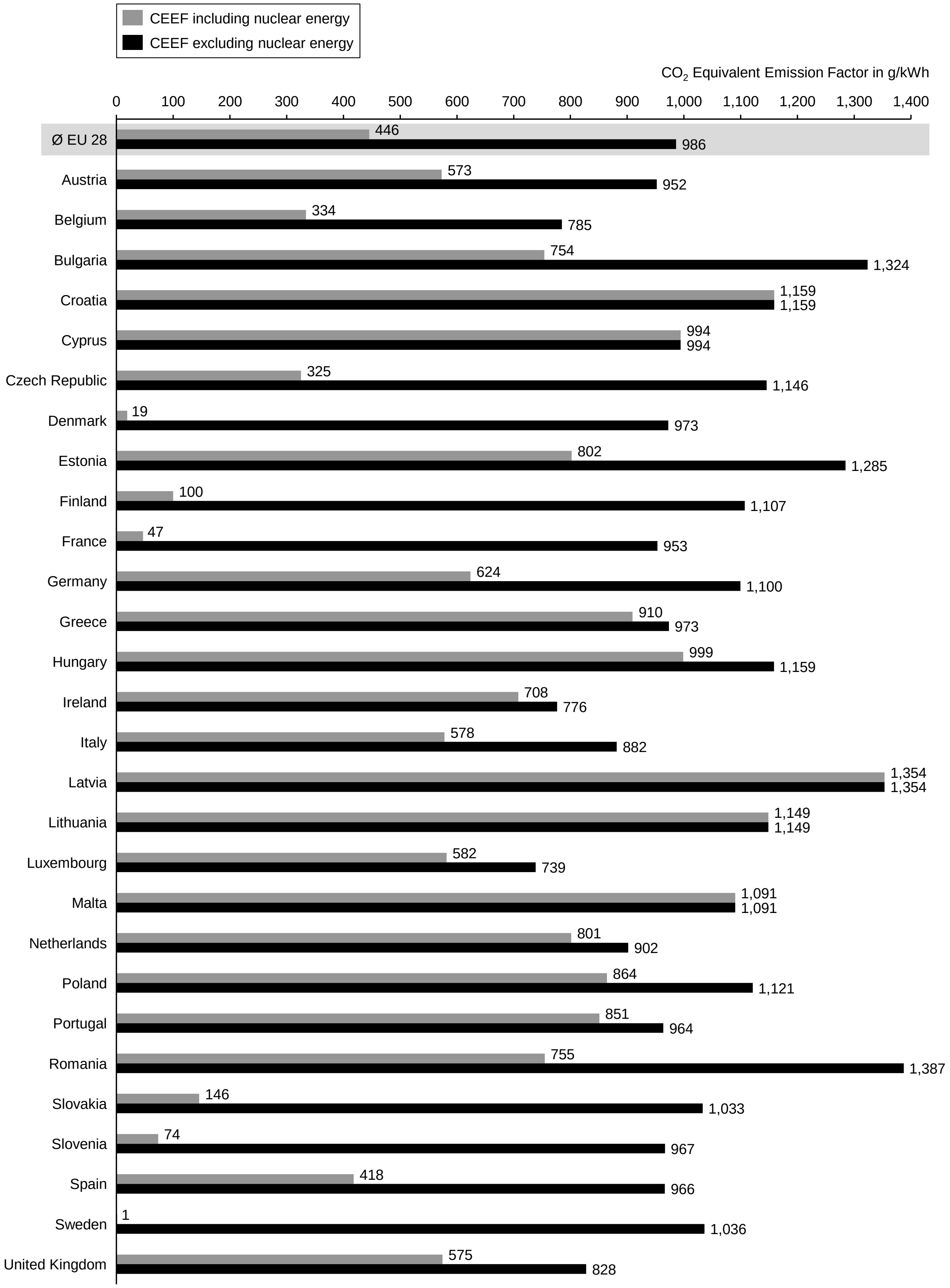

Figure 4-2: *Resulting CO_2 Equivalent Emission Factors for electricity of the EU-28 including grid losses according to displacement mix methodology*

4.6 Discussion and Comparison of the Results

This chapter explains the limitations of employed data set and provides recommendations for improvement of the method, addressing individual countries with specific energy mixes.

Limitations of the accesible data

Firstly, it is relevant that the Eurostat data does not contain information on generation units with installed capacities of less than 1 MW.

Furthermore, the data differentiates between electricity generation of CHP and electricity-only plants. Still, a CHP plant can run both in condensing (electricity-only) mode or cogeneration mode. For example, in the Czech Republic in 2015 about 32.5 TWh are generated by fossil fuel-based CHP plants /EPP-07 16/ of which only 10 TWh are generated in CHP mode, the remainder in condensing mode /ERU-01 16/. Employing this data in the displacement mix methodology leads to an increase in PEF from 3.2 to 3.3 (including nuclear energy) and from 3.13 to 3.14 (excluding nuclear energy). Including nuclear energy, the CEEF increases from 325 to 750 gCO_2/kWh_{el}, excluding nuclear energy it decreases from 1,146 to 1,128 gCO_2/kWh_{el}.

Data on this differentiation for the EU-28 possibly exists, but due to the limited time frame of this study and further required plausibility checks is not included in the calculation method.

Special case: France

Due to the high proportion of electricity from nuclear energy in France, nuclear power plants do not only serve as base load but also cover medium load. Therefore, the approach to exclude nuclear energy from the displacement mix is not suitable. For a realistic inclusion of nuclear power into the displacement mix hourly resolved time series of electricity generation such as transparency data according to /EC-06 14/ and /EC-06 14/ for all countries is required. Such detailed data analysis for the expansion of CHP in France was done in /ARTE-01 18/. They found that the system beneficial CHP-production will primarily substitute CCGT generation within France /ARTE-01 18/.

Special case: Denmark

In Denmark almost all electricity generation comes from CHP, renewable energies (basically wind) or imports. When excluding both from the displacement mix, only the import mix is left for the displacement mix. In fact, new CHP plants could displace older CHP with lower efficiency and higher marginal costs or imports. In winter electricity generation by wind is high in Denmark as well as electricity generation from CHP due to high thermal energy demand. Accordingly, additional CHP which covers heat demand in winter would replace renewable energies. This case was excluded for the approach in the displacement mix and can only be derived from analysis of timely resolved data for electricity generation composition.

PEF in EU legislation

The PEF proposed by the European Commission in the 2016 Revision of the Energy Efficiency Directive (EED) employs an average approach based on PRIMES projections for 2015, estimated at 2.09. This value differs significantly from the resulting displacement mix PEF estimated at 3.17 or 2.81 in- or excluding nuclear power plants, respectively. To a great extent, the difference is explained by applying different approaches: simplified yearly average PEF, as calculated for the Energy Efficiency Directive revision, vs. the simplified marginal PEF, as presented here. Further reasons for the difference seen in the values (2.09 vs. 2.81-3.71) may also be relevant and are presented in Table 4-5. For the PEF in the EED grid losses were neglected. Moreover, the PEF in the EED includes Norway in the calculation, while it is excluded in the approach employed in this study. Due to a high share of renewables in the Norwegian electricity mix, the overall PEF is reduced. Nevertheless, the EU-28 displacement mix indirectly and consistently accounts for the electricity imported from non-EU countries including Norway.

Table 4-5: *Comparison between characteristics of PEF of European Commission and Displacement Mix approach*

	EU PEF in EED Impact Assessment	EU PEF – Displacement Mix	Impact
Value	2.09	2.81 resp. 3.17 (for lower heating value)/ 2.99 resp. 3.26 (for higher heating value)	
Method	Average Electricity Mix	Discplacement Electricity Mix (simplified marginal mix)	High impact
Year	2015 (based on PRIMES projections)	2015 (based on Eurostat real values)	Some impact
Upstream losses	Excluded	Excluded (included in CEEF)	Some impact
Grid losses	Included (5.9 %)	Included (5 %)	Some impact
Heating value	Gross calorific value	Net calorific value and conversion to gross calorific value	Some impact
Geographical scope	EU-28 + Norway	EU-28, including imports from all relevant non-EU countries	Some impact

5 Displacement Mix Outlook in Short to Medium Term

During the next decade the share of renewable energies in the energy sector will increase primarily in the electricity sector. Depending on the calculation approach used, the PEF and CEEF for heat-connected electricity generation/demand in 2020 will be impacted differently by the increasing share of renewable electricity. The outlook given here can be seen as highly simplefied. Especially in medium and long term the composition of power generating and consuming plants may underlye vast changes, due to new market structures.

The average generation mix approach firstly neglects the composition of electricity generation at time of additional generation/consumption. Secondly, it neglects that additional electricity generation displaces dispatchable plants according to the merrit order curve (see chapter 3.2). Similarly additional demand usually has to be covered by dispatchable plants. Therefore, the average PEF and CEEF will decrease at a rate reflecting the increase in renewable electricity generation. In contrast to this the decrease of the marginal PEF and CEEF will be more gradual than the increasing share of renewable electricity. This is because most of the times the residual load (i.e. the difference between electricity demand and the supply of wind and sun electricity) in most countries is still positive in the short to medium term. Accordingly additional electricity from CHP will still displace conventional thermal power plants.

The same is valid for additional electricity consumption by energy sectors to be electrified. Only if times with negative residual load occur more frequent, i.e. the electricity harvest from renewable energies is larger than the consumer load, or the load is shifted towards times of large supply form renewable energy, the new electrical consumers affect the energy system in time slots including the PEF of renewable electricity generation. In these times with negative residual load, cogeneration plant should power down and serve the heat loads by heat storages and power-to-heat technologies /IFAM-01 18/.

Figure 5-1 illustrates a paradox in the PEF development: If the share of non-dispatchable renewables in the electric power system increases, the PEF of displaced electricity by additional generation or additional consumption may increase. This is true as long as baseload plants using cheap fuels can afford to operate at lower efficiencies as peak load plants using comparably expensive fuels. Yet, within one category of generation units (e.g. hard coal) the plants are sorted efficiency-decreasing. So if the marginal power plant is still of the same type, a decrease of the residual load may lead to a decrease in PEF.

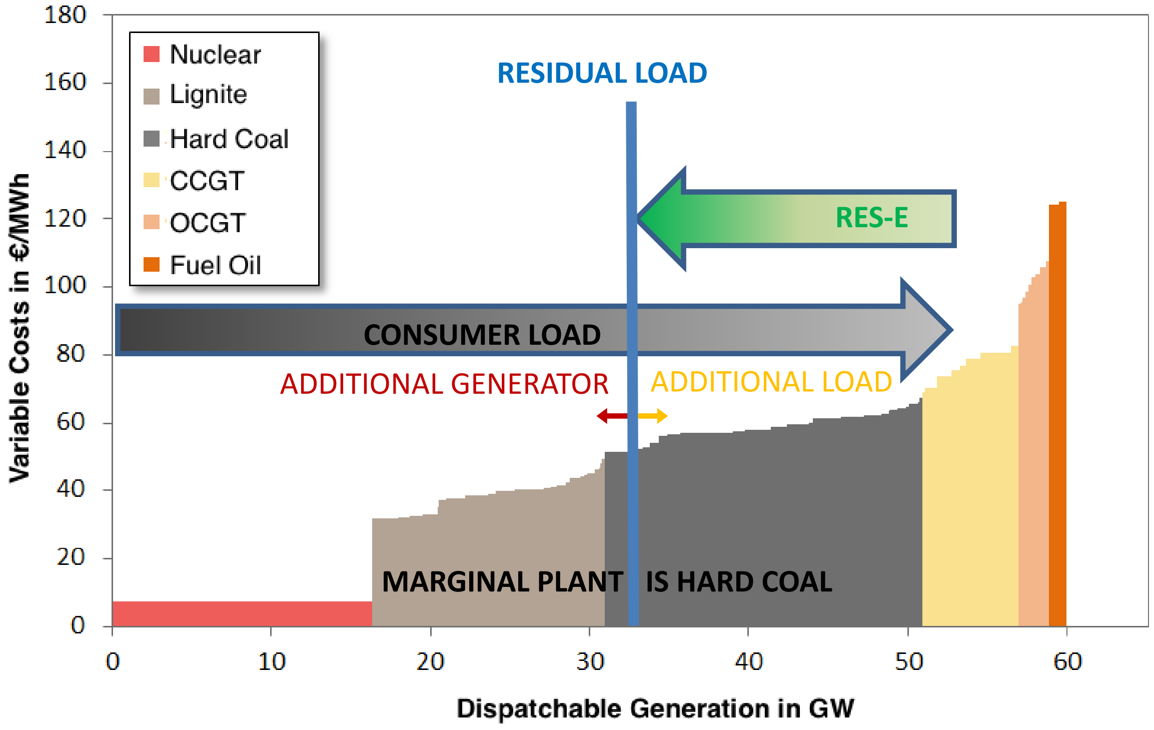

Figure 5-1: *Marginal plant determined by consumer load and RES-E yield, the higher the RES-E contribution the higher is the PEF of the displaced marginal plant*

When variable generation costs are not only dominated by fuel prices but also by additional generation costs, such as CO_2-emission certificates, the order of dispatch changes. Then power plants with low specific emissions will run in base load and those with high specific emissions in medium load. Accordingly the PEF of the marginal plant will always decrease with an increase in electricity generation from renewable energies.

