*Review of the default primary energy factor (PEF) reflecting the estimated average EU genera-
tion efficiency referred to in Annex IV of Directive 2012/27/EU and possible extension of the
approach to other energy carriers*

Final report
Evaluation of primary energy factor calcula-
tion options for electricity

Authors: Anke Esser (FhG-ISI), Frank Sensfuss (FhG-ISI),
Review: Christof Amann (e7), Patxi Hernandez Iñarra (Tecnalia)

Date 13.05.2016

REVIEW OF THE DEFAULT PRIMARY ENERGY FACTOR (PEF) REFLECTING THE ESTIMATED AVERAGE EU GENERATION EFFICIENCY REFERRED TO IN ANNEX IV OF DIRECTIVE 2012/27/EU AND POSSIBLE EXTENSION OF THE APPROACH TO OTHER ENERGY CARRIERS

Contact

Fraunhofer-Institut für System- und Innovationsforschung (ISI)
Breslauer Straße 48
D-76139 Karlsruhe
www.isi.fraunhofer.de
Frank Sensfuss (EUPEF@isi.fraunhofer.de)

Content

1
Executive summary

The goal of this study is to evaluate different options for the calculation of the primary energy factor (PEF) for electricity, in the context of the Energy Efficiency Directive 27/2012/EU. The analysis is carried out in three phases. The first phase seeks to provide a structure to the decision process by defining the different calculation options and deriving adequate evaluation criteria. The second phase seeks to select adequate calculation methods for the PEF of electricity. In this context in January 2016 a stakeholders meeting has been carried out at the European Commission premises to collect input regarding the structuring and the evaluation process. Based on the evaluation process four calculations methods are selected for the calculation process. The third phase deals with defining and executing the PEF calculation. The following calculation methods are selected for the calculation process.

- Calculation method 1 is designed to provide a calculation method that is in line with the Eurostat primary energy calculation.

- Calculation method 2 is designed to provide the most appropriate calculation method reflecting the total consumption of non renewable sources.

- Calculation method 3 is a variation of calculation method 1 in order to analyse the impact of changing the allocation method for CHP from the "IEA method" to the "Finish method".

- Calculation method 4 modifies calculation method 3 by adding the life cycle perspective to the conventional fuels.

The calculation is mainly based on the PRIMES 2012 Reference Scenario. This dataset is selected as it is the most recent dataset that is available to the European Commission and this consortium in all details. The results presented in Table 1 show the following central aspects:

- The PEF of 2.5 is not adequate and should be revised.

- All calculation methods show a considerable decrease of the PEF due to the projected growth of electricity generation from renewable sources of energy.

- The resulting PEF varies considerable depending on the calculation method:

  o The most important decision in the calculation process is the treatment of renewables in the accounting process.

  o By comparing method 1 and 3 it can be seen that the CHP allocation method can change the result by up to 0.14

  o Adding the life cycle perspective to fossil fuels increases the PEF by a similar order of magnitude of ca. 0.1

Table 1: Calculated PEF of electricity

Method	2000	2005	2010	2015	2020	2025	2030
Method 1	2.41	2.37	2.26	2.08	1.87	1.79	1.74
Method 2	2.41	2.36	2.14	1.90	1.59	1.46	1.35
Method 3	2.52	2.49	2.38	2.21	2.01	1.93	1.87
Method 4	2.65	2.61	2.49	2.30	2.09	2.00	1.93

The analysis in the project shows that no PEF calculation method can claim absoluteness. Therefore the calculation method for the PEF of electricity should be selected carefully and in line with the central goals of its application. The authors' preference is to include all non-renewable resource consumption in the calculation process in a simplified life cycle perspective. This leads to the lowest PEF of electricity and the most appropriate comparison with other fuels delivering services such as heat. It should be calculated as uniform value for the entire European region. However, due to the importance of the underlying projection of the development of the electricity sector we strongly recommend a regular review and adjustment of the PEF of electricity.

List of acronyms and relevant terminology

ACCT.	Accounting
CHP	Combined heat and power, cogeneration
CHP Heat bonus	Primary energy share for heat output in CHP
CSP	Concentrating solar power
Fuel	Any energy source or product which, once transformed into an intermediary carrier, can become electricity
IEA	International Energy Agency
EC	European Commission
EEA	European Economic Area
EED	Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC
ENTSOE	European Network of Transmission System Operators for Electricity
EPBD	Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings
EPR	European pressurized water reactor
EU	European Union
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
Mtoe	Mega ton of oil equivalent
MS	Member State
kWh	Kilowatt hour
PE	Primary energy
PED	Primary energy demand
PEE	Primary energy efficiency
PEF	Primary energy factor
PEX	Power exchange
PV	Photovoltaics
RES	Renewable energy sources
UN	United Nations

2
Introduction

The European Commission has set the target in the Energy Efficiency Directive (EED)[1] to reduce EU primary energy consumption in 2020 by 20% in comparison to a given baseline development. This amounts to total required savings of 368 Mtoe. Due to the fact that the target is defined on primary energy level the primary energy factor (PEF) that is applied for electricity is a crucial aspect in the overall assessment of energy saving measures that affect electricity demand.

The PEF is also used to define efficiency criteria for energy using products (ecodesign and energy labelling) and has hence an impact on the choice of electricity versus fossil fuel based technologies, e. g. for space and water heating purposes. In the case of heat pumps the PEF of electricity and the efficiency are the two central factors to assess the potential primary energy savings of the technology. A higher PEF of electricity reduces the calculated energy savings of heat pumps in comparison to other fuels. On another level, in case of electricity saving measures a lower PEF leads to a lower theoretical contribution to the stated target on reduction of primary energy demand. As a consequence electricity saving measures could rank lower in the strategy to define a cost efficient path towards the set target or vice versa. This approach might lead to a situation, in which high efficient electricity driven technologies are penalized in comparison to less efficient technologies. These two examples show the considerable importance of the PEF on the evaluation of electricity driven technologies in the path of cost efficient primary energy reduction. It also exemplifies that the implications of a given method on the different fields of application have to be evaluated to prevent detrimental effects for reaching the energy and climate targets.

There are various ways to calculate the PEF of electricity. In the simplest way, if only generation is considered, the primary energy factor of electricity can be calculated by dividing the raw primary energy demand of electricity generation by the electricity produced. However, system boundaries could be expanded to also include transmission and distribution losses or energy used to extract, clean and transport the fuels. For fossil fuels or directly combustible renewable fuels the raw primary energy demand is calculated as the heat value generated during combustion of the fuels divided by the efficiency of the conversion process. Regarding non-conventional energies, such as wind, solar PV, hydro, geothermal or nuclear, their energy content cannot easily be determined. Therefore, a wide range of methodological choices has to be taken to define the primary energy (PE) content of non-conventional fuels (see Annex 2).

Annex IV of the Directive 2012/27/EU states that: "For savings in kWh electricity Member States may apply a default coefficient of 2.5. Member States may

---

[1] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

apply a different coefficient provided they can justify it." The default coefficient is based on an average, European-wide conversion efficiency of 40%.[1] However, this approach has been criticised from various parties. In essence, the critique considers the approach of a unified PEF as overly simplified, thus neglecting the numerous factors that influence the primary energy consumption to generate one kWh of electricity. However, the debate on the PEF shows that several criteria are applied to the function and evaluation on the different ways to calculate and apply a PEF. Among these are stated criteria such as precision in terms of reflecting reality, simplicity and transparency. Besides these criteria one central aspect that drives the different statements on the ways to use and calculate a PEF is the impact on the incentives of the regulatory framework.

In addition, the application of one or several PEF to electricity leads to the question, whether or not a similar method has to be applied to other energy carriers as well. Currently, the final energy consumption of other energy carriers, such as coal, gas or oil is calculated to be equivalent to its primary energy consumption. The ratio behind using PEF is to convert final energy consumption into primary energy consumption, in order not to privilege secondary fuels, such as electricity. When comparing the energy consumption between alternate systems, for example to heating systems, the resulting primary energy consumption should be estimated regardless of the energy carrier used by the systems. For secondary energy carriers this means incorporating the upstream chain.

A similar logic could be applied to other energy carriers as well. At the time of consumption of a primary energy carrier, additional energy has been consumed for exploration and transport or lost for example through leakages. Using natural gas for heating at home leads to primary energy consumption in other parts of the energy system. When comparing for example two different heating systems it matters if natural gas or oil is used, as the upstream chain differs substantially. Including the additional consumption would lead to a more realistic comparison of systems using different fuels as final energy. Furthermore, incorporating the upstream chain might to some extent allow a more accurate comparison with electricity. For example, if transmission and distribution losses are considered as consumption in electricity, including them for natural gas could be appropriate. However, the PEF of other energy carriers will be relatively low compared to the PEF of electricity, and the same PEF would also have to be used for calculating the PEF of electricity if the corresponding fuels are used.

In the context of this discussion the European Commission has contracted this study to review and explore adequate ways to determine the PEF for electricity and fuels. This project is split into two tasks. Task 1 analyses the PEF for electricity and Task 2 deals with the PEF of fuels. The results of the two tasks are summarized in this report. Because of its higher significance, the focus is on the PEF of electricity. However, a short analysis of the PEF of fuels is included in the total calculation of PEF of electricity, being the preparation for the fuels part of the process in the production of electricity.

---

[1] Grid losses are not taken into account.

3
Our approach

The calculation of the Primary Energy Factor (PEF) is characterized by a high level of complexity and various decisions are required in the calculation process. In addition, the practical impact of the PEF calculation on the relevant EC Directives needs to be evaluated. Important aspects in this context are influence on the development of energy from renewable sources (RES) and high efficient technologies such as cogeneration and heat pumps. Therefore one central vision of our general approach to this project is to provide a clear and transparent structure for the decision process on the PEF calculation. This vision is substantiated by our central goals within this project. We seek to

- provide a structure consisting of thematic groups, categories and options for the characterisation of the relevant calculation options,
- develop a set of criteria for the evaluation,
- evaluate the calculation options and
- develop, select and execute an appropriate calculation methods.

Step 1: Characterise options	Step 2: Develop criteria	Step 3: Evaluate options	Step 4: Select final set	Step 5: Propose method	Step 6: Execute method

In order to reach these goals each step (subtask) in the process requires a development phase, discussion phase and a decision phase. These steps were carried out in close contact with the client. The output of the subtasks 1 – 3 has been a working paper which has been published prior to the stakeholders meeting held in January 2016.

This report describes in detail the process of evaluation as well as the results of each step. In Chapter 4 the categories and options defining a calculation methodology are described. Chapter 5 gives an overview of the criteria used to evaluate the option. In Chapter 6 a structured evaluation of the categories is carried out and sets of criteria that are clearly dominant over all other options within a category are pre-selected.

Based on this evaluation as well as based on the discussion with various stakeholders and the client, four appropriate sets of options defining four methods for the calculation of the PEF for electricity are identified and presented in Chapter 7. Finally, the methods are applied to calculate the PEF for electricity.

A general aspect regarding the calculation process of the PEF of electricity is that it can be structured according to the following simplified formula.

Formula

$$PEF\ Electricity = \frac{PEF\ Fuel}{Conversion\ efficiency}$$

Please note that in this simplified representation all energy sources are named as "fuel". This also includes wind, solar or hydro which are normally not called "fuel" in the classical sense[1].

The first phase is to determine the PEF of the fuels used in the conversion process to obtain electricity. In this context issues like system boundaries e.g. life cycle perspectives play a major role. In this context, also the chosen PEF of fuels need to be explained in relation to the chosen methodology. This is done for each fuel. A more detailed elaboration of different methodologies to determine the PEF of fuels as well as their consequences can be found in Annex 2.

The second phase is to determine the conversion efficiency of the electricity generation process and use it as divisor to the PEF of the fuel. In this context efficiency by statistical definition, averages of statistical data and efficiencies of single power plants need to be clearly separated in the context of the purpose of the calculation.

---

[1] E.g. Eurostat refers to them as energy products (see in Annex 2). Elsewhere (e.g. some UN standards) they are also called energy sources or carriers.

4
Characterisation of PEF calculation methods

4.1   Structure for the categorisation of the relevant calculation options

In order to define a first structure for the process of PEF calculation we define the following terms, which are used in this working paper.

- **Thematic groups:** Thematic groups are used to group categories according to the nature of the decision that has to be taken.
- **Category:** A category defines the issue which has to be decided upon during the calculation process. Examples are geographical or time resolution of the calculation.
- **Option:** Within each category several options for the calculation exist which can be chosen in the process. In the case of geographical resolution this could be regional calculation, national calculation or EU-wide calculation.

In our concept each suggested way to calculate the PEF of electricity is represented by a path through a decision tree. Each level of the decision tree is represented by a category. At a given category (level) one option has to be selected to determine a PEF calculation. An exemplary extract of a decision tree is given in Figure 1.
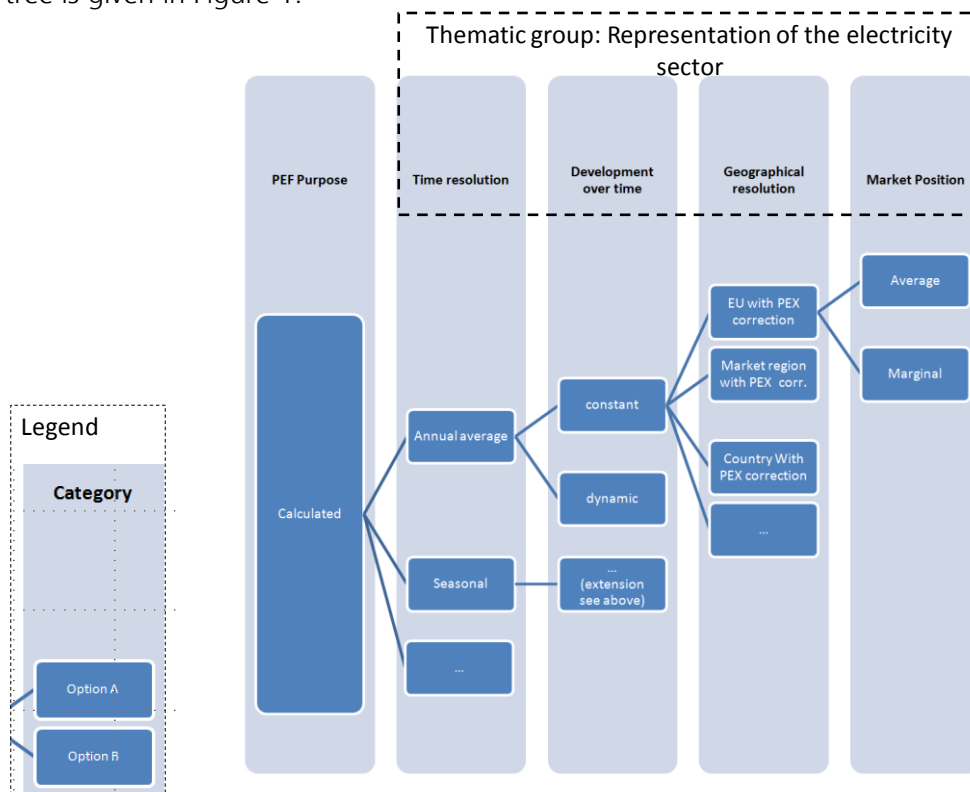
Figure 1: Example of a shortened decision tree for the PEF calculation

4.2 Thematic groups, categories and options for PEF calculation

In the following section, the categories and possible options for the PEF calculation approaches are introduced briefly according to their thematic groups. In the context of the project three thematic groups have been developed to structure the categories according to their nature:

- **Strategic and political considerations:** Categories represented in this group deal with decisions that are strongly dependent on political or strategic considerations.

- **Representation of the electricity sector:** These categories deal with aspects relating to the general representation of the electricity sector.

- **General PEF methodology:** The third group aggregates categories that deal with the general PEF methodology applied.

A table listing all relevant categories and options can be found in Section 4.3.

4.2.1 Thematic group "Strategic and political considerations"

In the following sections all categories dealing with issues that strongly depend on strategic and political considerations are presented. An overview of all relevant categories and options is presented in Table 2.

Table 2: Categories and options in the thematic group "Strategic and political considerations"

Category	Option
PEF purpose	Desired
	Calculated
Applicability	Abolish the use of a PEF
	No differentiation
	Different PEF for different policies
	Different PEF for different electric appliances
	Different PEF for different appliances and policies
	Different PEF for delivered and produced electricity
Adjustment and review process	Constant over time
	Regular review/adjustment
Database and calculation method	Based on statistics and studies
	Advanced calculations based on statistics and studies
	Power sector model calculations

a. Category "PEF purpose"

One central category is the "**Purpose"** of the PEF. A first option in this process is to choose a "Desired value" which can then be used to foster developments that are in line with political preferences. Thus, the "Desired value" can

be different for different purposes. The second option is to use a "Calculated value" that seeks to reflect real or expected situations or developments in the electricity sector. It has to be noted that this decision has a strong impact on the focus of the evaluation process for the PEF mechanisms. While the first option will put a strong focus on the impact of the PEF a "Calculated value" has a stronger focus on reflecting the actual situation in the electricity sector.

- Options
  - Desired value
  - Calculated value

b. Category "Applicability"

A crucial aspect with strong impact on other categories is the **"Applicability"** of the PEF. One option is that the same PEF is to be used for all policy fields in which the primary energy consumption of power is relevant, e. g. Energy Efficiency Directive, Ecodesign and Energy Labelling Directives, Energy Performance of Buildings Directive. Another option could be that the calculation method should differ for different appliances such as heat pumps or direct heaters. In the evaluation of decentralized renewables a differentiation between delivered and produced electricity is also discussed. Finally, abandon the use of the PEF could also be an option.

- Options:
  - Abolish the use of a PEF.
  - No differentiation (uniform PEF)
    This option stands for a uniform PEF no matter in which legislation, application or country it is used.
  - Different PEF for different policies
    This option represents the case that different PEF are proposed in different legislations.
  - Different PEF for different electric appliances
    This option signifies that different PEF should be applied for different appliances, such as electric heater and heat pumps.
  - Different PEF for different policies and appliances (combination of the previous two options)
  - Different PEF for delivered and produced electricity
    Regarding the Energy Performance of Buildings some Member States apply different PEF for delivered electricity and electricity produced on site.

c. Category "Adjustment and review process"

One category for the overall process for the use of the PEF is the **"Adjustment and review process"**. This has to be clearly differentiated from the category development over time which deals with the assessment of an energy consuming device at a given point in time. The category "Adjustment and review process" deals with the fact if the mechanics or value for the PEF calculation will be held "Constant over a longer period" or if "Regular reviews

and adjustments" are planned. In this context the time frame of reviews and adjustments represents sub-options.

- Options:
    o Constant over a longer time
    o Regular review and adjustments

d. Category "Database and calculation method"

During the selection of options, the **"Database and calculation method"** have to be kept in mind. This also includes methods on how to incorporate or exclude the losses originating from the distribution and storage of electricity. Some of the options described in this project require substantially different data than others; for example, determining the marginal generation units in a country utilises more often model-based data than the EU-average generation throughout the year. A large variety of options exists for the database, and for each of the options several methods exist to calculate the PEF. Like with many other categories, defining the data base involves trade-offs between transparency and simplicity on the one side versus accuracy or technical correctness on the other.

- Options:
    o Calculation based on statistics and studies
    o Advanced calculations based on statistics and studies (e.g. correcting demand values from statistics and studies, e.g. by power exchanges)
    o Power sector model calculations

4.2.2 Thematic group "Representation of the electricity sector"

In the following sections all categories in the calculation of the PEF of electricity dealing with the representation of the electricity sector are presented. An overview of all relevant categories and options is presented in Table 3.

a. Category "Geographical resolution"

The category **"Geographical resolution"** is one of the most important aspects of the representation of the electricity sector within the PEF methodology. It defines whether e.g. national values are calculated. Depending on the aggregation level, power exchange corrections might be necessary to avoid distortions, e.g. of the national PEF.

Setting the "Geographical resolution" means defining the location for which a PEF is applicable and the regional data that is used for its calculation. The EU-wide option has the advantage that only a single value is applied to all Member States, unifying the calculation and discussions.

Table 3: Categories and options of the thematic group "Representation of the electricity sector"

Category	Option	
Geographical resolution	Bigger EU[1]	With PEX[2] correction
		No PEX Correction
	EU	With PEX correction
		No PEX Correction
	Member States	With PEX correction
		No PEX Correction
	Market regions	With PEX correction
		No PEX Correction
	Subnational regions	With PEX correction
		No PEX Correction
Development over time	Constant	
	Dynamic	
Time resolution	Average over several years	
	Annual average	
	Seasonal	
	Hourly time of use	
Market position	Average electricity production	
	Marginal electricity production	

However, it has to be taken into account that the interconnected electricity system reaches beyond EU member states. This might call for the need to define an electricity region which differs from EU borders. Bottlenecks in the electricity grid and differences in the generation portfolio could require higher geographical resolutions going down to sub national level. This leads to the following options in the category geographical resolution.

- Options:
    - Electricity region (bigger EU), including EU and Norway[3]
    - EU
    - Aggregation of countries

---

[1] Bigger EU corresponds to the EU Member States and Norway.

[2] PEX: power exchange

[3] The choice representing the client's preferences is eventually on EU+Norway because of the relevance of the directive for Energy Efficiency for the EEA countries (Norway, Liechtenstein and Iceland). Of these, only Norway is studied due to its market dimension and connection to the EU energy system.

- o Countries

- o Sub national regions

Depending on the choice of geographical resolution additional **"Trade balance corrections"** concerning the consideration of power exchanges have to be defined. If a national or regional resolution is selected, the PEF can be calculated either only considering the power generation within the region itself or additionally considering power exchanges with other regions or nations. Especially for coupled markets with significant power flows between the markets, not considering power imports or exports can lead to significant distortions of the national PEF. This aspect represents the choice to apply trade correction or not. However, depending on the geographical resolution different aspects arise regarding the trade corrections are carried out. Issues that arise in this context are the difference between physical power flows and commercial flows and the methodology used to determine the sources of traded/transported electricity.

- • Options:

  - o No correction

  - o Consideration of power exchanges

Since the two issues "Geographical resolution" and "Power exchange correction" cannot be evaluated in isolation, they are combined as one category in the evaluation process. As a consequence each choice on regional resolution is characterized by two options with and without power exchange correction.

b. Category "Development over time"

The category **"Development over time"** concerns the decision if the PEF should be "Constant" for future years or if a development path should be defined. This is of importance, especially regarding the evaluation of new energy consuming devices with a longer life times. The first option offers a higher simplicity, while the latter allows for more accuracy in a changing energy system. Especially growing shares of renewable energy and the replacement of older power plants lead to decreases in the PE consumption of the power sector. If a "Dynamic" development over time is chosen several sub-options regarding the adjustment process exist. One example could be a linear reduction factor.

- • Options:

  - o Constant factor

  - o Dynamic (development path)

c. Category "Time resolution"

Defining the **"Time resolution"** means deciding between defining the PEF for longer time periods such as several years or for shorter time periods. "Average over several years" or "Annual average" means that consuming electricity statistically leads to the same consumption of primary energy in all hours of the year. By contrast, if time of use is taken into account, the primary energy consumption changes by the generation mix in certain situations. If for example the energy of a certain application is typically consumed in sunny hours with high generation from photovoltaic power plants, the resulting PE consumption could be lower than in the evening. In the evening hours, relatively

high demand typically leads to the utilisation of less efficient power plants. Several sub-options exist for time-of-use-based calculations, for example differentiated by hour of the day or by season[1].

- Options:
    - o Average over several years
    - o Annual average
    - o Seasonal
    - o Hourly time of use profile

d. Category "Market position"

The dimension "**Market position**" concerns the question, which power generator is taken as the basis for the calculation. While the average generation mix is relatively easy to estimate, determining the marginal generation unit requires more complex assumptions or the usage of an electricity model. The ratio behind using the marginal generation unit is that relatively small changes in consumption lead to changes only in the generation of the last units used to cover demand. If an efficiency measure reduces power consumption in hours of high demand, renewable energies and base load power plants will continue to produce and only the peak load plants (mostly gas and oil turbines) will adjust their generation accordingly. The PE consumption of the marginal generator often differs substantially from the average generation.

- Options:
    - o Average primary energy use
    - o Marginal primary energy use

4.2.3 Thematic group "General PEF methodology"

In the following sections, the categories and options in the thematic group **"General PEF methodology"** are explained. An overview of all categories and options within this group is given in Table 4.

a. Category "PEF indicator"

The category **"PEF indicator"** reflects the energy indicator chosen in calculating the PEF. It contains the options "Total primary energy" and "Non-renewable energy only". It is necessary to separate the decision regarding the consideration of total or non-renewable energies from the choice of system boundary.

- Options:
    - o Total primary energy
    - o Non-renewable energy only

---

[1] The actual impact of the season is a very complex issue. In this context CHP also plays a role which increases its output in the winter which has an inverse effect to the share of photovoltaics.

Table 4: Categories and options within the thematic group "General PEF methodology"

Category	Option
PEF indicator	Total primary energy
	Non-renewable energy only
System boundaries	Entire supply chain
	Conversion and transmission/distribution
Accounting method for nuclear electricity (and heat) generation	Technical conversion efficiencies
	Direct equivalent method
	Physical energy content method
Accounting method for power (and heat) genera-tion using non-combustible RES	Zero equivalent method
	Substitution method
	Direct equivalent method
	Physical energy content method
	Technical conversion efficiencies
Accounting method elec-tricity (and heat) genera-tion using biomass	Zero equivalent
	Technical conversion efficiencies
Accounting method for CHP	IEA method
	Efficiency method
	Finish method
Methodological consis-tency	Same method for all PEF in all MS
	Different methods for different Member States
	Different methods in different Member States with correction mechanism

b. Category "System boundaries"

The category **"System boundaries"** defines if only the primary energy that is used within the conversion and distribution process is considered or if addi-tional energy consumption, e.g. related to the construction of the energy in-frastructure or mining is taken into account. Calculation methods that take the entire supply chain into account in general follow a life cycle assessment approach (LCA), which allows for assessing the impact of electricity supply from a specific energy carrier considering the primary energy consumption of the conversion process as well as of the entire life cycle of the conversion, transmission and distribution infrastructure.

- Options:
  - Conversion and transmission/distribution
  - Entire supply chain (including plant construction and mining)

c. Categories regarding "PE accounting methods"

Further categories to be considered concern the **"PE accounting methods"**. A number of methods exist for accounting PE for electricity from nuclear en-

ergy, for non-combustible RES, such as wind, solar, hydro, as well as for combustible RES. The different methods are applied by various different organizations. Regarding fossil fuels, technical efficiencies of the conversion technologies are used to calculate the PEF for electricity.

In the following section the most relevant PE accounting methods for non-combustible non-renewable fuels (i.e. nuclear), non-combustible RES, and combustible RES (biomass) are presented. If in the category system boundaries the option entire supply chain is chosen, not only the PE of the fuel consumption, but also all other PE that are used downstream have to be taken into account.

Accounting methods for nuclear energy

Regarding the PEF **"Accounting method for nuclear"** power production three noteworthy options exist.

- Options:
    - o Direct equivalent
    - o Physical energy content
    - o Technical conversion efficiencies

The "Direct equivalent method" is used in UN statistics and IPCC reports for non-combustible fuels, whose energy content cannot easily be determined. It applies a direct equivalent of 100% for the conversion of fuel into electricity. It is used to underline that no fossil fuel is used.

The "Physical energy content" method, which is used by the IEA and Eurostat,[1] as well as the "Technical conversion efficiencies" methods both set the PEF for the nuclear fuel to 1 and apply a conversion efficiency of (in general) 33%.

Accounting methods for non-combustible RES

The selection of an **"Accounting method for non-combustible RES"** has a large impact especially in face of the growing share of renewable energies. It has been demonstrated that some methods penalize the use of renewable energy by resulting in lower calculated efficiency gains. Thus they are contradicting the climate target. It also has to be noted that for some statistics or national targets only the non-renewable primary energy usage is relevant.

Regarding the accounting methods for non-combustible RES noteworthy examples are the "Zero equivalent method", the "Direct equivalent method" and the "Substitution method" as well as methods based on "Physical energy content" or on "Technical conversion efficiencies".

- Options:
    - o Zero equivalent method (non-combustible fuels)

---

[1] http://ec.europa.eu/eurostat/statistics-explained/index.php/Calculation_methodologies_for_the_share_of_renewables_in_energy_consumption

- o Direct equivalent method
- o Substitution method
- o Physical energy content method
- o Technical conversion efficiencies method

If the entire supply chain is taken into account, in addition LCA based approaches have to be used.

The "Zero equivalent method" accounts no primary energy at all for the use non-combustible RES in electricity generation.

As for nuclear, the "Direct equivalent method" sets the PEF for electricity from non-combustible RES to 1. It highlights the positive effect of non-combustible RES fuels on climate change.

Moreover, the "Physical energy content method" sets the PEF of electricity from non-combustible RES to 1. The "Physical energy content method" is used by the IEA and Eurostat.[1] It defines primary energy as the first energy (downstream) for which multiple uses are possible. Consequently the PEF for electricity from non-combustible RES is 1.

The "Substitution method" is used by the U.S Energy Information Administration (EIA). It defines primary energy as the first energy accounted before any transformation in secondary or tertiary energy. Regarding e.g. wind turbines, originally the kinetic energy of wind would have to be estimated to use this method. To simplify matters for non-combustible RES, the PE (and PEF) of fossil fuelled power stations that were substituted, e.g. by the wind turbine is used.

Finally, the "Technical conversion efficiency method" defines the PEF of the (renewable) fuel as 1 and uses the conversion efficiencies of the technologies to determine the PE demand to generate one kWh of electricity.

Accounting methods for combustible renewable energies

For combustible renewable energy sources like biomass only two noteworthy options exist for the conversion process

- • Options:
  - o Zero equivalent method
  - o Technical conversion efficiencies method

If only the non-renewable energy is accounted and no life cycle perspective is taken into account, the "Zero equivalent method" is used. By contrast, if the energy of the renewable fuel is taken into account, too, the "Technical conversion efficiencies method" is used. In this case, the primary energy content of the fuel is used to determine the PEF of the fuel.

It can be argued that the accounting method used for biomass should correspond to the accounting method used for non-combustible RES. We assume

---

[1] http://ec.europa.eu/eurostat/statistics-explained/index.php/Calculation_methodologies_for_the_share_of_renewables_in_energy_consumption

that if the "Physical energy content method", the "Substitution method", the "Direct equivalent method" or the "Technical conversion efficiency method" is used for non-combustible RES, the "Technical conversion efficiency method" is used for biomass. In other words, the "Zero equivalent method" can be used for biomass only if it is used for non-combustible RES as well.

Accounting methods for CHP

In addition to the PE accounting methods for fuels, an accounting method allocating the share of primary energy to the outputs of a combined heat and power production has to be chosen. Those accounting methods divide the total primary input of a CHP process between the two outputs electricity and heat. In the context of calculating a PEF of electricity, three methods seem suitable.

- Options:
    - IEA method
    - Efficiency method
    - Finish method

All three CHP accounting methods are illustrated in Figure 2. They differ significantly in the amount of primary energy attributed to electricity. The **"IEA method"** allocates the primary energy input to the outputs in relation to their output energies. Consequently the share of primary energy allocated to electricity (PEshare$_{electricity}$ in Figure 2) corresponds to the conversion efficiency of the electricity process ($\eta_{electricity}$) of the CHP power plant divided by the conversion efficiency of the entire CHP process (η_{total}). Since, in general, the efficiency of the heat process is significantly higher than the efficiency of the electricity process, a larger share of primary energy is attributed to heat.

The **"Efficiency method"** is just the inverse of the IEA method. It attributes a share of primary energy to output 1 corresponding to the share of output 2 in total output. Consequently the share of primary energy allocated to electricity (PEshare$_{electricity}$ in Figure 2) corresponds to the conversion efficiency of the heat process (η_{heat}) of the CHP power plant divided by the conversion efficiency of the entire CHP process (η_{total}). Since, in general, the efficiency of the heat process is significantly higher than the efficiency of the electricity process, a larger share of primary energy is attributed to electricity.

