Determining primary energy factors for electricity

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ADAPT CONSULTING AS

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Summary of the methodology presented in the report

This report establishes principles and a framework for determining primary energy factors (PEFs) for electricity. Two general criteria form the basis for the determination of PEFs:

- The PEF shall be “accurate and goal-oriented” (Suitable for the concrete objective one aims at reaching)
- The calculation of the PEF shall have “sufficient precision” (It must not deviate too much from its true value)

The framework consists of two parts. Part 1 attempts at making PEF “goal-oriented and accurate”, and part 2 attempts to ensure that the PEF has “sufficient precision”.

Chapter 3 in this report describes part 1 of the methodology. It consists of four steps in which overarching principles are addressed:

1. Select assessment approach
2. Clarify calculation indicators
3. Establish system limits
4. Establish a time frame

Step 1 is to select the assessment approach, based on the objective. The assessment approach may be either an attributional assessment or a consequential assessment. The attributional assessment implies to allocate real (or expected) primary energy consumption associated with the production of electricity to the end-user consumption of electricity. A consequential assessment, on the other hand, tries to uncover to what extent changes in the end-user consumption of electricity results in changes in the primary energy consumption. The attributional assessment is usually applied for statistical purposes, while a consequential assessment is more suitable for decision-making.

Step 2 is to clarify the choice of calculation indicator. A PEF for electricity reflects the ratio between end-use consumption of electricity and primary energy consumption. For other objectives, other calculation indicators may be more suitable (, e.g. carbon emission indicators).

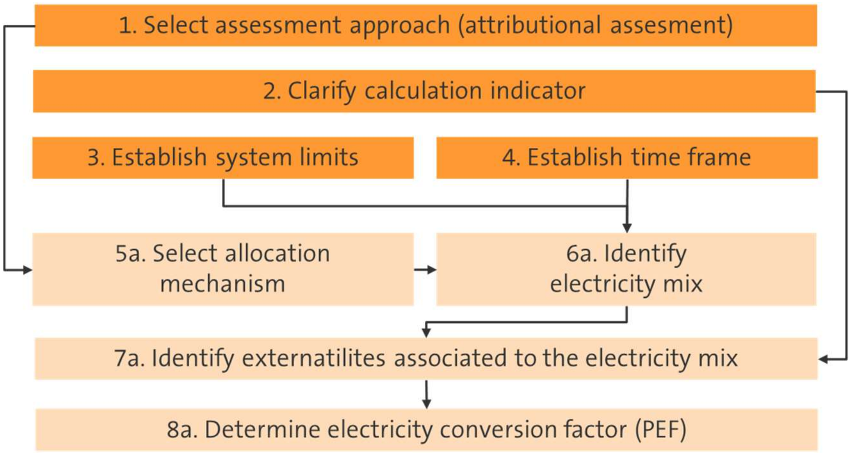
Step 3 is to delimitate the geographical area for which we want to investigate the relationship between the consumption of electricity and primary energy consumption.

Step 4 is establish a time frame, which is a relevant period of time over which primary energy consumption will be determined.

As mentioned, the first step in part 1 is to clarify whether the PEF shall be used to 1) attribute primary energy consumption or 2) assess consequences. These two approaches require the use of different data, assumptions and calculation principles, such that it is natural to divide the part 2 of the framework into two separate chapters.

Chapter 4 in this report describes part 2a of the methodology. Figure 1 shows a flowchart illustrating the complete set of steps needed in order to determine a PEF in an attributional assessment.

Figure 1 Flowchart for determining a PEF in an attributional assessment approach



Step 5a is to select the appropriate allocation mechanism suitable to the attributional assessment. There are two allocation mechanisms; the physical allocation mechanism and the financial allocation mechanism. Physical allocation implies that primary energy is attributed to electricity consumption by using average values, whereas financial allocation is conducted according to financial markets for environmental attributes (such as guarantees of origin).