The displacement mix methodology is based on the dispatchable conventional plants as load following unit. Therefore in short term an increasing share of renewable energies in the overall electricity generation mix will have little to no effect on the results. In medium and long term the composition of different dispatchable generation units per country will change, e.g. possibly higher share of gas-fired plants because they generate electricity more flexibly. Then the PEF and CEEF will also decrease.

6 Conclusions: Applicability of Primary Energy Factors and CO_2-Equivalent Emission Factors in the EU Framework

European and national legislation uses PEFs for electricity to convert electrical energy into primary energy. This is relevant for both the assessment of final energy consumption and the generation of electricity. In the heating sector electricity consuming and generating installations are used. Their environmental impact can be assessed by a Primary Energy Factor (PEF) or CO_2 Equivalent Emission Factor (CEEF). At EU level, the following legislative documents are the most important ones.

6.1 Overview of Existing EU Regulatory Framework

Energy Efficiency Directive

Directive 2012/27/EU of 25 October 2012 on energy efficiency /EC-01 12/ aims to increase energy efficiency across the entire energy value chain, from production to final consumption, in order to achieve the EU’s 20 % efficiency target. The conversion table in Annex IV of the directive specifies that for savings in final electricity consumption a PEF of 2.5 may be used. If justified, member states may choose a different factor in national legislation.

According to the legislative proposal COM(2016)0761 /EC-05 16/, published in November 2016, the European Commission recommended to lower the PEF for electricity from 2.5 to 2.0. The European Parliament adopted a counter proposal in January 2018 favoring a default PEF of 2.3 (cf. P8_TA-PROV (2018)0010) /EU-01 18/, only applicable to the Energy Efficiency Directive, which shall be revised every 5 years. Member states may apply a different PEF, provided that it is based on a transparent method, taking into account the national energy mix and is comparable across countries.

Energy Labelling (EL) of Space Heaters Regulation

Regulation (EU) No 811/2013 of 18 February 2013 /EU-12 13/ supplements the Energy Labelling Directive 2010/30/EU and defines in its Annex I a conversion coefficient of 2.5. This factor reflects an estimated efficiency of the average EU generation mix of 40 %. Cogeneration space heaters receive a bonus on the space heating efficiency by adding the electrical efficiency multiplied by the above factor. The same conversion factor is used to assess the efficiency of electric heaters.

Ecodesign (ED) Regulation

Regulation (EU) No 813/2013 of 2 August 2013 /EC-01 09/, implementing the Ecodesign Directive 2009/125/EC, uses also a conversion coefficient of 2.5 for multiplication of electrical energy when assessing the primary energy consumption. Similar to Regulation (EU) No 811/2013, a bonus of 2.5 times the electrical energy is granted for generated electricity.

Energy Performance of Buildings Directive

Directive 2010/31/EU of 19 May 2010 /EC-06 10/ promotes low-energy buildings by stipulating a common methodological framework for calculating the integrated energy performance of buildings including a relevant energy certification process using numerical indicators of primary energy. One target is to speed up the deployment of nearly zero-energy buildings. PEFs needed for the assessment of the primary energy consumption may be developed nationally according to national or regional yearly average values and relevant European standards.

Derived from the background that buildings in Europe are responsible for 40 % of final energy consumption, while energetic retrofitting proceeds at a low rate of 0.4-1.2 %, the European Commission issued in November 2016 a proposal to revise the directive (cf. COM/2016/0765) /EC-01 09/ with the motto “energy efficiency first”. According to the proposal, the calculation of the PEF may be based on national or regional data using weighted averages or on specific information to the relevant energy system. The share of renewable energy sources in the supply of final energy carriers shall be accounted for.

6.2 Discussion on the Methodology: Average vs Marginal

A study commissioned by the European Commission /ISI-103 16/ looked into several aspects of how to determine the efficiency of the electric power system including the question of whether to use the average generation mix or the marginal approach. The evaluation criteria focus on precision of the approaches (50 % weighting) while not neglecting complexity (4 % weighting), cf. Table 7, /ISI-103 16/.

The relevant impact assessment on the PEF review /EC-07 16/, /EC-08 16/, /EC-09 16/ states: “The rationale behind using the marginal generation unit is that relatively small changes in consumption lead to changes only in the generation of electricity in the last units used to cover demand. [..] The primary energy consumption of the marginal generator often differs substantially from the average generation” (Ibid p. 165). Nevertheless, there seems to be some uncertainty as to how complex these calculations are. “While the average generation mix is easy to estimate, determining the marginal generation unit requires more complex assumptions. [..] Complex and time-consuming power system model calculations would have to be carried out to determine the marginal supplier for a specific point in time.”

Being somewhat more complex than the generation mix as average approach, the marginal approach is in fact a weighted average and facile methods for its calculation exist. As demonstrated by this study, employing a simplified marginal approach needs manageable resources only. The main challenge for the full marginal method consists in collecting data on the national consumption profiles. Using the timeseries of the residual load (REMIT data is available at ENTSO-E's transparency platform) and the installed net generation capacity (cf. /ENTSOE-02 17/) the current marginal plant can be determined via the merit order. This timeseries of 8,760 hours with either the PEF or the CEEF of the marginal plant is weighted according to the production respectively consumption profile. In the case of heating profiles, gas consumption timeseries may serve as a proxy, the grid load of representative heat networks or meteorological data. In contrast to the processing of time series, the simplified marginal approach only uses aggregated yearly data.

The additional complexity of carrying out a marginal approach has to be traded off against the gain in precision and the importance of the sector it is applied to. The magnitude of difference between the average and marginal generation mix justifies a deeper investigation what happens in reality.

The choice of a PEF for electricity in the EED has fundamental implications for the development of the European energy system because this conversion coefficient is applied between different energy carriers similar to a fixed exchange rate. Given the common use of the default factor of 2.5 in several EU pieces of legislation today, the PEF to be adopted in the EED will probably spill over to other legal texts. The choice of the default factor, methods used for justification of a national deviation or the reuse of the PEF in other European legislative texts should be carefully assessed. Choosing a PEF which does not reflect the physical reality of energy conversion in terms of thermodynamics and electrodynamics and which does not respect the operating mode of liberalized energy markets, may result in a suboptimal performance of energy systems, causing sunk costs and corrective actions later in terms of reaching the EU energy and climate objectives.

6.3 Primary Energy Factor and CO_2 Equivalent Emission Factor

Primary energy factors are essential to address efficiency improvements in energy systems because they help us understand the whole energy chain from extraction, processing, transformation, utilisation and final disposal or recycling. In the Energy Efficiency Directive, the reduction of exergetic energy losses is the primary target. As a side effect, the greenhouse gas emissions are also reduced when considering a more efficient use of fossil fuels. As the mitigation of greenhouse gas emissions is also a key objective for EU policy makers, the question arises of whether both targets of low PEF and low CEEF should be merged into one criterium, as currently the mitigation of greenhouse gas emissions is in the spotlight.

With the future prospects of a 100 % renewable energy system, all energy carriers will be without GHG emissions. This is true not only for electricity but also for renewable fuels which are needed as feedstock for the chemical industry, for the transportation sector or as long-term storage. On this pathway the CEER will become less relevant. Nevertheless, the "energy efficiency first" principle implemented through the use of the PEF, will keep its importance. Even CO_2 emission free renewable energy has costs, both in CAPEX and in OPEX. Renewable electricity generating plants affect the environment as man-made installations, therefore their use should be efficient in order to decrease their environmental effect. The “not in my back yard” attitude shows that there are acceptance problems e.g. for wind farms. These occur even among supporters of the energy transition.

Therefore, there is a difference between the case where consumer needs can be fulfilled by energy harvesters using an installed capacity of e.g. 1,000 GW solar and 1,000 GW wind farms in an efficient energy system, or in the case with higher exergy losses where an installed capacity twice that big is needed. The correlation between economic activity and energy respectively exergy use has been shown repeatedly, cf. /CMER-01 01/, /KUEM-01 11/. Exergy as the ability to perform physical work is the valuable part of energy, and this fact is valid today and also in a future free of CO_2 emissions.

Both factors PEF and CEEF are needed to assess the two-dimensional characteristics in environmental impact. The factors should be determined correctly and disclose the qualities of an energy system transparently. It may be up to the policymaker to favour one of them as a secondary step.

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8 Annex – Profiles for EU-28 and individual countries

In the following charts the Average Mix according to /EC-06 17/ for in-country generation is given, while the Displacement Mix, calculated according to the methodology described in chapter 4, includes imports. The electricity generation composition included in the displacement mix, only makes up a share of overall electricity consumption. The share the displacement mix has of overall electricity consumption highly differs by country. Here the PEF is always given regarding the lower heating value.

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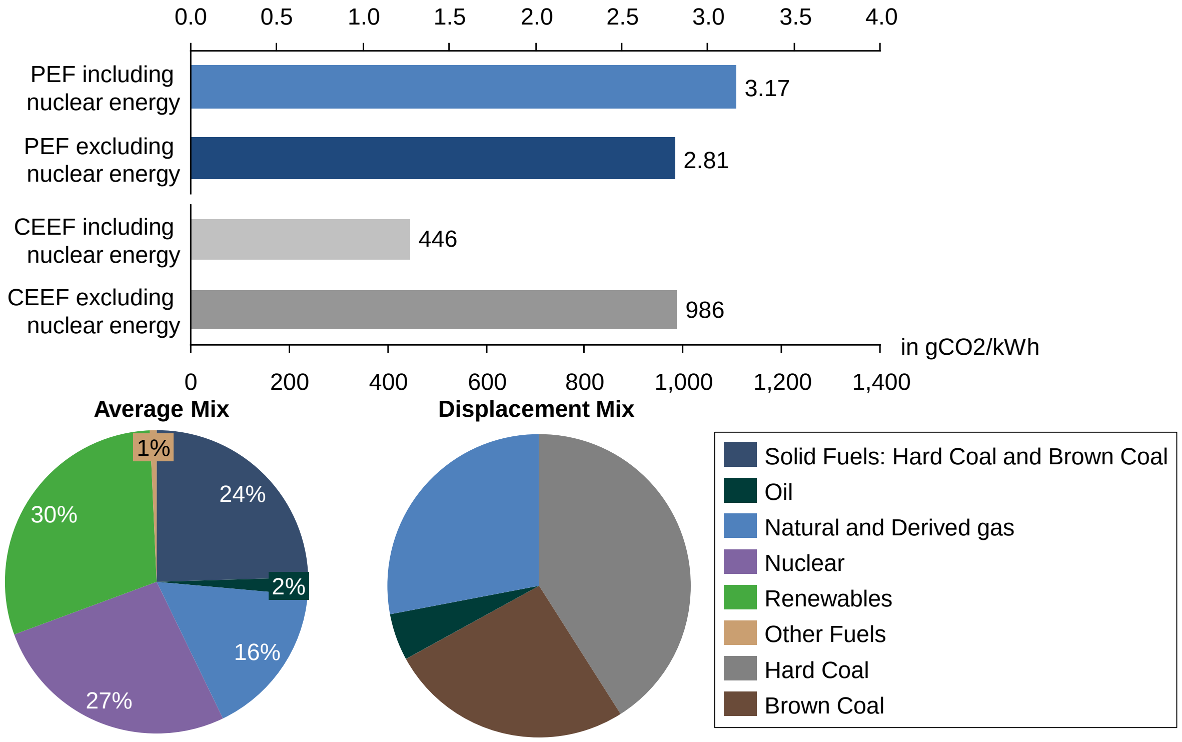