The third method, called **"Finish method"** (or "Reference system method"), uses a reference system to allocate the output. In a first step, the primary energy savings (PEE) compared to a reference system are calculated ((PE_{Ref}–PE_{CHP})/PE_{Ref}), by using the electrical ($\eta_{CHP,el}$) and thermal efficiencies ($\eta_{CHP,heat}$) of the CHP process in relation to the efficiencies of a separate heat ($\eta_{REF,heat}$) and electricity ($\eta_{REF,el}$) generation system. This methodology used to calculate the PES corresponds to the method defined in Annex II of the European Energy Efficiency Directive (2012/27/EU). In a second step, the share of primary energy attributed to each of the two outputs electricity and heat can be calculated. Regarding electricity this amounts to the efficiency factor (1-PEE) multiplied by the ratio of the efficiencies ($\eta_{CHP,el}$/$\eta_{Ref,el}$).
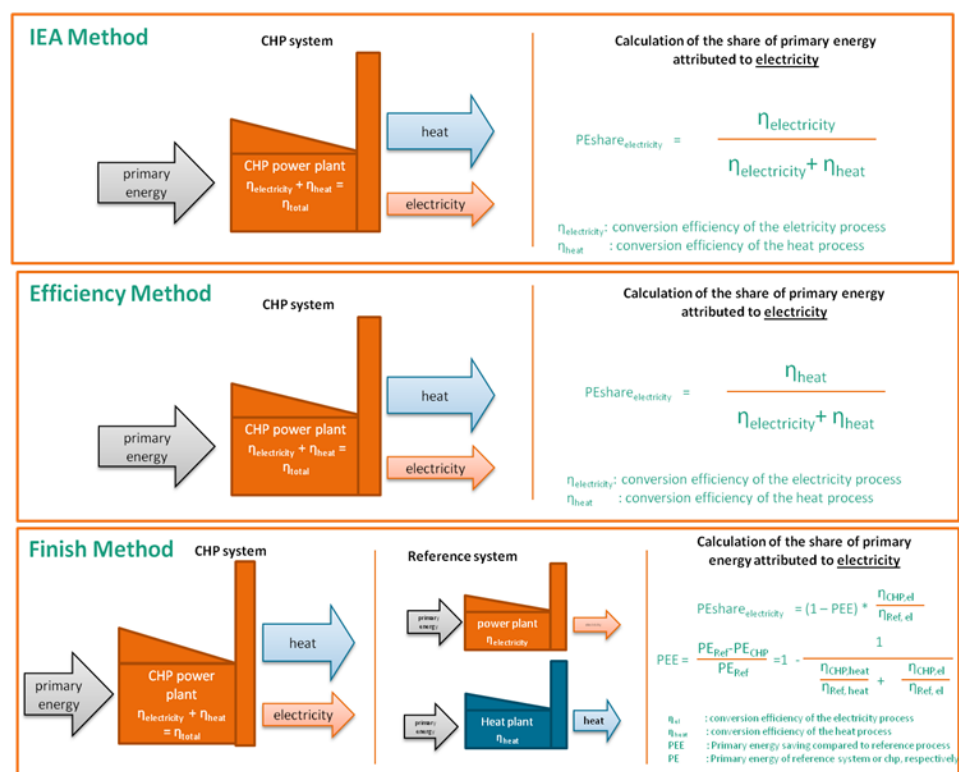
Figure 2: Illustration of the considered CHP accounting methods

d. Category "Methodological consistency"

The category **"Methodological consistency"** addresses the issue of a harmonized calculation method for all Member States. It contains the options "Same method for all PEF calculations in all Member States", "Different methods for different Member States", and "Different methods in different Member States with correction mechanism". The objective of this category is to address the pros and cons of the use of a consistent methodology by all Member States and to introduce the possibility of a correction mechanism that guarantees a minimum level of consistency even if different calculation methods are used. As the current EED allows for a national PEF calculation this discussion is based on a scientific perspective which reaches beyond the pure evaluation of the current PEF in the EED.

- Options:
    - No differentiation/ same method for all PEF calculations in all Member States
    - Different methods in different Member States
    - Different methods in different Member States with correction mechanism

4.3 Summary of categories and options for the calculation

The following Table 5 represents a condensed version of the structure of categories and options. A more precise representation is possible in a decision

tree. Due to the large number of categories and options a complete visualization of this decision tree is not possible in this document.

Therefore, in the following section, evaluation criteria are defined to rate the options within a category. The goal is to cut the vast number of options in this decision tree down to reasonable paths that can be discussed for the final selection of the PEF calculation method.

Table 5: Categories and options for the PEF calculation

Category	Option	
Strategic and political considerations		
PEF purpose	Desired	
	Calculated	
Applicability	Abolish the use of a PEF	
	No differentiation	
	Different for different policies	
	Different for different electric appliances	
	Different for different policies and electric appliances	
	Different for delivered and produced electricity	
Adjustment and review process	Constant over time	
	Regular review/adjustment	
Database and calculation method	Based on statistics and studies	
	Advanced calculations based on statistics and studies	
	Power sector model calculations	
Representation of the electricity sector		
Geographical resolution	Bigger EU[1]	With PEX[2] correction
		No PEX Correction
	EU	With PEX correction
		No PEX Correction
	Member States	With PEX correction
		No PEX Correction
	Market regions	With PEX correction
		No PEX Correction
	Subnational regions	With PEX correction
		No PEX Correction

---

[1] Bigger EU corresponds to the EU Member States and Norway.

[2] PEX: power exchange

Representation of the electricity sector	
Development over time	Constant
	Dynamic
Time resolution	Average over several years
	Annual average
	Seasonal
	Hourly time of use
Market position	Average electricity production
	Marginal electricity production
General PEF methodology	
PEF indicator	Total primary energy
	Non-renewable energy only
System boundaries	Entire supply chain
	Energy conversion and transmission/distribution
Accounting method for nuclear electricity (and heat) generation	Technical conversion efficiencies
	Direct equivalent method
	Physical energy content method
Accounting method for power (and heat) generation using non-combustible RES	Zero equivalent method
	Substitution method
	Direct equivalent method
	Physical energy content method
	Technical conversion efficiencies
Accounting method electricity (and heat) generation using biomass	Zero equivalent method
	Technical conversion efficiencies
Accounting method for CHP	IEA method
	Efficiency method
	Finish method
Methodological consistency	Same method in all Member States
	Different methods in different Member States
	Different methods in different Member States with correction mechanism

5
Criteria for the evaluation of PEF calculation options

In the following section, possible criteria to evaluate the options for PEF calculation approaches are introduced. The options will be ranked in 5 levels ranging from 1 (best) to 5 (worst) for each evaluation criterion. For some evaluation criteria a cut off criterion is defined that might lead to the exclusion of the option. The weighting of the criteria are discussed in Section 5.4. In the context of the development of this project two main topics have been developed to structure these criteria.

- **Topic 1 – Methodological suitability:** Methodological suitability summarizes criteria which assess the influence of the selected options on the method to calculate the PEF with regard to feasibility and achievement of objectives.

- **Topic 2 – Acceptance**: The topic acceptance sums up criteria which evaluate the selected option with a focus on a broad acceptance to use the PEF calculation later on.

5.1 Methodological suitability

Above all, the methodology chosen has to be suitable to calculate realistic PEF for electricity in an overall consistent, efficient and viable way. Therefore, two criteria groups have been selected that reflect the suitability of the chosen approach. They comprise the criteria "Precision" and "Data availability".

5.1.1 Evaluation criterion "Precision"

This criterion assesses the possible precision of the selected option to calculate the PEF. The global target for the criterion "Precision" is to calculate the primary energy consumption as realistic as possible from an environmental perspective such as consumption of resources and emissions.

Moreover, the exclusion of any option having a very low precision is suggested. It would exclude any options that don't have a minimum representation of the real world situation in the electricity sector.

Suggested ranks for the evaluation criterion "Precision" of the methodology:

1	2	3	4	5
very high precision	high precision	medium precision	low precision	very low precision

5.1.2 Evaluation criterion "Data availability"

This group is based on five criteria:

- Effort required,

- Credibility,

- Data quality,

- Uncertainty and

- Flexibility.

a) Effort required

The first criterion considers the "Effort required to collect and derive the data necessary for the PEF calculation. For example, a simple calculation based on public statistics is likely to score higher than data that is derived from commercial databases or is based on a complex estimation process. The lowest possible rating in this category is data that is considered as unavailable and cannot be derived with reasonable effort from existing sources. In this case the lowest rating would be a cut off criterion for the evaluation option.

Suggested ranks for the evaluation criterion "Effort required":

1	2	3	4	5
very low effort required	low effort required	medium effort required	high effort required	very high effort required

b) Credibility

The second criterion tries to evaluate the "Credibility" of the data source. As an example, in this case Eurostat data may score higher than data published by commercial data companies. A cut off level for this criterion would be a very poor credibility of the data source.

Suggested ranks for the evaluation criterion"Credibility" of the data source:

1	2	3	4	5
very high credibility	high credibility	medium credibility	poor credibility	very poor credibility

c) Data quality

The third criterion in the criteria group "Data availability" covers the quality of the data source. This category differs from the credibility of the data source in the way that a given institution may have a high credibility but the data required for the given calculation may have different quality levels.

Suggested ranks for the evaluation criterion quality of the data source:

1	2	3	4	5
very high data quality	high data quality	medium data quality	poor data quality	very poor data quality

d) Uncertainty

The fourth criterion is the "Uncertainty" connected with the used data. Although a certain indicator may be easily accessed and published by credible sources the uncertainty or possible range of the indicator may be high. This aspect is covered with the following ranks. A possible cut off for this sub criterion would be speculative indicators with very high uncertainty.

Suggested ranks for the evaluation criterion "Uncertainty":

1	2	3	4	5
very low uncertainty	low uncertainty	medium uncertainty	high uncertainty	very high uncertainty

e) Flexibility

The criterion "Flexibility" addresses the adaptability of the calculation approaches to changing framework conditions. Since the European electricity supply systems are subject to significant changes due to the challenges of climate change and a single European market, flexibility in the determination of the PEF for electricity is crucial. For a start, the methodology chosen should be applicable to contemporary as well as to future energy systems. However, since not all future changes can be encompassed when setting PEF today, the adaptability of the calculation process to a changing environment has to be ensured. This also comprises the controllability of the calculation process. In this context no cut off limit is foreseen at the current state of the discussion.

Suggested ranks for the evaluation criterion "Flexibility":

1	2	3	4	5
very high flexibility	high flexibility	medium flexibility	poor flexibility	very poor flexibility

5.2 Acceptance

In addition to the "Suitability of the calculation methodology", the "Acceptance" of the methodological approach as well as of the resulting PEF is of utmost importance to guarantee that all Member States use the methodology and support the calculation of the PEF, e.g. by providing the necessary data. The topic "Acceptance" sums up three main groups of criteria:

- Consistency with EU's political targets,

- Complexity and

- Transparency.

Via these criteria, the aim is to evaluate the selected option with a focus on a broad acceptance to use the PEF calculation later on.

5.2.1 Evaluation criterion concerning the consistency with EU's political targets

This group assesses to what extent the chosen calculation approach and resulting factor are suitable to support EU energy and environmental policies as much as possible. To allow for a high level of acceptance among the Member States, the chosen methodological approach and resulting PEF should be consistent with other EU policies and political targets as much as possible. This concerns especially the implementation of a single electricity market as well as the energy efficiency and renewable energy targets. However, especially concerning the latter two, conflicts of interest might exist. While a higher PEF

might better reflect the actual energy efficiency of the electricity generation and transmission supply chain, it also hinders the deployment, e.g. of heat pumps. Thus it is not in line with the long term climate protection targets, which include the promotion of renewable energies and a further electrification of transport and heat supply. Thus the European Commission will have to weigh carefully and decide which of the different targets should be supported in setting the PEF for electricity.

Please note that the energy efficiency target on primary energy level is dissolved into the main underlying criteria 2020 climate target, security of supply and long term decarbonisation. As such our approach follows the general idea of a target on primary energy level.

a) Consistency with the EU internal market

This criterion covers the assessment whether the considered option is in line with the central EU goal to strengthen the internal market. In this context very poor performance is foreseen a cut off limit.

Suggested ranks for the evaluation criterion "Consistency with the EU's internal market"

1	2	3	4	5
very high consistency with target	high consistency with target	medium consistency with target	poor consistency with target	very poor consistency with target

b) Consistency with EU's 2020 climate target

This criterion covers the assessment whether the considered option is in line with EU 2020 targets for climate protection. In this context very poor performance is foreseen as a cut off limit.

Suggested ranks for the evaluation criterion "Consistency with EU's 2020 climate target":

1	2	3	4	5
very high consistency with target	high consistency with target	medium consistency with target	poor consistency with target	very poor consistency with target

c) Security of supply

This criterion covers the assessment whether the options are in line with the EU target to maintain and strengthen security of supply. Calculation options that may foster consumption of scarce resources score lower in this criterion. In this context very poor performance with regard to the target is foreseen a cut off limit.

Suggested ranks for the evaluation criterion "Consistency with the EU's security of supply target":

1	2	3	4	5
very high consistency with target	high consistency with target	medium consistency with target	poor consistency with target	very poor consistency with target

d) Consistency with the long-term objective of strong decarbonisation

This criterion covers the assessment whether the considered option is in line with EU goal of strong decarbonisation of the energy system in the long run. This also comprises the electrification of other energy sectors and applications in line with the decarbonisation of the electricity sector. In this context very poor performance is foreseen a cut off limit.

Suggested ranks for the evaluation criterion "Consistency with the long-term objective of strong decarbonisation":

1	2	3	4	5
very high consistency	high consistency	medium consistency	poor consistency	very poor consistency

5.2.2 Evaluation criterion "Complexity"

The use of a simple methodology, which is easily comprehensible by all relevant stakeholders, can lead to a higher acceptance. Therefore, calculation approaches, which are less complex and thus more acceptable by a wide range of stakeholders, are preferable over methodologies that give more attention to details, but are too complex to be easily comprehensible.

Naturally, this criterion might compete with the criterion "Precision" which could require more complex and refined calculation methods. Considering both criteria ("Precision" and "Complexity") ensures that the chosen methodological approach is neither oversimplified nor too complex. In the current state of the discussion the cut off criterion is defined as very high. The potential limit of complexity to gain at least a very low acceptance has been explored in discussions with the stakeholders.

Suggested ranks for the evaluation criterion "Complexity" of the calculation method:

1	2	3	4	5
very low complexity	low complexity	medium complexity	high complexity	very high complexity

5.2.3 Evaluation criterion "Transparency"

This criterion evaluates whether the selected option is calculated using a transparent method so that many stakeholders can understand and apply it. Moreover, a transparent methodology allows for a straightforward review and adjustment of the PEF.

In addition, transparency reduces the potential for misinterpretation of the methodology and its results. Therefore, this criterion also evaluates to what extent the chosen approach is suitable to avoid misinterpretation. In this context very poor transparency is foreseen as cut off criterion at the current state of the discussion.

Suggested ranks for the evaluation criterion "Transparency":

1	2	3	4	5
Very high transparency	high transparency	medium transparency	poor transparency	very poor transparency

5.3 Applicability of the evaluation criteria on the categories

Not all evaluation criteria presented above are applicable to all calculation process categories. On the one hand, a criterion might not have any relation to a category. On the other hand the rating for a specific criterion might be the same for all options within a category. For example, the criterion "Flexibility" does not apply to the category "PEF purpose", since both a desired or calculated value could be equally adjusted to changing framework conditions. To reduce complexity, the evaluation is only carried out for those combinations of criteria and categories, which make sense and where an actual difference in the rating of the options of a category exists. Therefore, in the following Table 6 the evaluation criteria are attributed to the categories defining the calculation process.

Table 6: Applicability of evaluation criteria to the categories

Category	Criteria											
	Methodological suitability						Acceptance					
		Data availability					Political targets					
	Precision	Effort required	Credibility	Data quality	Uncertainty	Flexibility	Internal market	2020 Climate target	Security of supply	Decarbonisation	Complexity	Transparency
Strategic / Political considerations												
PEF Purpose	■	■	■	■	■	□	■	■	□	■	■	■
Applicability	■	■	■	■	■	□	■	■	■	■	■	■
Adjustment & review	■	■	■	■	■	□	□	■	■	■	■	■
Database/ calculation method	■	■	■	■	■	□	□	■	□	□	■	■
Representation of the electricity sector												
Geographical resolution	■	■	■	■	■	□	■	□	□	□	■	□
Development over time	■	■	■	■	■	■	■	■	■	■	■	■
Time Resolution	■	■	■	■	■	□	□	□	□	□	■	■
Market Position	■	■	■	■	■	□	□	□	□	□	■	■
General PEF Methodology												
PEF indicator	■	■	■	■	■	□	□	■	■	■	■	■
System boundaries	■	■	■	■	■	■	□	■	■	■	■	■
ACCT. method nuclear	■	■	■	■	■	□	■	□	■	□	■	■
ACCT. method non-comb. RES	■	■	■	■	■	□	■	□	■	■	■	■
ACCT. method biomass	■	■	■	■	■	□	■	□	■	■	■	■
ACCT. method CHP	■	■	■	■	■	□	□	■	■	■	■	■
Methodological consistency	■	■	■	■	■	□	■	■	□	■	■	■

5.4   Weightings of the evaluation criteria

To allow for a sophisticated evaluation of the options presented above, the different evaluation criteria have to be weighted according to their significance in calculating suitable PEF for electricity with reasonable effort. The suggested weightings are presented in Table 7.

To guarantee most meaningful PEF, a high **"Methodological suitability"** has to be ensured. Therefore, this group of evaluation criteria receives a high weighting (70%) compared to the criteria category acceptance.

According to the weightings displayed in Table 7 the criterion **"Precision"** is considered to be the most important evaluation criterion. The central reason for the high weighting of precision is that when applying a primary energy factor, the central goal is to define a level playing field for the comparison of the different energy carries used in the economy. In our point of view this goal requires that the precision of the primary energy calculation is high to support this overall goal of the PEF calculation. In this context it is important that the PEF calculation for electricity reflects the situation in the electricity sector as precisely as possible in order to facilitate a meaningful comparison of energy carriers. Moreover, in reflecting the energy consumption in the electricity sector as realistic as possible, the resource consumption is accounted for in a realistic manner, too. These considerations lead us to the conclusion that precision needs a strong weight in the evaluation process. Therefore we suggest a weighting of 50% for the evaluation criterion "Precision".

By contrast **"Data availability"** seems of less importance compared to "Precision". Some issues regarding data might be solved if resources are allocated to a given issue. Therefore, "Data availability" receives a weight of 20%. The highest single weightings within the criteria group "Data availability" are allocated to "Data quality" and "Uncertainty" with 6% since they are the most important data related issues. "Credibility of the data source" receives a weight of 4% while "Effort required" and "Flexibility" are more practical and resource dependent issues which are weighted with 2%.

In our opinion "**Acceptance"** requires a higher rating than data availability since the PEF is a value of political importance. Therefore a value of 30% is chosen for "Acceptance". Most sub criteria are weighted with 4%. One exception is "Consistency with the internal market" which is weighted with 8% because of its strong importance in the overall role of EU legislation. The long term goal of "Decarbonisation" also receives a higher rating of 6% as the long run perspective is important for the long term investment and infrastructure decisions. It should be noted, that the EU's 2020 energy efficiency target is covered by two criteria. The main motivation for the energy efficiency target is to decrease the EU's energy dependency (or increase security of supply) on the one hand, and climate change on the other hand. Therefore the two criteria used in this context are the "2020 climate target" and "Security of supply".

Table 7: Evaluation criteria with weightings

Methodological Suitability						Acceptance					
70 %						30 %					
Precision	Data Availability					Target: internal market	Target: 2020 climate	Target: 2020 security of supply	Target: Long-term decarboni-sation	Complex-ity	Transpar-ency
	20 %										
	Effort required	Credibility	Data quality	Uncer-tainty	Flexibility						
50 %	2 %	4 %	6 %	6 %	2 %	8 %	4 %	4 %	6 %	4 %	4 %

6
Evaluation and pre-selection of the options

In this chapter we propose a first evaluation of the different options for the PEF calculation. The ranking serves as first basis for the discussion. In order to save resources not all 500 evaluation decisions are described in detail. However, short explanations for options that are ruled out are given.

6.1 Evaluation of the options based on the suggested evaluation criteria

In the following the evaluation of the category options based on the evaluation criteria are presented. To reduce complexity only simplified extracts of the evaluation table are shown, in which only the high level criteria "Precision", "Data availability" and "Acceptance" are shown. A complete version of the evaluation table with all sub-criteria can be found in Annex 1 (Table 72). It has to be pointed out that the evaluation depends on two main factors: the actual rating on a single criterion and the weighting of the criterion. Those options that are rated best are considered to draw the decision tree, based on which the final calculation approaches are chosen. The sensitivity of the result in respect to the overall weighting factors is pointed out where possible.

In the evaluation tables, the suggested ratings of the options regarding the evaluation criteria are shown. A value of 1 signifies the best, a value of 5 the worst rating. An "x" in a cell signifies that the evaluation criterion does not apply to the category.

The column "Rank" of the table contains the aggregated rankings of the options. They are calculated for each option by considering the weightings of the evaluation criteria (see Table 7). Yet, if an option achieves a 5 for one of the evaluation criteria for which a cut off criterion is defined, this can be considered as a deciding factor for ruling out the option. Therefore, if an option is rated as very poor (5) for such a criterion, the overall rank will be set to 5, too.

By comparing the ranks of the options, the preferred options within a category can be identified. To easier identify the dominant option, the ranks are colour coded, with bright yellow signifying the best value and red representing the worst value.

Please note: The ratings are suggestions of the authors. They have been discussed with the client and during a stakeholder meeting in Brussels. Where appropriate, the arguments of the stakeholders were integrated in the discussion of the evaluation results.

6.1.1 Category "PEF purpose"

Table 8 contains the aggregated evaluation results of the category "PEF purpose". They are derived in three steps, as it can be seen in Table 9 as an example for the option "Desired (value)". In a first step, each of the two options is evaluated based on all individual criteria that apply to the category "PEF purpose". (In this case: "Precision", "Effort required", "Credibility", "Data quality", "Uncertainty", "2020 climate target", "Long term decarbonisation

target", "Complexity" and "Transparency".) The evaluation has been carried out by the project consortium, in coordination with DG Energy of the European Commission.

Table 8: Evaluation of the category PEF purpose

| Category | Option | Rank | Methodological suitability | | Acceptance |
			Precision	Data availability	
Strategic / political consideration					
PEF purpose	Desired	3.64	4.00	3.22	3.06
	Calculated	2.19	2.00	2.11	2.78

Robustness to weighting: Very high preference for calculated values

In a second step, the results are aggregated for each of the evaluation criteria groups "Precision", "Data availability", and "Acceptance. Since there is only one criterion in category "Precision" no further calculation needs to be carried out. For the other two criteria categories, the rating shown in Table 8 is calculated by weighing the ratings of the individual criteria within the group based on the values in Table 7. Thus the rating of 3.22 of the option "Desired" regarding "Data availability" is the weighted sum of the evaluation results of several sub-criteria. Since not all sub-criteria apply, the weighting has to be adapted to exclude those criteria. Thus, more weight is given to the remaining criteria. (For the detailed rating regarding each option and sub-criterion, please refer to Annex 1.)

Table 9: Illustration of the calculation process for the evaluation of the category "PEF purpose – option "Desired"

		Weighting in %	Rating	Weighting/ Sum of Weights*Rating
Precision		50	4	2.33
Data availability	Effort required	2	3	0.07
	Credibility	4	4	0.19
	Data quality	6	4	0.28
	Uncertainty	6	2	0.14
	Flexibility	//////	x	
Acceptance	EU Internal market target	//////	x	
	2020 climate target	4	3	0.14
	Security of supply	//////	x	
	Long-term decarbonisation target	6	2.5	0.17
	Complexity	4	3	0.14
	Transparency	4	4	0.19
Result (sum)		86	-	3.64

Finally, in a last step, the rating of the groups "Precision", "Data availability", and "Acceptance" are weighted based on the weightings shown in Table 7, to derive the overall rank of the option.[1]

Those three steps are carried out in the evaluation of each option of each category. The only difference is the number of evaluation criteria that apply.

As a result of this evaluation, the option "Calculated (value)" should be preferred over the option "Desired (value)", since it ranks much higher in the overall evaluation (2.19 compared to 3.64). For example, the option "Desired" of the category "PEF purpose" is rated with a poor value of 4 regarding the precision (in terms of calculating the primary energy consumption as realistic as possible from an environmental perspective), while the option "Calculated" is rated with a good 2. Since the value desired performs lower in all three aggregated criteria this result is independent from the weighting of the criteria given the authors rating.

6.1.2 Category "Applicability"

As shown in Table 10, the category "Abolish" the PEF can be eliminated. This option is part of the analysis, because in the opinion of some stakeholders the PEF sets false incentives. However abolishing the PEF would prohibit the possibility to compare energy carriers and is thus not acceptable for the criteria "Precision" and the "EU targets for 2020", as well as the "Long term target of decarbonisation".

Moreover, the rankings in Table 10 show that the option "No differentiation" is superior to all other options. The main reason for this is that it ranks best regarding the evaluation criterion "Precision". The most important reasoning in favour of this option is that in an interconnected (and uncongested) electricity system the primary energy used in the generation of electricity is independent from the place of use or from the appliance in which it is used.

Regarding the option "Different for different policies", some stakeholders argue that different PEF should be used in the EED and the Energy Performance of Buildings Directive. Such a differentiation could be explained by different degrees of market harmonization or different political targets in different Member States. "Different PEF for different appliances" could be justifiable if the use of electricity in different appliances generates different (non-economic) benefits or the need to support the market introduction of different appliances (e.g. due to political targets).

However, such a differentiation by policy or appliance would correspond to the assumption that electricity used in one process has not the same PEF as electricity used in another process. This might be true in strongly congested electricity systems or if the applications strongly differ in time of use. However, in an interconnected electricity system it is very difficult to determine the correct PEF for different policies (or appliances). Moreover data availability and acceptance problems might occur.

Regarding the Energy Performance of Buildings some Member States apply different PEF for delivered electricity and electricity produced on site. They argue that e.g. electricity from PV generated on site should have a lower than the average PEF. However, this argumentation neglects a) that the PV system is still connected to the grid and thus part of the electricity system and b) that if the PV production is considered with an individual PEF, the PEF of the remaining system would have to be corrected, too.

Therefore, all options that differentiate in any way rank poorly regarding "Precision", "Acceptance" and "Data availability".

Table 10: Evaluation of the category "Applicability"

Category	Option	Rank	Methodological suitability		Acceptance
			Precision	Data availability	
Strategic / political consideration					
Applicability	Abolish	5.00	5.00	1.78	5.00
	No differentiation	1.99	2.00	1.94	2.00
	Different for different policies	3.38	3.50	3.22	3.27
	Different for different appliances	3.40	3.50	3.33	3.27
	Different for different policies and appliances	3.46	3.50	3.44	3.40
	Different for delivered and produced	3.04	3.00	3.00	3.13

Robustness to weighting: Very High (Preference for No differentiation)

6.1.3 Category "Adjustment and review process"

The option "Regular review and adjustment" allows for an adjustment of the PEF if the framework conditions of electricity supply change. Therefore it is superior to the option "Constant", in particular regarding the evaluation criteria "Precision" and "Data availability" (cp. Table 11). Thus only the option "Regular review and adjustment" will be considered in the further evaluation process.

Table 11: Evaluation of the category "Adjustment and review process"

Category	Option	Rank	Methodological suitability		Acceptance
			Precision	Data availability	
Strategic / political consideration					
Adjustment	Constant	3.71	4.00	3.70	3.05
and review	Regular Review / adjustment	1.26	1.00	1.40	1.73

Robustness to weighting: Very High (Preference for regular review)

6.1.4 Category "Database and calculation method"

Regarding the category "Database and calculation method" the options "Advanced calculations based on statistics and studies" and "Power sector model" receive similarly high ranks (cp. Table 12). While the option "Advanced calculation based on statistics and studies" ranks higher regarding the "Data availability", the option "Power sector model" receives a top rank regarding "Precision". The option "Basic calculation based on statistics and studies" without any data processing or correction receives a much lower rank in the aggregation and thus can be neglected in further considerations.

Table 12: Evaluation of the category "Database and calculation method"

Category	Option	Rank	Methodological suitability		Acceptance
			Precision	Data availability	
Strategic / political consideration					
Database and calculation method	Based on statistics and studies	2.58	3.00	2.11	1.00
	Advanced calculations based on statistics and studies	1.84	2.00	1.33	2.00
	Power sector model	1.82	1.00	3.33	3.50

Robustness to weighting: Low (No solid preference between advanced calculations and power sector model)

6.1.5 Category "Geographical resolution" (including power exchange correction)

As described above, the categories "Geographical resolution" and the "Power exchange correction" have been combined.

In the course of the evaluation the two sub-national geographical resolution options within the category "Geographical resolution" could be ruled out, because of high "Effort required", "Complexity", "Uncertainty" and low "Consistency with the EU's internal market target" (cp. Table 13)

Regarding "Precision", the options with power exchange correction generally receive higher ranks than the options without power exchange correction. Moreover, since the EU electricity system is not fully interconnected and congestion might occur between certain Member States as well as because of different national legislation, the option "Member States with power exchange correction" is considered the most precise one.

However it is considered more difficult to derive reliable and credible data for a power exchange correction with regions other than Europe. As such a power exchange correction with uncertain data is likely to lead to a lower precision in the end. Therefore the option "Bigger EU with power exchange correction" is limited to EU + Norway[1] and still receives worse ranks than the option "EU with power exchange correction".

In the further evaluation process the following options will be considered:

- Bigger EU without power exchange correction[2],
- EU with power exchange corrections,
- Member States with power exchange correction[3] and
- Market regions with power exchange correction.

---

[1] The choice representing the client's preference is eventually on EU+Norway because of the relevance of the directive for Energy Efficiency for the EEA countries (Norway, Liechtenstein and Iceland). Of these, only Norway is studied due to its market dimension and connection to the EU energy system.

[2] The choice representing the client's preference is eventually on EU+Norway because of the relevance of the directive for Energy Efficiency for the EEA countries (Norway, Liechtenstein and Iceland). Of these, only Norway is studied due to its market dimension and connection to the EU energy system.

[3] Today the Energy Efficiency Directive allows for national PEF for electricity in the annual report on national energy savings (if justifiable).

They all receive similar ranks regarding between 2.29 and 2.50.

Table 13: Evaluation of the category "Geographical resolution"

Category	Option		Rank	Methodological suitability		Acceptance
				Precision	Data availability	
Representation of the electricity sector						
Geographical resolution	Bigger EU	With PEX correction	2.56	2.50	2.89	2.38
		No PeX Correction	2.29	2.75	1.94	1.25
	EU	With PEX correction	2.33	2.50	2.39	1.75
		No PeX Correction	3.12	4.00	1.89	1.75
	Member States	With PEX correction	2.35	1.50	3.36	3.88
		No PeX Correction	3.52	4.00	2.67	3.00
	Market regions	With PEX correction	2.50	2.00	3.44	3.00
		No PeX Correction	3.40	4.00	2.78	2.25
	Subnational	With PEX correction	5.00	2.00	5.00	5.00
		No PeX Correction	5.00	4.00	5.00	5.00

Robustness to weighting: Low among the top rated options, high with regard
to ruled out or rating above 2.5

6.1.6 Category "Development over time"

Regarding the category "Development over time" a dynamic value is superior
to a constant value regarding all evaluation criteria, in particular regarding the
"Precision" of the chosen methodology (cp. Table 14)

Table 14: Evaluation of the category "Development over time"

Category	Option	Rank	Methodological suitability		Acceptance
			Precision	Data availability	
Representation of the electricity sector					
Development over time	Constant	3.04	4.00	1.20	2.67
	Dynamic	1.70	1.00	2.90	2.07

Robustness to weighting: High, only very high rating of data availability could
change the result

6.1.7 Category "Time resolution"

In the category "Time resolution" the precision of the PEF rises with a higher
time resolution. However, at the same time the complexity of the approach
increases (cp. Table 15).

The fuel composition of electricity generation changes constantly, e. g. be-
cause of fluctuating availabilities of RES, fluctuating demand or power plant
restrictions. Therefore the option "Hourly time of use" guarantees the highest
precision within the category "Time resolution". Yet determining the actual
composition of the hourly electricity generation necessitates very complex
power sector model calculations, which, in the case of PEF would have to be
carried out using a highly detailed European model. Since the effort required
seems to be too high for the determination (and regular actualisation) of the
PEF, the option "Hourly time of use" is ruled out.

All other options receive similar aggregated rankings and will be considered in
the further decision process. However, while a "Seasonal" resolution is fa-
vourable regarding the precision, the options "Average over several years"
and "Annual average" benefit from better "Data availability" and less "Ef-
fort" to determine the PEF.

Table 15: Evaluation of the category "Time resolution"

| Category | Option | Rank | Methodological suitability | | Acceptance |
			Precision	Data availability	
Representation of the electricity sector					
Time resolution	Average over several years	2.75	3.50	1.44	1.00
	Annual average	2.53	3.00	1.89	1.00
	Seasonal	2.66	2.00	3.89	4.00
	Hourly time of use	5.00	1.00	5.00	5.00

Robustness to weighting: Low among the top rated options

6.1.8 Category "Market position"

One important purpose of using a PEF is to reflect and compare the primary energy consumptions of different generation technologies or appliances. Regarding the category "Market position", various stakeholders argue however that only if the PEF is determined based on a "Marginal market position" effects of the deployment of new appliances could be shown. Yet, normally the effect of one single new appliance in the system normally is marginally low. The marginal PEF of an appliance depends, above all, on its time of use and the RES feed in situation at that specific point in time (also cp. 4.2.2.d). Moreover, very 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 in the future. Since such calculations seem too complex to be carried out in each revision cycle of the PEF, an "Average market position" is favoured by the authors of this project (cp. Table 16).

Yet due to the political significance attributed to this decision by various stakeholders, the option "Marginal" will still be considered in the further decision process.

Table 16: Evaluation of the category "Market position"

| Category | Option | Rank | Methodological suitability | | Acceptance |
			Precision	Data availability	
Representation of the electricity sector					
Market position	Average	1.87	2.00	1.89	1.00
	Marginal	5.00	4.00	5.00	5.00

Robustness to weighting: Very High

6.1.9 Category "System boundaries"

Regarding the "System boundaries", both options receive similar rankings (cp. Table 17). The option "Entire supply chain" is characterised by a higher precision. However, to consider PE of the "Entire supply chain" a LCA has to be carried out. Since an LCA approach is more time consuming and the data basis is often rather weak, the option "Entire supply chain" ranks much lower regarding "Data availability" and "Acceptance".

Since both options receive similar overall rating, they will both be considered in the further decision process.