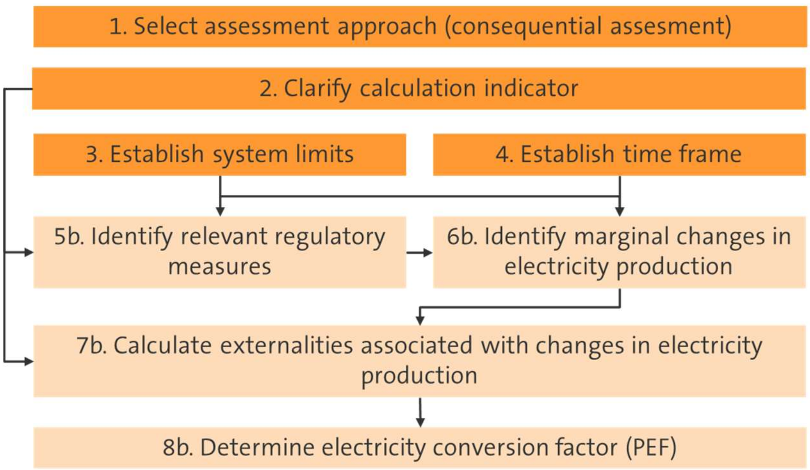
Step 6a is to identify the share of different electricity production technologies in the electricity mix that is relevant for the determination of the PEF. The identification of the electricity mix should be based on previous clarifications in step 3, 4 and 5a.

Step 7a is to identify the primary energy consumption associated with different production technologies in the relevant electricity mix.

The final step 8a in the process is to determine the PEF, by multiplying primary energy associated with each electricity production technology with its share in the total electricity mix.

Chapter 5 in this report describes part 2b of the methodology. Figure 2 shows a flowchart illustrating the complete set of steps needed in order to determine a PEF in a consequential assessment.

Figure 2 Flowchart for determining a PEF in a consequential assessment approach



Step 5b is to identify relevant regulatory measures that influence power producers' adaption to changes in electricity consumption.

Step 6b is to identify marginal changes in electricity production caused by changes in electricity consumption based on clarifications in step 3, 4 and 5b.

Step 7b is to calculate or identify primary energy consumption associated with the production technologies that respond to consumption variations.

The final step 8b is to determine the PEF. It is achieved by multiplying the primary energy per kWh for each production technology with the share each technology has in the marginal electricity production mix.

1. Introduction

A primary energy factor (PEF) for electricity describes the ratio between end-user consumption of electricity and primary energy consumption. In recent years, the EU has implemented regulatory use of PEFs in the energy policy framework. As a result, PEFs now play a role in the regulation of production and consumption of electricity throughout Europe.

A key challenge is the lack of professional and/or political agreement on how the PEF shall be determined. Up until today, approaches used to determine PEFs have lacked grounding in objective methodologies, and the discussions have often been plagued by sectorial interest and political goals. Regulatory application of PEFs can create enormous challenges for European authorities and other energy market interests in the future. Depending on the case, the determination of a PEF may push end-users to alter their consumption of energy, decisions on energy efficiency and/or choice of energy fuels. Thus, PEFs may affect European countries' ability to achieve long-term energy- and climate goals.

There is a need to establish objective principles and a framework to determine PEFs for electricity, so that these factors are suitable to various goals and cases in a transparent and appropriate manner. In addition to PEFs, CO2-factors and other electricity factors are applied for other purposes in Europe, such as environmental declarations, GHG -reporting systems, etc. The objective framework should therefore be relevant for all types of electricity conversion factors. This report address this need by:

- Establishing principles and a framework for determining PEFs and other conversion factors for electricity drawn from the distribution grid. The work stems from existing standards, reflecting physical and geographical constraints. In addition, the framework is supported by economic theory.
- Discussing how the use of such conversion factors are appropriate or required for use in the context of EU energy policy.