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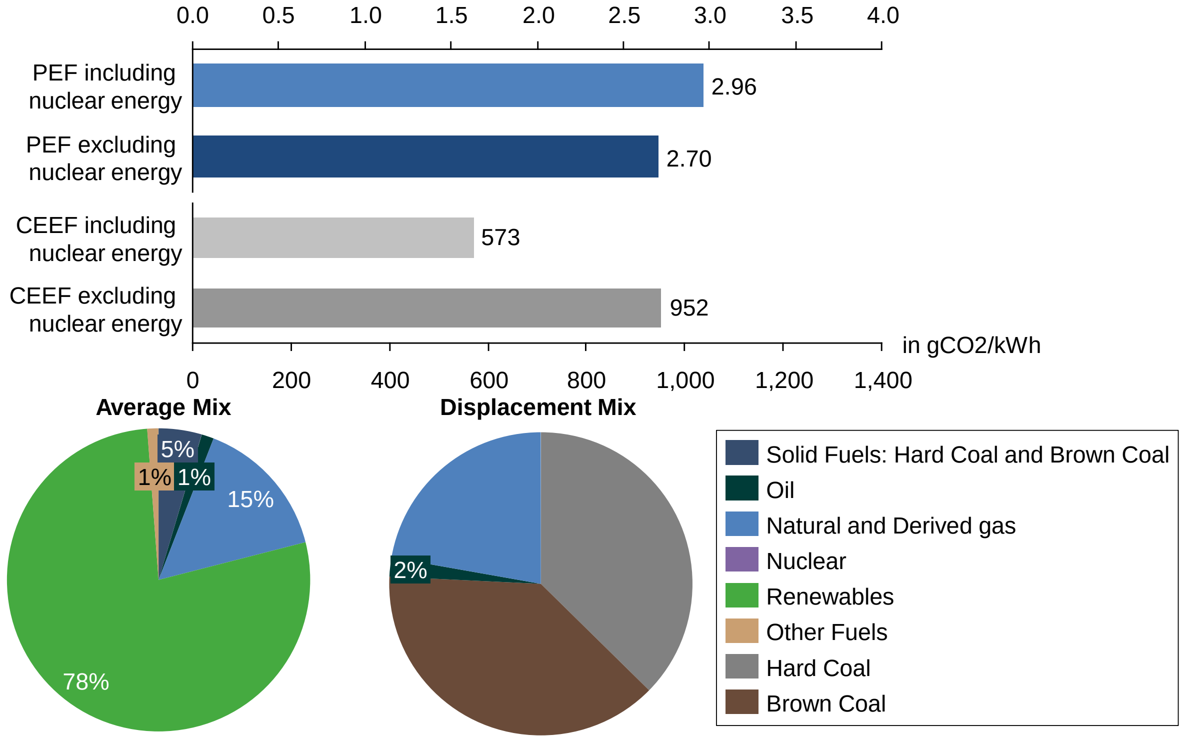

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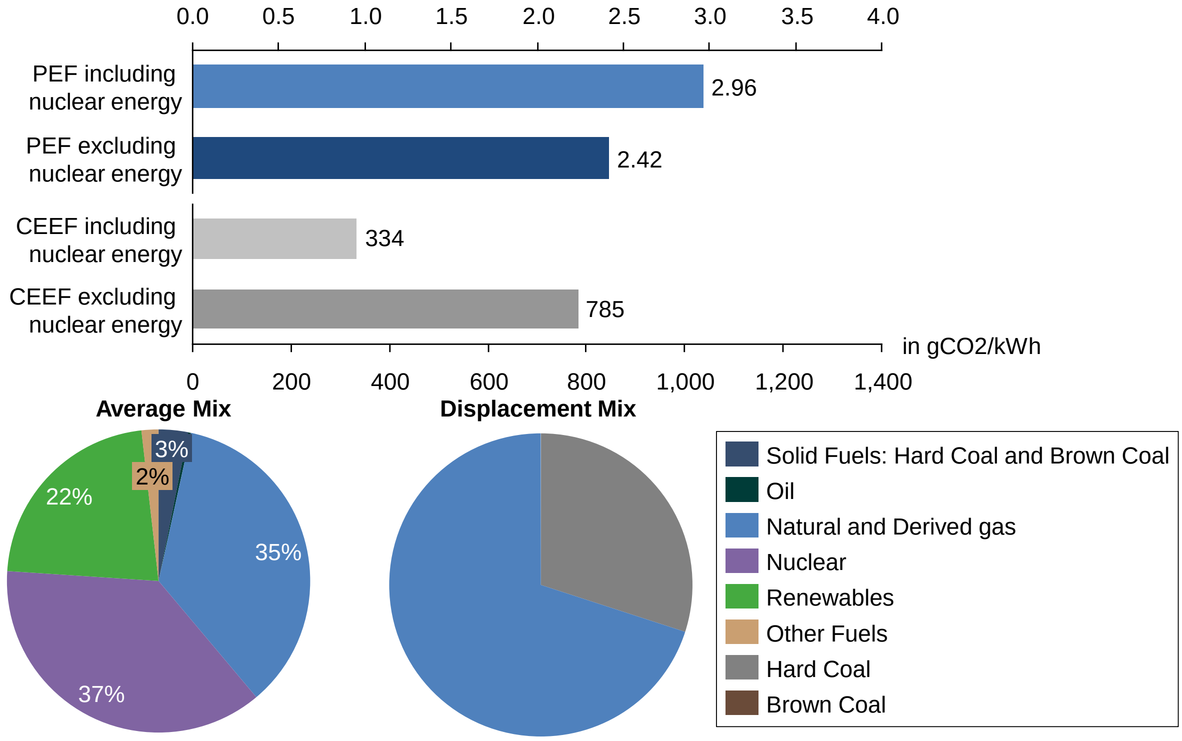

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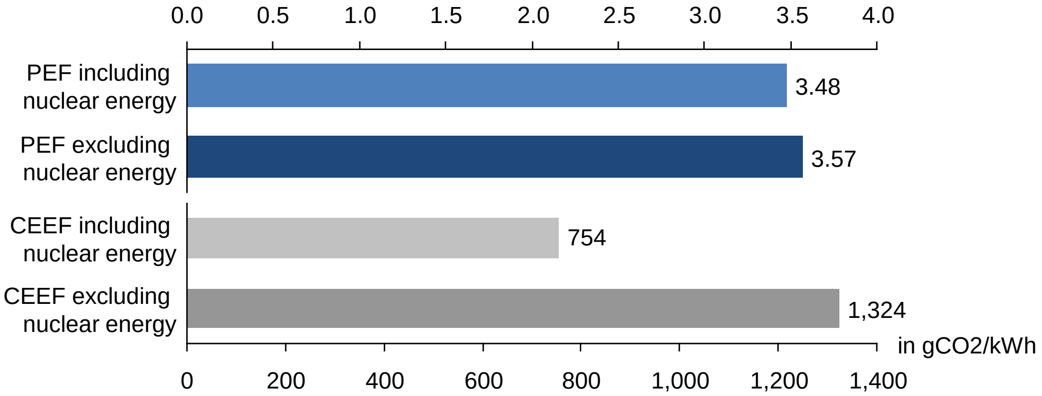

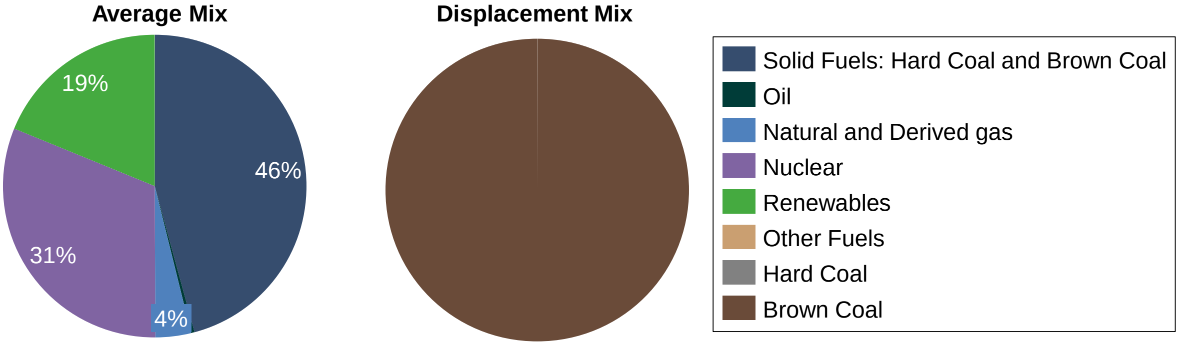

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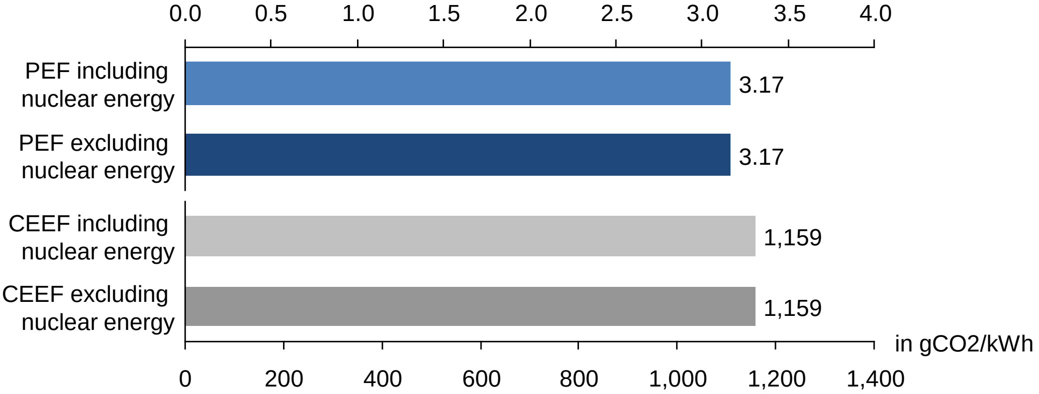

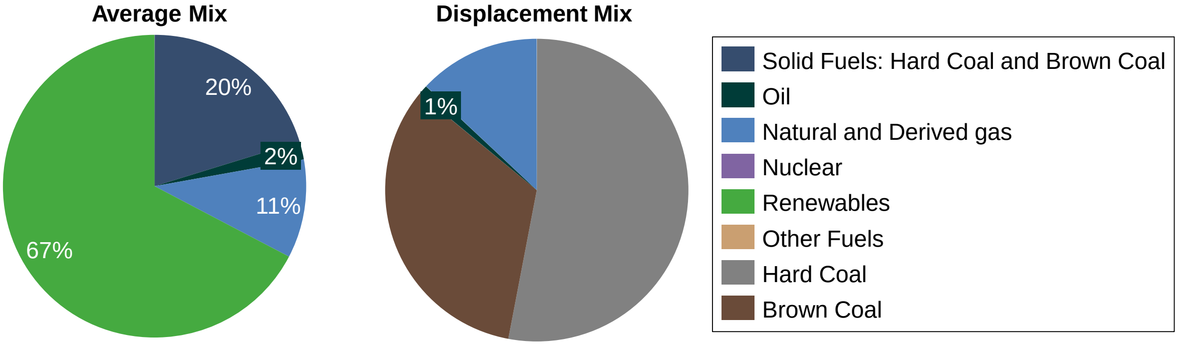

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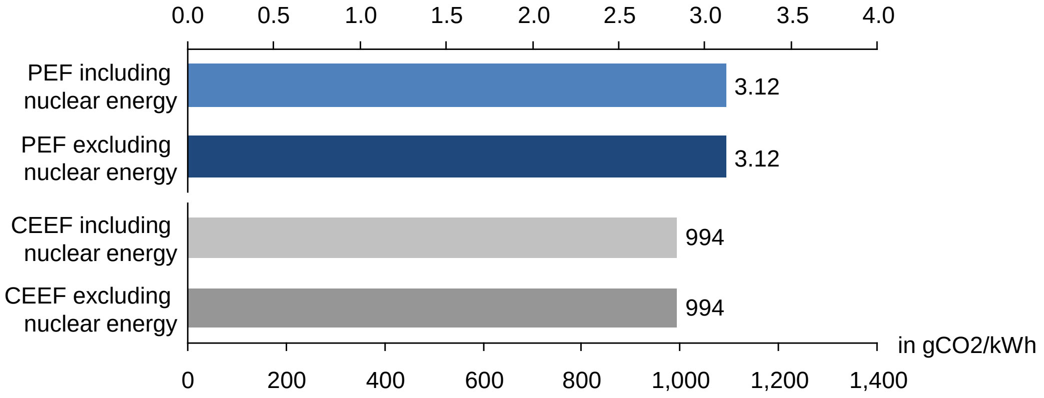