Table 17: Evaluation of the category "System boundaries"

| Category | Option | Rank | Methodological suitability | | Acceptance |
			Precision	Data availability	
General PEF methodology					
System boundaries	Entire supply chain	1.96	1.00	3.67	2.73
	Energy conversion and transmission/distribution	2.16	2.00	2.11	2.55

Robustness to weighting: Low

6.1.10 Category "PEF indicator"

Accounting the total primary energy is more realistic and thus more precise than accounting non-renewable energy consumption only (cp. Table 18). Therefore, the option "Total primary energy" receives a better value than the option "Non-renewable energy only" regarding "Precision". However determining the energy consumption of RES is much more complex and will probably encounter data availability issues. Therefore the option "Total primary energy" receives worse ranks regarding "Data availability" and "Acceptance".

Since the aggregated rankings are quite similar, both options will be considered in the further evaluation.

Table 18: Evaluation of the category "PEF indicator"

| Category | Option | Rank | Methodological suitability | | Acceptance |
			Precision	Data availability	
General PEF Methodology					
PEF indicator	Total primary energy	2.04	1.00	3.44	3.27
	Non-renewable energy only	1.96	2.00	2.00	1.82

Robustness to weighting: Medium

6.1.11 Category "Accounting method for nuclear"

Since no fossil fuels are used in electricity generation in nuclear power stations, all options receive the same ranking regarding precision (cp. Table 19). Using the "Direct equivalent method", the PEF for electricity from nuclear is set to one. Since in contrast to the other methods no efficiencies have to be estimated and no calculation has to be carried out, this method requires less effort. Therefore, it ranks higher regarding "Data availability". However, the consumption of the scarce resource nuclear fuel is not accounted for. Thus, the method is only poorly consistent with EU's security of supply target and the option receives lower ratings regarding "Acceptance".

As presented in Chapter 4, the options "Technical conversion efficiencies method" and the "Physical energy content method" yield the same PEF results. Thus they also receive exactly the same rating.

Finally, since all three options receive similar aggregated rankings and thus will be considered in the further evaluation.

Please note: As accounting method for combustible fossil fuels the "Technical conversion efficiency method" is considered to be the only existing relevant option.

Table 19: Evaluation of the category "Accounting method for converted resource nuclear"

| Category | Option | Rank | Methodological suitability | | Acceptance |
			Precision	Data availability	
General PEF methodology					
Accounting method	Technical conversion efficiencies	1.88	2.00	1.67	1.67
converted resource	Direct equivalent	1.90	2.00	1.44	2.17
nuclear	Physical energy content	1.88	2.00	1.67	1.67

Robustness to weighting: medium

6.1.12 Category "Accounting method for non-combustible RES"

Regarding the "Accounting method for non-combustible RES" the "Zero equivalent method" ranks highest regarding all evaluation criteria (cp. Table 20). Above all, it best reflects the positive effects of RES on environmental aspects and is more precise than all other methods. Yet, the "Direct equivalent method" and the "Physical energy content method" also receive good ratings, in particular regarding precision. The "Technical conversion efficiencies method", however, is ruled out for non-combustible RES since it seems too complex to derive conversion efficiencies for very diverse renewable generation technologies.

Therefore, in addition to the "Zero equivalent method", the "Direct equivalent method" and the "Physical energy content method" are considered in the further evaluation.

The choice of method is not independent from the category PEF indicator. If "Only non-renewable energy" is accounted for, only the "Zero equivalent method" can be applied for non-combustible RES. If the option "Total primary energy" is chosen, another accounting method for RES can be selected, too.

Table 20: Evaluation of the category "Accounting method for converted resource non-combustible RES"

| Category | Option | Rank | Methodological suitability | | Acceptance |
			Precision	Data availability	
General PEF methodology					
Accounting method	Zero equivalent	1.07	1.00	1.00	1.43
converted resource	Substitution method	3.39	4.00	2.44	2.43
non-combustible	Direct equivalent	1.96	2.00	1.72	2.14
RES	Physical energy content	2.06	2.00	2.06	2.29
	Technical conversion efficiencies	5.00	4.00	3.78	5.00

Robustness to weighting: Very High

6.1.13 Category "Accounting method for combustible RES"

As presented in Chapter 4 only the "Zero equivalent method" and the "Technical conversion efficiencies method" apply for biomass. As for non-combustible RES the "Zero equivalent method" only applies if only non-renewable energy is accounted.

While the "Zero equivalent method" ranks higher regarding "Data availability", the "Technical conversion efficiency method" receives higher ranks regarding precision and acceptance (cp. Table 21). The main reason for this is that by contrast to the non-combustible RES the efficiency of the conversion technology is of much higher importance, because (higher) competition between different ways of using biomass as fuel exists compared to wind or solar radiation.

Therefore, only the "Technical conversion efficiencies method" will be considered as a feasible option in the further evaluation process.

Please note, that the PEF of biomass as fuel is still an open issue in this case.

Table 21: Evaluation of the category "Accounting method for biomass"

Category	Option	Rank	Methodological suitability		Acceptance
			Precision	Data availability	
General PEF methodology					
Accounting method converted resource biomass	Zero equivalent	2.08	2.50	1.00	2.00
	Technical conversion efficiencies	1.16	1.00	1.22	1.56

Robustness to weighting: High (Only very high rating of data availability could change the result)

6.1.14 Category "CHP accounting method"

In this project three methods to allocate the primary energy input of CHP processes to the outputs electricity and heat are considered. Various other options exist, but the selected options represent most of the spectrum regarding the impact of the results.

The "IEA method" and the "Conversion efficiency method" are both quite simple approaches that do not necessitate a lot of data input. Therefore, they receive good ratings regarding "Data availability" (cp. Table 22). Yet, regarding "Acceptance" as well as regarding "Precision", they rank fairly poor, because the main focus of these methods is their simplicity at the expense of "Precision". Since attributing a share of input to one process based on the efficiency of the other output is not intuitive, the "Efficiency method" receives a worse rating regarding "Transparency" than the "IEA method". Moreover, the "efficiency method" can be criticized as it does not take into account the quality of the output (higher exergy of electricity versus heat).

By contrast, the "Finish method" is more complex, but yields more precise and thus better results. It uses a reference system approach, which attributes the primary energy according to savings which can be realised using CHP compared to a reference system. Thus, not only the ratio of the electrical and thermal efficiencies of a single the CHP system but also those of alternative means of production are considered. The "Finish method" also leads to more balanced results regarding the competitiveness of heat and electricity on primary energy level. Finally, the Finish method corresponds to the method used in the Energy Efficiency Directive for determining the efficiency of the cogeneration process[1].

The "Finish method" will therefore be considered in the further decision process. In addition, the "IEA method" will be taken into account, because it is used by European institutions such as Eurostat.

---

[1] See Annex II of Directive 2012/27/EU on energy efficiency, point (b) on Calculation of primary energy savings.

Table 22: Evaluation of the category "Accounting method for CHP"

Category	Option	Rank	Methodological suitability		Acceptance
			Precision	Data availability	
General PEF methodology					
Accounting method for chp	IEA Method	2.83	3.50	1.44	2.45
	Conversion efficiency method	2.83	3.50	1.44	2.45
	Finish / Reference system method	1.54	1.00	2.56	1.95

Robustness to weighting: Very high

6.1.15 Category "Methodological consistency"

Regarding the category "Methodological consistency", using the same PEF calculation method for all countries, political issues etc. is preferable compared to a variety of different PEF and PEF calculation methods – even with a correction method that allows for a minimum of consistency (cp. Table 23). But it has to be noted that the current EED allows Member States to use a national PEF value different from the EED reference. As such this recommendation goes beyond the simple review of the current PEF calculation method within the general framework of the directive.

Table 23: Evaluation of the category "Methodological consistency"

Category	Option	Rank	Methodological suitability		Acceptance
			Precision	Data availability	
General PEF methodology					
Methodological consistency	Same method for all PEF	2.06	2.50	1.78	1.00
	Different methods for different Member States	3.89	4.50	2.78	3.25
	Different methods for different Member States with correction mechanism	2.67	3.00	2.56	1.75

Robustness to weighting: Very high

6.2 Decision tree of the pre-selected options

Based on the evaluation in Section 6.1 the dominant options for each category can be identified. For the categories "Methodological consistency", "Applicability", "PEF purpose", "Adjustment and review process", and "Development over time" a clear dominance of one option can be identified. Thus, for those categories the suggestion is to rule out the other options. For other categories, two or more options with similar ratings remain.

Figure 3 shows the reduced decision tree that results from the evaluation presented in Section 6.1. In its root node the categories with clearly dominant options are summarized. Read from left to right, the similarly ranked options determine the splitting paths of the decisions tree. To reduce complexity, circles or repetitions of the same sub-branches are not drawn. They are rather represented by a node in lighter blue. They signify that after deciding on an option on that specific category level the branch would continue with the same splitting into further sub-branches as if the option for which the extension of the sub-branches is drawn would have been chosen.

Figure 3: Reduced decision tree resulting from the evaluation of the options

Categories and options with clear preference	Time resolution	Market Position	Database and calculation method	Geographical resolution	System boundaries	PEF indicator	Accounting methods converted resource RES	Accounting methods converted resource non-RES*	Accounting method CHP
Consistent method	Marginal		… (extension see below)						
No differentiation for different policies, appliances etc.	Annual average		Based on statistics & studies	… (extension see below)					
Calculated value				Market region with PEF correction	… (extension see below)				
Dynamic with regular review				Country with PEX correction	… (extension see below)				
		Average	Advanced calculation based on s.&s.	EU with PEX correction	… (extension see below)		Physical energy content & LCA*	… (extension see below)	
						Total primary energy	Direct equivalent & LCA*	Tech. conv. eff. or phys. energy content & LCA	IEA method
									Finish method
	Average over several years		… (extension see above)		Entire supply chain			Direct equivalent & LCA	… (extension see above)
	Seasonal		… (extension see above)	Bigger EU without PEX correction		Non-renewable PE only	Zero equivalent & LCA	Tech. conv. eff. or phys. energy content & LCA	… (extension see above)
					Conversion and transmission/ distribution			Direct equivalent & LCA	… (extension see above)
			Power sector model	… (extension see above)	… (extension see above without LCA)				

45

On the second category level, which addresses the **Time resolution**, it has to be decided if either "Annual averages" or an "Average over several years" is preferred. On the third category level, a clear dominance in favour of an "Average market position" exists. However, since both market positions are still widely discussed, e.g. by the relevant stakeholder, the "Marginal market position" is included in the decision tree.

On the next category level, the **Database and calculation method** has to be chosen. For this category, all identified options seem applicable and have a similar rating. The decision regarding the "Database and calculation method" is independent from the previous decision regarding the temporal resolution. Yet, to reduce complexity, only one sub-branch is drawn as mentioned above. It applies for both options on the first level.

On the fifth category level, which addresses the **Geographical resolution** (including possible power exchange corrections), four options remain: "Bigger EU without power exchange correction", "EU with power exchange correction", "Market regions with power exchange correction" and "Countries with power exchange correction". Again, the decision is independent from the choices made on the previous levels.

The sixth category level addresses the **System boundaries**. Since all options obtain a similar rating, none can be excluded. Whether or not the entire supply chain is chosen, the methods chosen to calculate the PEF will be combined with an LCA-approach or not.

On the seventh category level, the **PEF indicator** has to be chosen. Like the decision nodes on the previous levels, the chosen indicator has an influence on the set of options applicable on the following category levels. If the choice is to consider the "Total primary energy", the "Direct equivalent method" or the "Physical energy content method" are applicable as **Accounting methods for non-combustible RES** (seventh eight). In case the "Entire supply chain" is considered, they are combined with an LCA-approach. However, if "Only non-renewable energy" is to be considered, the "Zero equivalent method" (with or without additional LCA) can be applied as accounting method for RES. The **PEF for combustible RES** (biomass) should always be calculated using the conversion efficiencies, if needed in combination with a LCA.

On the final decision level, the **Accounting method for non-combustible non-renewable energy sources** (i.e. nuclear) has to be chosen. Fossil fuels should always be accounted for using the "Technical conversion efficiencies method" and, if the "Entire supply chain" is chosen as "System boundary", a LCA of the supply chain. Electricity generation from nuclear can be either accounted for using the "Technical conversion efficiencies" or the "Direct equivalent method". Both can be combined with a LCA, if the entire supply chain is to be considered.

Since the choice of the primary energy method has a great influence on the outcome of the results, the underlying assumption regarding PE factors of the fuels and conversion efficiencies as well as the resulting PEF for electricity of each method are summarized in Table 24, Table 25 and Table 26. Please note that the efficiencies presented for the "Physical energy content method" are largely based on Eurostat definitions. These data are used for illustration purposes only. All efficiencies used in the final calculation procedures are docu-

mented in the corresponding chapter. The tables show that the "Zero equivalent method" results in the lowest PEF of electricity (PEF of fuel divided by conversion efficiency). The "Direct equivalent method" and the "Physical energy content method" (Eurostat[1]) both yield a PEF of 1 for electricity from hydro, wind and solar PV. However regarding geothermal and nuclear the "Physical energy content method", as applied by Eurostat, leads to much higher PEF for electricity (Geothermal: 10; Nuclear: 3). Regarding biomass and nuclear, the "Physical energy content method" and the "Technical conversion efficiency method" lead to identical results. These resulting PEF should be kept in mind when choosing the most appropriate calculation approach.

In the following section the selected options are described which are based on a discussion of the advantages and shortcomings of the options with the client and relevant stakeholders.

Table 24: Assumed PEF of the fuel[2] in the different calculations

	Zero equivalent	Direct equivalent	Physical energy content	Technical conversion efficiencies
Hydro, wind	0	1	1	n.a.
Solar PV	0	1	1	n.a.
Geothermal	0	1	1	n.a.
Biomass	0	n.a.	1	1
Nuclear	n.a.	1	1	1

---

[1] Although some technologies such as biomass, EPR (nuclear) reactors etc. may have higher efficiencies for new plants, we propose to stay in line with the Eurostat definitions..
http://ec.europa.eu/eurostat/statistics-explained/index.php/Calculation_methodologies_for_the_share_of_renewables_in_energy_consumption

[2] Renewable generation technologies such as wind are treated as fuel in our wording to provide an aggregate name for the energy source used in the generation process of electricity.

Table 25: Assumed conversion efficiencies by fuel[1] in the different calculation methods

	Zero equivalent	Direct equiva-lent	Physical energy content1	Technical con-version effi-ciencies
Hydro, wind	n.a.	100%	100%	n.a.
Solar PV	n.a.	100%	100%	n.a.
Geothermal	n.a.	100%	10%[2]	n.a.
Biomass	n.a.	n.a.	Ca. 30[3]%	30%1
Nuclear	n.a.	100%	33%[4]	33%

Table 26: PEF of electricity resulting from the different calculation methods (assumption: conversion only)

	Zero equivalent	Direct equiva-lent	Physical energy content	Technical con-version effi-ciencies
Hydro, wind	0	1	1	n.a.
Solar PV	0	1	1	n.a.
Geothermal	0	1	10	n.a.
Biomass	0	n.a.	Ca. 3-4	Ca. 3-4
Nuclear	n.a.	1	Ca. 3	Ca. 3

[1] Renewable generation technologies such as wind are treated as fuel in our wording to provide an aggregate name for the energy source used in the generation process of electricity.

[2] Conventional value by, among others, Eurostat – see Annex 2.

[3] In case of the category biomass and waste the efficiency used for the PEF calculation will be calculated based on the underlying scenario data. In this example 30% is used for the illustration.

[4] Conventional value by, among others, Eurostat – see Annex 2.

7
Identification of the four most appropriate methods for PEF calculation and calculation of the PEF

In this chapter, the four sets of calculation options are identified among the different paths of the decision tree. The bases for the decision are the results of three things: our evaluation, the discussion at the stakeholder meeting in Brussels in January 2016 and the client preferences for exploration of calculation options. Each set of calculation options chosen defines one specific method to determine the PEF for electricity, which is used to calculate the PEF for electricity.

Each calculation method is represented in a complete way. This leads to redundancies. The benefit is that each path description can be used as an independent documentation.

7.1 Calculation method 1

7.1.1 Description of the calculation method

The first calculation method is defined by the path shown in red in the decision tree in Figure 4. This calculation method corresponds in wide parts to the assumptions and calculation approaches of Eurostat, in particular regarding the accounting methods for primary energy.

An overview is also given in Table 27. Please note that categories that are constant in all selected calculation methods are marked in grey.

The categories with clearly dominant options are summarized in the root of the decision tree. They determine that a **consistent methodology** should be used for all Member States and that the **same PEF for electricity** should be used **in all legal acts**, such as the Energy Efficiency Directive and the Energy Performance of Buildings Directive, for all appliances etc. This is the only way to avoid distortions and to take account of the interconnected European electricity system. Moreover, there is a clear preference of a **calculated value** implying a **dynamic development**, which should be **revised regularly.**

Those options are chosen to reflect reality as best as possible and to allow for an adaptation of the PEF on changing framework conditions.

Concerning all other options, no clearly dominant option existed. Thus a choice between similar ranked options has to be made. Regarding "Time resolution" seasonal values would require more complex calculations, because most statistical and projected data only exists on a yearly basis and hence a power sector model would have to be used. Since such a complex effort with considerable issues regarding transparency and communication seems not advisable for a regular process such as calculating PEF, the option with seasonal values can be excluded. Moreover, annual averages seem more advisable than averages over several years, because they are more precise. As a result, **annual average** is chosen as the best option from the category time resolution.

Table 27: Definition of calculation method 1

Category	Option
PEF purpose	Calculated
Applicability	No differentiation
Adjustment and review process	Regular review/adjustment
Database and calculation method	Advanced calculations based on statistics and studies
Geographical resolution	Bigger EU, No PEX correction
Development over time	Dynamic
Time resolution	Annual average
Market position	Average electricity production
Methodological consistency	Same method for all PEF/MS
Accounting method for nuclear electricity (and heat) generation	Physical energy content
Accounting method electricity (and heat) generation using biomass	Technical conversion efficiencies
PEF indicator	Total primary energy
System boundaries	Total energy conversion only (including transport losses)
Accounting method for power (and heat) generation using non-combustible RES	Direct equivalent
Accounting method for CHP	IEA method

One main purpose of using a PEF is to reflect and compare the primary energy consumptions of different generation technologies or appliances. Regarding the category "Market position", various stakeholders argue however that only if the PEF is determined based on a marginal market position effects of the deployment of new appliances could be shown. Yet, normally the effect of one single new appliance in the system normally is marginally low. The marginal PEF of an appliance depends, above all, on its time of use and the RES feed in situation at that specific point in time (also cp. 4.2.2.d). Moreover, very 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 in the future. Since such calculations seem too complex to be carried out in each revision cycle the PEF for electricity, an **average market position** is favoured in this project.

However, in order to pick up the long term perspective that has been requested by some stakeholders the PEF calculation is extended to provide **results until 2030**. This should cover the long term changes in the power system which is one of the goals of the stakeholders arguing for marginal analysis. The results provided until 2030 can also allow for the consideration of lifetime PEFs for electricity consuming devices.

Figure 4: Decision path designing calculation method 1

Categories and options with clear preference	Time resolution	Market Position	Database and calculation method	Geographical resolution	System boundaries	PEF indicator	Accounting methods converted resource RES	Accounting methods converted resource non-RES*	Accounting method chp
Consistent method

No differentiation for different policies, appliances etc.

Calculated value

Dynamic with regular review | Marginal

Annual average

Average over several years

Seasonal | Marginal

Average | ... (extension see below)

Based on statistics & studies

Advanced calculation based on s.&s.

... (extension see above)

... (extension see above)

Power sector model | ... (extension see below)

Market region with PEF correction

Country with PEX correction

EU with PEX correction

Bigger EU without PEX correction | ... (extension see below)

... (extension see below)

... (extension see below)

Conversion and transmission only

Entire supply chain | ... (extension see above with LCA) | Total primary energy

Non-renewable PE only | Physical energy content

Direct equivalent*

Zero equivalent | Tech. conv. eff. / phys. energy content

Direct equivalent

Tech. conv. eff. / phys. energy content

Direct equivalent | IEA method

Finish method

... (extension see below)

... (extension see above)

... (extension see above) |

Regarding the database and calculation method, power sector model calculations seem too complex for the above mentioned reasons. Since however precision is the key aspect in PEF calculation **advanced calculations based on statistics and studies** are preferred.

In the category "Geographical resolution" a trade off between precision and data availability and complexity has to be made. While PEF values for each Member State or Market region might yield more precise result than an average PEF, the necessary power exchange corrections would be rather complex and might encounter data availability problems. Moreover, a common PEF for all Member States is consistent with the internal market perspective of the EU. Finally, the option **Bigger EU** (here: EU plus Norway[1]) is preferred over the option EU, because no complex correction mechanisms are necessary within a single electricity market that includes Norway as an important trading partner.

Regarding the "System boundaries" **only conversion and transmission** will be taken into account in this calculation method. The choice to consider conversion and transmission only corresponds to Eurostat assumptions which are a main driver for this calculation method.

Furthermore, in this path **total primary energy** is taken into account which is in line with the Eurostat definitions.

Regarding the accounting methods for primary energy, method 1 is based on the Eurostat methodology, too. **For renewable energies as well as for nuclear**, the **physical energy content method** is used. The underlying assumptions regarding the PEF and the conversion efficiencies are taken from Table 24 - Table 26 in Chapter 6.2. A short overview of the assumptions in method 1 is given in Table 28.

The PEF of the fuels is assumed to be 1. For non-combustible renewable a conversion efficiency of 100% is assumed. By contrast, for geothermal power stations a conversion efficiency of 10% is assumed, while for nuclear power stations a conversion efficiency of 33% applies. For combustible renewables such as biomass, the conversion efficiency is calculated from data.

The resulting PEF for electricity from the various sources are 1 for hydro, wind and solar PV, 10 for geothermal energy, 3-4[2] for biomass and 3 for solar thermal and nuclear. As explained in the previous chapters, combustible non-renewable fuels are assessed using the technical conversion efficiencies method. Regarding CHP, the **IEA method** is used to assign the shares of primary energy to the outputs electricity and heat.

---

[1] The choice representing the client's preference is eventually on EU+Norway because of the relevance of the directive for Energy Efficiency for the EEA countries (Norway, Liechtenstein and Iceland). Of these, only Norway is studied due to its market dimension and connection to the EU energy system.

[2] This corresponds to the net calorific value of the biomass needed to produce 1 kWh of electricity. (Net calorific value / 1 kWh)

Table 28: Assumptions on PEF of the fuel and conversion efficiency for method 1

	PEF of the fuel	Conversion efficiency	PEF for electricity
Hydro	1	100%	1
Wind	1	100%	1
Solar PV	1	100%	1
Geothermal	1	10%	10
Biomass	1	From real data	From real data
Nuclear	1	33%	3
Fossil fuels	1	From real data	From real data
CHP	IEA method		

7.1.2   Description of the calculation process and data basis

The calculation of an official European PEF should be based on officially approved input data. Since a dynamic development is considered better than a constant factor, the input data needs to comprise projections at least for the next 20 – 30 years.

In this project, PRIMES data (Detailed Analytical Results of the 2012 Reference Scenario) is used to calculate the PEF for electricity. PRIMES data seems an appropriate choice, because it offers a consistent set of data for all 28 EU Member States. It is officially approved and available at the Directorate-General for Energy of the European Commission. Moreover, it contains projections of the development of the energy sector until 2050. Finally, the historical years in the PRIMES scenarios are calibrated based on official European statistics from Eurostat. Thus, consistency with the official statistics of the European Commission can be reached.

Since the PRIMES dataset does not contain Norway, an extra dataset for Norway has been developed by Fraunhofer ISI, which is mainly based on ENTSO-E[1] data.

In the following sections the input data which are used to calculate the PEF as well as the actual PEF calculation are presented in detail.

7.1.2.1   Scenario data gross electricity generation

The central basis for the calculation is a scenario for the development of gross electricity generation (see Figure 5). In case of the region EU28 this is covered by the PRIMES scenario data selected as the central data basis for this project. This is supplemented by additional data on Norway provided by Fraunhofer ISI. The data on Norway is based on an extrapolation of the current generation mix (based on ENTSO-E production data) and moderate growth of wind energy by 2015. The data is provided in Annex 1.

---

[1] ENTSO-E is the European network of transmission system operators for electricity. It provides freely accessible data on the electricity system in Europe. https://www.entsoe.eu/disclaimer/Pages/default.aspx

Figure 5: Scenario of gross electricity generation for EU28+Norway – Source: PRIMES 2012 Reference Scenario and ISI projection for Norway based on ENTSO-E data[1]

7.1.2.2 Calculation of the net electricity demand

The primary energy factor calculated in this project corresponds to the primary energy factor of the electricity consumed. Therefore the first step is to calculate the net electricity demand by subtracting the self consumption of power plants and grid losses (cp. Table 29). The data for self consumption and grid losses is taken from the PRIMES scenario data used as basis for the whole calculation process.

Formula

$$Net\ el.\ demand = Gross\ el.\ generation \times (1 - Self\ cons. - Gridlosses)$$

Table 29: Calculation of the net electricity demand

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Electricity		Gross Gen.	3143	3423	3464	3553	3565	3668	3802	TWh
	-	Self. C. **	5.1%	5.0%	4.6%	4.4%	4.0%	3.8%	3.5%	none
	-	Grid losses	7.2%	6.7%	5.9%	5.9%	5.8%	5.9%	6.1%	none
	=	Net Demand	2756	3025	3100	3187	3215	3311	3439	TWh
** Self C.= Self consumption										

7.1.2.3 PEF of fuels and efficiencies

The calculation method 1 "Closest to Eurostat" is defined by the idea to apply Eurostat convention to the PEF calculation based on the PRIMES/ENTSOE scenario data wherever possible. Eurostat has published its definitions on the primary energy content of fuels. These definitions are quoted in the following text box. One of the main aspects of the Eurostat approach is the application

---

[1] The category renewables includes geothermal.

of the "Physical energy content" method, in which primary energy is defined at first step of practical energy use.

Correspondingly, in our calculation procedure the Eurostat definition can be translated into a **PEF of 1 for all fuels**.

> ### Direct quote: Eurostat
> ### "Definition of the primary energy content of fuels
> For directly combustible fuels (fossil and renewable fuels/ products[1]) the primary energy content is calculated as the heat value generated during combustion of this fuel.
>
> For non-conventional energies (hydro, wind, solar photovoltaic, geothermal, nuclear and others) it is necessary to establish energy boundaries and make methodological choices in order to define their nature and quantity of primary energy.
>
> The choice for Eurostats's energy statistics and energy balances [1] is to use the physical energy content method. The general principle of this method is that the primary energy form is taken as the first flow in the production process that has a practical energy use. This leads to different situations depending on the energy product:
>
> * For directly combustible energy products (for example coal, natural gas, oil, biogas, bioliquids, solid biomass and combustible municipal/industrial waste) the primary energy is defined as the heat generated during combustion.
> * For products that are not directly combustible, the application of this principle leads to:
>   o the choice of heat as the primary energy form for nuclear, geothermal and solar thermal; and
>   o the choice of electricity as the primary energy form for solar photovoltaic, wind, hydro, tide, wave, ocean.
>
> In cases when the amount of heat produced in the nuclear reactor is not known, the primary energy equivalent is calculated from the electricity generation by assuming an efficiency of 33 %. In the case of electricity and heat generated by geothermal energy: if the actual amount of geothermal heat is not known, the primary energy equivalent is calculated assuming an efficiency of 10 % for electricity production and 50 % for derived heat production. If two energy balances are constructed with different methodological choices and respective assumptions on efficiency conversions and calorific values, it will lead to different results for the share of renewables."
>
> [1]Source: http://ec.europa.eu/eurostat/statistics-explained/index.php/Calculation_methodologies_for_the_share_of_renewables_in_energy_consumption

The other main aspects in calculating the PEF of electricity for the fuel categories are the assumed conversion technology efficiencies, which are used to translate the PEF of fuel into the PEF of electricity (cp. Table 30). For nuclear energy the physical energy content is applied and approximated by 33% efficiency. A similar approximation is used for geothermal energy where an efficiency of 10% is applied. In case of other non-combustible renewables such as wind energy with the exemption of solar thermal this translates to an efficiency of 100%. These defined efficiencies are applied for the entire calculation period from 2000 to 2030 in our calculation.

In the case of combustible fuels we have applied the physical energy content method by calculating the efficiency of the generation process. This efficiency is calculated by dividing the gross electricity generation by the fuel consumption of the electricity production. As a result of these calculations the following efficiencies and primary energy factors for fuels are used as basis for the further steps in this calculation method.

Formula

$$Efficiency = \frac{Gross\ electricity\ generation}{Fuel\ consumption}$$

Table 30: Efficiencies and PEF of the fuels in calculation method 1

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Nuclear		Efficiency	33%	33%	33%	33%	33%	33%	33%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none
Renewables		Efficiency	100%	100%	100%	100%	100%	100%	100%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none
Geothermal		Efficiency	10%	10%	10%	10%	10%	10%	10%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none
Fossil		Gross El. Gen.	1635	1826	1727	1646	1485	1424	1281	TWh
	/	Fuel Cons.	4267	4615	4283	3845	3392	3214	2742	TWh
	=	Efficiency	38.3%	39.6%	40.3%	42.8%	43.8%	44.3%	46.7%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none
Biomass & waste		Gross El. Gen.	47	80	138	152	184	199	203	TWh
	/	Fuel Cons.	185	320	537	562	650	658	675	TWh
	=	Efficiency	25.5%	25.0%	25.6%	27.1%	28.3%	30.3%	30.0%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none

7.1.2.4 Calculation of the raw primary energy demand

The raw primary energy demand can now be calculated using the gross electricity generation, the conversion efficiencies and the PEF of the fuels. As explained in the previous sections the development of the gross generation is taken from PRIMES. The efficiencies of the conversion processes are either predefined by the physical energy content method (this is the case for nuclear and non-combustible RES) or calculated based on PRIMES data. The PEF of the fuel is 1 for all fuels, because the physical energy content method applied by Eurostat is used.

Formula

$$Raw\ Primary\ Energy\ demand = \sum_{fuel} \frac{Gross\ el.\ generation \times PEF.fuel}{efficiency}$$

Table 31 shows in detail the calculation of the raw primary energy demand. It comprises two major steps. First, the gross primary energy demand (PED) per year of each fuel group is calculated by dividing the gross generation by the efficiency of the conversion technology and then multiplying it by the PEF of the fuel. In the second step, the raw primary energy demand per year is calculated by adding up all the gross primary energy demands (PED) of the fuel groups.

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Nuclear		Gross Gen.	945	998	917	887	749	706	799	TWh
	/	Efficiency	33%	33%	33%	33%	33%	33%	33%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED	**2864**	**3023**	**2778**	**2689**	**2271**	**2139**	**2422**	TWh
Renewables		Gross Gen.	511	514	677	859	1139	1330	1510	TWh
	/	Efficiency	100%	100%	100%	100%	100%	100%	100%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED *	**511**	**514**	**677**	**859**	**1139**	**1330**	**1510**	TWh
Geothermal		Gross Gen.	5	5	6	7	8	8	9	TWh
	/	Efficiency *	10%	10%	10%	10%	10%	10%	10%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED *	**48**	**54**	**56**	**73**	**82**	**83**	**89**	TWh
Fossil		Gross Gen.	1,635	1,826	1,727	1,646	1,485	1,424	1,281	TWh
	/	Efficiency	38.3%	39.6%	40.3%	42.8%	43.8%	44.3%	46.7%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED	**4267**	**4615**	**4283**	**3845**	**3392**	**3214**	**2742**	TWh
Biomass & waste		Gross Gen.	47	80	138	152	184	199	203	TWh
	/	Efficiency	25.5%	25.0%	25.6%	27.1%	28.3%	30.3%	30.0%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED	**185**	**320**	**537**	**562**	**650**	**658**	**675**	TWh
Raw Primary Energy Demand			**7875**	**8527**	**8331**	**8028**	**7533**	**7424**	**7438**	TWh

(PED=Primary Energy demand)

7.1.2.5 Calculation of the Heat Bonus for CHP

The next step in the calculation process is the calculation of the bonus for heat generated in CHP power plants (i.e. the primary energy share for heat from CHP) which needs to be subtracted from the raw primary energy demand of power generation. To calculate the bonus for heat generated in CHP, we need the heat output and the fuel consumption (input); in total three steps are necessary, which are described in the next three sections.

7.1.2.5.1 Calculation of the heat generation

The first step in calculating the CHP bonus is the calculation of the heat output related to the CHP process. It is not part of the PRIMES scenario dataset provided to this project, but it can be derived from the indicators provided. The PRIMES dataset provides the net electricity to steam generation ratio and the CHP electricity generation. It is assumed that the CHP data provided in the PRIMES dataset is gross generation. Therefore it needs to be corrected to net electricity generation. In this context an aggregate self consumption of 8% is assumed. The heat generation of the CHP plants can then be calculated by dividing the net electricity generation in CHP plants by the net electricity to heat ratio according to the following formula.

Formula

$$CHP\ heat\ gen. = \frac{CHP\ electricity\ generation \times (1 - self\ cons.)}{electricity\ to\ heat\ ratio}$$

PRIMES data shows that the electricity generation in CHP plants grows from 345 TWh in 2000 to approx. 591 TWh in 2030 (cp. Table 32). This doubling of electricity generation by CHP does not translate directly to a similar growth in heat production from CHP plants as the PRIMES scenario data projects a growth in the net electricity to steam ratio of CHP from 0.36 in 2000 to 0.61 in 2030. As a result the calculated heat output of CHP plants grows at lower

pace. It starts with approx. 872 TWh in 2000 and grows to 1012 TWh in 2030.

Table 32: Calculation of the heat generation in CHP plants

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		CHP El. Gen	345	387	419	490	541	580	591	TWh
	/	El/heat ratio	36%	38%	42%	46%	47%	51%	54%	none
		1-Self consumption	92%	92%	92%	92%	92%	92%	92%	none
	=	CHP Heat Gen	**872**	**942**	**924**	**984**	**1056**	**1052**	**1012**	TWh

7.1.2.5.2 Calculation of the fuel consumption

As a further step in the calculation process the fuel consumption of CHP plants needs to be calculated. The total output of CHP plants is the sum of the electricity and heat produced. In order to calculate the fuel consumption related to CHP generation an assumption on the average efficiency of CHP plants is required. Eurostat data on CHP generation and output suggests that the average efficiency of CHP plants is close to 70%[1]. Therefore an average efficiency of 70% is used and kept constant until 2030 for simplicity reasons. It is very likely that the average efficiency of CHP plants is going to increase. But it is beyond the scope of this project to create an efficiency projection of CHP plants in Europe that is in line with the underlying PRIMES scenario. It has to be kept in mind that the efficiency assumption is rather low and needs to be checked in the next evaluation of the PEF.

> **Formula**
> $$Fuel\ cons.CHP = \frac{CHP\ electricity\ gen. + CHP\ heat\ gen.}{CHP\ efficiency}$$

The results show that the fuel consumption of CHP plants grows in line with total growth of the output which is mainly driven by the strong growth in electricity generation (cp. Table 33). Resulting fuel consumption grows from 1738 TWh in 2000 to 2290 TWh in 2030.

Table 33: Calculation of the fuel consumption of CHP plants

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		CHP El. Gen	345	387	419	490	541	580	591	TWh
	+	CHP Heat Gen	872	942	924	984	1056	1052	1012	TWh
	=	Total CHP Output	1217	1328	1343	1474	1597	1632	1603	TWh
	/	CHP Efficiency	70%	70%	70%	70%	70%	70%	70%	none
	=	Fuel Consumption	**1738**	**1898**	**1919**	**2106**	**2281**	**2332**	**2290**	TWh

7.1.2.5.3 Calculation of the heat bonus

The IEA method applied in this calculation method allocates the fuel consumption according to the shares of electricity and heat in total output. So the heat bonus can be calculated by dividing the heat generation by CHP plants by the total output of the CHP plants and multiplying it by the total fuel consumption of CHP plants and the PEF of the fuels used in CHP plants. The PEF of the fuels is calculated as weighted average of fossil fuels and the fuel category

---

[1] Source: http://ec.europa.eu/eurostat/web/energy/data

biomass and waste. Weighting is based on gross generation. In this calculation method the PEF of fuel is 1 for all fuels. Therefore the average PEF CHP fuels has the same value.

> **Formula**
>
> $$Heat\ bonus\ CHP = \frac{CHP\ heat\ gen. \times Fuel\ cons. \times PEF\ CHP\ fuels}{Total\ CHP\ output}$$

The results show that the heat bonus of CHP grows from 1246 TWh in 2000 to 1446 in 2030 (cp. Table 34). This is due to the fact that heat generation in CHP plants grows slower than electricity generation in the given scenario.

The average PEF of electricity from CHP plants amounts to 1.43 in this calculation. The same value applies for heat. This example shows the consequences of the IEA method. While the PEF of electricity produced is very low compared to other fossil options the PEF of heat is very high compared to the alternatives (see Box – Impact of the CHP accounting method at the end of Section 7.1).

Table 34: Calculation of the heat bonus (IEA method)

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		CHP Heat Gen	872	942	924	984	1056	1052	1012	TWh
	/	Total CHP Output	1217	1328	1343	1474	1597	1632	1603	TWh
	*	Fuel Consumption	1738	1898	1919	2106	2281	2332	2290	TWh
	*	PEF CHP Fuels	1	1	1	1	1	1	1	none
	=	HEAT Bonus CHP	**1246**	**1345**	**1320**	**1406**	**1508**	**1503**	**1446**	TWh

7.1.2.6 Calculation of the primary energy factor for electricity

The final step in the calculation process is the calculation of the final primary energy factor for electricity. Based on the calculated raw primary energy demand the heat bonus is subtracted. The resulting corrected primary energy demand is divided by the net electricity demand to calculate the final PEF of consumed electricity (cp. Table 35).

> **Formula**
>
> $$Final\ PEF\ el. = \frac{Raw\ primary\ en.\ demand - Heat\ bonus\ CHP}{Net\ electricity\ demand}$$

Table 35: Calculation of the final PEF using method 1

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Electricity		Raw PED	7875	8527	8331	8028	7533	7424	7438	TWh
	-	Heat Bonus CHP	1246	1345	1320	1406	1508	1503	1446	TWh
	/	Net el. Demand	2756	3025	3100	3187	3215	3311	3439	TWh
	=	Final PEF	**2.41**	**2.37**	**2.26**	**2.08**	**1.87**	**1.79**	**1.74**	none

7.1.3 Results of the PEF calculation using method 1

The results and the full representation of the calculation which includes all numbers of the parameters are documented in the previous sections and tables. In 2000 the resulting PEF for electricity is 2.41 (cp. Table 35). The calculated PEF decreases to 1.74 in 2030. Main drivers of this development are the projected growth of renewable electricity generation and CHP in the underly-

Identification of the four most
appropriate methods for PEF
calculation and calculation of the
PEF

ing PRIMES scenario. Annual values are calculated by linear interpolation of the PEF between the 5 year results. A table of the annual results in the period 2000-2030 is presented in Annex 1.

In the following, the contribution of the fuel groups to this decrease in PEF is discussed. The contribution to the PEF of electricity of different generation technologies is calculated by dividing the raw primary energy demand by the net electricity demand.

> **Formula**
>
> $$Contribution\ to\ PEF = \frac{Impact\ on\ primary\ energy\ demand}{Net\ electricity\ demand}$$

The resulting contributions are presented in Figure 6. In general the development of the contribution of different generation methods follows the development of gross electricity generation.

Gross electricity generation from biomass grows from 47 TWh in 2000 to 203 TWh in 2030. In the same period the gross generation efficiency grows from ca. 25% to 30%, while overall electricity production grows by more than 20%. As a result of these effects an increase of generation by factor four leads to a growth of the contribution to the PEF by approx. factor three. The contribution of biomass increases from 0.07 in 2000 to 0.2 in 2030.
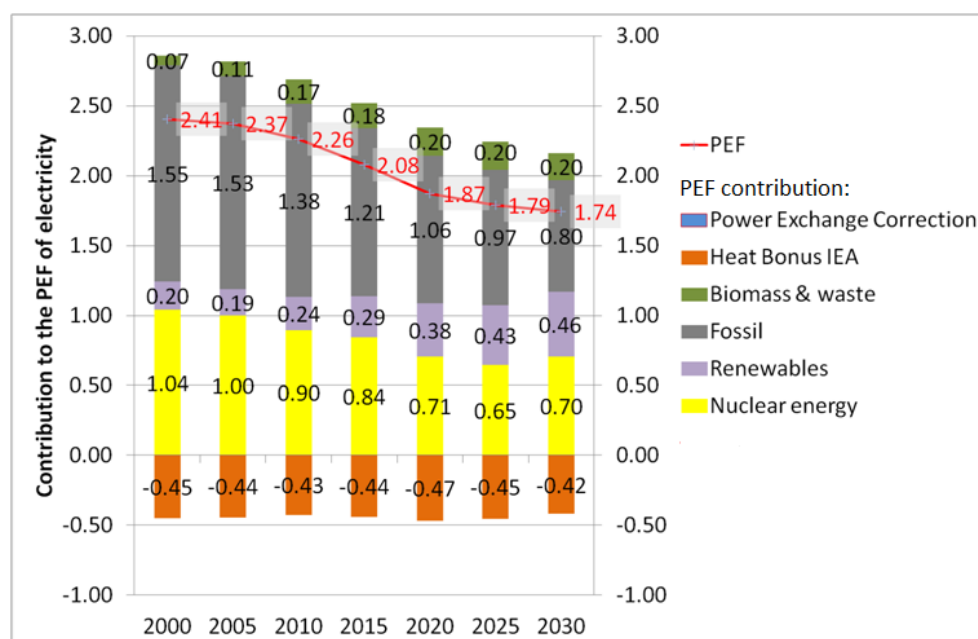
Figure 6: Contribution to the PEF of electricity by source

Fossil generation decreases from 1635 TWh in 2000 to 1281 TWh in 2030. This decline in generation is accompanied by an increase in average generation efficiency from 38% in 2020 to ca. 47% in 2030. In combination with the growth of electricity demand these developments lead to a decrease of the contribution of fossil fuels to the PEF of 1.55 in 2000 to 0.8 in 2030.

The gross electricity generation of RES grows from 516 TWh in 2000 to 1518 TWh in 2030. This translates into a growing contribution to the PEF from 0.2 in 2000 to 0.46 in 2030. The PRIMES generation data shows a decline of nu-

clear generation between 2000 und 2025. Thereafter generation grows again. As the efficiency remains constant by definition of the calculation method this development is also reflected in the contribution to the PEF.

The contribution of nuclear decreases from 1.04 in 2000 to 0.7 in 2030.

The bonus for heat generated in CHP power plants is influenced by several factors. The first aspect is the development of electricity generation from CHP plants which grows from 344 TWh in the underlying PRIMES scenario to ca. 702 TWh in 2030. This doubling of electricity generation by CHP does not translate directly to a similar growth in heat production from CHP plants as the PRIMES scenario data projects a growth in the net electricity to steam ratio of CHP from 0.36 in 2000 to 0.61 in 2030. As a result the calculated heat output of CHP plants grows at lower pace. It starts with 870 TWh in 2000 and grows to 1012 TWh in 2030. The IEA method allocates the fuel input according to the output of the process. In combination with the increasing electricity demand this leads to an almost constant reduction of the PEF by ca. 0.45.

On the aggregate level of the total region EU28+NO no power exchange correction is carried out since generation flows to neighbouring countries are not part of the dataset.

The sum of the different effects the PEF of electricity consumed decreases from 2.41 in 2000 to 1.74 in 2030.

Box – Impact of the CHP accounting method

Method 1 and method 3 differ in the allocation method of fuel input applied for combined heat and power (CHP). The comparison of method 1 and method 3 shows the impact of the CHP accounting method. In the year 2010 924 TWh heat and 419 TWh electricity are generated in CHP power plants. These outputs are connected with a fuel consumption of 1919 TWh.

The IEA method allocates 1320 TWh of fuel consumption to the heat generation and 599 TWh to the electricity generation. As a result the PEF for electricity generated in the CHP process is 1.43 which is very below any thermal electricity generation technologies. On the other hand the PEF for heat is also 1.43 which is above any alternative heat generation technology. In total IEA method leads to a reduction of the PEF of electricity of 0.43 in our calculation for 2010.

The Finish method allocates 950 TWh of fuels consumption to the heat generation of 924 TWh in 2010. 969 TWh of fuel consumptions are allocated to the electricity generation of 419 TWh in 2010. This leads to a PEF of 2.31 for the electricity generation of CHP processes which is below the average value PEF of electricity generation. The resulting PEF for heat generated in the CHP processes is 1.03 which is slightly below most alternative heat generation technologies. Due to the higher allocation of fuel consumption to electricity generated in CHP processes the PEF for electricity is 0.12 higher in 2010 in calculation method 3.

7.2 Calculation method 2

7.2.1 Description of the calculation method

The second calculation method is defined by the path shown in red in the decision tree in Figure 7. It is designed to put an emphasis on climate change issues and a sound representation regarding heat and electricity, especially regarding electricity as competitor to other sources of heat generation. An overview on calculation method 2 is also given in Table 36. Please note that categories that are constant in all selected calculation methods are marked in grey.
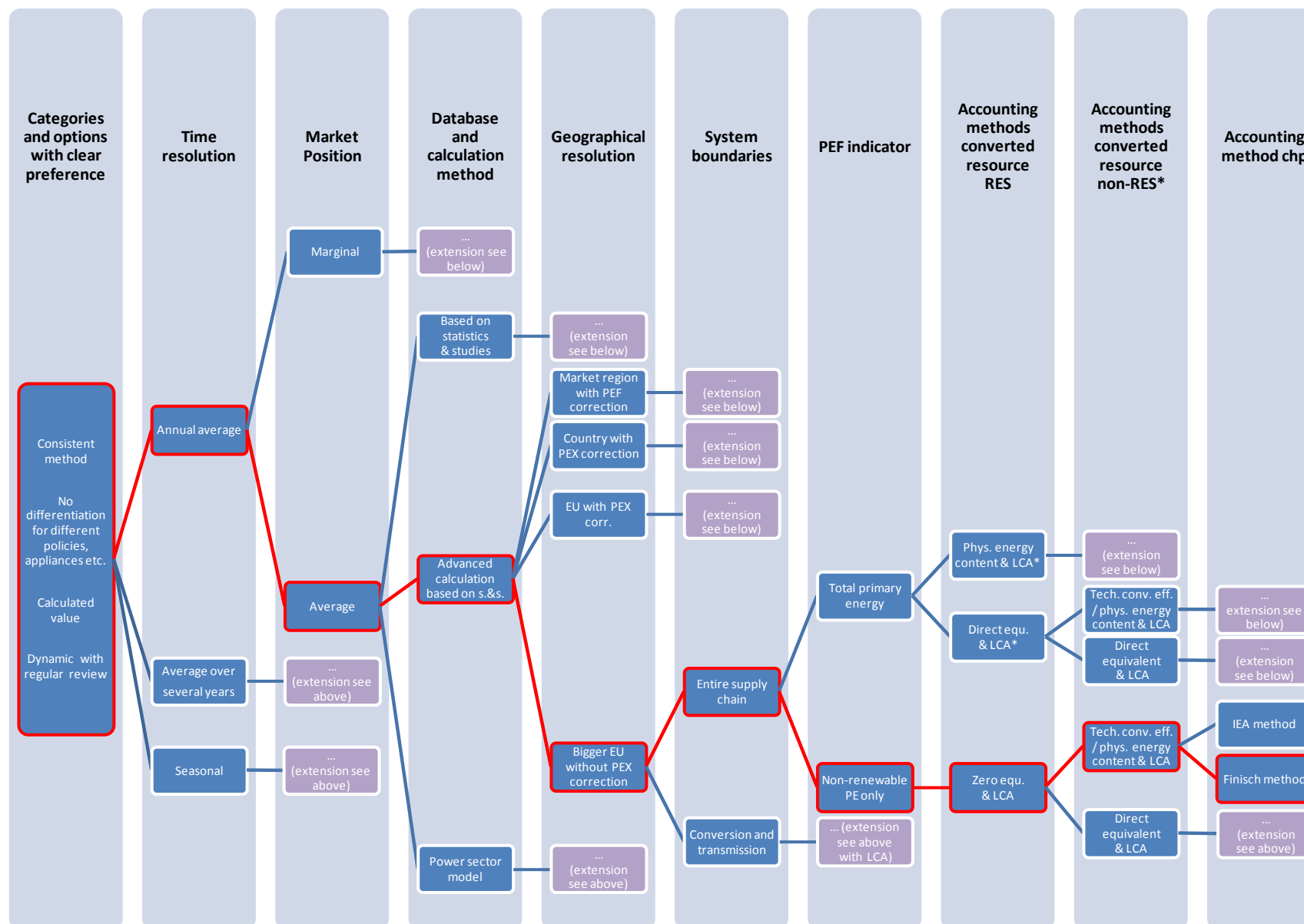
The categories with clearly dominant options are summarized in the root of the decision tree. They determine that a **consistent methodology** should be used for all Member States and that the **same PEF for electricity** should be used **in all legal acts**, such as the Energy Efficiency Directive and the Energy Performance of Buildings Directive, for all appliances etc. This is the only way to avoid distortions and to take account of the interconnected European electricity system. Moreover, there is a clear preference of a **calculated value** implying a **dynamic development**, which should be **revised regularly.**

Those options are chosen to reflect reality as best as possible and to allow for an adaptation of the PEF on changing framework conditions.

Table 36: Definition of calculation method 2

Category	Option
PEF purpose	Calculated
Applicability	No differentiation
Adjustment and review process	Regular review/adjustment
Database and calculation method	Advanced calculations based on statistics and studies
Geographical resolution	Bigger EU, No PEX correction
Development over time	Dynamic
Time resolution	Annual average
Market position	Average electricity production
Methodological consistency	Same method for all PEF/MS
Accounting method for nuclear electricity (and heat) generation	Physical energy content
Accounting method electricity (and heat) generation using biomass	Technical conversion efficiencies
PEF indicator	Non-Renewable primary energy only
System boundaries	Entire supply chain
Accounting method for power (and heat) generation using non-combustible RES	Zero equivalent
Accounting method for CHP	Finish method

Figure 7: Decision path designing calculation method 2

Concerning all other options, no clearly dominant option existed. Thus a choice between similar ranked options has to be made. Regarding "Time resolution" seasonal values would require more complex calculations, because most statistical and projected data only exists on a yearly basis and hence a power sector model would have to be used. Since such a complex effort with considerable issues regarding transparency and communication seems not advisable for a regular process such as calculating PEF, this option can be excluded. Moreover, annual averages seem more advisable than averages over several years, because they are more precise. As a result, **annual average** is chosen as the best option from the category time resolution.

One main purpose of using a PEF is to reflect and compare the primary energy consumptions of different generation technologies or appliances. Regarding the category market position, various stakeholders argue however that only if the PEF is determined based on a marginal market position effects of the deployment of new appliances could be shown. Yet, normally the effect of one single new appliance in the system normally is marginally low. The marginal PEF of an appliance depends, above all, on its time of use and the RES feed in situation at that specific point in time. Moreover, very 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 in the future. Since such calculations seem too complex to be carried out in each revision cycle the PEF for electricity, an **average market position** is favoured in this project (cp. also Section 4.2.2.d).

Regarding the database and calculation method, power sector model calculations seem too complex for the above mentioned reasons. Since however precision is the key aspect in PEF calculation **advanced calculations based on statistics and studies** are preferred.

In the category "Geographical resolution" a trade off between precision and data availability and complexity has to be made. While PEF values for each Member State or Market region might yield more precise result than an average PEF, the necessary power exchange corrections would be rather complex and might encounter data availability problems. Moreover, a common PEF for all Member States is consistent with the internal market perspective of the EU. Finally, the option **Bigger EU** (here: EU plus Norway[1]) is preferred over the option EU.

In calculation method 2 the **entire supply chain** will be taken into account. Even though this requires more complex calculation and a higher effort to derive the necessary data, it leads to more accurate results in terms of the actual impact e.g. of a conversion technology on total primary energy demand. Also considering upstream primary energy consumption is thus more suitable to account for the total consumption of resources. To emphasise the positive impact of renewable energies on these issues **only non-renewable energy consumption** is considered. Consequently, the **zero equivalent method**, which set the PEF to a default value of 0, is used for all renewable

---

[1] The choice representing the client's preference is eventually on EU+Norway because of the relevance of the directive for Energy Efficiency for the EEA countries (Norway, Liechtenstein and Iceland). Of these, only Norway is studied due to its market dimension and connection to the EU energy system.

fuels based on hydro, wind and solar to account for the renewable part of the electricity generation from renewable energies. Additionally, a LCA approach is used to assess the non-renewable primary energy demand in the upstream supply of renewable energy conversion technologies.

Regarding the category "other renewables" such as geothermal as well as biomass, the non-renewable primary energy parts are additionally divided by the efficiencies of the conversion technologies taken from Table 24 - Table 26 in Chapter 6.2 A short overview of the assumptions in method 2 is given in Table 37.

Regarding **nuclear** energy, the **physical energy content** method is used, too. However, no LCA is carried out. The resulting PEF for electricity from nuclear is thus close to three (see Table 26). This seems to be a reasonable approach given the resource consumption of current generation technology. Adding a LCA to the physical energy content method is complex task for nuclear fuels given the various sources and the issues of waste deposition. As for fossil fuels, the technical conversion efficiency method is used in combination with a life cycle assessment.

In the case of fossil fuels, the technical conversion efficiency method is used in combination with a life cycle assessment. Finally, as accounting method for CHP, the **Finish method** has been chosen. As shown in Chapter 4 it allocates a higher share of fuel input to electricity. Thus it seems more realistic and better suited than the IEA method to reflect the actual primary energy consumption of electricity generation in combined processes. It results in a reasonable competitive position of heat and electricity as output of the power plant which is explained in more detail in the representation of the calculation process.

Table 37: Assumptions on PEF of the fuel and conversion efficiency for method 2

	PEF of the fuel	Conversion efficiency	PEF for electricity
Hydro	0.06	100%	1
Wind	0.03	100%	1
Solar PV	0.08	100%	1
Geothermal	0.1	10%	10
Biomass	0.15	From real data	From real data
Nuclear	1	33%	3
Fossil fuels	1.1	From real data	From real data
CHP	Finish method		

7.2.2 Description of the calculation process and data basis

The calculation of official European PEF should be based on officially approved input data. Since a dynamic development is considered better than a constant factor, the input data needs to comprise projections at least for the next 20 – 30 years.

In this project, PRIMES data (Detailed Analytical Results of the 2012 Reference Scenario) is used to calculate the PEF for electricity. PRIMES data seems an

appropriate choice, because it offers a consistent set of data for all 28 EU Member States. It is officially approved and available at the Directorate-General for Energy of the European Commission. Moreover, it contains projections of the development of the energy sector until 2050. Finally, the historical years in the PRIMES scenarios are calibrated based on official European statistics from Eurostat. Thus, consistency with the official statistics of the EC can be reached.

Since the PRIMES dataset does not contain Norway, an extra dataset for Norway has been developed by Fraunhofer ISI, which is mainly based on ENTSO-E[1] data.

In the following section the input data which are used to calculate the PEF as well as the actual PEF calculation are presented in detail.

7.2.2.1 Scenario data gross electricity generation

The central basis for the calculation is a scenario for the development of gross electricity generation. In case of the region EU28 this is covered by the PRIMES scenario data selected as the central data basis for this project (see Figure 8). This is supplemented by additional data on Norway provided by Fraunhofer ISI. The data on Norway is based on an extrapolation of the current generation mix (based on ENTSO-E production data) and moderate growth of wind energy by 2015. The data is provided in Annex 1.
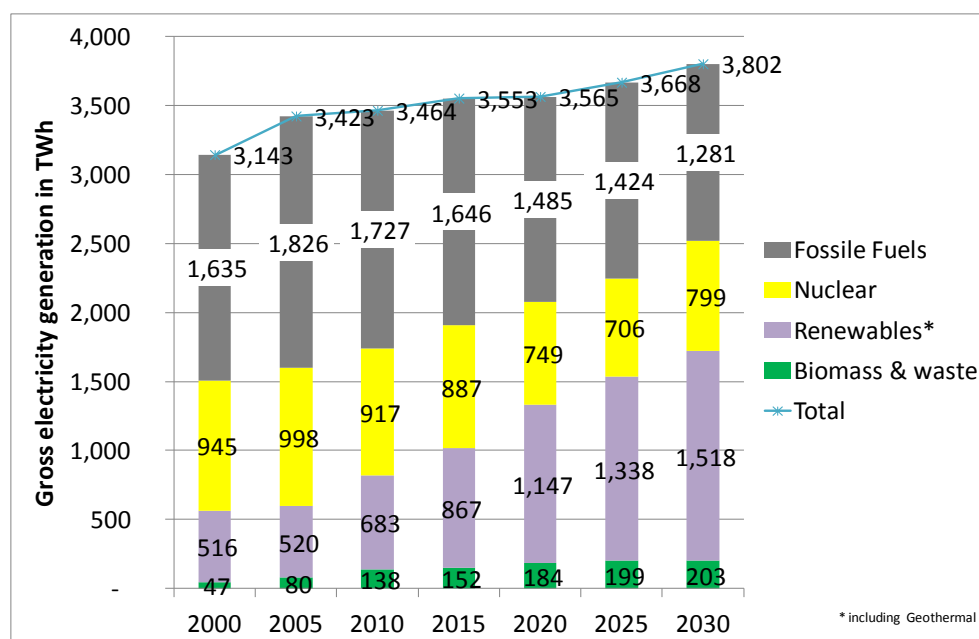
Figure 8: Scenario of gross electricity generation for EU28+Norway Source: PRIMES 2012 Reference Scenario and ISI projection for Norway based on ENTSO-E data

7.2.2.2 Calculation of the net electricity demand

The primary energy factor calculated in this project corresponds to the primary energy factor of the electricity consumed. Therefore the first step is to calcu-

---

1 ENTSO-E is the European network of transmission system operators for electricity. It provides freely accessible data on the electricity system in Europe. https://www.entsoe.eu/disclaimer/Pages/default.aspx

late the net electricity demand by subtracting the self consumption of power plants and grid losses (cp. Table 38). The data for self consumption and grid losses is taken from the PRIMES scenario data used as basis for the whole calculation process.

> ### Formula
> $$Net\ el. demand = Gross\ el. generation \times (1 - Self\ cons. - Grid losses)$$

Table 38: Calculation of net electricity demand

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Electricity		Gross Gen.	3143	3423	3464	3553	3565	3668	3802	TWh
	-	Self. C. **	5.1%	5.0%	4.6%	4.4%	4.0%	3.8%	3.5%	none
	-	Grid losses	7.2%	6.7%	5.9%	5.9%	5.8%	5.9%	6.1%	none
	=	Net Demand	**2756**	**3025**	**3100**	**3187**	**3215**	**3311**	**3439**	TWh
** Self C.= Self consumption										

7.2.2.3 PEF of fuels and efficiencies

The PEF of fuels in calculation method 2 is based on the GEMIS database as well as on a literature review.

For fossil fuels it is set to 1.1. This corresponds to the PEF applied in the majority of countries, for which the PEF of fossil fuels used in various legislation acts has been analyzed (please confer to the following text box). Moreover, it is very close to the values derived from GEMIS. Using standardized values has the advantage that the effort for deriving fuel PEF from GEMIS can be avoided when revising and updating the PEF for electricity. (For more detail, please confer the text box on the following page.)

As for renewable fuels, the GEMIS model is the basis for the primary energy factor of fuels. Based on the analysis shown in the textbox on the previous page the following PEF have been used to calculate the PEF of electricity:

- Solar: 0.08
- Wind. 0.03
- Geothermal energy: 0.1
- Hydro: 0.06
- Biomass: 0.15.

Finally, regarding nuclear fuel, no LCA is carried out as described in Chapter 6. By contrast, the PEF of nuclear fuel is set to a value of 1 (for more detailed explanations please refer to Chapter 6).

The other main aspects in calculating the PEF of electricity for the fuel categories are the assumed conversion technology efficiencies, which are used to translate the PEF of fuel into the PEF of electricity (cp. Table 39). For nuclear energy the physical energy content method is applied and approximated by a conversion efficiency of 33%. A similar approximation is used for geothermal energy where an efficiency of 10% is applied. In case of other non-combustible renewables such as wind energy the approach translates to an efficiency of 100%. These defined efficiencies are applied for the entire calculation period from 2000 to 2030 in our calculation.

Excursus: PEF of fuels based on a LCA approach

Fuel PEF that take into account primary energy consumption of the entire supply chain can be calculated using a LCA model like GEMIS.
(Source: http://www.iinas.org/gemis-de.html)

Fossil fuels:

Using GEMIS, the following PEF of fossil fuels can be derived:

- Gas (EU mix): 1.11 in 2010 and 1.13 in 2030.

- Coal (Australian coal imported into the EU): 1.07

- Oil (EU mix oil refinery products): 1.1

Yet, most European countries apply standardized values as PEF of fossil fuels. An overview is given in the table below. It shows that most countries apply a common PEF for all three fuels. Moreover the PEF of fossil fuels all range between 1.0 and 1.22, while the majority of countries apply a common PEF of 1.1.
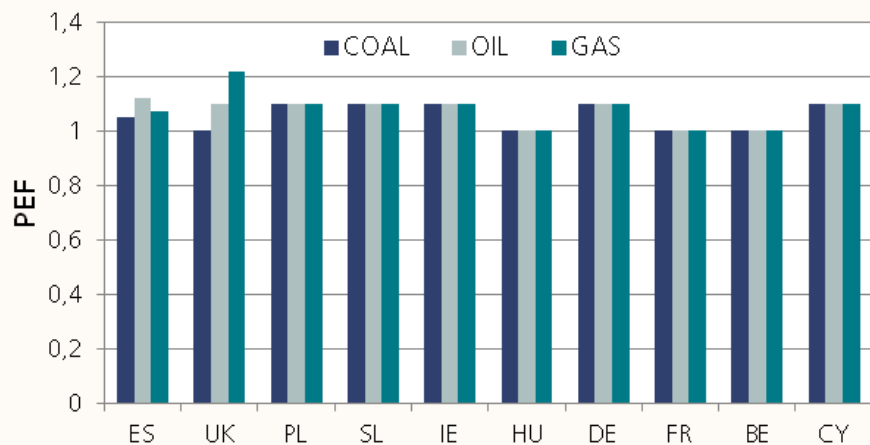
Figure 9: PEF of fuels for different EU Member States (European Performance of Buildings Directive - National Cost-Optimal Regulations)

Renewable energies:

From GEMIS the following PEF for renewable fuels can be derived:

- Solar (PV produced in China): 0.08

- Wind (wind turbine inland). 0.03

- Geothermal energy: The PEF for geothermal energy varies vastly between different installations. An average can be estimated to be about 0.1.

- Hydro: depending on the region, the PEF ranges between 0.01 and 0.06

- Biomass: The biomass comprises biogas, liquid biofuels, solid biomass as well as waste. Consequently the range of PEF is quite large. An average can be estimated to be about 0.15.

For some renewable energy sources only ranges of PEF can be indicated, such as geothermal energy, hydro and biomass

In the case of combustible fuels we have applied the physical energy content method by calculating the efficiency of the generation processes. This efficiency is calculated by dividing the gross electricity generation by the fuel consumption of the electricity production. As a result of this process the following efficiencies and primary energy factors for fuels are used as basis for the further steps in this calculation method.

> **Formula**
>
> $$Efficiency = \frac{Gross\ electricity\ generation}{Fuel\ consumption}$$

Table 39: Efficiencies and PEF of the fuels in calculation method 2

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Nuclear		Efficiency	33%	33%	33%	33%	33%	33%	33%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none
Solar		Efficiency	100%	100%	100%	100%	100%	100%	100%	none
		PEF$_{Fuel}$	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	none
Wind		Efficiency	100%	100%	100%	100%	100%	100%	100%	none
		PEF$_{Fuel}$	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	none
Hydro		Efficiency	100%	100%	100%	100%	100%	100%	100%	none
		PEF$_{Fuel}$	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	none
Geothermal		Efficiency	10%	10%	10%	10%	10%	10%	10%	none
		PEF$_{Fuel}$	0.1	0.1	0.1	0.1	0.1	0.1	0.1	none
Other Renew.		Efficiency	100%	100%	100%	100%	100%	100%	100%	none
		PEF$_{Fuel}$	0.1	0.1	0.1	0.1	0.1	0.1	0.1	none
Fossil		Gross El. Gen.	1635	1826	1727	1646	1485	1424	1281	TWh
	/	Fuel Cons.	4267	4615	4283	3845	3392	3214	2742	TWh
	=	Efficiency	38.3%	39.6%	40.3%	42.8%	43.8%	44.3%	46.7%	none
		PEF$_{Fuel}$	1.1	1.1	1.1	1.1	1.1	1.1	1.1	none
Biomass & waste		Gross El. Gen.	47	80	138	152	184	199	203	TWh
	/	Fuel Cons.	185	320	537	562	650	658	675	TWh
	=	Efficiency	25.5%	25.0%	25.6%	27.1%	28.3%	30.3%	30.0%	none
		PEF$_{Fuel}$	0.15	0.15	0.15	0.15	0.15	0.15	0.15	none

7.2.2.4   Consequences for the discussion on the PEF of fuels

If this calculation method with fuel PEF higher than 1 is taken for electricity we recommend to apply the same PEF in the calculation of energy demand for other purposes such us heat. Otherwise there will be inconsistency in the primary energy calculation approach and the comparison between electricity and other sources e. g. in heat generation will not be adequate.

7.2.2.5   Calculation of the raw primary energy demand

The raw primary demand can now be calculated using the gross electricity generation, the conversion efficiencies and the PEF of the fuels. As explained in Section 7.2.2.1 the development of the gross generation is taken from PRIMES.

As explained in detail in Section 7.2.2.3 the efficiencies of the conversion technologies are either predefined by the PE calculation method (this is the case for nuclear and non-combustible RES) or calculated based on PRIMES data. For nuclear power generation an efficiency of 33% is assumed, while for geothermal power generation an efficiency of 10% applies. By contrast, for other non-combustible RES an efficiency of 100% applies. Those efficiencies correspond to the efficiencies used by Eurostat.

The PEF of fuels are set based on the results of the GEMIS model for life cycle assessment. For a detailed description of the individual values please refer to

Section 7.2.2.3. The only exception is nuclear fuel, for which a PEF of 1 is assumed.

Table 40 shows in detail the calculation of the raw primary energy demand. It comprises two major steps. First, the gross primary energy demand (PED) per year of each fuel group is calculated by dividing the gross generation by the efficiency of the conversion technology and then multiplying it by the PEF of the fuel. In the second step, the raw primary energy demand per year is calculated by adding up all the gross primary energy demands (PED) of the fuel groups.