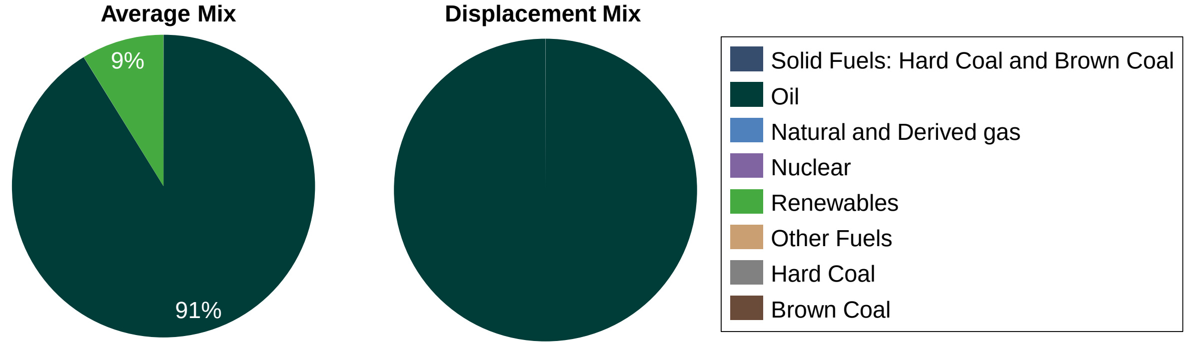

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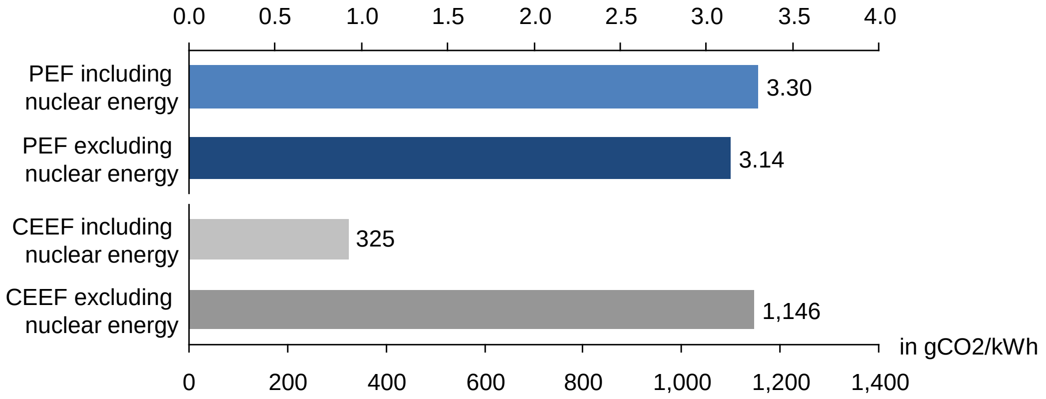

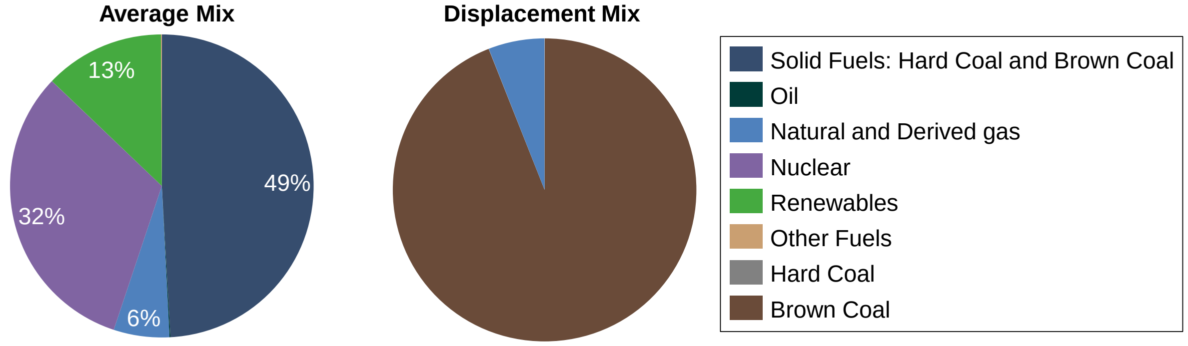

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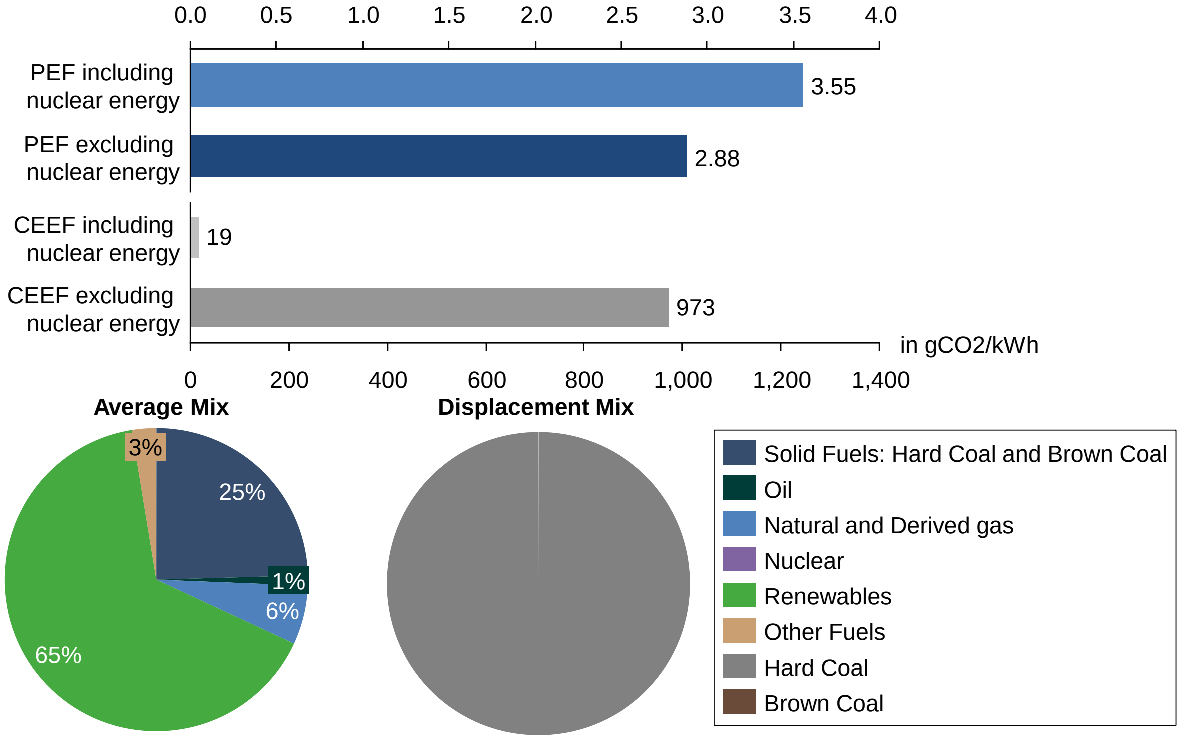

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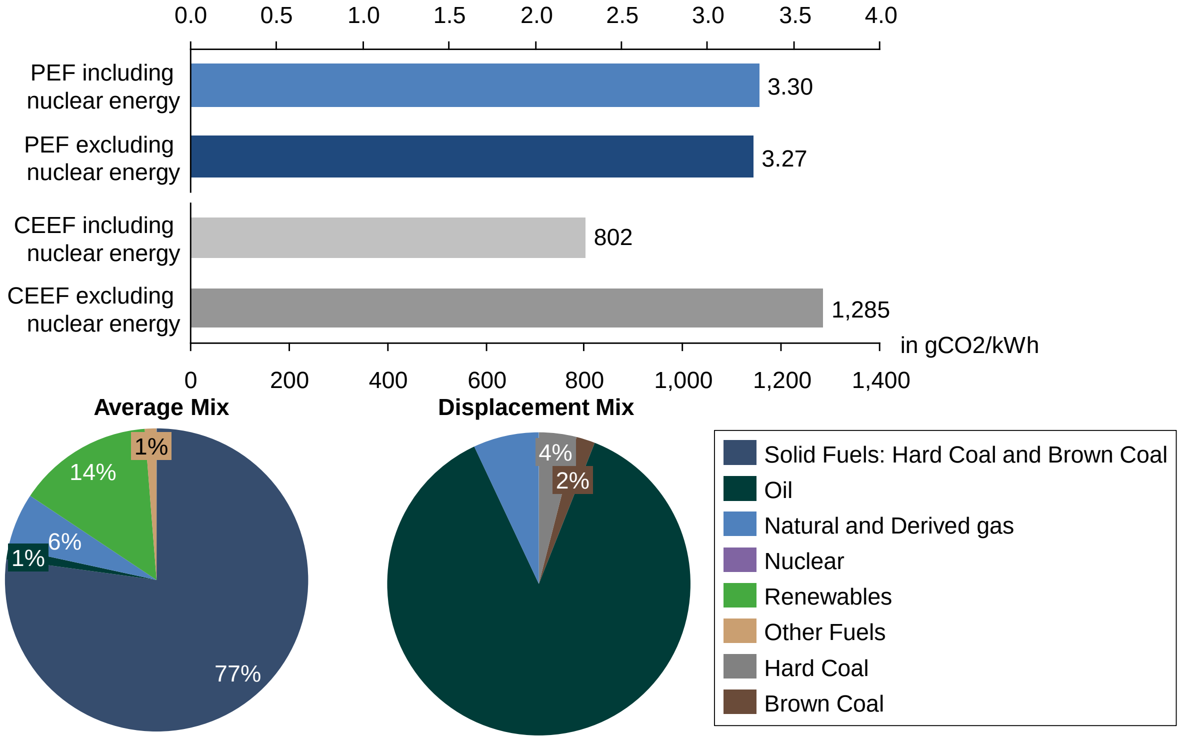

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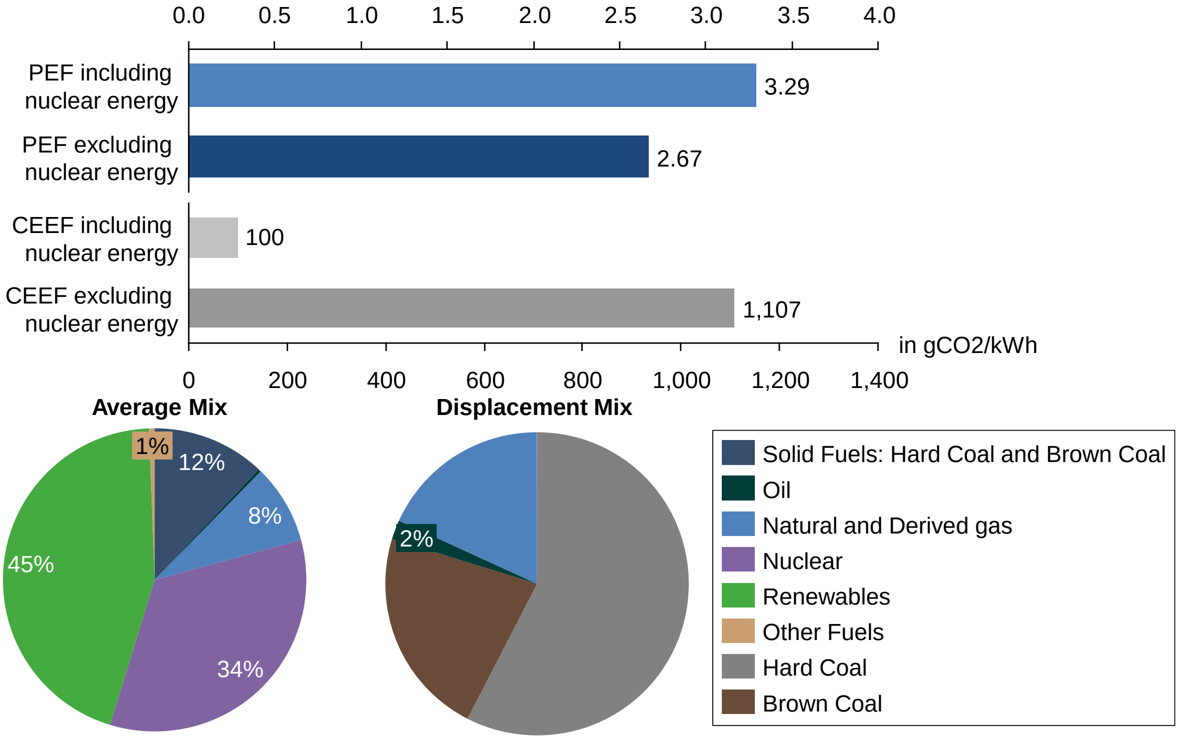