Formula

$$Raw\ primary\ energy\ demand = \sum_{fuel} \frac{Gross\ el.\ generation.\ fuel \times PEF.\ fuel}{efficiency.\ fuel}$$

Table 40: Calculation of the raw primary energy demand

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Nuclear		Gross Gen.	945	998	917	887	749	706	799	TWh
	/	Efficiency	33%	33%	33%	33%	33%	33%	33%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED	2864	3023	2778	2689	2271	2139	2422	TWh
Solar		Gross Gen.	0	1	23	96	143	177	206	TWh
	/	Efficiency	100%	100%	100%	100%	100%	100%	100%	none
	*	PEF$_{fuel}$	0.08	0.08	0.08	0.08	0.08	0.08	0.08	none
	=	Gross PED	0	0	2	8	11	14	17	TWh
Wind		Gross Gen.	24	73	151	266	490	635	772	TWh
	/	Efficiency	100%	100%	100%	100%	100%	100%	100%	none
	*	PEF$_{fuel}$	0.03	0.03	0.03	0.03	0.03	0.03	0.03	none
	=	Gross PED	1	2	5	8	15	19	23	TWh
Hydro		Gross Gen.	486	440	502	496	502	511	524	TWh
	/	Efficiency	100%	100%	100%	100%	100%	100%	100%	none
	*	PEF$_{fuel}$	0.06	0.06	0.06	0.06	0.06	0.06	0.06	none
	=	Gross PED	29	26	30	30	30	31	31	TWh
Geothermal		Gross Gen.	5	5	6	7	8	8	9	TWh
	/	Efficiency	10%	10%	10%	10%	10%	10%	10%	none
	*	PEF$_{fuel}$	0.1	0.1	0.1	0.1	0.1	0.1	0.1	none
	=	Gross PED	5	5	6	7	8	8	9	TWh
Other Renew.		Gross Gen.	1	1	1	1	4	7	7	TWh
	/	Efficiency	100%	100%	100%	100%	100%	100%	100%	none
	*	PEF$_{fuel}$	0.1	0.1	0.1	0.1	0.1	0.1	0.1	none
	=	Gross PED	0	0	0	0	0	1	1	TWh
Fossil		Gross Gen.	1635	1826	1727	1646	1485	1424	1281	TWh
	/	Efficiency	38.3%	39.6%	40.3%	42.8%	43.8%	44.3%	46.7%	none
	*	PEF$_{fuel}$	1.1	1.1	1.1	1.1	1.1	1.1	1.1	TWh
	=	Gross PED	4694	5077	4711	4230	3731	3536	3016	TWh
Biomass & waste		Gross Gen.	47	80	138	152	184	199	203	TWh
	/	Efficiency	25.5%	25.0%	25.6%	27.1%	28.3%	30.3%	30.0%	none
	*	PEF$_{fuel}$	0.15	0.15	0.15	0.15	0.15	0.15	0.15	none
	=	Gross PED	28	48	80	84	97	99	101	TWh
Raw Primary Energy Demand			7620	8182	7612	7056	6164	5847	5620	TWh

7.2.2.6   Calculation of the heat bonus for CHP

The next step in the calculation process is the calculation of the bonus for heat generated in CHP power plants (i.e. the primary energy share for heat from CHP) which needs to be subtracted from raw primary energy demand of power generation. To calculate the bonus for heat generated in CHP, we need the heat output and the fuel consumption (input); in total three steps are necessary, which are described in the next three sections.

7.2.2.6.1 Calculation of the heat generation

The first step in calculating the CHP bonus is the calculation of the heat output related to the CHP process. It is not part of the PRIMES scenario dataset provided to this project, but it can be derived from the indicators provided. The PRIMES dataset provides the net electricity to steam generation ratio and the CHP electricity generation. It is assumed that the CHP data provided in the PRIMES dataset is gross generation. Therefore it needs to be corrected to net electricity generation. In this context an aggregate self consumption of 8% is assumed. The heat generation of the CHP plants can then be calculated by dividing the net electricity generation in CHP plants by the net electricity to heat ratio according to the following formula (cp Table 41).

Formula

$$CHP\ Heat\ gen. = \frac{CHP\ elecitricity\ generation \times (1 - self\ cons.)}{electricity\ to\ heat\ ratio}$$

Table 41: Calculation of the heat generation by CHP plants

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		CHP El. Gen	345	387	419	490	541	580	591	TWh
	/	El/heat ratio	36%	38%	42%	46%	47%	51%	54%	none
		1-Self consumption	92%	92%	92%	92%	92%	92%	92%	none
	=	CHP Heat Gen	**872**	**942**	**924**	**984**	**1056**	**1052**	**1012**	TWh

PRIMES data shows that the electricity generation from CHP plants grows from 345 TWh in 2000 to ca. 591 TWh in 2030. This doubling of electricity generation in CHP plants does not translate directly to a similar growth in heat production from CHP plants as the PRIMES scenario data projects a growth in the net electricity to steam ratio of CHP from 0.36 in 2000 to 0.61 in 2030. As a result the calculated heat output of CHP plants grows at lower pace. It starts with 872 TWh in 2000 and grows to 1012 TWh in 2030.

7.2.2.6.2 Calculation of the fuel consumption

As a further step in the calculation process the fuel consumption of CHP plants needs to be calculated (cp. Table 42). The total output of CHP plants is the sum of the electricity and heat produced. In order to calculate the fuel consumption related to CHP generation an assumption on the average efficiency of CHP plants is required. Eurostat data on CHP generation and output suggests that the average efficiency of CHP plants is close to 70%[1]. Therefore an average efficiency of 70% is used and kept constant until 2030 for simplicity reasons. It is very likely that the average efficiency of CHP plants is going to increase. But it is beyond the scope of this project to create an efficiency projection of CHP plants in Europe that is in line with the underlying PRIMES scenario. It has to be kept in mind that the efficiency assumption is rather low and needs to be checked in the next evaluation of the PEF.

---

[1] Source: http://ec.europa.eu/eurostat/web/energy/data

> **Formula**
>
> $$Fuel\ cons.CHP = \frac{CHP\ electricity\ gen. + CHP\ heat\ gen.}{CHP\ efficiency}$$

Table 42: Calculation of the fuel consumption of CHP plants

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		CHP El. Gen	345	387	419	490	541	580	591	TWh
	+	CHP Heat Gen	872	942	924	984	1056	1052	1012	TWh
	=	Total CHP Output	1217	1328	1343	1474	1597	1632	1603	TWh
	/	CHP Efficiency	70%	70%	70%	70%	70%	70%	70%	none
	=	Fuel Consumption	**1738**	**1898**	**1919**	**2106**	**2281**	**2332**	**2290**	TWh

The results show that the fuel consumption of CHP plants grows in line with total growth of the output which is mainly driven by the strong growth in electricity generation. Resulting fuel consumption grows from 1738 TWh in 2000 to 2290 TWh in 2030.

7.2.2.6.3 Calculation of the process efficiencies

In addition, the electrical and thermal conversion efficiencies of the CHP process need to be determined. They correspond to the ratio of fuel input to the respective output of the CHP plants. The following table shows the calculation of the electrical and thermal efficiencies. The electrical efficiency results from dividing the CHP electricity generation from PRIMES by the fuel consumption determined in the previous section. The results show that the electrical process efficiency increases 19.8% in 2000 to 25.8% in 2030.

The thermal efficiency of the process is calculated by dividing the CHP heat generation (cp. Section 7.2.1.6.1) by the fuel consumption determined in the previous Section. The resulting thermal efficiencies of the CHP process decrease from 50.2% in 2000 to 44.2% in 2030 (Table 43).

> **Formulas**
>
> $$CHP\ efficiency.electr = \frac{CHP\ electricity\ gen.}{CHP\ fuel\ cons.}$$
>
> $$CHP\ efficiency.heat = \frac{CHP\ heat\ gen.}{CHP\ fuel\ cons.}$$

Table 43: Calculation of the electrical and thermal efficiencies of the CHP process

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		CHP El. Gen	345	387	419	490	541	580	591	TWh
	/	Fuel Consumption	1738	1898	1919	2106	2281	2332	2290	TWh
	=	Eta $_{el,CHP}$	**19.8%**	**20.4%**	**21.8%**	**23.3%**	**23.7%**	**24.9%**	**25.8%**	none
		CHP Heat Gen	872	942	924	984	1056	1052	1012	TWh
	/	Fuel Consumption	1738	1898	1919	2106	2281	2332	2290	TWh
	=	Eta $_{th,CHP}$	**50.2%**	**49.6%**	**48.2%**	**46.7%**	**46.3%**	**45.1%**	**44.2%**	none

7.2.2.6.4 Calculation of efficiency ratio compared to the reference system

The next step in calculating the heat bonus are the efficiency ratios which compare the process efficiencies of the CHP process to the efficiencies of an alternative generation system with uncoupled electricity and heat generation. The efficiency ratios of to the reference system are calculated by dividing the

electrical (or thermal) efficiency of the CHP process by the electrical efficiency of the electricity (or heat) reference system.

The detailed calculation results for this scenario are shown in Table 4. The efficiencies of the CHP process correspond to the results from the previous Section. While the efficiency of an alternative electricity generation in an average modern power plant is assumed to be 40%, the efficiency of the reference heat plant is set to 90%. As shown in Table 44 the sum of the efficiency ratio rises from 105% in 2000 to 114% in 2030.

Formulas

$$Ratio\ Ref\ System.electr = \frac{CHP\ efficiency.electr}{Ref\ efficiency.electr}$$

$$Ratio\ Ref\ System.heat = \frac{CHP\ efficiency.heat}{Ref\ efficiency.heat}$$

Table 44: Calculation of the efficiency ratios to the reference system

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		Eta $_{el,CHP}$	19.8%	20.4%	21.8%	23.3%	23.7%	24.9%	25.8%	none
	/	Eta $_{el,Ref}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	none
	=	eta ratio ele	**49.6%**	**51.0%**	**54.6%**	**58.1%**	**59.3%**	**62.2%**	**64.5%**	none
		Eta $_{heat,CHP}$	50.2%	49.6%	48.2%	46.7%	46.3%	45.1%	44.2%	none
	/	Eta $_{heat,Ref}$	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	none
	=	eta ratio heat	**55.7%**	**55.1%**	**53.5%**	**51.9%**	**51.4%**	**50.1%**	**49.1%**	none
		eta ratio sum	**105%**	**106%**	**108%**	**110%**	**111%**	**112%**	**114%**	none

7.2.2.6.5 Calculation of efficiency factor (1-PEE)

The efficiency factor (1-PEE) of the CHP plant (compared to the reference system) can now be determined by calculating the reciprocal value of the sum of the efficiency ratios (cp. Table 45). Correspondingly to the increasing total efficiency ratio the efficiency factor decreases from 95% in 2000 to 88% in 2030.

Table 45: Calculation of the efficiency factor

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	none
	/	eta ratio sum	1.05	1.06	1.08	1.10	1.11	1.12	1.14	none
	=	1-PEE	**95%**	**94%**	**92%**	**91%**	**90%**	**89%**	**88%**	none

7.2.2.6.6 Calculation of heat bonus

Finally the bonus for heat generated in CHP power plants can be calculated. It needs to be subtracted from raw primary energy demand of power generation. The formula to accomplish the final step of the Finish method, which is shown in the following box, consists of multiplying the fuel consumption of the CHP process by the efficiency ratio compared to the heat reference system, the efficiency factor and the PEF of the fuel used. The PEF of the CHP fuel in this scenario decreases from 1.07 in 2000 to 0.97 in 2030.

The results shown in Table 46 indicate, that the heat bonus, which has to be subtracted from the raw primary energy demand decreases from 988 TWh in 2000 to 961 TWh in 2030.

Identification of the four most
appropriate methods for PEF
calculation and calculation of the
PEF

> **Formula**
>
> $$Bonus\ heat = Fuel\ Cons. \cdot Ratio\ Ref\ System.heat \cdot (1 - PEE) \cdot PEFfuel$$

Table 46: Calculation of the heat bonus

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
		Fuel Consumption	1738	1898	1919	2106	2281	2332	2290	TWh
	*	eta ratio heat	56%	55%	54%	52%	51%	50%	49%	none
CHP	*	1-PEE	95%	94%	92%	91%	90%	89%	88%	none
	*	PEF CHP Fuels*	1.07	1.06	1.03	1.02	1.00	0.98	0.97	none
	=	Heat Bonus CHP	**988**	**1045**	**978**	**1013**	**1055**	**1023**	**961**	TWh

7.2.2.7 Calculation of the primary energy factor for electricity

The final step in the calculation process is the calculation of the final primary energy factor for electricity. Based on the calculated raw primary energy demand the heat bonus is subtracted (cp. Table 47). The resulting corrected primary energy demand is divided by the net electricity demand to calculate the final PEF of consumed electricity.

> **Formula**
>
> $$Final\ PEF\ el. = \frac{Raw\ primary\ energy\ demand - Heat\ bonus\ CHP}{Net\ electricity\ demand}$$

Table 47: Calculation of the final PEF using calculation method 2

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
		Raw PED	7620	8182	7612	7056	6164	5847	5620	TWh
Electricity	-	Heat Bonus CHP	988	1045	978	1013	1055	1023	961	TWh
	/	Net el. Demand	2756	3025	3100	3187	3215	3311	3439	TWh
	=	Final PEF	**2.41**	**2.36**	**2.14**	**1.90**	**1.59**	**1.46**	**1.35**	none

7.2.3 Results of the PEF calculation

The results and the full representation of the calculation which includes all numbers of the parameters are documented in the previous sections and tables. In 2000 the resulting PEF for electricity calculated with method 2 is 2.41. The calculated PEF decreases to 1.35 in 2030. Main drivers of this development are the projected growth of renewable electricity generation and the increase of CHP assumed in the underlying PRIMES scenario Annual values are calculated by linear interpolation of the PEF between the 5 year results. A table of the annual results in the period 2000-2030 is presented in Annex 1.

In the following, the contribution of the fuel groups to this decrease in PEF is discussed. The contribution to the PEF of electricity is calculated by dividing the raw primary energy demand by the net electricity demand.

> **Formula**
>
> $$Contribution\ to\ PEF = \frac{Impact\ on\ primary\ energy\ demand}{net\ electricity\ demand}$$

The results are presented in Figure 10. In general the development of the contribution of different generation method follows the development of gross

electricity generation. Gross electricity generation from biomass grows from 47 TWh in 2000 to 203 TWh in 2030. In the same period the gross generation efficiency grows from ca. 25% to 30% and overall electricity grows by more than 20%. The overall contribution of biomass to the primary energy demand is low as the fuel demand is multiplied with the PEF of biomass and waste of 0.15. As a result of these effects an increase of generation by factor four leads to a growth of the contribution of the PEF by approx. factor three. The Contribution of biomass grows on a very low level from 0.01 in 2000 to 0.03 in 2030.

Fossil generation decreases from 1635 TWh in 2000 to 1281 TWh in 2030. This decline in generation is accompanied by an increase in average generation efficiency from 38% in 2020 to approx. 47% in 2030. In combination with the growth of electricity demand these developments lead to a decrease of the contribution of fossil to the PEF of 1.7 in 2000 to 0.88 in 2030. Due to the higher PEF of fossil fuels of 1.1, the resulting impact of fossil fuels is higher than using calculation method 1.

The gross electricity generation of RES grows from 516 TWh in 2000 to 1518 TWh in 2030. Due to low PEF of the different renewable generation technologies the contribution to the PEF only grows from 0.01 to 0.02.

The PRIMES generation data shows a decline of nuclear generation between 2000 und 2025. Thereafter nuclear electricity generation grows again. As the efficiency remains constant by definition of the calculation method this development is also reflected in the contribution to the PEF. The contribution of nuclear decreases from 1.04 in 2000 to 0.7 in 2030.

The bonus for heat generated in CHP plants is influenced by several aspects. The first aspect is the development of electricity generation from CHP plants which grows from 344 TWh in 2000 to ca. 702 TWh in 2030. This doubling of electricity generation by CHP does not translate directly to a similar growth in heat production from CHP plants as the PRIMES scenario data projects a growth in the net electricity to steam ratio of CHP from 0.36 in 2000 to 0.61 in 2030. As a result the calculated heat output of CHP plants grows at lower pace. It starts with 870 TWh in 2000 and grows to 1012 TWh in 2030. The Finish method allocates the fuel input according a comparison of the efficiency of the process compared to a reference system. In general this leads to a lower heat bonus in the calculation than in the IEA method. The heat bonus is than multiplied by the average PEF of CHP fuels which is lower in method 2 than, e.g. in calculation method 4, because lower fuel PEF of biomass and waste are assumed. In combination with the increasing electricity demand this leads to a heat bonus reduction of the PEF from approx. -0.36 in 2000 to -0.28 in 2030.

On the aggregate level of the total region EU28+NO no power exchange correction is carried out since generation flows to neighbouring countries are not part of the dataset. The sum of the different effect discussed lead to a decrease of the PEF of electricity consumed from 2.41 in 2000 to 1.35 in 2030. Among all four calculation methods this calculation method yields the lowest future PEF for electricity consumed.
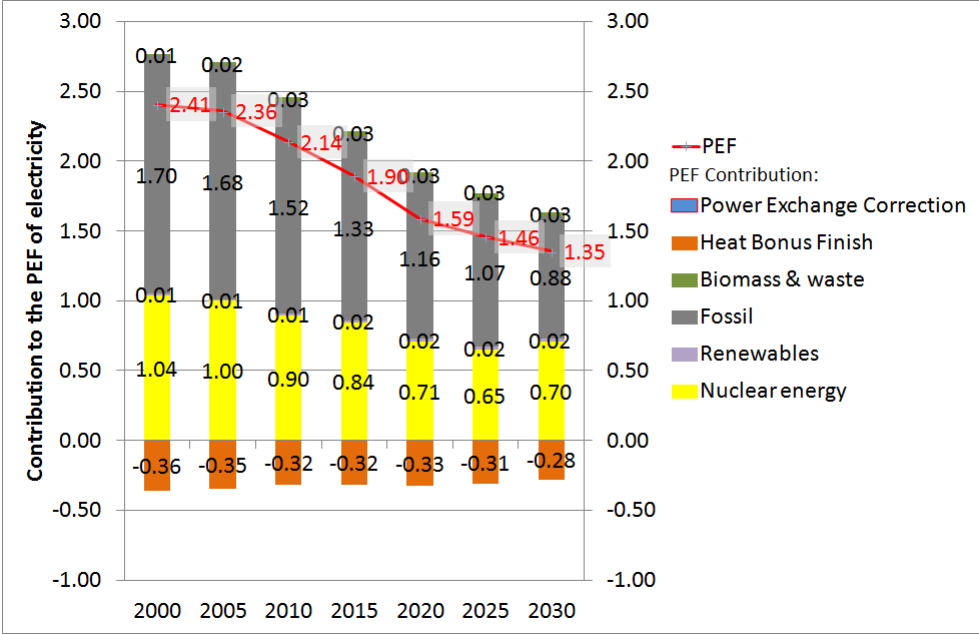
Figure 10: Contribution to the PEF of electricity by source

7.3 Calculation method 3

7.3.1 Description of the calculation method

The third calculation method is defined by the path shown in red in the decision tree in Figure 11. This calculation method corresponds to a large extent to the assumptions and calculation approaches of Eurostat, in particular regarding the accounting methods for renewable primary energy. It is identical to calculation method 1 but uses the Finish method instead of the IEA method for the CHP calculation.

An overview on calculation method 3 is also given in Table 48. Please note that categories that are constant in all selected calculation methods are marked in grey.

The categories with clearly dominant options are summarized in the root of the decision tree. They determine that a **consistent methodology** should be used for all Member States and that the **same PEF for electricity** should be used **in all legal acts**, such as the Energy Efficiency Directive and the Energy Performance of Buildings Directive, for all appliances etc. This is the only way to avoid distortions and to take account of the interconnected European electricity system. Moreover, there is a clear preference of a **calculated value** implying a **dynamic development**, which should be **revised regularly.**

Those options are chosen to reflect reality as best as possible and to allow for an adaptation of the PEF on changing framework conditions.

Concerning all other options, no clearly dominant option existed. Thus a choice between similar ranked options has to be made. Regarding "Time resolution" seasonal values would require more complex calculations, because most statistical and projected data only exists on a yearly basis and hence a power sector model would have to be used. Since such a complex effort with considerable issues regarding transparency and communication seems not advisable for a regular process such as calculating PEF, this option can be excluded. Moreover, annual averages seem more advisable than averages over several years, because they are more precise. As a result, **annual average** is chosen as the best option from the category time resolution.

One main purpose of using a PEF is to reflect and compare the primary energy consumptions of different generation technologies or appliances. Regarding the category market position, various stakeholders argue however that only if the PEF is determined based on a marginal market position effects of the deployment of new appliances could be shown. Yet, normally the effect of one single new appliance in the system normally is marginally low. The marginal PEF of an appliance depends, above all, on its time of use and the RES feed in situation at that specific point in time (also cp. 4.2.2.d).

Moreover, very 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 in the future. Since such calculations seem too complex to be carried out in each revision cycle the PEF for electricity, an **average market position** is favoured in this project.

Figure 11: Decision path designing calculation method 3

Figure 11: Decision path designing calculation method 3

Columns:
Categories and options with clear preference | **Time resolution** | **Market Position** | **Database and calculation method** | **Geographical resolution** | **System boundaries** | **PEF indicator** | **Accounting methods converted resource RES** | **Accounting methods converted resource non-RES*** | **Accounting method chp**

- Consistent method
- No differentiation for different policies, appliances etc.
- Calculated value
- Dynamic with regular review

Time resolution: Annual average; Average over several years; Seasonal

Market Position: Marginal; Average

Database and calculation method: Based on statistics & studies; Advanced calculation based on s.&s.; Power sector model

Geographical resolution: Market region with PEF correction; Country with PEX correction; EU with PEX correction; Bigger EU without PEX correction

System boundaries: Conversion and transmission only; Entire supply chain

PEF indicator: Total primary energy; Non-renewable PE only

Accounting methods converted resource RES: Phys. energy content *; Direct equivalent*; Zero equivalent

Accounting methods converted resource non-RES*: Tech. conv. eff. / phys. energy content; Direct equivalent; Tech. conv. eff. / phys. energy content; Direct equivalent

Accounting method chp: IEA method; Finish method

(extension see below) / (extension see above) / ... (extension see above with LCA)

78

Identification of the four most
appropriate methods for PEF
calculation and calculation of the
PEF

Table 48: Definition of calculation method 3

Category	Option
PEF purpose	Calculated
Applicability	No differentiation
Adjustment and review process	Regular review/adjustment
Database and calculation method	Advanced calculations based on statistics and studies
Geographical resolution	Bigger EU, No PEX correction
Development over time	Dynamic
Time resolution	Annual average
Market position	Average electricity production
Methodological consistency	Same method for all PEF/MS
Accounting method for nuclear electricity (and heat) generation	Physical energy content
Accounting method electricity (and heat) generation using biomass	Technical conversion efficiencies
PEF indicator	Total primary energy (fossil fuels only)
System boundaries	Total energy conversion only (including transport losses)
Accounting method for power (and heat) generation using non-combustible RES	Direct equivalent
Accounting method for CHP	Finish method

However, in order to pick up the long term perspective that has been requested by some stakeholders the PEF calculation is extended to provide results until 2030. This should cover the long term changes in the power system which is one of the goals of the stakeholders arguing for marginal analysis. The results provided until 2030 can also allow for the consideration of lifetime PEFs for electricity consuming devices.

Regarding the database and calculation method, power sector model calculations seem too complex for the above mentioned reasons. Since however precision is the key aspect in PEF calculation **advanced calculations based on statistics and studies** are preferred.

In the category geographical resolution a trade off between precision and data availability and complexity has to be made. While PEF values for each Member State or Market region might yield more precise result than an average PEF, the necessary power exchange corrections would be rather complex and might encounter data availability problems. Moreover, a common PEF for all Member States is consistent with the internal market perspective of the EU.

Finally, the option **Bigger EU** (here: EU plus Norway[1]) is preferred over the option EU, because no complex correction mechanisms are necessary to remove the impacts of imports and exports.

Regarding the system boundaries **only conversion and transmission** will be taken into account. In this context the choice "conversion and transmission only" corresponds to Eurostat assumptions.

Furthermore, in this path **total primary energy** is taken into account which is in line with the Eurostat definitions. Regarding the accounting methods for primary energy, method 1 is based on the Eurostat methodology, too. **For renewable energies as well as for nuclear,** the **physical energy content method** is used.

The underlying assumptions regarding the PEF and the conversion efficiencies are taken from Table 24 - Table 26 in Chapter 6.2. A short overview of the assumptions in method 3 is given in Table 49.

The PEF of the fuels is assumed to be 1. For non-combustible renewable a conversion efficiency of 100% is assumed. By contrast, for geothermal power stations a conversion efficiency of 10% is assumed, while for nuclear power stations a conversion efficiency of 33% applies. For combustible Renewables such as biomass, a conversion efficiency of 30% is used in this example. The resulting PEF for electricity from the various sources are 1 for hydro, wind and solar PV, 10 for geothermal energy, 3.3[2] for biomass and ca. 3 for nuclear. As explained in the previous chapters, combustible non-renewable fuels are assessed using the technical conversion efficiencies method.

Table 49: Assumptions on PEF of the fuel and conversion efficiency for method 3

	PEF of the fuel	Conversion efficiency	PEF for electricity
Hydro	1	100%	1
Wind	1	100%	1
Solar PV	1	100%	1
Geothermal	1	10%	10
Biomass	1	From real data	From real data
Nuclear	1	33%	3
Fossil fuels	1	From real data	From real data
CHP	Finish method		

---

[1] The choice representing the client's preference is eventually on EU+Norway because of the relevance of the directive for Energy Efficiency for the EEA countries (Norway, Liechtenstein and Iceland). Of these, only Norway is studied due to its market dimension and connection to the EU energy system.

[2] This corresponds to the net calorific value of the biomass needed to produce 1 kWh of electricity. (Net calorific value / 1 kWh)

Finally, as accounting method for CHP, the **Finish method** has been chosen. As shown in Chapter 4 it allocates a higher share of fuel input to electricity. Thus it seems more realistic and better suited than the IEA method to reflect the actual primary energy consumption of electricity generation in combined processes. I results in a reasonable competitive position of heat and electricity as output of the power plant.

7.3.2   Description of the calculation process and data basis

The calculation of official European PEF should be based on officially approved input data. Since a dynamic development is considered better than a constant factor, the input data needs to comprise projections at least for the next 20 – 30 years.

In this project, Primes data (Detailed Analytical Results of the 2012 Reference Scenario) is used to calculate the PEF for electricity. PRIMES data seems an appropriate choice, because it offers a consistent set of data for all 28 EU Member States. It is officially approved and available at the Directorate-General for Energy of the European Commission. Moreover, it contains projections of the development of the energy sector until 2050. Finally, the historical years in the PRIMES scenarios are calibrated based on official European statistics from Eurostat. Thus, consistency with the official statistics of the EC is guaranteed.

Since the PRIMES dataset does not contain Norway, an extra dataset for Norway has been developed by Fraunhofer ISI, which is mainly based on ENTSO-E[1] data.

In the following the input data which are used to calculate the PEF as well as the actual PEF calculation are presented in detail.

7.3.2.1   Scenario data gross electricity generation

The central basis for the calculation is a scenario for the development of gross electricity generation. In case of the region EU28 this is covered by the PRIMES scenario data selected as the central data basis for this project. This is supplemented by additional data on Norway provided by Fraunhofer ISI (see Figure 12). The data on Norway is based on an extrapolation of the current generation mix (based on ENTSO-E production data) and moderate growth of wind energy by 2015. The data is provided in Annex 1.

---

[1] ENTSO-E is the European network of transmission system operators for electricity, It provides freely accessible data on the electricity system in Europe. https://www.entsoe.eu/disclaimer/Pages/default.aspx
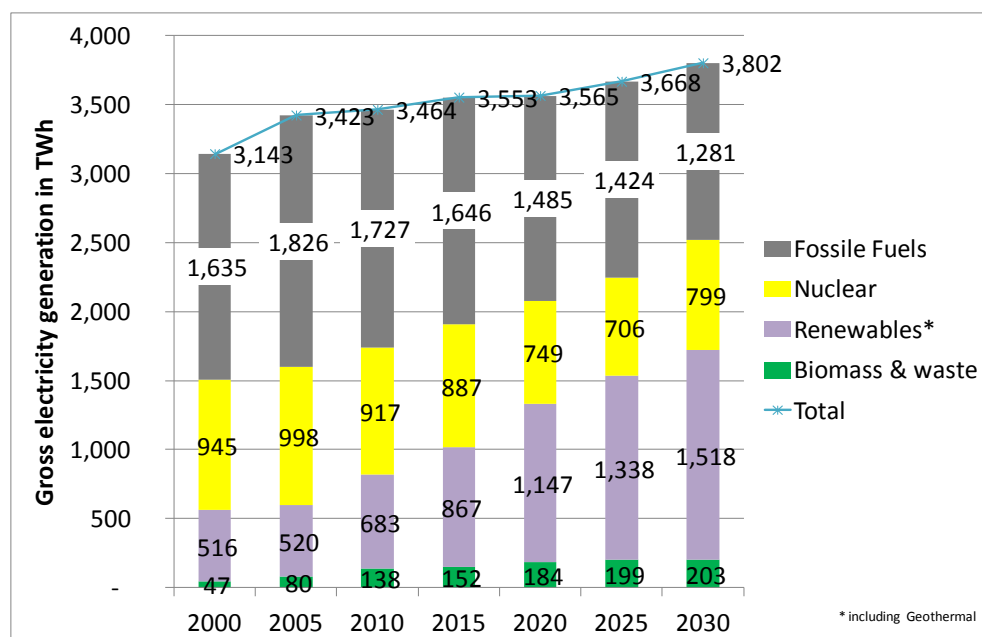
Figure 12: Scenario of gross electricity generation for EU28+Norway Source: PRIMES 2012 Reference Scenario and ISI projection for Norway based on ENTSO-E data

7.3.2.2 Calculation of the net electricity demand

The primary energy factor calculated in this project corresponds to the primary energy factor of the electricity consumed. Therefore the first step is to calculate the net electricity demand by subtracting the self consumption of power plants and grid losses (cp. Table 50). The data for self consumption and grid losses is taken from the PRIMES scenario data used as basis for the whole calculation process.

> **Formula**
>
> $$Net\ el.\ demand = Gross\ el.\ generation \times (1 - Self\ cons. - Gridlosses)$$

Table 50: Calculation of net electricity demand

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Electricity		Gross Gen.	3143	3423	3464	3553	3565	3668	3802	TWh
	-	Self. C. **	5.1%	5.0%	4.6%	4.4%	4.0%	3.8%	3.5%	none
	-	Grid losses	7.2%	6.7%	5.9%	5.9%	5.8%	5.9%	6.1%	none
	=	Net Demand	2756	3025	3100	3187	3215	3311	3439	TWh
** Self C.= Self consumption										

7.3.2.3 PEF of fuels and efficiencies

This calculation method 3 is a modification of the method 1"Closest to Eurostat". It is defined by the idea to apply Eurostat convention to the PEF calculation based on the PRIMES/ENTSOE scenario data wherever possible. Method 3 deviates from method 1 one in the allocation method applied for combined heat and power (CHP). While Eurostat uses the IEA method the Finish method is used in this method. Eurostat has published its definitions on the primary energy content of fuels. This definition is quoted in the following text box:

> **Direct quote: Eurostat**
> **"Definition of the primary energy content of fuels**
>
> For directly combustible fuels (fossil and renewable fuels/ products[)] the primary energy content is calculated as the heat value generated during combustion of this fuel.
>
> For non-conventional energies (hydro, wind, solar photovoltaic, geothermal, nuclear and others) it is necessary to establish energy boundaries and make methodological choices in order to define their nature and quantity of primary energy.
>
> The choice for Eurostat's energy statistics and energy balances is to use the physical energy content method. The general principle of this method is that the primary energy form is taken as the first flow in the production process that has a practical energy use. This leads to different situations depending on the energy product:
>
> - For directly combustible energy products (for example coal, natural gas, oil, biogas, bioliquids, solid biomass and combustible municipal/industrial waste) the primary energy is defined as the heat generated during combustion.
> - For products that are not directly combustible, the application of this principle leads to:
>   - the choice of heat as the primary energy form for nuclear, geothermal and solar thermal; and
>   - the choice of electricity as the primary energy form for solar photovoltaic, wind, hydro, tide, wave, ocean.
>
> In cases when the amount of heat produced in the nuclear reactor is not known, the primary energy equivalent is calculated from the electricity generation by assuming an efficiency of 33 %. In the case of electricity and heat generated by geothermal energy: if the actual amount of geothermal heat is not known, the primary energy equivalent is calculated assuming an efficiency of 10 % for electricity production and 50 % for derived heat production. If two energy balances are constructed with different methodological choices and respective assumptions on efficiency conversions and calorific values, it will lead to different results for the share of renewables."
>
> Source: http://ec.europa.eu/eurostat/statistics-explained/index.php/Calculation_methodologies_for_the_share_of_renewables_in_energy_consumption

One of the main aspects of the Eurostat approach is the application of the physical energy content method, in which primary energy is defined at first step of practical energy use. In our calculation procedure the Eurostat definition can be translated into a **PEF of 1 for all fuels**.

The other main aspects in calculating the PEF of electricity for the fuel categories are the assumed conversion technology efficiencies, which are used to translate the PEF of fuel into the PEF of electricity (cp. Table 51). For nuclear energy the physical energy content is applied and approximated by 33% efficiency. A similar approximation is used for geothermal energy where an efficiency of 10% is applied. In case of other non-combustible renewables such as wind energy with the exemption of solar thermal this translates to an efficiency of 100%. These defined efficiencies are applied for the entire calculation period from 2000 to 2030 in our calculation.