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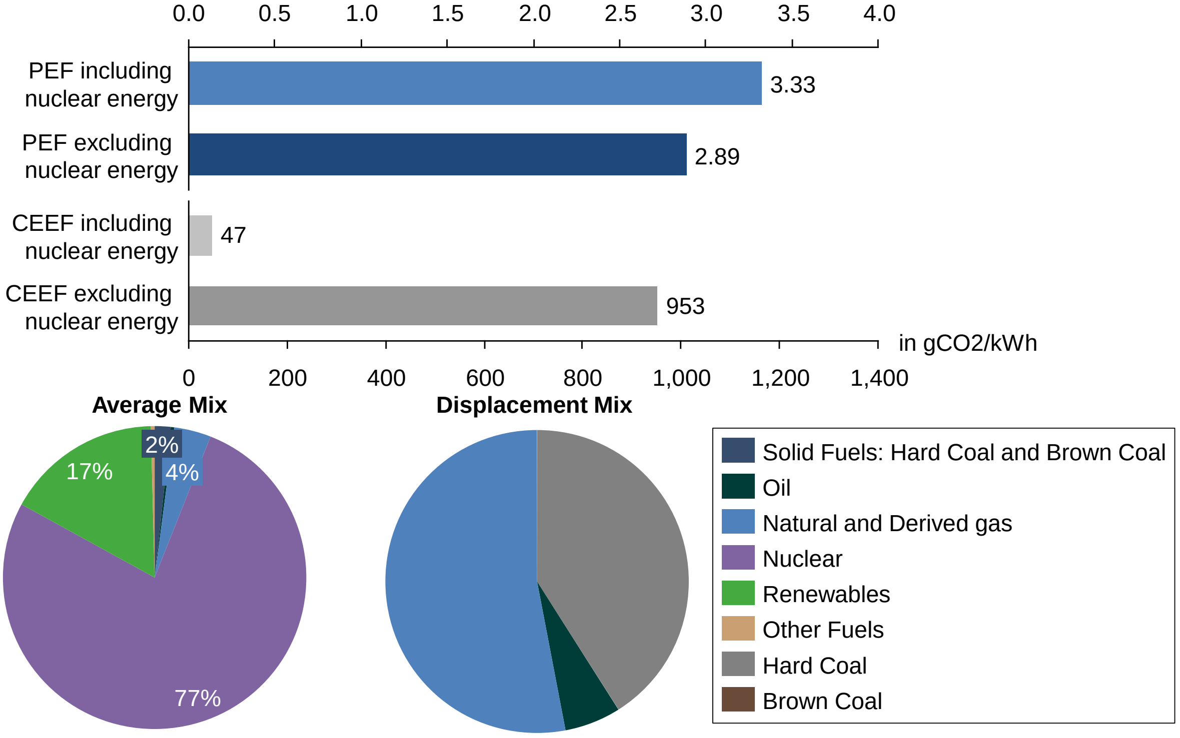

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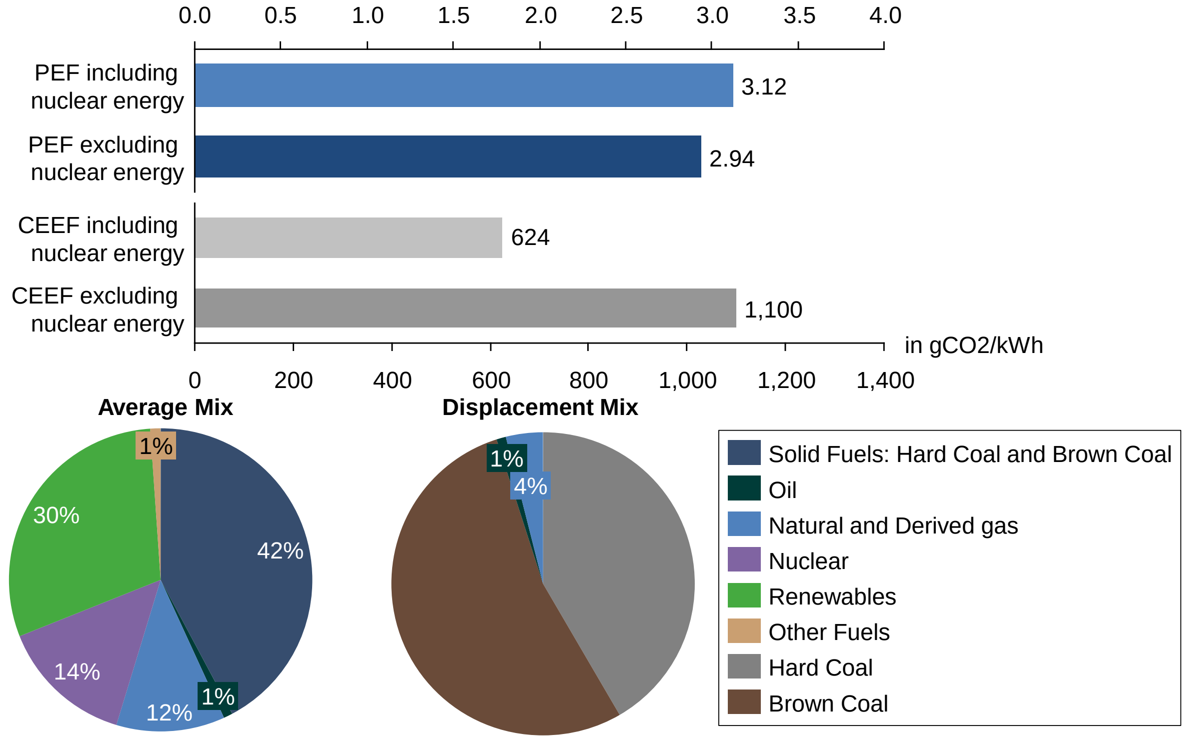

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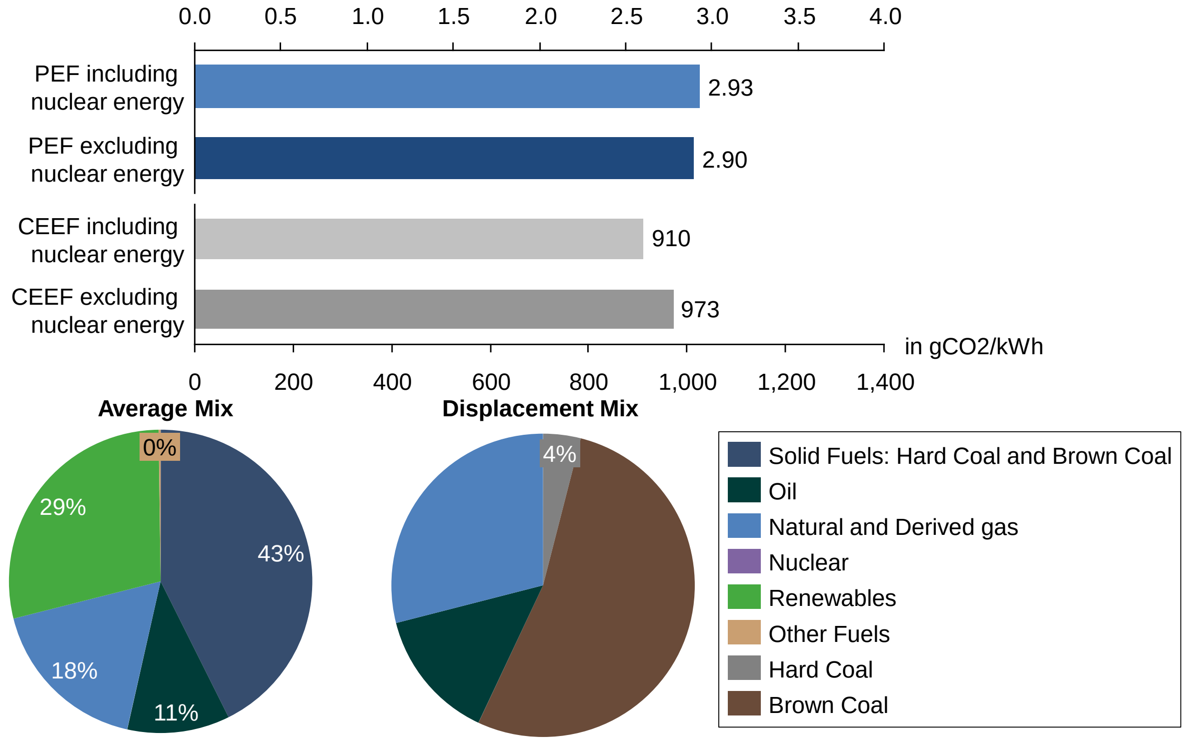

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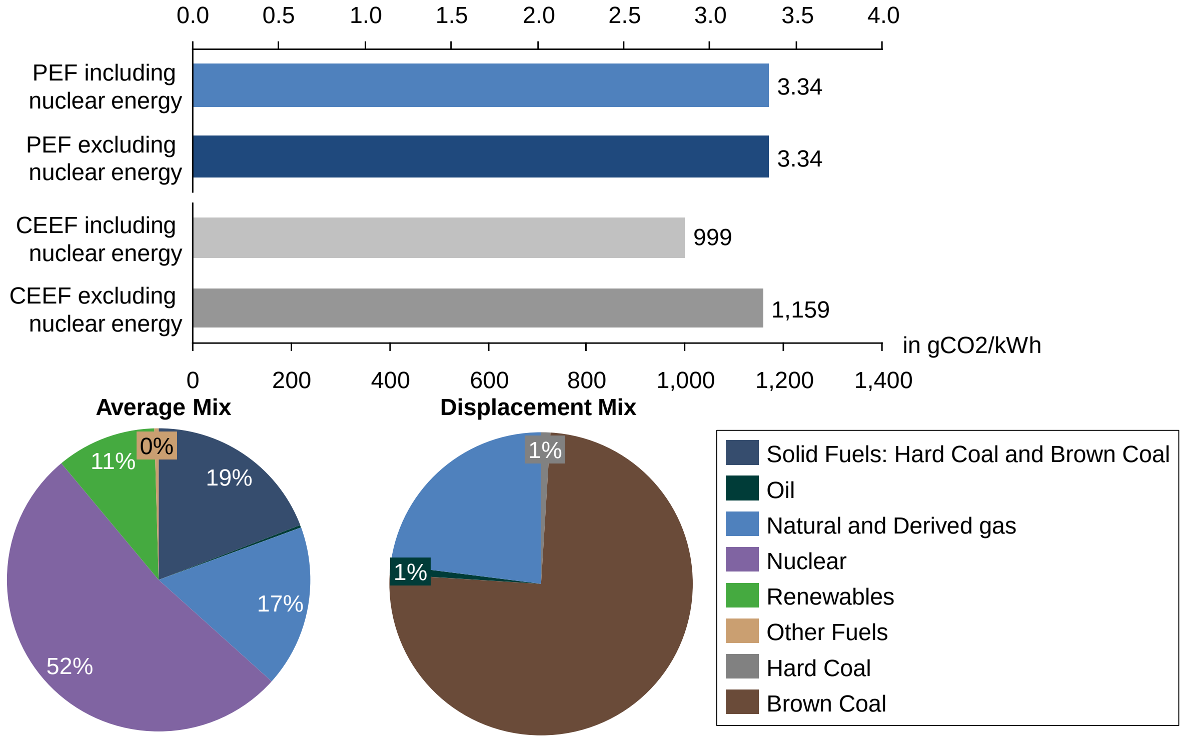

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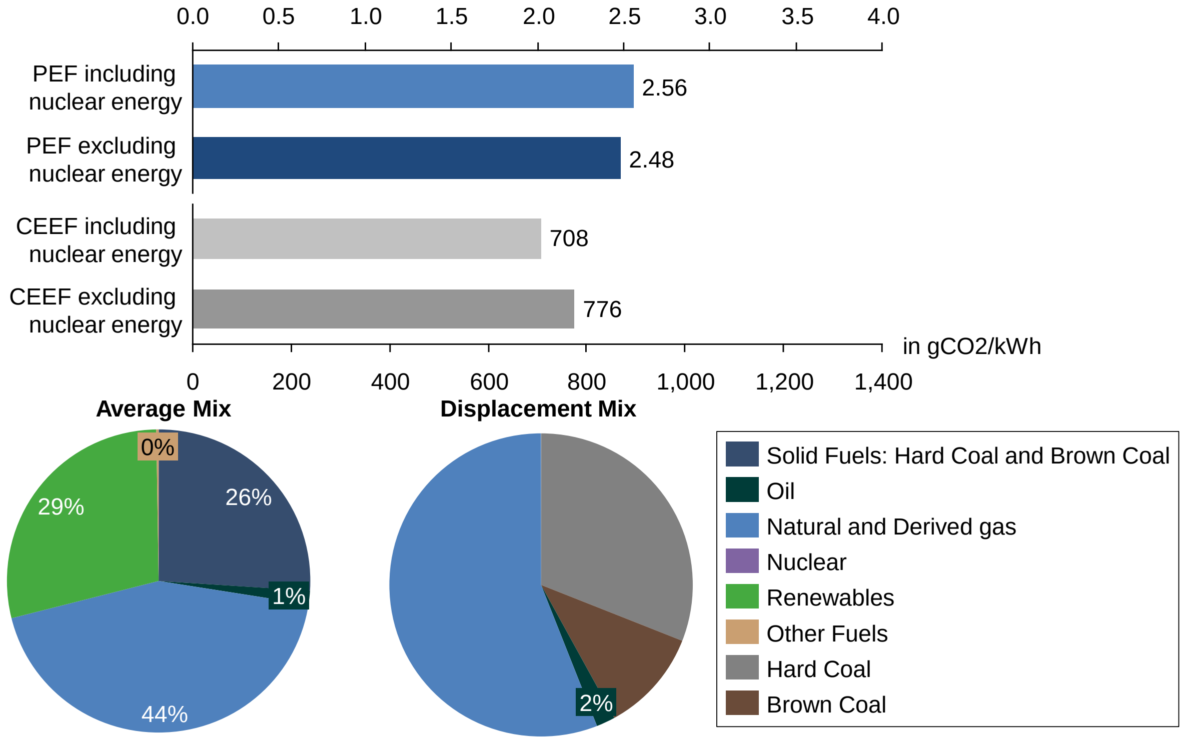

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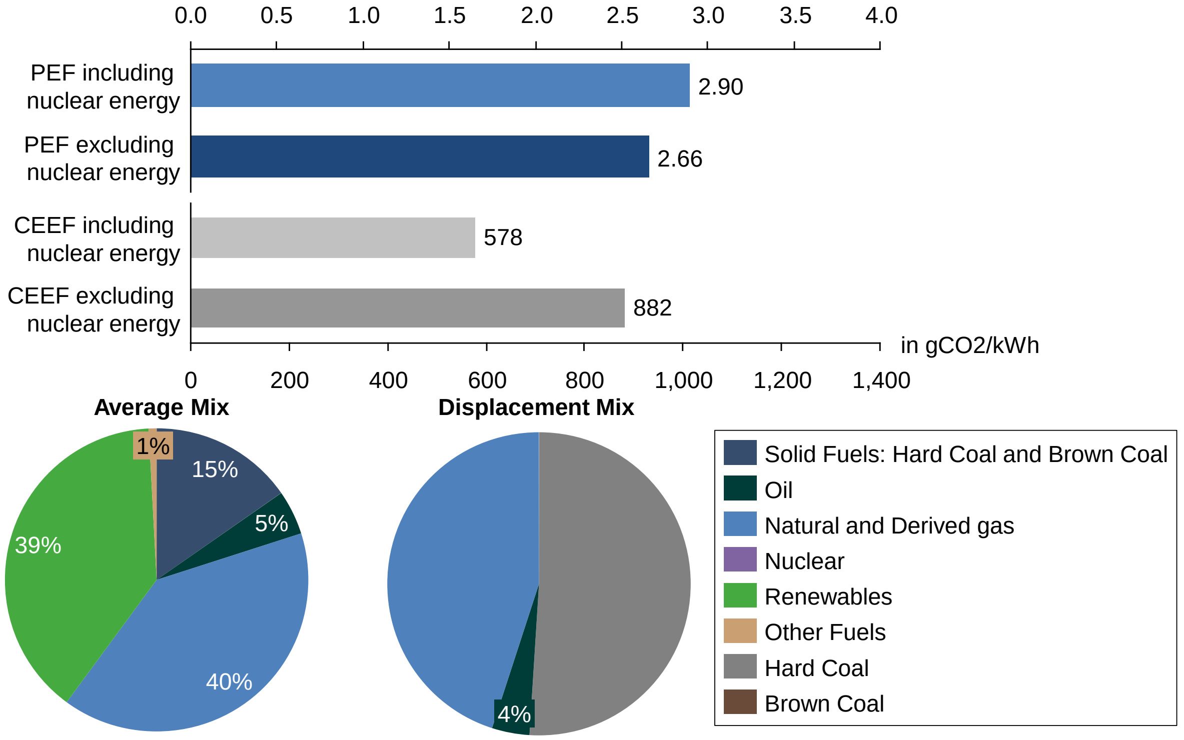

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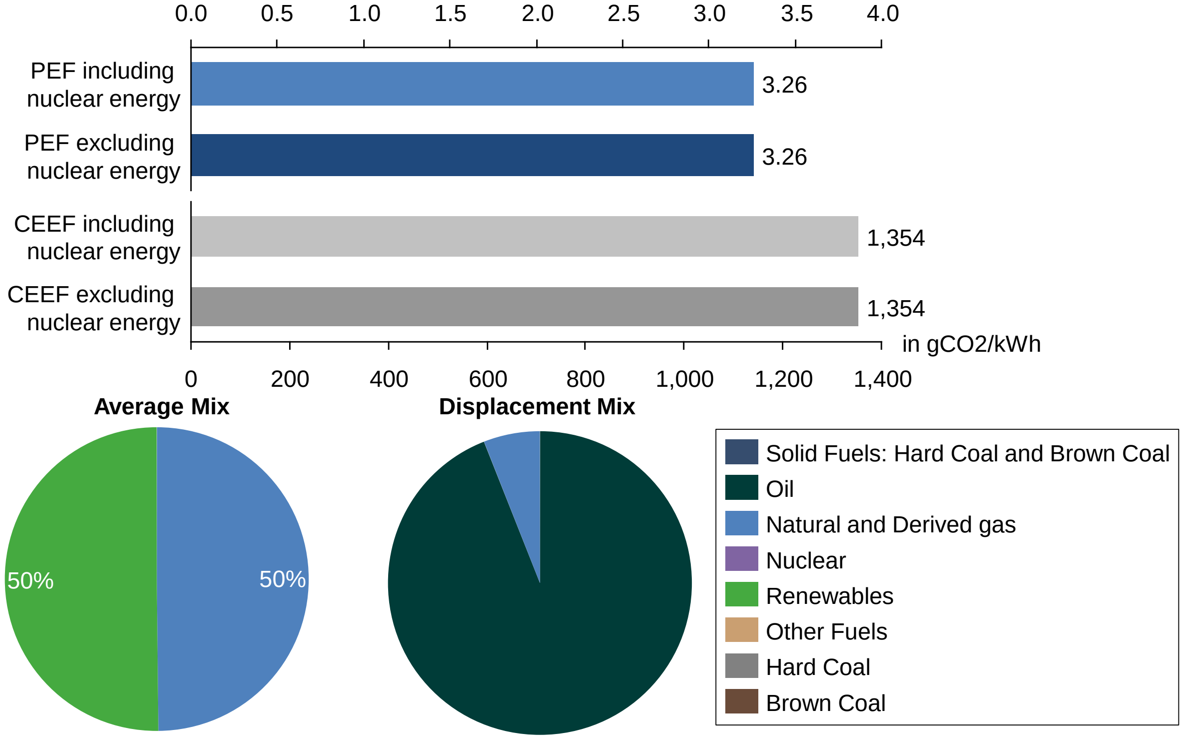

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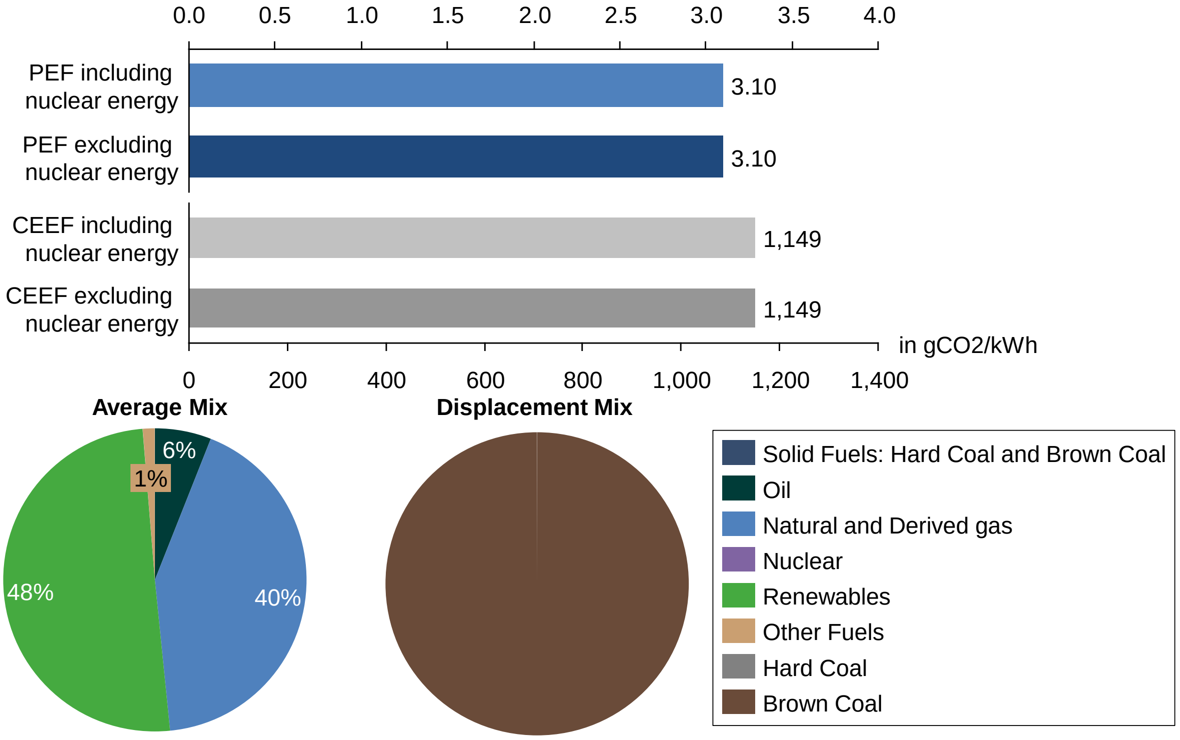

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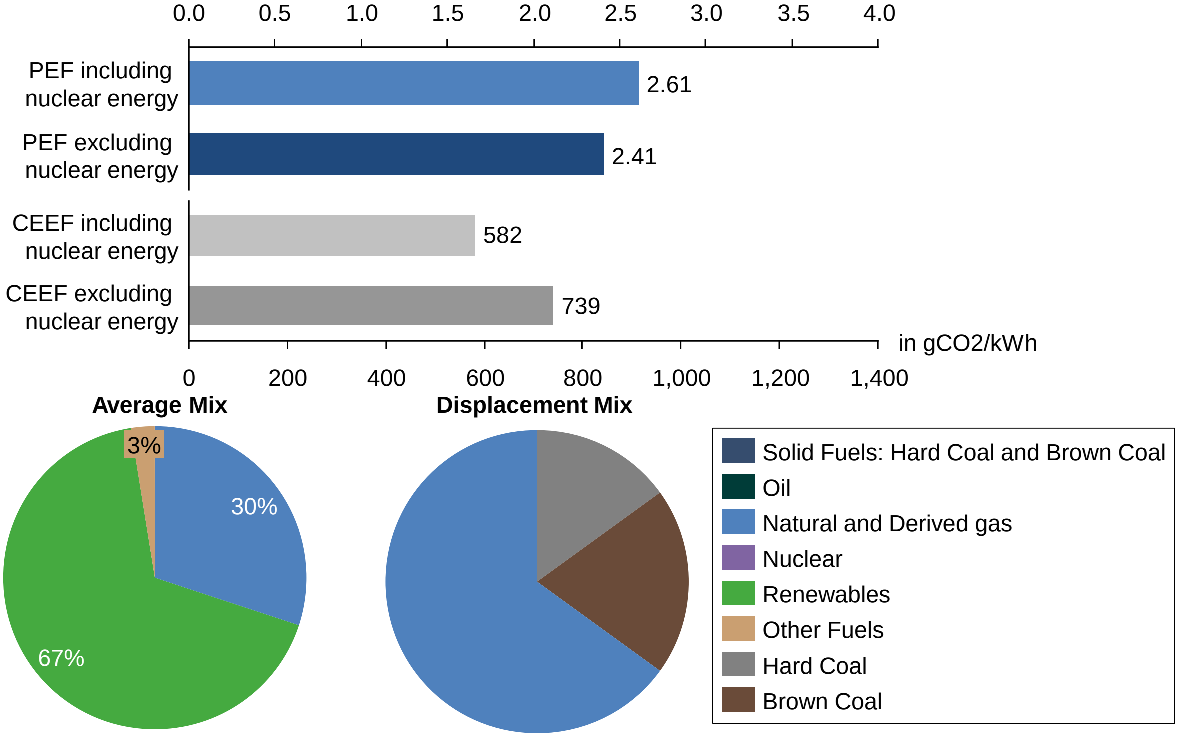