Identification of the four most
appropriate methods for PEF
calculation and calculation of the
PEF

In the case of combustible fuels we have applied the physical energy content method by calculating the efficiency of the generation process. This efficiency is calculated by dividing the gross electricity generation by the fuel consumption of the electricity production. As a result of these calculations the following efficiencies and primary energy factors for fuels are used as basis for the further steps in this calculation method.

Formula

$$Efficiency = \frac{Gross\ electricity\ generation}{Fuel\ consumption}$$

Table 51: Efficiencies and PEF of the fuels in calculation method 3

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Nuclear		Efficiency	33%	33%	33%	33%	33%	33%	33%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none
Renewables		Efficiency	100%	100%	100%	100%	100%	100%	100%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none
Geothermal		Efficiency	10%	10%	10%	10%	10%	10%	10%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none
Fossil		Gross El. Gen.	1635	1826	1727	1646	1485	1424	1281	TWh
	/	Fuel Cons.	4267	4615	4283	3845	3392	3214	2742	TWh
	=	Efficiency	38.3%	39.6%	40.3%	42.8%	43.8%	44.3%	46.7%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none
Biomass & waste		Gross El. Gen.	47	80	138	152	184	199	203	TWh
	/	Fuel Cons.	185	320	537	562	650	658	675	TWh
	=	Efficiency	25.5%	25.0%	25.6%	27.1%	28.3%	30.3%	30.0%	none
		PEF$_{Fuel}$	1	1	1	1	1	1	1	none

7.3.2.4 Calculation of the raw primary energy demand

The raw primary demand can now be calculated using the gross electricity generation, the conversion efficiencies and the PEF of the fuels. As explained in Section 7.3.2.1 the development of the gross generation is taken from PRIMES. The efficiencies of the conversion processes are either predefined by the physical energy content method (this is the case for nuclear and non-combustible RES) or calculated based on PRIMES data (cp. Section 7.3.2.3). The PEF of the fuel is 1 for all fuels, because the physical energy content method applied by Eurostat is used (cp. Section 7.3.2.3).

Table 52 shows in detail the calculation of the raw primary energy demand. It comprises two major steps. First, the gross primary energy demand (PED) per year of each fuel group is calculated by dividing the gross generation by the efficiency of the conversion technology and then multiplying it by the PEF of the fuel. In the second step, the raw primary energy demand per year is calculated by adding up all the gross primary energy demands (PED) of the fuel groups.

Formula

$$Raw\ Primary\ Energy\ demand = \sum_{fuel} \frac{Gross\ el.\ generation \times PEF.\ fuel}{efficiency}$$

Table 52: Calculation of the raw primary energy demand

Nuclear		Gross Gen.	945	998	917	887	749	706	799	TWh
	/	Efficiency	33%	33%	33%	33%	33%	33%	33%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED	2864	3023	2778	2689	2271	2139	2422	TWh
Renewables		Gross Gen.	511	514	677	859	1139	1330	1510	TWh
	/	Efficiency	100%	100%	100%	100%	100%	100%	100%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED *	511	514	677	859	1139	1330	1510	TWh
Geothermal		Gross Gen.	5	5	6	7	8	8	9	TWh
	/	Efficiency *	10%	10%	10%	10%	10%	10%	10%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED *	48	54	56	73	82	83	89	TWh
Fossil		Gross Gen.	1,635	1,826	1,727	1,646	1,485	1,424	1,281	TWh
	/	Efficiency	38.3%	39.6%	40.3%	42.8%	43.8%	44.3%	46.7%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED	4267	4615	4283	3845	3392	3214	2742	TWh
Biomass & waste		Gross Gen.	47	80	138	152	184	199	203	TWh
	/	Efficiency	25.5%	25.0%	25.6%	27.1%	28.3%	30.3%	30.0%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED	185	320	537	562	650	658	675	TWh
Raw Primary Energy Demand			7875	8527	8331	8028	7533	7424	7438	TWh

(PED=Primary Energy demand)

7.3.2.5 Calculation of the heat bonus for CHP

The next step in the calculation process is the calculation of the bonus for heat generated in CHP power plants (i.e. the primary energy share for heat from CHP) which needs to be subtracted from raw primary energy demand of power generation. To calculate the bonus for heat generated in CHP, we need the heat output and the fuel consumption (input); in total three steps are necessary, which are described in the next three sections.

7.3.2.5.1 Calculation of the heat generation

The first step in calculating the CHP bonus is the calculation of the heat output related to the CHP process. It is not part of the PRIMES scenario dataset provided to this project, but it can be derived from the indicators provided. The PRIMES dataset provides the net electricity to steam generation ratio and the CHP electricity generation. It is assumed that the CHP data provided in the PRIMES dataset is gross generation. Therefore it needs to be corrected to net electricity generation. In this context an aggregate self consumption of 8% is assumed. The heat generation of the CHP plants can then be calculated by dividing the net electricity generation in CHP plants by the net electricity to heat ratio according to the following formula.

PRIMES data shows that the electricity generation from CHP plants grows from 345 TWh in 2000 to ca. 591 TWh in 2030. This doubling of electricity generation in CHP plants does not translate directly to a similar growth in heat production from CHP plants as the PRIMES scenario data projects a growth in the net electricity to steam ratio of CHP from 0.36 in 2000 to 0.61 in 2030. As a result the calculated heat output of CHP plants grows at lower pace. It starts with 872 TWh in 2000 and grows to 1012 TWh in 2030 (Table 53).

Table 53: Calculation of the heat generation by CHP plants

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		CHP El. Gen	345	387	419	490	541	580	591	TWh
	/	El/heat ratio	36%	38%	42%	46%	47%	51%	54%	none
		1-Self consumption	92%	92%	92%	92%	92%	92%	92%	none
	=	CHP Heat Gen	872	942	924	984	1056	1052	1012	TWh

7.3.2.5.2 Calculation of the fuel consumption

As a further step in the calculation process the fuel consumption of CHP plants needs to be calculated. The total output of CHP plants is the sum of the electricity and heat produced (cp. Table 54). In order to calculate the fuel consumption related to CHP generation an assumption on the average efficiency of CHP plants is required. Eurostat data on CHP generation and output suggests that the average efficiency of CHP plants is close to 70%[1]. Therefore an average efficiency of 70% is used and kept constant until 2030 for simplicity reasons. It is very likely that the average efficiency of CHP plants is going to increase. But it is beyond the scope of this project to create an efficiency projection of CHP plants in Europe that is in line with the underlying PRIMES scenario. It has to be kept in mind that the efficiency assumption is conservative and needs to be checked in the next evaluation of the PEF.

Formula

$$Fuel\ cons.\ CHP = \frac{CHP\ electricity\ gen. + CHP\ heat\ gen.}{CHP\ efficiency}$$

Table 54: Calculation of the fuel consumption of CHP plants

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
		CHP El. Gen	345	387	419	490	541	580	591	TWh
	+	CHP Heat Gen	872	942	924	984	1056	1052	1012	TWh
CHP	=	Total CHP Output	1217	1328	1343	1474	1597	1632	1603	TWh
	/	CHP Efficiency	70%	70%	70%	70%	70%	70%	70%	none
	=	Fuel Consumption	**1738**	**1898**	**1919**	**2106**	**2281**	**2332**	**2290**	TWh

The results show that the fuel consumption of CHP plants grows in line with total growth of the output which is mainly driven by the strong growth in electricity generation. Resulting fuel consumption grows from 1738 TWh in 2000 to 2290 TWh in 2030.

7.3.2.5.3 Calculation of the process efficiencies

In addition, the electrical and thermal conversion efficiencies of the CHP process need to be determined. They correspond to the ratio of fuel input to the respective output of the CHP plants. The following table shows the calculation of the electrical and thermal efficiencies. The electrical efficiency results from dividing the CHP electricity generation from PRIMES by the fuel consumption determined in the previous section. The results show that the electrical process efficiency increases 19.8% in 2000 to 25.8% in 2030.

The thermal efficiency of the process is calculated by dividing the CHP heat generation (cp. Section 7.3.2.5.1) by the fuel consumption determined in the previous section. The resulting thermal efficiencies of the CHP process decrease from 50.2% in 2000 to 44.2% in 2030 (Table 55).

---

[1] Source: http://ec.europa.eu/eurostat/web/energy/data

Formulas

$$CHP\ efficiency.electr = \frac{CHP\ electricity\ gen.}{CHP\ fuel\ cons.}$$

$$CHP\ efficiency.heat = \frac{CHP\ heat\ gen.}{CHP\ fuel\ cons.}$$

Table 55: Calculation of the electrical and thermal efficiencies of the CHP process

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		CHP El. Gen	345	387	419	490	541	580	591	TWh
	/	Fuel Consumption	1738	1898	1919	2106	2281	2332	2290	TWh
	=	Eta el,CHP	19.8%	20.4%	21.8%	23.3%	23.7%	24.9%	25.8%	none
		CHP Heat Gen	872	942	924	984	1056	1052	1012	TWh
	/	Fuel Consumption	1738	1898	1919	2106	2281	2332	2290	TWh
	=	Eta th,CHP	50.2%	49.6%	48.2%	46.7%	46.3%	45.1%	44.2%	none

7.3.2.5.4 Calculation of efficiency ratio compared to the reference system

The next step in calculating the heat bonus are the efficiency ratios which compare the process efficiencies of the CHP process to the efficiencies of an alternative generation system with uncoupled electricity and heat generation. The efficiency ratios of to the reference system are calculated by dividing the electrical (or thermal) efficiency of the CHP process by the electrical efficiency of the electricity (or heat) reference system.

The detailed calculation results for this scenario are shown in Table 56. The efficiencies of the CHP process correspond to the results from the previous section. While the efficiency of an alternative electricity generation in an average modern power plant is assumed to be 40%, the efficiency of the reference heat plant is set to 90%. As shown in Table 56 the sum of the efficiency ratio rises from 105% in 2000 to 114% in 2030.

Formulas

$$Ratio\ Ref\ System.electr = \frac{CHP\ efficiency.electr}{Ref\ efficiency.electr}$$

$$Ratio\ Ref\ System.heat = \frac{CHP\ efficiency.heat}{Ref\ efficiency.heat}$$

Table 56: Calculation of the efficiency ratios to the reference system

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		Eta el,CHP	19.8%	20.4%	21.8%	23.3%	23.7%	24.9%	25.8%	none
	/	Eta el,Ref	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	none
	=	eta ratio ele	49.6%	51.0%	54.6%	58.1%	59.3%	62.2%	64.5%	none
		Eta heat,CHP	50.2%	49.6%	48.2%	46.7%	46.3%	45.1%	44.2%	none
	/	Eta heat,Ref	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	none
	=	eta ratio heat	55.7%	55.1%	53.5%	51.9%	51.4%	50.1%	49.1%	none
		eta ratio sum	105%	106%	108%	110%	111%	112%	114%	none

7.3.2.5.5 Calculation of efficiency factor (1-PEE)

The efficiency factor (1-PEE) of the CHP plant (compared to the reference system) can now be determined by calculating the reciprocal value of the sum of the efficiency ratios (see Table 57). Correspondingly to the increasing total

efficiency ratio the efficiency factor decreases from 95% in 2000 to 88% in 2030.

Table 57: Calculation of the efficiency factor

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
			1.00	1.00	1.00	1.00	1.00	1.00	1.00	none
CHP	/	eta ratio sum	1.05	1.06	1.08	1.10	1.11	1.12	1.14	none
	=	1-PEE	95%	94%	92%	91%	90%	89%	88%	none

7.3.2.5.6 Calculation of heat bonus

Finally the bonus for heat generated in CHP power plants can be calculated, which needs to be subtracted from raw primary energy demand of power generation. The formula to accomplish the final step of the Finish method, which is shown in the following box, consists of multiplying the fuel consumption of the CHP process by the efficiency ratio to the heat reference system, the efficiency factor and the PEF if the fuel used. As discussed in Section 7.3.2.3 the PEF of the fossil fuel in this scenario is 1.

The results shown in Table 58 indicate, that the heat bonus, which has to be subtracted from the raw primary energy demand increases from 920 TWh in 2000 to 990 TWh in 2030.

Formula

$$Bonus\ heat = Fuel\ Cons. \cdot Ratio\ Ref\ System. heat \cdot (1 - PEE) \cdot PEF fuel$$

Table 58: Calculation of the heat bonus

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
		Fuel Consumption	1738	1898	1919	2106	2281	2332	2290	TWh
	*	eta ratio heat	56%	55%	54%	52%	51%	50%	49%	none
CHP	*	1-PEE	95%	94%	92%	91%	90%	89%	88%	none
	*	PEF CHP Fuels	1	1	1	1	1	1	1	none
	=	Heat Bonus CHP	920	986	950	994	1059	1040	990	TWh

7.3.2.6 Calculation of the primary energy factor for electricity

The final step in the calculation process is the calculation of the final primary energy factor for electricity. Therefore, the heat bonus is subtracted from the calculated raw primary energy demand. The resulting corrected primary energy demand is divided by the net electricity demand to calculate the final PEF for consumed electricity.

Formula

$$Final\ PEF\ el. = \frac{Raw\ primary\ energy\ demand - Heat\ bonus\ CHP}{net\ electricity\ demand}$$

Table 59: Calculation of the final PEF in calculation method 3

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
		Raw PED	7875	8527	8331	8028	7533	7424	7438	TWh
Electricity	-	Heat Bonus CHP	920	986	950	994	1059	1040	990	TWh
	/	Net el. Demand	2756	3025	3100	3187	3215	3311	3439	TWh
	=	Final PEF	2.52	2.49	2.38	2.21	2.01	1.93	1.87	none

7.3.3   Results of the PEF calculation

The results and the full representation of the calculation which includes all numbers of the parameters are documented in the previous sections and tables. In 2000 the resulting PEF for electricity is 2.52. The calculated PEF decreases to 1.87 in 2030. Main drivers of this development are the projected growth of renewable electricity generation and CHP in the scenario.

However, the application of the PEF_{fuel} of 1 for all values leads a higher PEF than using calculation method 2, which uses lower primary energy factors for RES. This effect compensates the effect of the higher PEF of fossil fuels in method 1. Calculation method 3 is identical to calculation method 1 with the exception of the CHP accounting method. The Finish method applied in calculation method 3 leads to a lower primary energy bonus for the heat output of CHP plants. Therefore the resulting PEFs for electricity in this path are higher than in calculation method 1. Annual values are calculated by linear interpolation of the PEF between the 5 year results. A table of the annual results in the period 2000-2030 is presented in Annex 1.

In the following section, the contribution of the fuel groups to this decrease in PEF is discussed. The contribution to the PEF of electricity is calculated by dividing the raw primary energy demand by the net electricity demand.

> **Formula**
>
> $$Contribution\ to\ PEF = \frac{Impact\ on\ primary\ energy\ demand}{net\ electricity\ demand}$$

The results are presented in Figure 13. In general the development of the contribution of different generation method follows the development of gross electricity generation. Gross electricity generation from biomass grows from 47 TWh in 2000 to 203 TWh in 2030. In the same period the gross generation efficiency grows from approx. 25% to 30% and overall electricity grows by more than 20%. As a result of these effects an increase of generation by factor four leads to a growth of the contribution to the PEF by approx. factor three. Thus, the Contribution of biomass grows from 0.07 in 2000 to 0.2 in 2030.

Fossil generation decreases from 1635 TWh in 2000 to 1281 TWh in 2030. This decline in generation is accompanied by an increase in average generation efficiency from 38% in 2020 to approx. 47% in 2030. In combination with the growth of electricity demand these developments lead to a decrease of the contribution of fossil fuels to the PEF from 1.55 in 2000 to 0.8 in 2030.

The gross electricity generation of RES grows from 516 TWh in 2000 to 1518 TWh in 2030. This translates into a growing contribution to the PEF from 0.2 in 2000 to 0.46 in 2030.

PRIMES generation data shows a decline of nuclear generation between 2000 und 2025. Thereafter generation in nuclear power plants increases again. As the efficiency remains constant by definition of the calculation method this development is also reflected in the contribution to the PEF. The contribution of nuclear decreases from 1.04 in 2000 to 0.7 in 2030.

The bonus for heat generated in CHP plants are influenced by several aspects. The first aspect is the development of electricity generation from CHP plants

which grows from 344 TWh in 2000 to ca. 702 TWh in 2030. This doubling of electricity generation by CHP does not translate directly to a similar growth in heat production from CHP plants as the PRIMES scenario data projects a growth in the net electricity to steam ration of CHP from 0.36 in 2000 to 0.61 in 2030. As a result the calculated heat output of CHP plants grows at a lower pace. It starts with 870 TWh in 2000 and grows to 1012 TWh in 2030. The Finish method allocates the fuel input based on a comparison of the efficiency of the process compared to a reference system. Thus, the Finish method generally leads to a lower heat bonus than the IEA method. In combination with the increasing electricity demand this leads to an almost constant reduction of the PEF by approx. 0.3.

On the aggregate level of the region EU28+NO no power exchange correction is carried out since generation flows to neighbouring countries are not part of the dataset.

As a result of the different effects the PEF of electricity consumed decreases from 2.52 in 2000 to 1.87 in 2030.
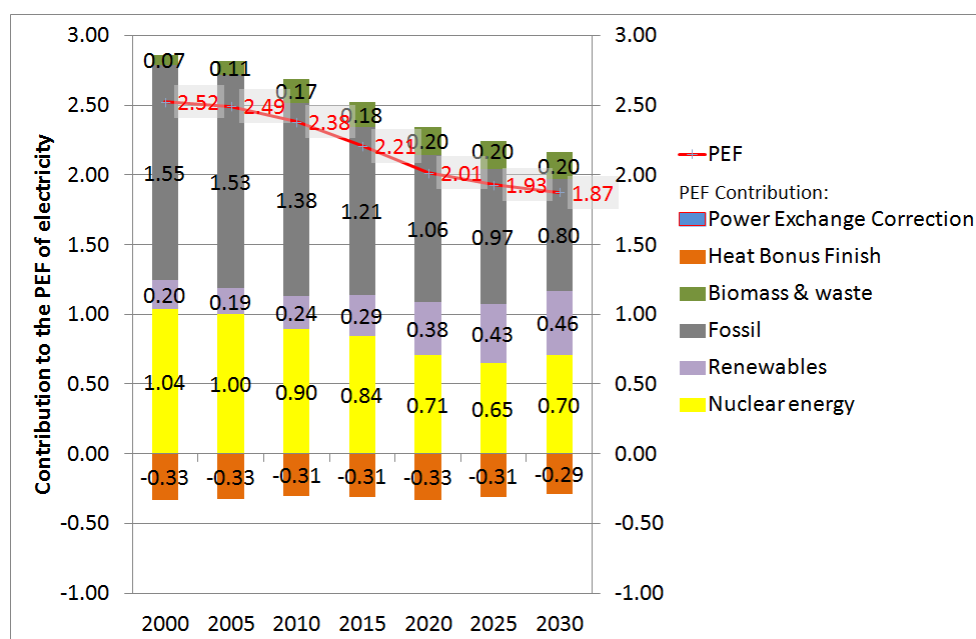

Figure 13: Contribution to the PEF of electricity by source

Box – Impact of the CHP accounting method

Method 1 and method 3 differ in the allocation method of fuel input applied for combined heat and power (CHP). The comparison of method 1 and method 3 shows the impact of the CHP accounting method. In the year 2010 924 TWh heat and 419 TWh electricity are generated in CHP power plants. These outputs are connected with a fuel consumption of 1919 TWh.

The IEA method allocates 1320 TWh of fuel consumption to the heat generation and 599 TWh to the electricity generation. As a result the PEF for electricity generated in the CHP process is 1.43 which is very below any thermal electricity generation technologies. On the other hand the PEF for heat is also 1.43 which is above any alternative heat generation technology. In total IEA method leads to a reduction of the PEF of electricity of 0.43 in our calculation for 2010.

The Finish method allocates 950 TWh of fuels consumption to the heat generation of 924 TWh in 2010. 969 TWh of fuel consumptions are allocated to the electricity generation of 419 TWh in 2010. This leads to a PEF of 2.31 for the electricity generation of CHP processes which is below the average value PEF of electricity generation. The resulting PEF for heat generated in the CHP processes is 1.03 which is slightly below most alternative heat generation technologies. Due to the higher allocation of fuel consumption to electricity generated in CHP processes the PEF for electricity is 0.12 higher in 2010 in calculation method 3-

7.4 Calculation method 4

7.4.1 Description of the calculation method

The fourth calculation method is defined by the path shown in red in the decision tree in Figure 14. It is identical to calculation method 3 with the exemption of the primary energy factor of fossil fuels. In this context a LCA perspective is taken into account.

An overview on calculation method 4 is also given in Table 60. Please note that categories that are constant in all selected calculation methods are marked in grey.

The categories with clearly dominant options are summarized in the root of the decision tree. They determine that a **consistent methodology** should be used for all Member States and that the **same PEF for electricity** should be used **in all legal acts**, such as the Energy Efficiency Directive and the Energy Performance of Buildings Directive, for all appliances etc. This is the only way to avoid distortions and to take account of the interconnected European electricity system. Moreover, there is a clear preference of a **calculated value** implying a **dynamic development**, which should be **revised regularly.**

Those options are chosen to reflect reality as best as possible and to allow for an adaptation of the PEF on changing framework conditions.

Concerning all other options, no clearly dominant option existed. Thus a choice between similar ranked options has to be taken. Regarding "Time resolution" seasonal values would require more complex calculations, because most statistical and projected data only exists on a yearly basis and hence a power sector model would have to be used. Since such an effort seems not advisable for a regular process such as calculating PEF, this option can be excluded. Moreover, annual averages seem more advisable than averages over several years, because they are more precise. As a result, **annual average** is chosen as the best option from the category time resolution.

One main purpose of using a PEF is to reflect and compare the primary energy consumptions of different generation technologies or appliances. Regarding the category market position, various stakeholders argue however that only if the PEF is determined based on a marginal market position effects of the deployment of new appliances could be shown. Yet, normally the effect of one single new appliance in the system normally is marginally low. The marginal PEF of an appliance depends, above all, on its time of use and the RES feed in situation at that specific point in time (also cp.4.2.2.d).

Moreover, very 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 in the future. Since such calculations seem too complex to be carried out in each revision cycle the PEF for electricity, an **average market position** is favoured in this project. Regarding the database and calculation method, power sector model calculations seem too complex for the above mentioned reasons. Since however precision is the key aspect in PEF calculation **advance calculations based on statistics and studies** are preferred.

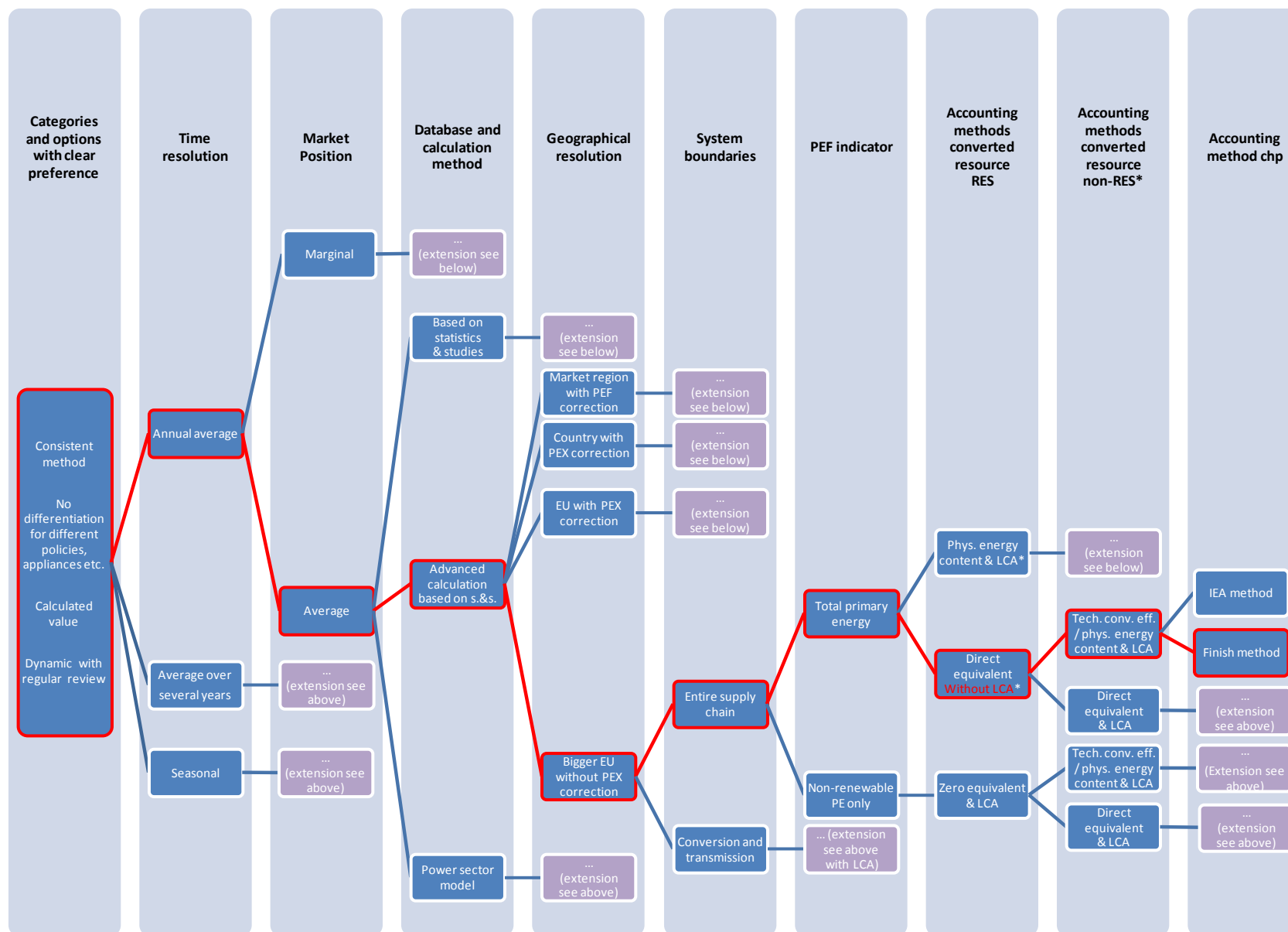# Figure 14: Decision path designing calculation method 4

Categories and options with clear preference

- Consistent method
- No differentiation for different policies, appliances etc.
- Calculated value
- Dynamic with regular review

Time resolution

- Annual average
- Average over several years
- Seasonal

Market Position

- Marginal
- Average

Database and calculation method

- … (extension see below)
- Based on statistics & studies
- Advanced calculation based on s.&s.
- Power sector model

Geographical resolution

- … (extension see below)
- Market region with PEF correction
- Country with PEX correction
- EU with PEX correction
- Bigger EU without PEX correction

System boundaries

- … (extension see below)
- … (extension see below)
- … (extension see below)
- Entire supply chain
- Conversion and transmission

PEF indicator

- Total primary energy
- Non-renewable PE only

Accounting methods converted resource RES

- Phys. energy content & LCA*
- Direct equivalent Without LCA*
- Zero equivalent & LCA

Accounting methods converted resource non-RES*

- … (extension see below)
- Tech. conv. eff. / phys. energy content & LCA
- Direct equivalent & LCA
- Tech. conv. eff. / phys. energy content & LCA
- Direct equivalent & LCA

Accounting method chp

- IEA method
- Finish method
- … (extension see above)
- … (Extension see above)
- … (extension see above)

93

Table 60: Definition of calculation method 4

Category	Option
PEF purpose	Calculated
Applicability	No differentiation
Adjustment and review process	Regular review/adjustment
Database and calculation method	Advanced calculations based on statistics and studies
Geographical resolution	Bigger EU, No PEX correction
Development over time	Dynamic
Time resolution	Annual average
Market position	Average electricity production
Methodological consistency	Same method for all PEF/MS
Accounting method for nuclear electricity (and heat) generation	Physical energy content
Accounting method electricity (and heat) generation using biomass	Technical conversion efficiencies
PEF indicator	Total primary energy
System boundaries	Entire supply chain
Accounting method for power (and heat) generation using non-combustible RES	Direct equivalent
Accounting method for CHP	Finish method

In calculation method 4 the **entire supply chain** will be taken into account. Even though this requires more complex calculation and a higher effort to derive the necessary data, it leads to more accurate results in terms of the actual impact e.g. of a conversion technology on total primary energy demand. Also considering upstream primary energy consumption is thus more suitable to account for the effects on climate change and resource sustainability.

Furthermore, in calculation method 4 **total primary energy** is taken into account.

Regarding the accounting methods for **nuclear as well as renewable energies**, primary energy is calculated based on the **physical energy content method** (which is used by Eurostat). Yet, for renewable energies and nuclear, no LCA is made for two reasons. Firstly, the physical energy content method already results in a relatively high PEF for those fuels, and thus only imperfectly reflects their benefits regarding climate protection. And secondly, a full LCA involves a much higher effort. Thus, a PEF for nuclear and renewable fuel can be seen as a good compromise between a not to complex method and considering total primary energy of the entire supply chain.

The underlying assumptions regarding the PEF and the conversion efficiencies are taken from Table 24 - Table 26 in Chapter 6.2. A short overview of the assumptions in method 4 is given in Table 61.

The PEF of the fuels is assumed to be 1. For non-combustible renewable a conversion efficiency of 100% is assumed. By contrast, for geothermal power stations a conversion efficiency of 10% is assumed, while for nuclear power stations a conversion efficiency of 33% applies. For combustible Renewables such as biomass, a conversion efficiency of 30% is assumed in this example. The resulting PEF for electricity from the various sources are 1 for hydro, wind and solar PV, 10 for geothermal energy, 3,3[1] for biomass and 3 for solar thermal and nuclear. As explained in the previous chapters, combustible non-renewable fuels are assessed using the technical conversion efficiencies method.

Table 61: Assumptions on PEF of the fuel and conversion efficiency for method 4

	PEF of the fuel	Conversion efficiency	PEF for electricity
Hydro	1	100%	1
Wind	1	100%	1
Solar PV	1	100%	1
Geothermal	1	10%	10
Biomass	1	From real data	From real data
Nuclear	1	33%	3
Fossil fuels	1.1	From real data	From real data
CHP	Finish method		

Regarding CHP, the **Finish method** is used to assign the shares of primary energy to the outputs electricity and heat. This is the most important discrepancy from the Eurostat approach that uses the IEA method. However, this approach seems more appropriate. As shown in Chapter 4 it allocates a higher share of fuel input to electricity. Thus it seems better suited than the IEA method to reflect the actual primary energy consumption of electricity generation in combined processes.

7.4.2 Description of the calculation process and data basis

The calculation of official European PEF should be based on officially approved input data. Since a dynamic development is considered better than a constant factor, the input data needs to comprise projections at least for the next 20 – 30 years.

In this project, PRIMES data (Detailed Analytical Results of the 2012 Reference Scenario) is used to calculate the PEF for electricity. Primes data seems an appropriate choice, because it offers a consistent set of data for all 28 EU Member States. It is officially approved and available at the Directorate-General for Energy of the European Commission. Moreover, it contains projections of the development of the energy sector until 2050. Finally, the historical years in the

---

[1] This corresponds to the net calorific value of the biomass needed to produce 1 kWh of electricity. (Net calorific value / 1 kWh)

Identification of the four most
appropriate methods for PEF
calculation and calculation of the
PEF

PRIMES scenarios are calibrated based on official European statistics from Eurostat. Thus, consistency with the official statistics of the EC is guaranteed.

Since the PRIMES dataset does not contain Norway, an extra dataset for Norway has been developed by Fraunhofer ISI, which is mainly based on ENTSO-E[1] data.

In the following the input data which are used to calculate the PEF as well as the actual PEF calculation are presented in detail.

Calculation method 3 is a modification of the method 1 "Closest to Eurostat". It is defined by the idea to apply Eurostat convention to the PEF calculation based on the PRIMES/ENTSOE scenario data wherever possible. Calculation method 3 differs from method 1 regarding two aspects. Firstly a different allocation method is applied for combined heat and power (CHP). While Eurostat uses the IEA method the Finish method is used in this method. Secondly, regarding fossil fuels, the primary energy consumption of the whole upstream process is taken into account.

7.4.2.1 Scenario data gross electricity generation

The central basis for the calculation is a scenario for the development of gross electricity generation. In case of the region EU28 this is covered by the PRIMES scenario data selected as the central data basis for this project (see Figure 15). This is supplemented by additional data on Norway provided by Fraunhofer ISI. The data on Norway is based on an extrapolation of the current generation mix (based on ENTSO-E production data) and moderate growth of wind energy by 2015. The data is provided in Annex 1.
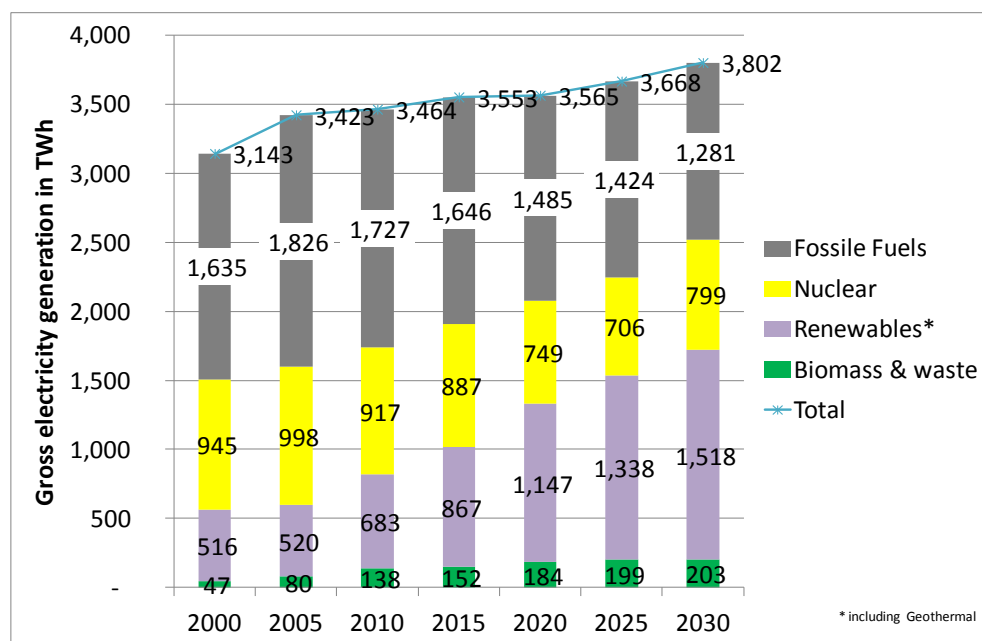

Figure 15: Scenario of gross electricity generation for EU28+Norway Source: PRIMES 2012 Reference Scenario and ISI projection for Norway based on ENTSO-E data

---

[1] ENTSO-E is the European network of transmission system operators for electricity, It provides freely accessible data on the electricity system in Europe. https://www.entsoe.eu/disclaimer/Pages/default.aspx

7.4.2.2 Calculation of the net electricity demand

The primary energy factor calculated in this project corresponds to the primary energy factor of the electricity consumed. Therefore the first step is to calculate the net electricity demand by subtracting the self consumption of power plants and grid losses (Table 62). The data for self consumption and grid losses is taken from the PRIMES scenario data used as basis for the whole calculation process.

> **Formula**
> $$Net\ el.\ demand = Gross\ el.\ generation \times (1 - Self\ cons. - Gridlosses)$$

Table 62: Calculation of net electricity demand

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Electricity		Gross Gen.	3143	3423	3464	3553	3565	3668	3802	TWh
	-	Self. C. **	5.1%	5.0%	4.6%	4.4%	4.0%	3.8%	3.5%	none
	-	Grid losses	7.2%	6.7%	5.9%	5.9%	5.8%	5.9%	6.1%	none
	=	Net Demand	**2756**	**3025**	**3100**	**3187**	**3215**	**3311**	**3439**	TWh

** Self C.= Self consumption

7.4.2.3 PEF of fuels and efficiencies

In calculation method 4 the IEA method (Eurostat approach) is used for RES and nuclear fuel. Eurostat has published its definitions on the primary energy content of fuels. This definition is quoted in the following text box. One of the main aspects of the Eurostat approach is the application of the physical energy content method, in which primary energy is defined at first step of practical energy use. Correspondingly a **PEF of 1 for all renewable fuels and nuclear** applies.

The other main aspects in calculating the PEF of electricity for the fuel categories are the assumed conversion technology efficiencies, which are used to translate the PEF of fuel into the PEF of electricity (cp. Table 63). For nuclear energy the physical energy content is approximated by 33% efficiency. A similar approximation is used for geothermal energy where an efficiency of 10% applies. In case of other non-combustible RES such as wind energy with the exemption of solar thermal this translates to an efficiency of 100%. These defined efficiencies are applied for the entire calculation period from 2000 to 2030 in our calculation.

Table 63: Efficiencies and PEF of the fuels in the calculation method 4

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Nuclear		Efficiency	33%	33%	33%	33%	33%	33%	33%	none
		PEFFuel	1	1	1	1	1	1	1	none
Renewables		Efficiency	100%	100%	100%	100%	100%	100%	100%	none
		PEFFuel	1	1	1	1	1	1	1	none
Geothermal		Efficiency	10%	10%	10%	10%	10%	10%	10%	none
		PEFFuel	1	1	1	1	1	1	1	none
Fossil		Gross El. Gen.	1635	1826	1727	1646	1485	1424	1281	TWh
	/	Fuel Cons.	4267	4615	4283	3845	3392	3214	2742	TWh
	=	Efficiency	38.3%	39.6%	40.3%	42.8%	43.8%	44.3%	46.7%	none
		PEFFuel	1.1	1.1	1.1	1.1	1.1	1.1	1.1	none
Biomass & waste		Gross El. Gen.	47	80	138	152	184	199	203	TWh
	/	Fuel Cons.	185	320	537	562	650	658	675	TWh
	=	Efficiency	25.5%	25.0%	25.6%	27.1%	28.3%	30.3%	30.0%	none
		PEFFuel	1	1	1	1	1	1	1	none

Identification of the four most appropriate methods for PEF calculation and calculation of the PEF

Direct quote: Eurostat
"Definition of the primary energy content of fuels
For directly combustible fuels (fossil and renewable fuels/ products the primary energy content is calculated as the heat value generated during combustion of this fuel.

For non-conventional energies (hydro, wind, solar photovoltaic, geothermal, nuclear and others) it is necessary to establish energy boundaries and make methodological choices in order to define their nature and quantity of primary energy.

The choice for Eurostat's energy statistics and energy balances is to use the physical energy content method. The general principle of this method is that the primary energy form is taken as the first flow in the production process that has a practical energy use. This leads to different situations depending on the energy product:

- For directly combustible energy products (for example coal, natural gas, oil, biogas, bioliquids, solid biomass and combustible municipal/industrial waste) the primary energy is defined as the heat generated during combustion.
- For products that are not directly combustible, the application of this principle leads to:
  - the choice of heat as the primary energy form for nuclear, geothermal and solar thermal; and
  - the choice of electricity as the primary energy form for solar photovoltaic, wind, hydro, tide, wave, ocean.

In cases when the amount of heat produced in the nuclear reactor is not known, the primary energy equivalent is calculated from the electricity generation by assuming an efficiency of 33 %. In the case of electricity and heat generated by geothermal energy: if the actual amount of geothermal heat is not known, the primary energy equivalent is calculated assuming an efficiency of 10 % for electricity production and 50 % for derived heat production. If two energy balances are constructed with different methodological choices and respective assumptions on efficiency conversions and calorific values, it will lead to different results for the share of renewables."

Source: http://ec.europa.eu/eurostat/statistics-explained/index.php/Calculation_methodologies_for_the_share_of_renewables_in_energy_consumption

In the case of combustible fuels we have applied the physical energy content method by calculating the efficiency of generation process. This efficiency is calculated by dividing the gross electricity generation by the fuel consumption of the electricity production. As a result of this process the following efficiencies and primary energy factors for fuels are used as basis for the further steps in this calculation method.

Formula

$$Efficiency = \frac{Gross\ electricity\ generation}{Fuel\ consumption}$$

Yet, by contrast to the Eurostat methodology, a PEF of 1.1 for fossil fuels is used. This corresponds to the PEF used for fossil fuels in the majority of analysed countries (please also confer to the excursus in the following text box).

Moreover, it is very close to the values derived from GEMIS. Using standard-ized values has the advantage that the effort for deriving fuel PEF from GEMIS can be avoided when revising and updating the PEF for electricity.

> **Excursus: PEF of fuels based on a LCA approach**
>
> Fuel PEF that take into account primary energy consumption of the entire sup-ply chain can be calculated using a LCA model like GEMIS.
> (Source: http://www.iinas.org/gemis-de.html)
>
> <u>Fossil fuels:</u>
>
> Using GEMIS, the following PEF for fossil fuels can be derived:
>
> - Gas (EU mix): 1.11 in 2010 and 1.13 in 2030.
>
> - Coal (Australian coal imported in the EU): 1.07
>
> - Oil (EU mix oil refinery products): 1.1
>
> Yet, most European countries apply standardized values as PEF for fossil fuels. An overview is given in Figure 16. It shows that most countries apply a com-mon PEF for all three fuels. Moreover the PEF for fossil fuels all range between 1.0 and 1.22, while the majority of countries apply a common PEF of 1.1. A further explanation is given in Annex 2.
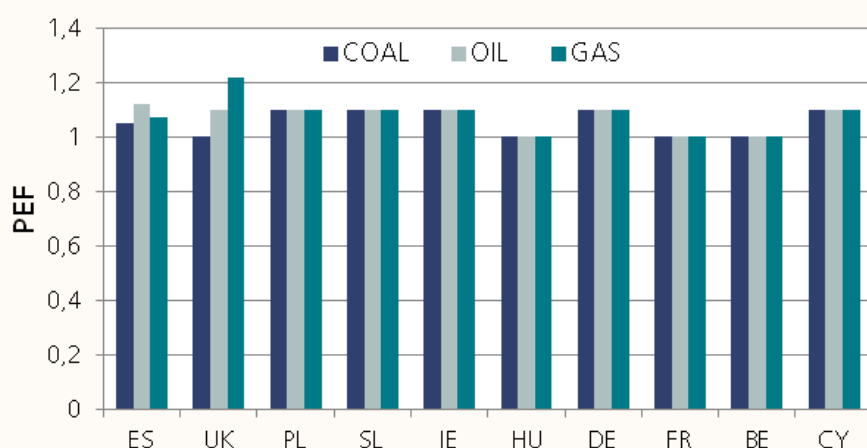>
>
>
> **Figure 16: PEF of fuels for different EU countries (EPBD National Cost-Optimal Regulations)**

7.4.2.4 Calculation of the raw primary energy demand

The raw primary demand can now be calculated using the gross electricity generation, the conversion efficiencies and the PEF of the fuels. As explained in Section 7.4.2.1 the development of the gross generation is taken from PRIMES. The efficiencies of the conversion processes are either predefined by the physical energy content method (this is the case for nuclear and non-combustible renewables) or calculated based on PRIMES data (cp. Section 7.4.2.2). For fossil fuels, the PEF is set to 1.1 as approximation of an LCA ap-proach. The PEF of all other fuels is 1, because the physical energy content method applied by Eurostat is used. For a more detailed explanation of the PEF please refer to Section 7.4.2.2.

Table 64 shows in detail the calculation of the raw primary energy demand. It comprises two major steps. First, the gross primary energy demand (PED) per year of each fuel group is calculated by dividing the gross generation by the

efficiency of the conversion technology and then multiplying it by the PEF of the fuel. In the second step, the raw primary energy demand per year is calculated by adding up all the gross primary energy demands (PED) of the fuel groups.

Formula

$$Raw\ Primary\ Energy\ demand = \sum_{fuel} \frac{Gross\ el.\,generation.\,fuel \times PEF.\,fuel}{efficiency.\,fuel}$$

Table 64: Calculation of the raw primary energy demand

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Nuclear		Gross Gen.	945	998	917	887	749	706	799	TWh
	/	Efficiency	33%	33%	33%	33%	33%	33%	33%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED	2864	3023	2778	2689	2271	2139	2422	TWh
Renewables		Gross Gen.	511	514	677	859	1139	1330	1510	TWh
	/	Efficiency	100%	100%	100%	100%	100%	100%	100%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED *	511	514	677	859	1139	1330	1510	TWh
Geothermal		Gross Gen.	5	5	6	7	8	8	9	TWh
	/	Efficiency *	10%	10%	10%	10%	10%	10%	10%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED *	48	54	56	73	82	83	89	TWh
Fossil		Gross Gen.	1,635	1,826	1,727	1,646	1,485	1,424	1,281	TWh
	/	Efficiency	38.3%	39.6%	40.3%	42.8%	43.8%	44.3%	46.7%	none
	*	PEF$_{fuel}$	1.1	1.1	1.1	1.1	1.1	1.1	1.1	none
	=	Gross PED	4694	5077	4711	4230	3731	3536	3016	TWh
Biomass & waste		Gross Gen.	47	80	138	152	184	199	203	TWh
	/	Efficiency	25.5%	25.0%	25.6%	27.1%	28.3%	30.3%	30.0%	none
	*	PEF$_{fuel}$	1	1	1	1	1	1	1	none
	=	Gross PED	185	320	537	562	650	658	675	TWh
Raw Primary Energy Demand			8302	8988	8759	8413	7872	7746	7712	TWh

7.4.2.5 Calculation of the heat bonus for CHP

The next step in the calculation process is the calculation of the bonus for heat generated in CHP power plants (i.e. the primary energy share for heat from CHP) which needs to be subtracted from raw primary energy demand of power generation. To calculate the bonus for heat generated in CHP, we need the heat output and the fuel consumption (input); in total three steps are necessary, which are described in the next three sections.

7.4.2.5.1 Calculation of the heat generation

The first step in calculating the CHP bonus is the calculation of the heat output related to the CHP process. It is not part of the PRIMES scenario dataset provided to this project, but it can be derived from the indicators provided. The PRIMES dataset provides the net electricity to steam generation ratio and the CHP electricity generation. It is assumed that the CHP data provided in the PRIMES dataset is gross generation. Therefore it needs to be corrected to net electricity generation. In this context an aggregate self consumption of 8% is assumed. The heat generation of the CHP plants can then be calculated by dividing the net electricity generation in CHP plants by the net electricity to heat ratio according to the following formula.

Formula

$$CHP\ Heat\ gen. = \frac{CHP\ electricity\ generation \times (1 - self\ cons.)}{electricity\ to\ heat\ ratio}$$

PRIMES shows that the electricity generation from CHP plants grows from 345 TWh in 2000 to ca. 591 TWh in 2030 (cp. Table 65). This doubling of electricity generation in CHP plants does not translate directly to a similar growth in heat production from CHP plants as the PRIMES scenario data projects a growth in the net electricity to steam ratio of CHP from 0.36 in 2000 to 0.61 in 2030. As a result the calculated heat output of CHP plants grows at lower pace. It starts with 872 TWh in 2000 and grows to 1012 TWh in 2030.

Table 65: Calculation of the heat generation by CHP Plants

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		CHP El. Gen	345	387	419	490	541	580	591	TWh
	/	El/heat ratio	36%	38%	42%	46%	47%	51%	54%	none
		1-Self consumption	92%	92%	92%	92%	92%	92%	92%	none
	=	CHP Heat Gen	**872**	**942**	**924**	**984**	**1056**	**1052**	**1012**	TWh

7.4.2.5.2 Calculation of the fuel consumption

As a further step in the calculation process the fuel consumption of CHP plants needs to be calculated. The total output of CHP plants is the sum of the electricity and heat produced. In order to calculate the fuel consumption related to CHP generation an assumption on the average efficiency of CHP plants is required. Eurostat data on CHP generation and output suggests that the average efficiency of CHP plants is close to 70%[1]. Therefore an average efficiency of 70% is used and kept constant until 2030 for simplicity reasons (cp. Table 66). It is very likely that the average efficiency of CHP plants is going to increase. But it is beyond the scope of this project to create an efficiency projection of CHP plants in Europe that is in line with the underlying PRIMES scenario. It has to be kept in mind that the efficiency assumption is conservative and needs to be checked in the next evaluation of the PEF.

Formula

$$Fuel\ cons.CHP = \frac{CHP\ elecitricity\ gen. + CHP\ heat\ gen.}{CHP\ efficiency}$$

Table 66: Calculation of the fuel consumption of CHP plants

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
CHP		CHP El. Gen	345	387	419	490	541	580	591	TWh
	+	CHP Heat Gen	872	942	924	984	1056	1052	1012	TWh
	=	Total CHP Output	1217	1328	1343	1474	1597	1632	1603	TWh
	/	CHP Efficiency	70%	70%	70%	70%	70%	70%	70%	none
	=	Fuel Consumption	**1738**	**1898**	**1919**	**2106**	**2281**	**2332**	**2290**	TWh

The results show that the fuel consumption of CHP plants grows in line with total growth of the output which is mainly driven by the strong growth in electricity generation. Resulting fuel consumption grows from 1738 TWh in 2000 to 2290 TWh in 2030.

---

[1] Source: http://ec.europa.eu/eurostat/web/energy/data

7.4.2.5.3 Calculation of the process efficiencies

In addition, the electrical and thermal conversion efficiencies of the CHP process need to be determined. They correspond to the ratio of fuel input to the respective output of the CHP plants. The following table shows the calculation of the electrical and thermal efficiencies. The electrical efficiency results from dividing the CHP electricity generation from PRIMES by the fuel consumption determined in the previous section. The results show that the electrical process efficiency increases 19.8% in 2000 to 25.8% in 2030.

The thermal efficiency of the process is calculated by dividing the CHP heat generation by the fuel consumption determined in the previous section. The resulting thermal efficiencies of the CHP process decrease from 50.2% in 2000 to 44.2% in 2030 (cp. Table 67)

Formulas

$$CHP\ efficiency.electr = \frac{CHP\ electricity\ gen.}{CHP\ fuel\ cons.}$$

$$CHP\ efficiency.heat = \frac{CHP\ heat\ gen.}{CHP\ fuel\ cons.}$$

Table 67: Calculation of the electrical and thermal efficiencies of the CHP process

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
		CHP El. Gen	345	387	419	490	541	580	591	TWh
	/	Fuel Consumption	1738	1898	1919	2106	2281	2332	2290	TWh
CHP	=	Eta $_{el,CHP}$	**19.8%**	**20.4%**	**21.8%**	**23.3%**	**23.7%**	**24.9%**	**25.8%**	none
		CHP Heat Gen	872	942	924	984	1056	1052	1012	TWh
	/	Fuel Consumption	1738	1898	1919	2106	2281	2332	2290	TWh
	=	Eta $_{th,CHP}$	**50.2%**	**49.6%**	**48.2%**	**46.7%**	**46.3%**	**45.1%**	**44.2%**	none

7.4.2.5.4 Calculation of efficiency ratio compared to the reference system

The next step in calculating the heat bonus are the efficiency ratios which compare the process efficiencies of the CHP process to the efficiencies of an alternative generation system with uncoupled electricity and heat generation. As shown in the following box, the efficiency ratios of the reference system is calculated by dividing the electrical (or thermal) efficiency of the CHP process by the electrical efficiency of the electricity (or heat) reference system.

The detailed calculation results for this scenario are shown in Table 68. The efficiency of the CHP processes corresponds to the results from the previous section. While the efficiency of an alternative electricity generation in an average power plant is assumed to be 40%, the efficiency of the reference heat plant is set to 90%. As shown in Table 68 the sum of the two efficiency ratios rises from 105% in 2000 to 114% in 2030.

Formulas

- $$eta\ ratio\ ele = \frac{Eta_{el,CHP}}{Eta_{el,Ref}}$$

- $$eta\ ratio\ heat = \frac{Eta_{heat,CHP}}{Eta_{heat,Ref}}$$

Table 68: Calculation of the eta ratio sum as efficiency indicator

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
		Eta el,CHP	19.8%	20.4%	21.8%	23.3%	23.7%	24.9%	25.8%	none
	/	Eta el,Ref	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	none
	=	eta ratio ele	**49.6%**	**51.0%**	**54.6%**	**58.1%**	**59.3%**	**62.2%**	**64.5%**	none
CHP		Eta heat,CHP	50.2%	49.6%	48.2%	46.7%	46.3%	45.1%	44.2%	none
	/	Eta heat,Ref	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	none
	=	eta ratio heat	**55.7%**	**55.1%**	**53.5%**	**51.9%**	**51.4%**	**50.1%**	**49.1%**	none
		eta ratio sum	**105%**	**106%**	**108%**	**110%**	**111%**	**112%**	**114%**	none

7.4.2.5.5 Calculation of efficiency factor (1-PEE)

The efficiency factor (1-PEE) of the CHP plant (compared to the reference system) can now be determined by calculating the reciprocal value of the sum of the efficiency ratios (see Table 69). Correspondingly to the increasing total efficiency ration the efficiency factor decreases from 95% in 2000 to 88% in 2030.

Table 69: Calculation of the efficiency factor

Name	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
			1.00	1.00	1.00	1.00	1.00	1.00	1.00	none
CHP	/	eta ratio sum	1.05	1.06	1.08	1.10	1.11	1.12	1.14	none
	=	1-PEE	**95%**	**94%**	**92%**	**91%**	**90%**	**89%**	**88%**	none

7.4.2.5.6 Calculation of heat bonus

Finally the bonus for heat generated in CHP power plants can be calculated, which needs to be subtracted from raw primary energy demand of power generation. The formula to accomplish the final step of the Finish method, which is shown in the following box, consists of multiplying the fuel consumption of the CHP process by the efficiency ratio to the heat reference system, the efficiency factor and the PEF if the fuel used. The PEF of the CHP fuel in this scenario decreases ranges between 1.1 and 1.09 between 2000 and 2030.

The results shown in Table 70 indicate, that the heat bonus, which has to be subtracted from the raw primary energy demand, increases from 1010 TWh in 2000 to 1075 TWh in 2030.

> **Formula**
> $$Bonus\ heat = Fuel\ Cons. \cdot Ratio\ Ref\ System.heat \cdot (1 - PEE) \cdot PEF fuel$$

Table 70: Calculation of the heat bonus

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
		Fuel Consumption	1738	1898	1919	2106	2281	2332	2290	TWh
	*	eta ratio heat	56%	55%	54%	52%	51%	50%	49%	none
CHP	*	1-PEE	95%	94%	92%	91%	90%	89%	88%	none
	*	PEF CHP Fuels	1.10	1.10	1.09	1.09	1.09	1.09	1.09	none
	=	Heat Bonus CHP	**1010**	**1081**	**1038**	**1084**	**1154**	**1132**	**1075**	TWh

7.4.2.6 Calculation of the primary energy factor for electricity

The final step in the calculation process is the calculation of the final primary energy factor for electricity. Based on the calculated raw primary energy demand the heat bonus is subtracted (cp. Table 71). The resulting corrected primary energy demand is divided by the net electricity demand to calculate the final PEF of consumed electricity.

Formula

$$Final\ PEF\ el. = \frac{Raw\ primary\ energy\ demand - Heat\ bonus\ CHP}{net\ electricity\ demand}$$

Table 71: Calculation of the final PEF in calculation method 4

Fuel	Operator	Indicator	2000	2005	2010	2015	2020	2025	2030	Unit
Electricity		Raw PED	8302	8988	8759	8413	7872	7746	7712	TWh
	-	Heat Bonus CHP	1010	1081	1038	1084	1154	1132	1075	TWh
	/	Net el. Demand	2756	3025	3100	3187	3215	3311	3439	TWh
	=	Final PEF	**2.65**	**2.61**	**2.49**	**2.30**	**2.09**	**2.00**	**1.93**	none

7.4.3 Results of the PEF calculation

The results and the full representation of the calculation which includes all numbers of the parameters are documented the previous sections. In 2000 the resulting PEF for electricity is 2.65. The calculated PEF decreases to 1.93 in 2030. Main drivers of this development are the projected growth of renewable electricity generation and CHP in the scenario. However, the application of the PEF_{fuel} of 1.1 for fossil fuels in combination with a PEF_{fuel} for RES of 1 and the Finish method for CHP leads to the highest PEFs calculated in our calculation method. Annual values are calculated by linear interpolation of the PEF between the 5 year results. A table of the annual results in the period 2000-2030 is presented in Annex 1.

In the following, the contribution of the fuel groups to this decrease in PEF is discussed. The contribution to the PEF of electricity is calculated by dividing the raw primary energy demand by the net electricity demand.

Formula

$$Contribution\ to\ PEF = \frac{Impact\ on\ primary\ energy\ demand}{net\ electricity\ demand}$$

The results are presented in Figure 17. In general the development of the contribution of different generation method follows the development of gross electricity generation. Gross electricity generation from biomass grows from 47 TWh in 2000 to 203 TWh in 2030. In the same period the gross generation efficiency grows from approx. 25% to 30% and overall electricity grows by more than 20%. As a result of these effects an increase of generation by factor four leads to a growth of the contribution of the PEF by approx. factor three. The contribution of biomass grows from 0.07 in 2000 to 0.2 in 2030.

Fossil generation decreases from 1635 TWh in 2000 to 1281 TWh in 2030. This decline in generation is accompanied by an increase in average generation efficiency from 38% in 2020 to ca. 47% in 2030. In combination with the growth of electricity demand these developments lead to a decrease of the contribution of fossil fuel PEF to the PEF for electricity from 1.7 in 2000 to 0.88 in 2030. Due to fact the PEF of fossil fuels is 1.1 instead of 1 (as in calculation method 3) the contribution of fossil fuels to the PEF for electricity is also higher.

104

The gross electricity generation of RES grows from 516 TWh in 2000 to 1518 TWh in 2030. This translates into a growing contribution to the PEF from 0.2 in 2000 to 0.46 in 2030.

The PRIMES generation data shows a decline of nuclear generation between 2000 und 2025. Thereafter nuclear generation increases again. As the efficiency remains constant by definition of the calculation method this development is also reflected in the contribution to the PEF. The contribution of nuclear fuel decreases from 1.04 in 2000 to 0.7 in 2030.
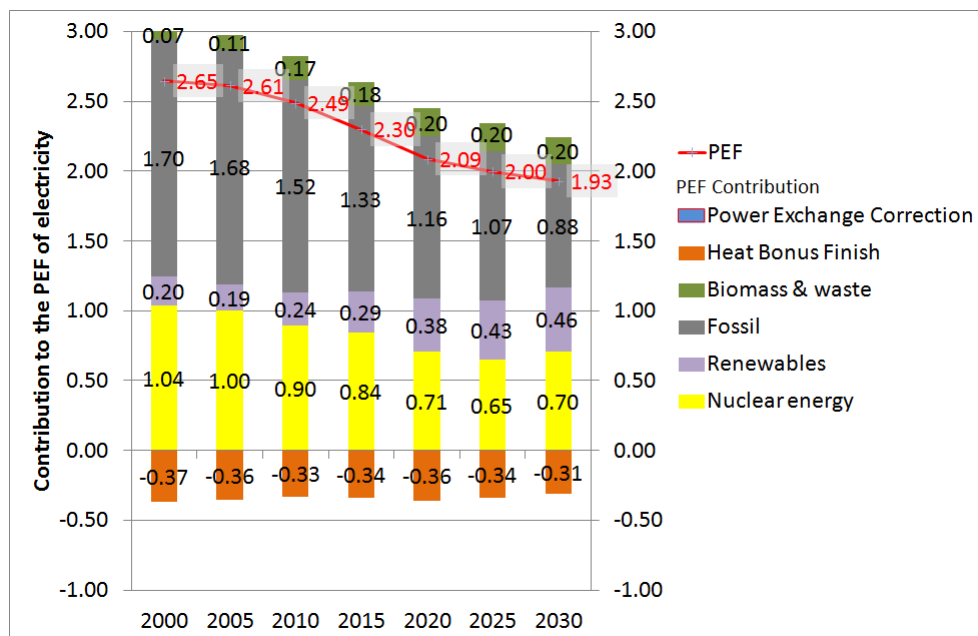

Figure 17: Contribution to the PEF of electricity by source

The bonus for heat generated in CHP power plants depends on several factors. The first is the development of electricity generation from CHP plants which grows from 344 TWh in the scenario to approx. 702 TWh in the scenario. This doubling of electricity generation by CHP does not translate directly to a similar growth in heat production from CHP plants as the PRIMES scenario data projects a growth in the net electricity to steam ratio of CHP from 0.36 in 2000 to 0.61 in 2030. As a result the calculated heat output of CHP plants grows at a slower pace. It starts with 870 TWh in 2000 and grows to 1012 TWh in 2030. The Finish method allocates the fuel input based on the comparison of the efficiency of the CHP process compared to a reference system. Therefore, the Finish method generally yields to a lower heat bonus than the IEA method. In combination with the increasing electricity demand this leads to a reduction of the PEF from approx. 0.37 in 2000 to 0.31 in 2030. Another aspect of the comparison to the other calculation methods is the different average PEF of CHP fuels. Since the average PEF of CHP fuels is higher in calculation method 4 than in calculation method 3 a slightly higher heat bonus for CHP plants results.

On the aggregate level of the total region EU28+NO no power exchange correction is carried out since generation flows to neighbouring countries are not part of the dataset.

The sum of the different effects discussed results in a decrease of the PEF for consumed electricity from 2.65 in 2000 to 1.93 in 2030. In comparison to

Identification of the four most
appropriate methods for PEF
calculation and calculation of the
PEF

calculation method 3 this shows the impact of raising the PEF of fossil fuels from 1 to 1.1.

7.5   Comparison of the calculation methods

In this chapter four calculation methods have been presented, which seem appropriate for calculating PEF for electricity in the context of the European Energy Efficiency Directive 2012/27/EU.

Calculation methods 1 and 3 are orientated on the approach used by Eurostat. They only differ in the choice of method used to assess the shares of power and heat on primary energy consumption of CHP power stations. While in calculation method 1 (like by Eurostat) the IEA method is used, in calculation method 3 the Finish method is applied. While the IEA method attributes the primary energy to the outputs power and heat in relation to their output shares – and thus a high share to heat – the Finish method attributes a higher share of primary energy consumption to electricity.

By contrast method 2 is designed to put an emphasis on a sound competition of electricity and other sources for heat generation. This is mainly accomplished by taking the entire supply chain into account, but only considering non-renewable energies. Regarding the CHP method, again the Finish method is used, to put a higher share of fossil fuel used as input in the CHP process on electricity.

Finally, method 4 is designed to define the upper end of PEF calculation options for electricity as it combines the perspective of total primary energy consumption including renewables and adds the LCA perspective to fossil fuels.

Figure 18 compares the results of the development of the four calculation methods. Calculation method 4 yields the highest PEF for electricity. Between 2000 and 2030 it decreases from 2.65 to 1.93. The main reasons for the higher PEF compared to the other calculation methods are the higher PEF values for fuels, in particular those of fossil fuels.

The higher PEF of fossil fuels make out the difference between the results of calculation method 4 and calculation method 3. While in method 4 they amount to 1.1, in method 3 they are assumed to be 1. The difference between the two methods decreases by the end of the shown time period, because by 2030 fossil fuels play a less decisive role in the energy system.

The only difference between calculation method 3 and calculation method 1 (the one closest to Eurostat) is the choice of CHP accounting method. The higher PEF values in method 3 compared to method 1 are due to the use of the Finish method, which attributes more consumption of primary energy to electricity in CHP than the IEA method.
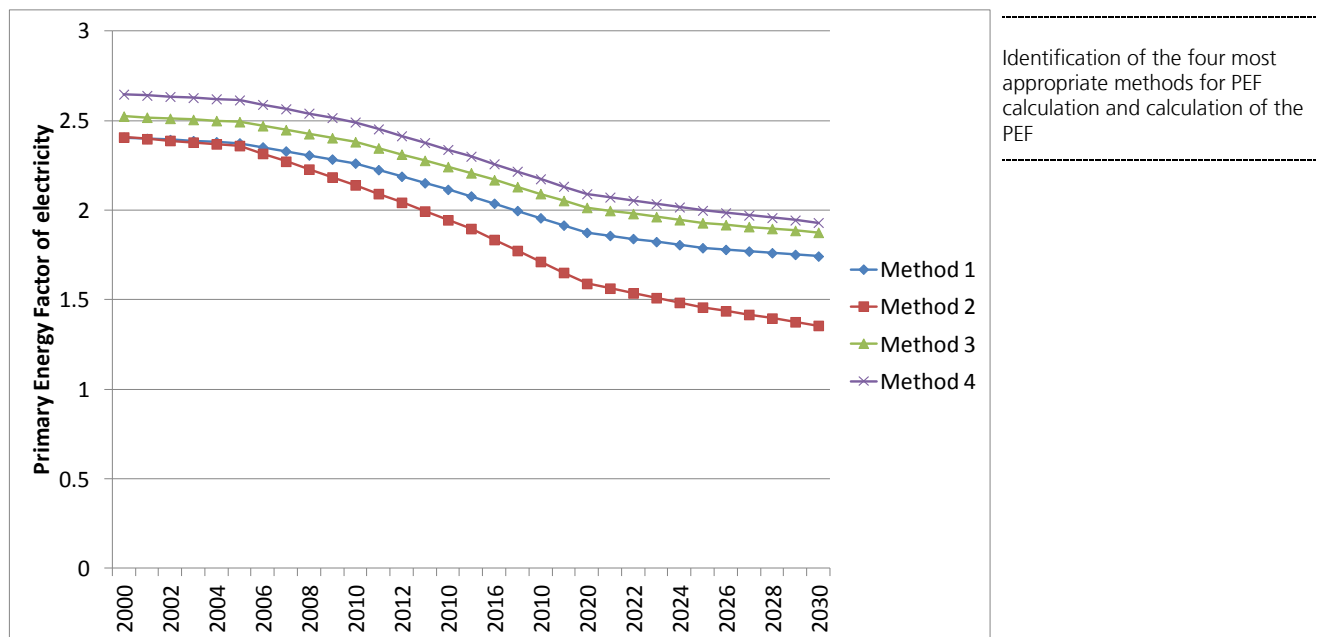
Figure 18: Comparison of the results for the different PEF calculation methods

Calculation method 1 results in a decrease of the PEF for electricity from 2.41 in 2000 to 1.74 in 2030. In parallel the PEF for electricity calculated with method 3 decreases from 2.52 in 2000 to 1.87 in 2030.

The calculation method which yields the lowest PEF for electricity is the LCA-based method 2. To put an emphasis on the positive effects of RES on climate protection and sustainability, only non-renewable energies are considered and a zero equivalent is applied for RES (compared to a minimum of 1 in the other calculation methods). Consequently the difference between method 2 and the other calculation methods increases with increasing shares of RES by the end of the assessment period. In 2000, with only low shares of RES in power generation, the PEF of electricity still amounts to 2.52 and thus is even higher than in method 1. The reason for this is the difference in the CHP method, which levels out the lower PEF for renewable fuels. By contrast, by 2030 the PEF of electricity which results from method 2 amounts to 1.35 and is thus even by 0.29 points lower than PEF derived using method 1.