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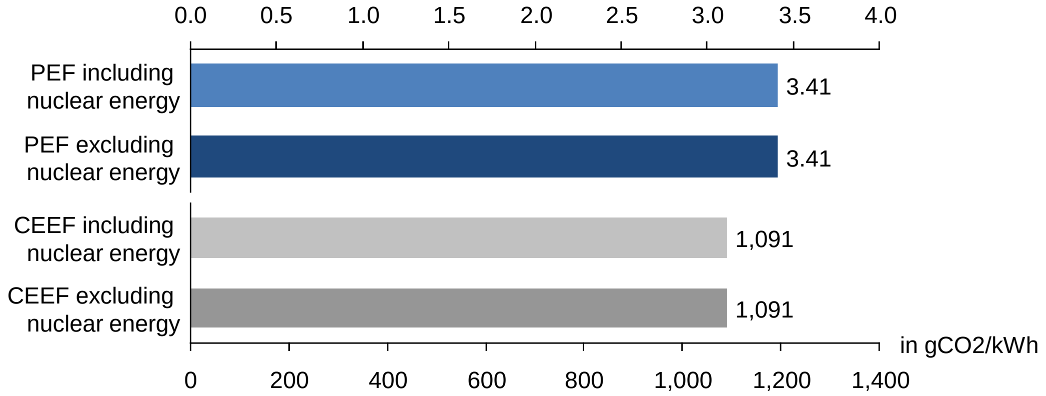

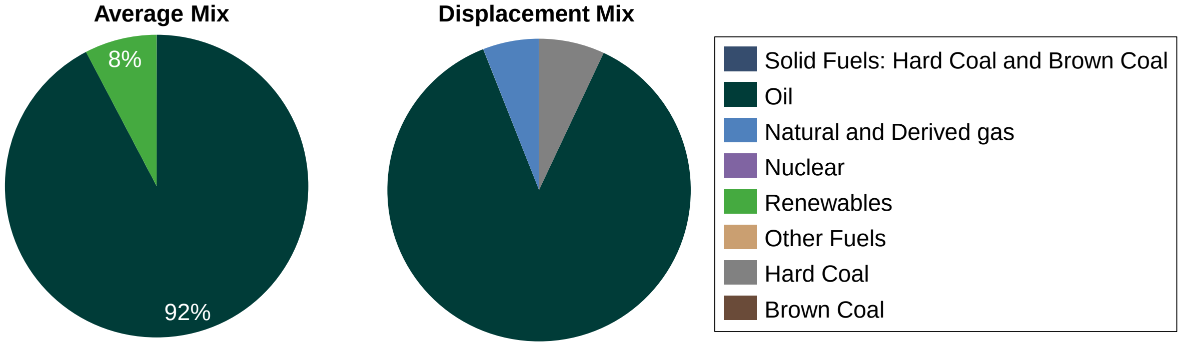

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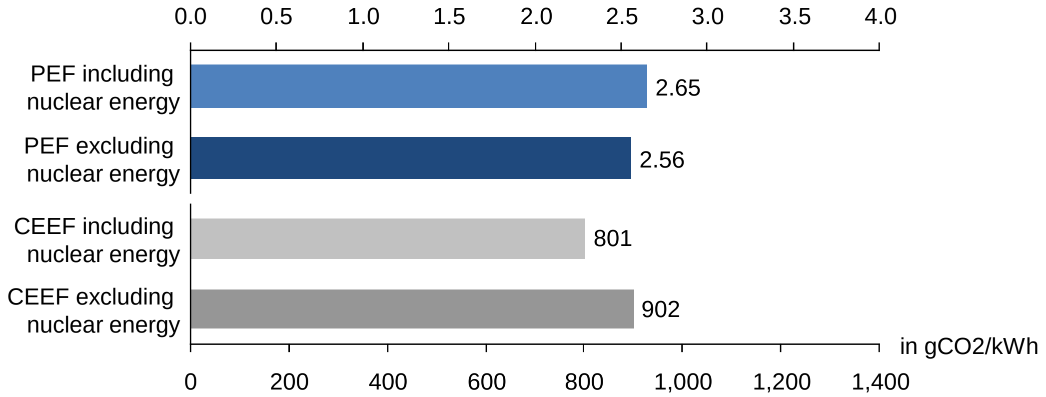

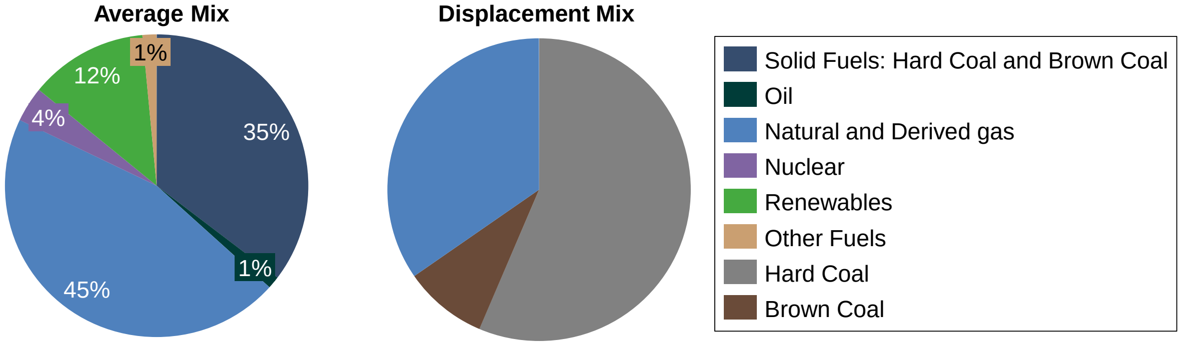

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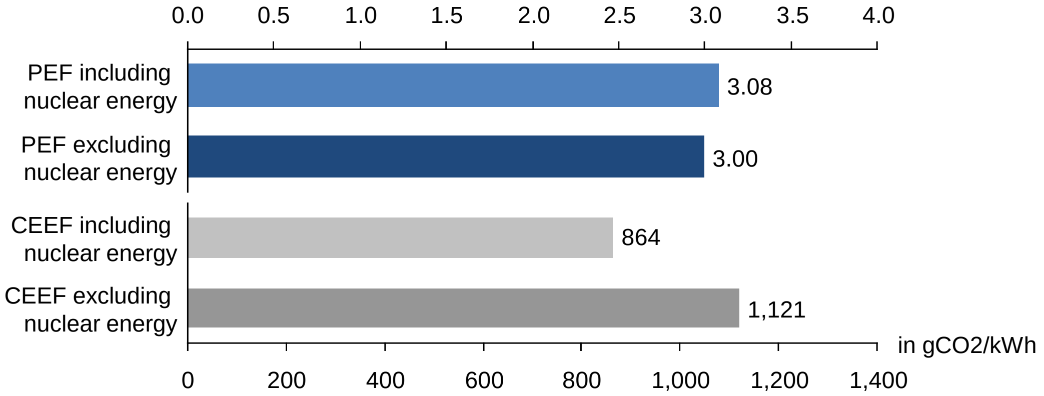

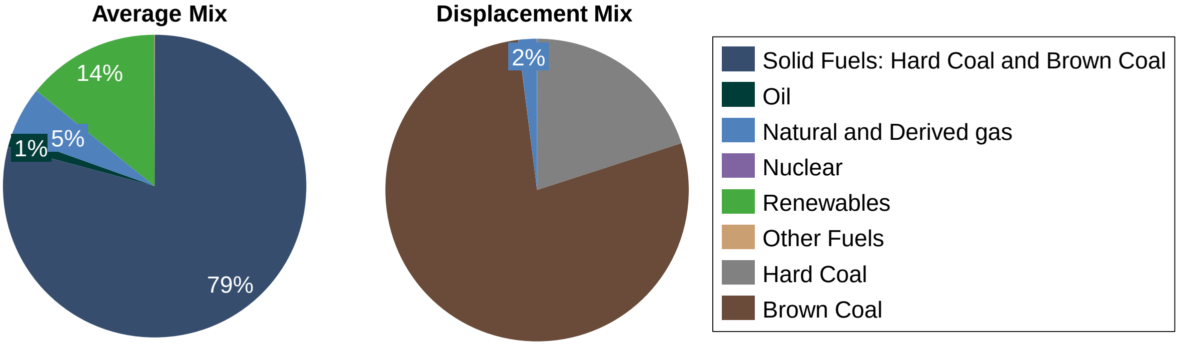

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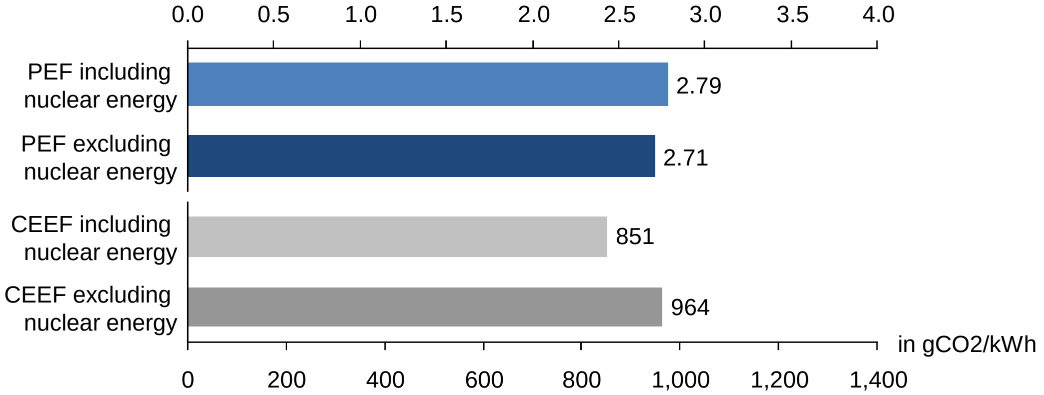

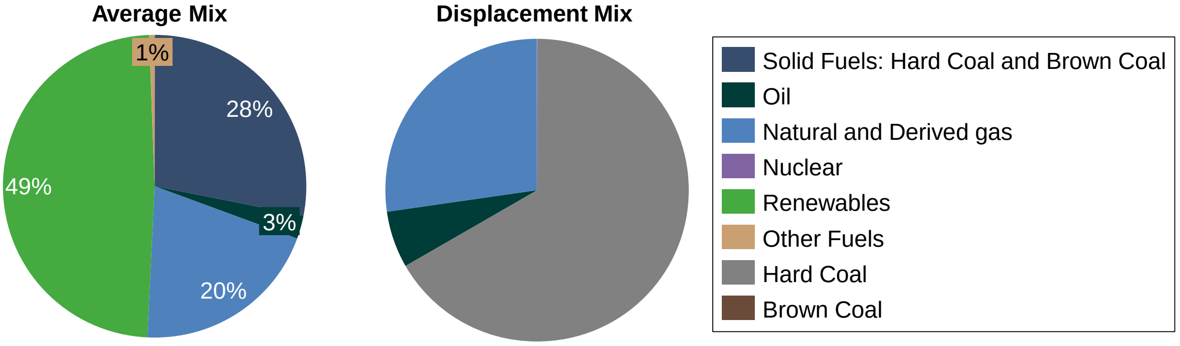

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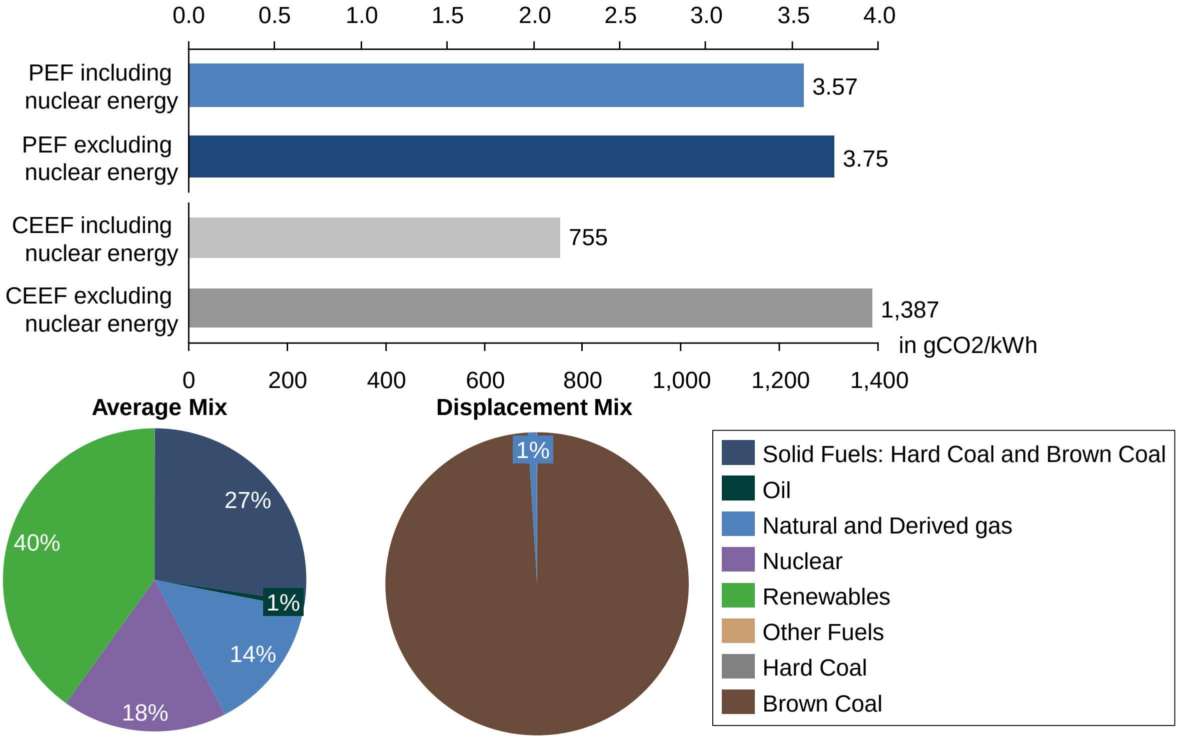

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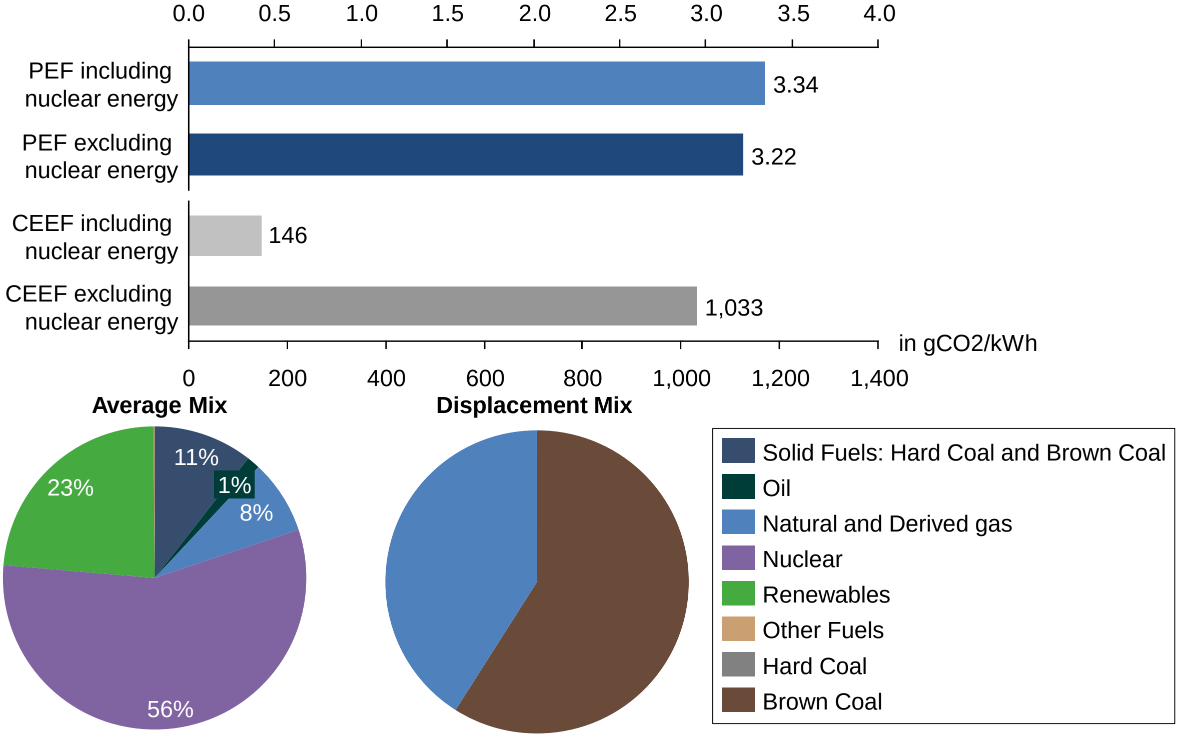

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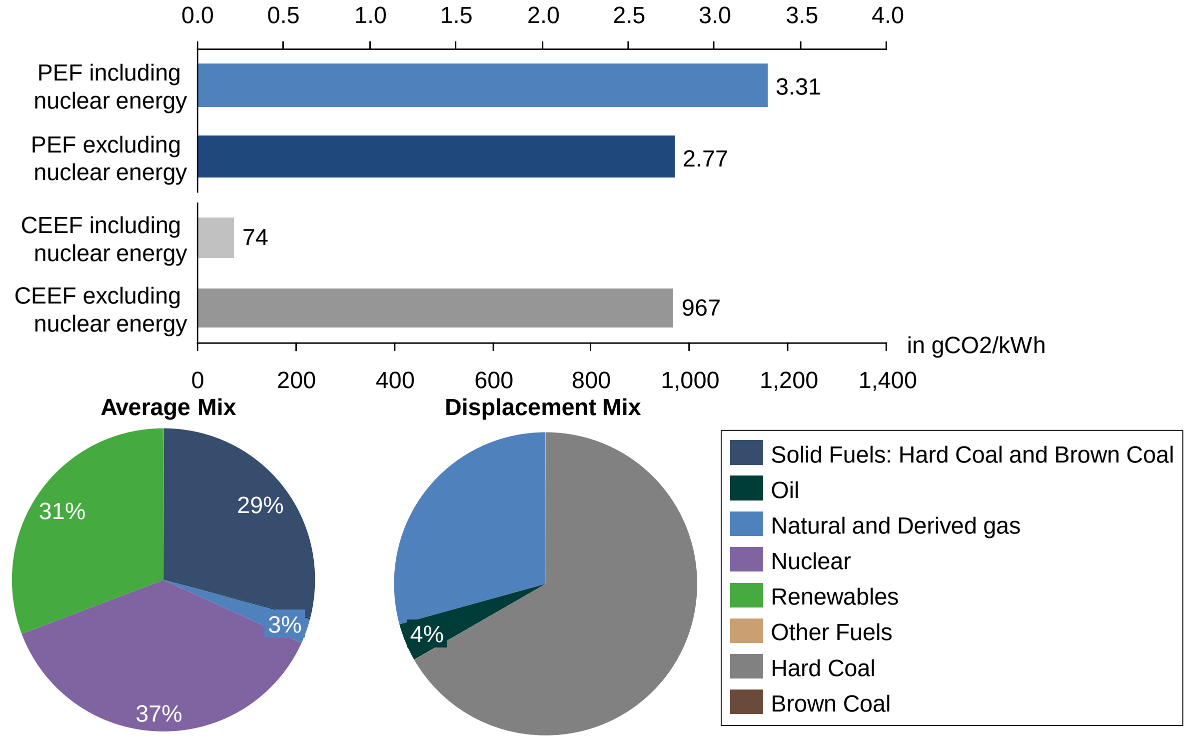

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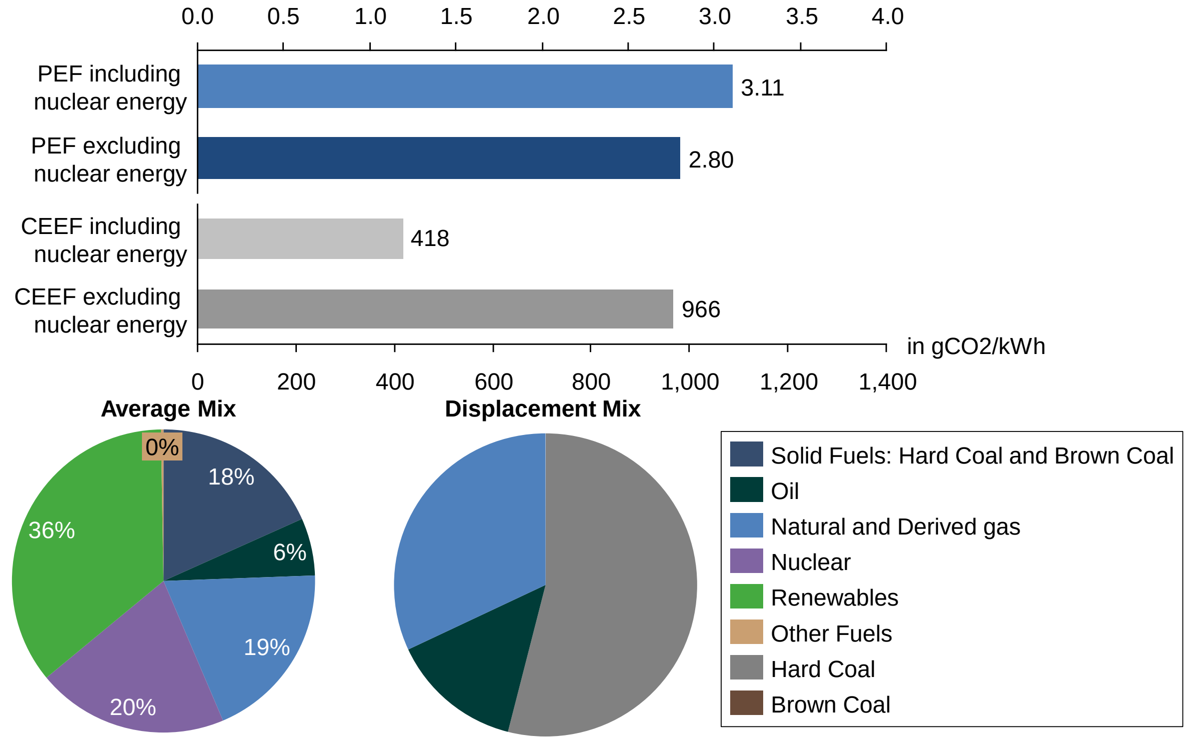

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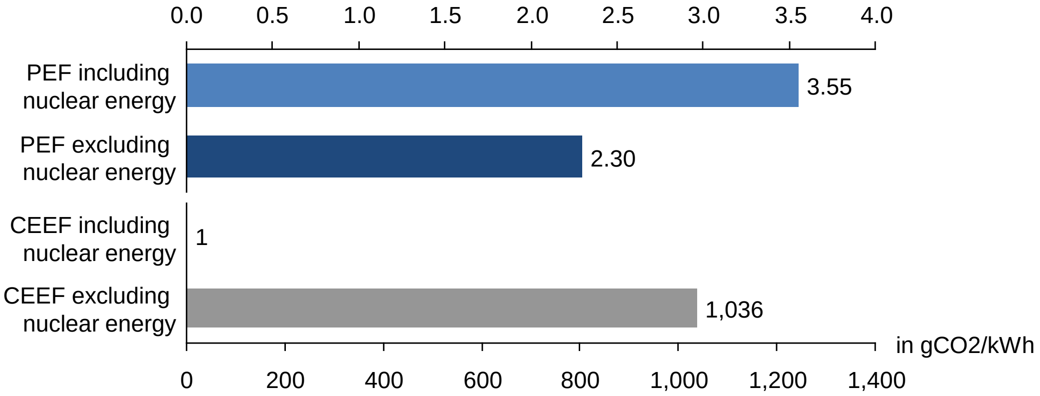

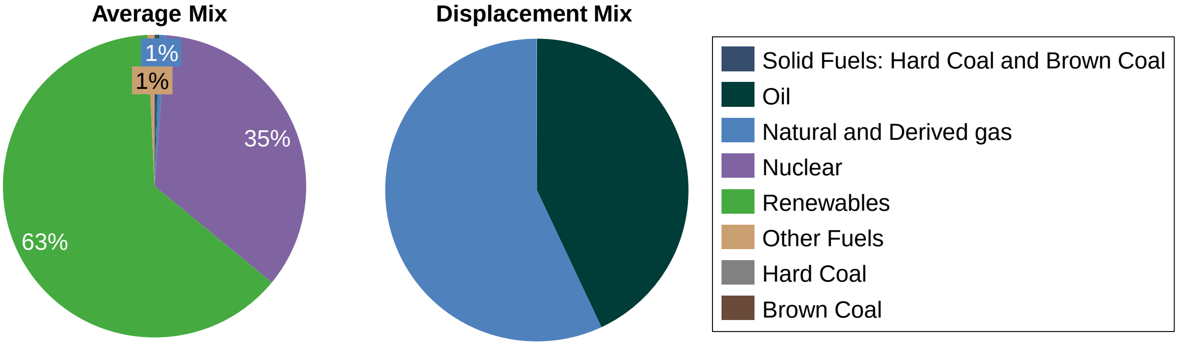

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