Identification of the four most appropriate methods for PEF calculation and calculation of the PEF

8
Conclusions

This study shows that there are various ways to define and calculate the PEF of electricity. No PEF calculation method can claim absoluteness. Therefore the calculation method for the PEF of electricity should be selected carefully and in line with the central goals of its application. In the evaluation process of this study four calculation methods have been selected for a detailed calculation. Based on the projection of the electricity sector of the PRIMES Reference Scenario 2012[1] all calculation methods show a decline of the PEF throughout the whole time period up to 2030. All calculated PEF values after the year 2015 are below 2.5 which show strong evidence that the PEF value applied in the EED needs to be revised. Our recommendation is to use a uniform PEF for the entire European region. This calculation should be based on annual values. Having in mind that the PEF of electricity should indicate a sound competition between electricity and other fuels for energy services our recommendation is to base the calculation on a life cycle perspective of the consumption of non-renewable resources. Regarding the CHP allocation method we recommend the Finish method as it allows for a more balanced distribution of resource consumption between heat and electricity.

An analysis of the calculation results shows that the PEF heavily depends on a few central factors. The most important aspect is the treatment of renewables. Focusing the calculation on the non-renewable resource consumption of the electricity generation process leads to considerably lower PEF values.

Another aspect is the allocation method used for CHP. In our calculation approach the Finish method leads to a reduction of the PEF of electricity in the order of magnitude of over. 0.1 compared to the IEA method.

A similar effect in the opposite direction occurs if the life cycle assessment perspective is integrated into the calculation. Our research on the available data of life cycle energy consumption of electricity generation technologies has shown a considerable range of possible values for any technology. This leads us to the suggestion to use simplified approximate values to include the life cycle of fuels/sources transformed into electricity in the counting.

Another aspect that clearly calls for a regular review and update of the PEF of electricity is the underlying scenario data for the development of renewable electricity generation. The projected development of the electricity sector changes regularly and especially technologies such as nuclear, renewables and CHP are subject to considerable political influence which may change their future development.

---

[1] Detailed Analytical Results of the 2012 Reference Scenario

Annex 1 – Additional data and results

Category	Option		Rank	Precision High-1	Effort required Low-1	Credibility High-1	Data quality High-1	Uncertainty Low-1	Flexibility High-1	Consistency with EU's internal market High-1	2020 Climate High-1	Security of supply High-1	Consistency with the long-term objective of decarbonisation High-1	Complexity Low-1	Transparency High-1
Strategic / political consideration															
PEF purpose	Desired		3.64	4	3	4	4	2	x	x	3	x	2.5	3	4
	Calculated		2.19	2	3	2	2	2	x	x	2	x	3	3	3
Applicability	Abolish		5.00	5	1	4.5	1	1	x	2	5	5	5	1	1
	No differentiation		1.99	2	1.5	2	2	2	x	2	2	2	2	2	2
	Different for different policies		3.38	3.5	2	3	3.5	3.5	x	3	4	4	3	3	3
	Different for different appliances		3.40	3.5	3	3	3.5	3.5	x	3	4	4	3	3	3
	Different for different policies and appliances		3.46	3.5	4	3	3.5	3.5	x	3	4	4	3	3.5	3.5
	Different for delivered and produced electricity		3.04	3	3	3	3	3	x	2	3.5	3.5	3	4	4
Adjustment and review process	Constant		3.71	4	1	4	4	4	4	x	4	4	4.5	1	1
	Regular Review / adjustment		1.26	1	2	1	2	1	1	x	2	2	1	2	2
Database and calculation method	Based on statistics and studies		2.58	3	1	3	2	2	x	x	x	x	x	1	1
	Advanced calculations based on statistics and studies		1.84	2	2	2	1	1	x	x	x	x	x	2	2
	Power sector model		1.82	1	4	4	3	3	x	x	x	x	x	3	4
Representation of the electricity sector															
Geographical resolution	Bigger EU	With PEX correction	2.56	2.5	3	2.5	2.5	3.5	x	2	x	x	x	3.5	2
		No PeX Correction	2.29	2.75	1.5	2	2	2	x	1	x	x	x	2	1
	EU	With PEX correction	2.33	2.5	2.5	2	2	3	x	1	x	x	x	3	2
		No PeX Correction	3.12	4	1	2	2	2	x	2	x	x	x	2	1
	Member States	With PEX correction	2.35	1.5	4.75	3	3.5	3	x	3.5	x	x	x	4.5	4
		No PeX Correction	3.52	4	3	3	3	2	x	4	x	x	x	3	1
	Market regions	With PEX correction	2.50	2	4.5	3.5	3.5	3	x	2.5	x	x	x	4	3
		No PeX Correction	3.40	4	3	3.5	3	2	x	2.5	x	x	x	3	1
	Subnational	With PEX correction	5.00	2	5	4.5	4.5	5	x	5	x	x	x	5	5
		No PeX Correction	5.00	4	4	4.5	4.5	5	x	5	x	x	x	4.5	5
Development over time	Constant		3.04	4	1	1	1	1	3	3	3	3	4	1	1
	Dynamic		1.70	1	3	3	3	3	2	2	1	2	1	4	3
Time resolution	Average over several years		2.75	3.5	2	1	2	1	x	x	x	x	x	1	1
	Annual average		2.53	3	1	2	2.5	1.5	x	x	x	x	x	1	1
	Seasonal		2.66	2	4	3.5	4	4	x	x	x	x	x	4	4
	Hourly time of use		5.00	1	4.5	5	4.5	4.5	x	x	x	x	x	5	4.5
Market position	Average		1.87	2	1	2	2	2	x	x	x	x	x	1	1
	Marginal		5.00	4	5	4	5	5	x	x	x	x	x	5	5

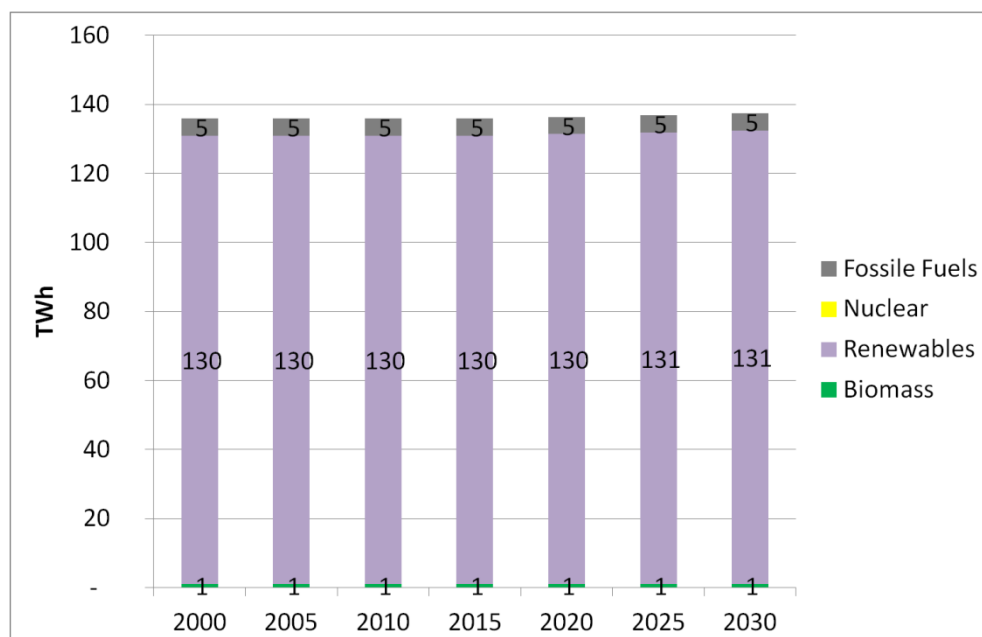| Category	Option	Rank	Precision	Data availability				Flexibility	Acceptance				Complexity	Transparency
				Effort required	Credibility	Data quality	Uncertainty		Consistency with EU's internal market	2020 Climate	Securtiy of supply	Consistency with the long-term objective of decarbonisation		
			High - 1	Low - 1	High - 1	High - 1	Low - 1	High - 1	High - 1	High - 1	High - 1	High - 1	Low - 1	High - 1
General PEF Methodology														
System Boundaries	Entire supply chain (including plant construction and mining)	1.96	1	3.5	3.5	3	4.5	x	x	3.5	2	1	4	4
	Total energy conversion only	2.16	2	2	2.5	2	2	x	x	2	2.5	3	2.5	2.5
PEF indicator	Total primary energy	2.04	1	4	3	3	4	x	x	4	2	3	4	3.5
	Non-renewable energy only	1.96	2	2	2	2	2	x	x	2	2.5	1	2	2
Accounting Method converted resource nuclear	Technical conversion efficiencies	1.88	2	1	1	2	2	x	x	x	1	x	2	2
	Direct equivalent	1.90	2	1	3	1	1	x	x	x	4	x	1	1.5
	Physical energy content	1.88	2	1	1	2	2	x	x	x	1	x	2	2
Accounting method converted resource non-combustible RES	Zero equivalent	1.07	1	1	1	1	1	x	x	x	x	2	1	1
	Substitution method	3.39	4	3	2	3	2	x	x	x	x	2	2.5	3
	Direct equivalent	1.96	2	2.5	2	2	1	x	x	x	x	2	2	2.5
	Physical energy content	2.06	2	2.5	2	2	2	x	x	x	x	2	2.5	2.5
	Technical conversion efficiencies	5.00	4	4	3	4	4	x	x	x	x	4	5	4
Accounting method converted resource biomass	Zero equivalent	2.08	2.5	1	1	1	1	x	x	x	4	2	1	1
	Technical conversion efficiencies	1.16	1	1.5	1	1.5	1	x	x	x	1	2	2	1
Methodological consistency	Same method for all PEF	2.06	2.5	2	1	2	2	x	1	x	x	x	1	1
	Different methods for different Member States	3.89	4.5	3	2	3	3	x	3	x	x	x	3	4
	Different methods for different Member States with correction mechanism	2.67	3	3.5	1.5	3	2.5	x	1.5	x	x	x	2	2
Accounting method for CHP	IEA Method	2.83	3.5	2	1	2	1	x	x	3	3	3	1	2
	Conversion efficiency method	2.83	3.5	2	1	2	1	x	x	3	3	3	1	2
	Finish / Reference system method	1.54	1	3	1	3	3	x	x	1.5	1.5	1.5	2.5	3

Figure 19: Assumed development of electricity generation in Norway

Table 73: Annual results for the PEF in different calculation methods

Year	2000	2001	2002	2003	2004	2005
Method 1	2.41	2.40	2.39	2.39	2.38	2.37
Method 2	2.41	2.40	2.39	2.38	2.37	2.36
Method 3	2.52	2.52	2.51	2.50	2.50	2.49
Method 4	2.65	2.64	2.63	2.63	2.62	2.61
Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Method 1	2.37	2.35	2.33	2.31	2.28	2.26
Method 2	2.36	2.32	2.27	2.23	2.18	2.14
Method 3	2.49	2.47	2.45	2.43	2.40	2.38
Method 4	2.61	2.59	2.56	2.54	2.52	2.49
Year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Method 1	2.26	2.22	2.19	2.15	2.11	2.08
Method 2	2.14	2.09	2.04	1.99	1.94	1.90
Method 3	2.38	2.35	2.31	2.28	2.24	2.21
Method 4	2.49	2.45	2.41	2.38	2.34	2.30
Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Method 1	2.08	2.04	2.00	1.96	1.91	1.87
Method 2	1.90	1.83	1.77	1.71	1.65	1.59
Method 3	2.21	2.17	2.13	2.09	2.05	2.01
Method 4	2.30	2.26	2.22	2.17	2.13	2.09
Year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Method 1	1.87	1.86	1.84	1.82	1.81	1.79
Method 2	1.59	1.56	1.54	1.51	1.48	1.46
Method 3	2.01	2.00	1.98	1.96	1.95	1.93
Method 4	2.09	2.07	2.05	2.03	2.02	2.00
Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Method 1	1.79	1.78	1.77	1.76	1.75	1.74
Method 2	1.46	1.44	1.42	1.40	1.38	1.35
Method 3	1.93	1.92	1.91	1.90	1.89	1.87
Method 4	2.00	1.98	1.97	1.96	1.94	1.93

Annex 2 – PEFs of fuels as
input for PEF calculation for
electricity

Annex 2 – PEFs of fuels as input for PEF calculation for electricity

Contact

TECNALIA,

Parque Tecnológico Bizkaia.

Calle Geldo, Edif. 700.

48160. Derio. Spain

Patxi Hernandez (patxi.hernandez@tecnalia.com)

www.tecnalia.com

Annex 2 – PEFs of fuels as
input for PEF calculation for
electricity

Primary Energy Factor definitions and calculation methods

This Annex elaborates on the PEF of fuels as presented in Chapter 3 "Our approach" of the report. The focus is on the (non-renewable and renewable) combustible fuels.

On the discussion of primary energy factors of fuels, it is important to come back to the basic definitions of primary energy.

According to the United Nations (1982)[1] "*Primary energy should be used to designate those sources that only involve extraction or capture, with or without separation from contiguous material, cleaning or grading, before the energy embodied in that source can be converted into heat or mechanical work. Secondary energy should be used to designate all sources of energy that results from transformation of primary sources*".

The Energy Statistics Manual from OECD/IEA/Eurostat (2005)[2], defines primary energy commodities as those extracted or captured directly from natural resources such as crude oil, hard coal, natural gas. Energy commodities produced from primary commodities are termed secondary commodities. More specifically in relation to the accounting of primary energy, Eurostat[3] states the following:

"For directly combustible fuels (fossil and renewable fuels/ products) the primary energy content is calculated as the heat value generated during combustion of this fuel.

For non-conventional energies (hydro, wind, solar photovoltaic, geothermal, nuclear and others) it is necessary to establish energy boundaries and make methodological choices in order to define their nature and quantity of primary energy.

The choice for Eurostats's energy statistics and energy balances is to use the Physical energy content method. The general principle of this method is that the primary energy form is taken as the first flow in the production process that has a practical energy use. This leads to different situations depending on the energy product:

- *For directly combustible energy products (for example coal, natural gas, oil, biogas, bioliquids, solid biomass and combustible municipal/industrial waste) the primary energy is defined as the heat generated during combustion.*

- *For products that are not directly combustible, the application of this principle leads to:*

---

[1] United Nations (1982)
2 OECD/IEA/Eurostat, Energy Statistics Manual, Paris, 2005.
[3] http://ec.europa.eu/eurostat/statistics-explained/index.php/Calculation_methodologies_for_the_share_of_renewables_in_energy_consumption

[4] For comparison, in the report energy products are worded as "fuels".

o *the choice of heat as the primary energy form for nuclear, geothermal and solar thermal; and*

o *the choice of electricity as the primary energy form for solar photovoltaic, wind, hydro, tide, wave, ocean.*

In cases when the amount of heat produced in the nuclear reactor is not known, the primary energy equivalent is calculated from the electricity generation by assuming an efficiency of 33 %. In the case of electricity and heat generated by geothermal energy: if the actual amount of geothermal heat is not known, the primary energy equivalent is calculated assuming an efficiency of 10 % for electricity production and 50 % for derived heat production. If two energy balances are constructed with different methodological choices and respective assumptions on efficiency conversions and calorific values, it will lead to different results for the share of renewables."

This Eurostat approach to accounting primary energy, does not consider a life cycle perspective, where entire supply chain is analysed accounting the processes which have involved additional energy inputs.

A life cycle perspective would entail considering these additional energy inputs on the supply chain up to the point the energy carrier is used. This perspective is used for example in the standard for building energy performance evaluation EN 15603 (CEN, 2008[1]), which describes PEF as the following:

"For a given energy carrier, non-renewable and renewable primary energy divided by delivered energy, where the primary energy is that required to supply one unit of delivered energy, taking account of the energy required for extraction, processing, storage, transport, generation, transformation, transmission, distribution, and any other operations necessary for delivery to the building in which the delivered energy will be used"

The standard goes on defining separate PEFs for renewable and non-renewable energies, but the concept of including the different phases of the supply chain remains, and is further detailed as follows:

"*The primary energy factors shall include at least:*

- *Energy to extract the primary energy carrier;*

- *Energy to transport the energy carrier from the production site to the utilization site;*

- *Energy used for processing, storage, generation, transmission, distribution, and any other operations*

- *Energy necessary for delivery to the building in which the delivered energy is used.*

The primary energy factors may also include:

- *Energy to build the transformation units;*

- *Energy to build the transportation system;*

- *Energy to clean up or dispose the wastes.*"

---

[1] CEN (2008) Energy performance of buildings. Overall energy use and definition of energy ratings

Annex 2 – PEFs of fuels as
input for PEF calculation for
electricity

This definition is quite detailed, and gives some indication about the life cycle phases that can be considered when analysing PEFs.

The standard EN 15603 also contains separate definitions for total PEF and non-renewable PEF, as follows:

- "***Total primary energy factor:*** *For a given energy carrier, non-renewable and renewable primary energy divided by delivered energy, where the primary energy is that required to supply one unit of delivered energy, taking account of the energy required for extraction, processing, storage, transport, generation, transformation, transmission, distribution, and any other operations necessary for delivery to the building in which the delivered energy will be used.*
  NOTE: The total primary energy factor always exceeds unity.

- ***Non-renewable primary energy factor:*** *For a given energy carrier, non-renewable primary energy divided by delivered energy, where the primary energy is that required to supply one unit of delivered energy, taking account of the energy required for extraction, processing, storage, transport, generation, transformation, transmission, distribution, and any other operations necessary for delivery to the building in which the delivered energy will be used.*
  NOTE: The non-renewable primary energy factor can be less than unity if renewable energy has been used."

The following section discusses how PEFs can be calculated in current practice taking into account the life cycle perspective.

Calculation of PEFs for fuels considering the entire supply chain (life cycle approach)

This section considers the PEF definition which implies consideration of the energy used on the whole supply chain, up to the point where the gas, liquid or solid fuel can be considered an energy carrier. This whole life cycle consideration gives a better understanding of the potential influence of the different life cycle phases on the calculation of PEFs for fuels. Despite not having the methodological complexity of the PEF calculations for electricity, which involves multiple factors as discussed in Task 1 (in the report) RE. PEF for electricity, PEF calculation of fuels taking a life cycle perspective can be a very arduous and time consuming task, entailing the collection of various data across the supply chain of the different fuels.

As an example of the magnitude of this task, it can be considered for example that for the calculation of an average PEF for a particular fuel on a specific country (or the whole EU), data on the original sources of this fuel should be gathered. The primary fuels, particularly taking into account the highly sensitive international energy market, has a large variability and will likely be sourced from a large number of locations. The extraction and transformation processes that the fuels have gone through can largely differ. Table 74 (JRC, 2013[1]), shows significant differences on the specific energy needed even in

---

[1] JRC(2013),WELL-TO-TANK Report Version 4.0 . JEC WELL-TO-WHEELS ANALYSIS

initial life cycle phases for crude oil or gas production in different energy exporting regions. The differences on the energy needed for fuel processing and transport should be also considered before the energy commodity reaches end user.

Table 74: Energy and GHG emissions from crude oil and gas production for producers around the world members of the International Association of Oil & Gas Producers (OGP)

Data for 2011 oil & gas production		Total	Africa	Asia	Europe	FSU	ME	NA	SA
OGP reported production	Mt/a	2221	387	355	452	127	411	295	194
	%	100%	17%	16%	20%	6%	19%	13%	9%
Total production (BP Statistical Review)	Mt/a	6951	600	819	406	1366	1775	1454	531
	%	100%	9%	12%	6%	20%	26%	21%	8%
OGP coverage[1]	% of total	32%	65%	43%	111%	9%	23%	20%	37%
Energy Consumption (OGP production only)									
Total energy	PJ/a	3333	515	611	515	141	321	903	328
Specific energy	GJ/t	1.50	1.33	1.72	1.14	1.11	0.78	3.06	1.69
Specific energy[3]	MJ/MJ	0.036	0.032	0.041	0.027	0.026	0.019	0.073	0.040

Figure 20 shows the results for the primary energy factor calculated from the non-renewable primary energy demand of natural gas supplied in different countries (taken from the Ecoinvent 3.1[1] life cycle database, one of the most recognized databases worldwide), and a standard gross calorific value of 39 MJ/m^3 considered for natural gas.
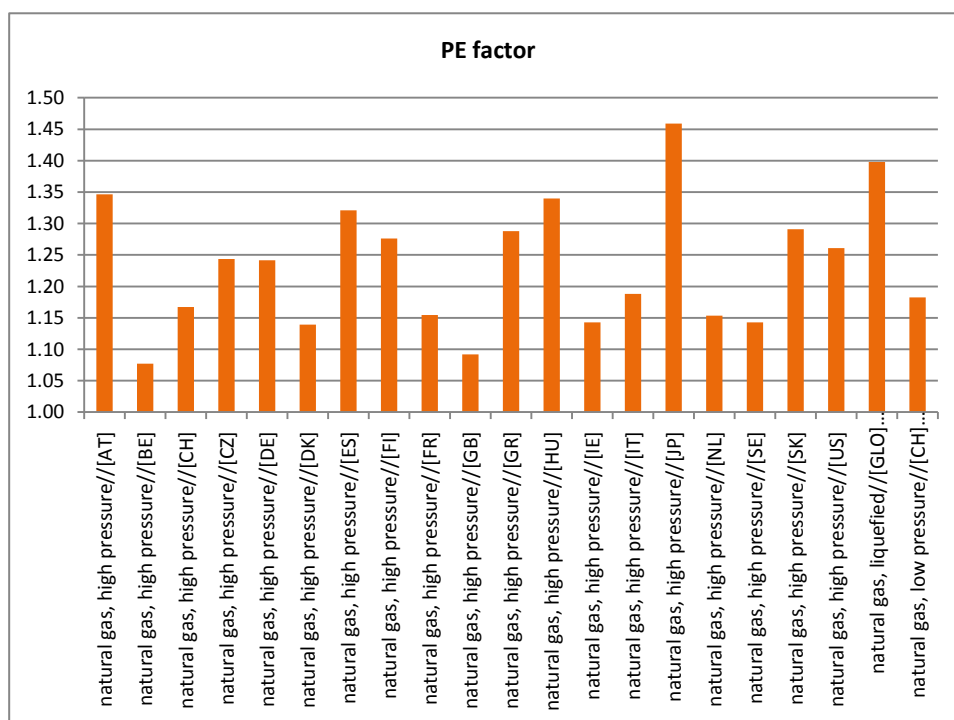

Figure 20: PEF calculated for natural gas supply in different countries.

---

[1] Ecoinvent Association (2015), Ecoinvent Database 3.1, available at www.ecoinvent.org

Annex 2 – PEFs of fuels as
input for PEF calculation for
electricity

These sample results for natural gas show that when a detailed analysis of the supply chain has been carried through life cycle analysis for one particular fossil fuel, very different results for the countries can be obtained.

These large differences can be the result not only from actual variations on supply chains and processes, but also from different assumptions and default values which had been applied in the calculations and from differences on quality of the source data.

Due to the continuously changing energy geopolitics, which mean that supply from one or other country can vary in a large amount and in very short term, uncertainties on country or EU level PEF calculations for fossil fuels taking into account all the different life cycle phases can be very high.

For biomass fuels, the complexity and the potential uncertainty of a PEF calculation is even larger, as a wide range of biomass feedstocks can be used for heat and/or electricity production. Examples can include direct supplies from forestry and agriculture (i.e. thinning, branches, straw, purpose-grown energy crops, including short-rotation coppice); processing residues (i.e. saw dust, black liquor soap); and, dry or wet organic wastes (i.e. sewage sludge, manure, the organic fraction of municipal solid waste (European Commission, 2014[1]). Intending to calculate with a detailed life cycle perspective a common PEF factor or a set of PEF factors at EU or national level is therefore an arduous task also for biomass fuels.

For other fuels such as hydrogen, the PEF factor would largely depend on the production process, and particularly on the source of electricity used[2].

Overall, we can conclude that calculation of primary energy factors for fuels from a life cycle perspective presents data gathering complexity and very large uncertainties.

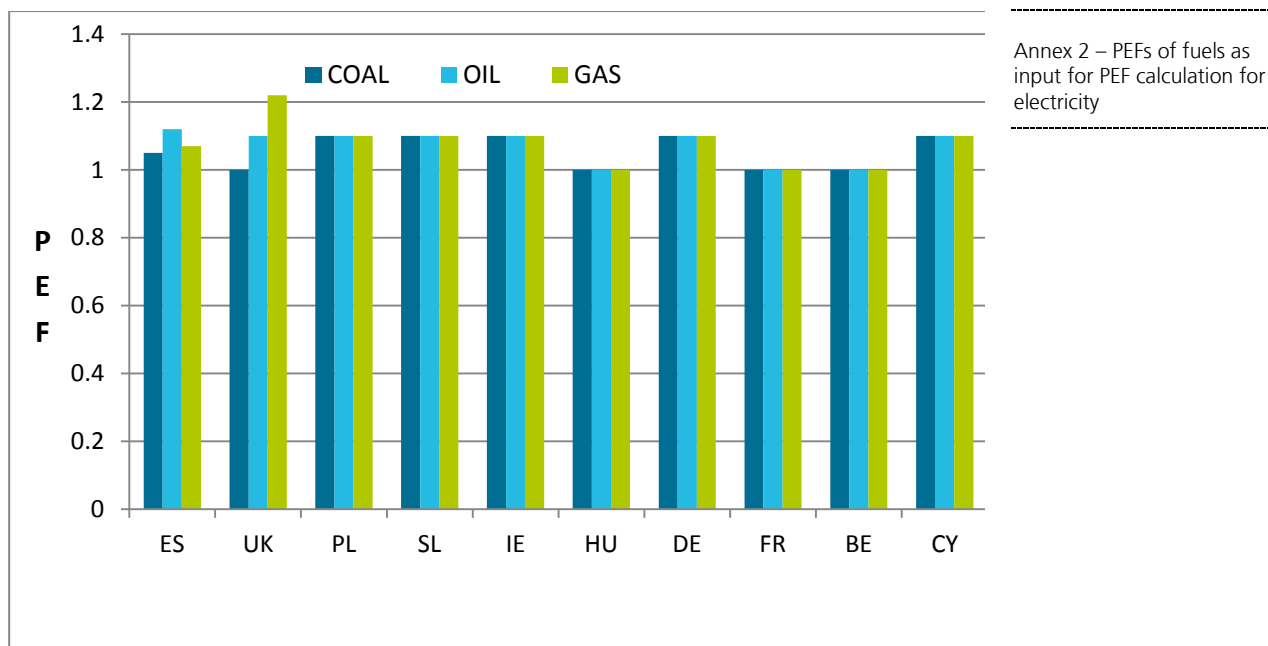## Simplifying PEF of fuels: Examples in current national regulations

In the previous section the large uncertainty associated to the PEF calculation for fuels, which is not currently standardized and involves large quantity of data sources, has been discussed. In current practice, the PEFs used in policies in EU countries present very different values, which depend on the approach taken in the calculation, particularly in relation to the degree of application of the life cycle and supply chain perspective.

Figure 21 includes some of the PEFs for fuels for some European countries, taken from the national reports for cost-optimal minimum energy performance requirements developed in the context of the Energy Performance of Buildings Directive (EPBD)[3].

---

[1] European Commission – State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU - Commission Staff Working Document SWD(2014) 259 final:

[2] For clarity, hydrogen is however as of today not used as a fuel to produce electricity and is therefore not a fuel/carrier included in the calculation of the PEF for electricity: on the contrary, it requires electricity to be produced.

[3] National reports on energy performance requirements for the Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings

*BE= Brussels region

Figure 21: PEFs for fuels for different EU countries. (EPBD National Cost-Optimal Regulations)

The first observation can be that the values for gas do not correspond to the values calculated from a life cycle perspective, shown in Figure 20. This means that these regulations generally have not applied the life cycle perspective, or at least with the same boundaries and assumptions as for the calculations in Figure 20.

However it can be observed that in most of the cases the PEF of fossil fuels is higher than 1, which means that to some extent the supply chain has been considered, i.e. at least the energy needed for some of the processes needed to deliver the final energy carrier has been taken into account (mainly production and distribution processes).

Two main values for PEF stand out: 1 and 1.1. Many countries choose to adopt a standard typical value of 1.1 for fossil fuels, which relates to a simplification of energy inputs in processing and distribution of the primary fuels equalling 10% of the energy delivered by the energy carrier.

Some countries however use a PEF of 1, which in practice means the energy carrier is directly considered as a primary energy source.

As shown in Figure 21, in UK or Spain values differ from the most common 1 or 1.1 values. The reason of this is because a more detailed analysis is carried, considering the energy inputs in different phases of the life cycle.

Figure 22 shows the systems boundaries considered in the UK PEF calculation methodology.
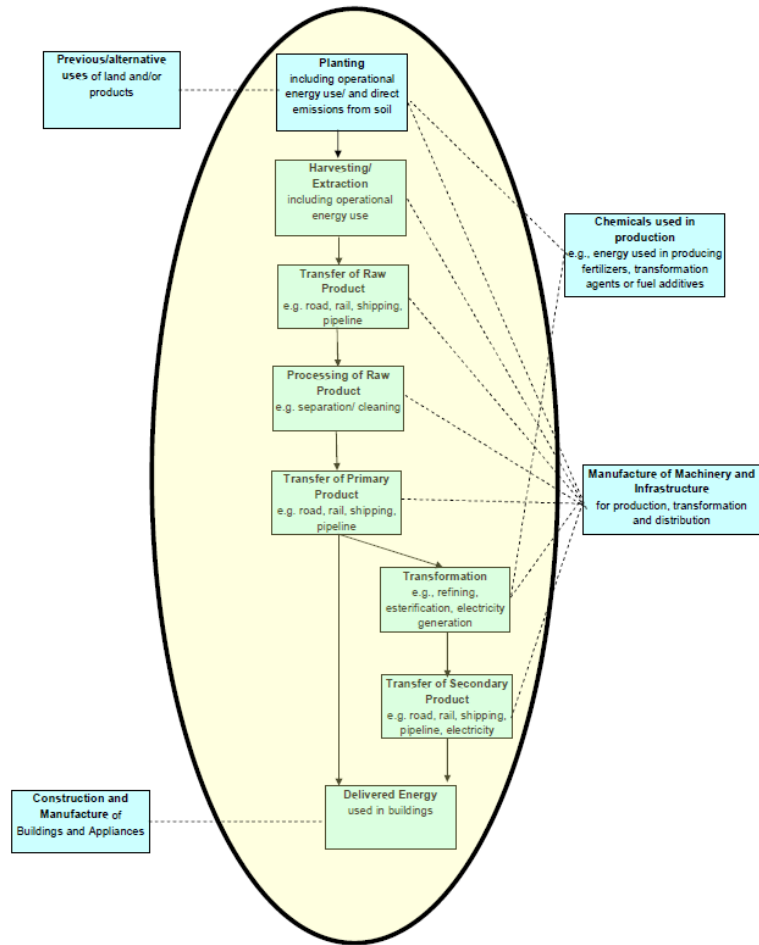

Annex 2 – PEFs of fuels as
input for PEF calculation for
electricity

Figure 22: System boundaries used for PEF calculation in UK SAP (Standard Assessment Procedure for Energy Performance)

Biomass fuels have not been included in Figure 21, as they are not really comparable between countries, due to the large variation on biomass sources as already commented in part 2 of this Annex. There is also a large uncertainty and a lack of harmonised criteria on calculation of biomass. In the countries where some PEF for biomass have been published in the EPBD "National cost-optimal regulations", it can be observed that the differences not only relate to life cycle boundaries, but also largely to the indicator that is used. Some countries only consider non-renewable primary energy PEF (and therefore bio-based fuels appear with a very low PEF, close to zero), while other countries consider the total primary energy factor. In this second case, the renewable energy content of the fuel is also added to the primary energy inputs of life cycle energy use and PEF is therefore always above 1.

The use of one or another definition of PEF is a key decision, which should be consistent with the PEF indicator (non-renewable or total primary energy).

X

Conclusions and definitions of PEFs for fuels in the context of PEF calculations for electricity

----
Annex 2 – PEFs of fuels as
input for PEF calculation for
electricity

This Annex has presented a brief review and description of primary energy concepts and approaches for calculating and assigning a PEF to solid, liquid and gas fuels.
Two main observations can be extracted from this review:

- There is a data gathering complexity and very large uncertainty on the calculation of PEFs for fuels taking into account a life cycle perspective.

- Application of PEF of fuels in policy is currently not harmonised, and methodologies and PEF values are very different in EU countries.

It is therefore very difficult to propose a consistent PEF of solid, liquid or gas fuels in the EU based on detailed life cycle and supply chain considerations. Taking into account this fact, simplifications regarding the PEF of fuels have been included in the various calculation methods presented in this report for the calculation of a PEF for electricity, notably in:

- Calculation Method 1:

It follows the Eurostat procedure for energy accounting, and therefore does not consider a life cycle approach in the calculations. All fuels have a PEF of 1.

- Calculation Method 2:

A life cycle approach is considered in this case. Non-renewable primary energy is accounted.
For fossil fuels, a PEF value of 1.1 has been chosen as an approximation of life cycle non-renewable primary energy.
For the category including biomass and waste fuels, a PEF value of 0.15 has been considered as best approximation of life cycle non-renewable primary energy

- Calculation Method 3:

It follows the Eurostat procedure for energy accounting, and therefore does not consider a life cycle approach in the calculations. All fuels have a PEF of 1.

- Calculation Method 4:

A life cycle approach is considered for fossil fuels. Total primary energy is accounted.
For fossil fuels, a PEF value of 1.1 has been chosen as an approximation of life cycle total primary energy. For the category including biomass and waste fuels, a PEF value of 1 has been considered.