2. Methodological approach

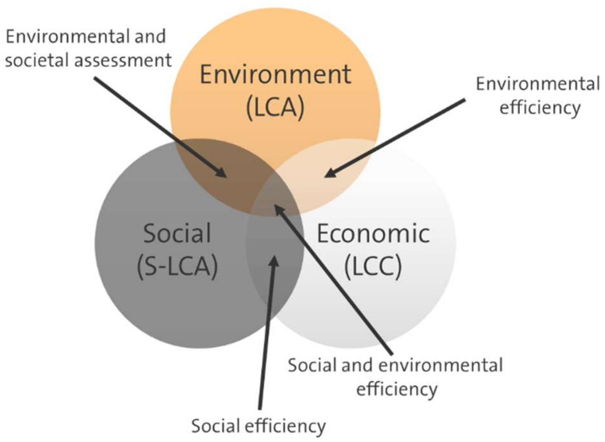
2.1. How to calculate externalities resulting from the use of electricity

Electricity conversion factors aim to disclose information about externalities. Externalities are costs or benefits that affect a party who did not choose to incur that cost or benefit. An example of an externality is pollution that arises from the combustion of fossil fuels. In the literature, externalities are often categorized as follows:

- Economical externalities
- Environmental externalities
- Social externalities

Several approaches have been developed in order to incite end-users to consider externalities when making decisions. An example of an approach is the life-cycle costing (LCC). The aim of an LCC is usually to optimize cash flows, e.g. via net present value analysis. Another example is the life-cycle assessment (LCA) used to estimate environmental externalities. With environmental externalities, we refer to e.g. primary energy use, other use of resources, waste production, greenhouse gases emissions, etc. Less widespread is the use of the so-called social life cycle assessment (S-LCA) which aims at highlighting social impact of, e.g. equality, animal welfare, poverty, etc.

Figure 2.1 Categorizing externalities



The purpose for using a LCC, LCA or an S-LCA may vary, although it is often sought to assess how negative externalities can be minimized (e.g. environmental efficiency). It is possible to combine different methods in order to optimize a combination of objectives, as illustrated in figure 2.1.

Electricity end-use causes externalities. For example, there may be environmental impacts arising throughout the electricity value chain (from the recovery of primary energy, the production of electricity, and the transport/distribution of electricity). The common approach to calculate environmental impacts resulting from each activity in the value chain in an LCA is to determine and apply conversion factors for electricity. Conversion factors should reflect the ratio between the use of electricity and externalities. By multiplying the consumption of electricity with conversion factors, one is able to calculate the externalities that can be allocated to electricity end-use. Examples of conversion factors are primary energy factors (PEF) and CO2-factors (gCO2/kWh).

2.2. Relevant International and European standards

Principles for calculating externalities are only partially standardized. In some areas, especially when it comes to stipulating CO2-factors and primary energy factors for electricity, there are no universal guidelines on how the conversion factors should be determined.

An example of a relevant standard is *EN ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework.* The standard describes the principles and framework for a holistic LCA. Four different phases compose such an analysis. Yet, the standard does not describe the LCA-approach in detail, nor does it specify calculations for the individual phases that compose the LCA. In addition, it does not clearly relate the choice of assessment method to the purpose of conducting an LCA. This relation is only shortly referred to in appendix A (A.2), where it is stated that it is necessary to consider whether the LCA will purely be used to report on environmental effects or whether it will be used as a basis for decision-making. In this regard, it may be appropriate to distinguish between attributional assessments and consequential assessments.

Other standards specify conditions for the use of CO2-factors and primary energy factors. One example is the standard *ISO 16745:2015 Environmental performance of buildings – Carbon metric of a building – Use stage.* The standard describes the principles for determining a carbon metric associated with the operation of a building. According to this standard, greenhouse gas emissions caused by energy consumption is calculated with the use of greenhouse gas metrics[1]. This involves multiplying delivered energy to the building with a carbon metric (which is determined for each specified energy fuel). Yet, the standard gives little guidance on how the metric itself shall be calculated. There is only a requirement to provide information about the references used to determine the metric.

The standard *ISO 16346:2013 Energy performance of buildings – Assessment of overall energy performance* describes a similar approach. ISO 16346 defines various performance indicators used to calculate the building's overall energy performance. Such indicators may reflect primary energy consumption, GHG emissions, or energy policy objectives. We find the same approach in the equivalent European standard *EN 15603:2008 Energy performance of buildings. Overall energy use and definition of energy ratings*[2]*.* However, the two standards give no specific guidelines on how the performance indicators shall be determined. However, various options are discussed, such as the necessity to choose between designing "marginal" indicators (that reflect changes in the power system as a result of changes in the consumption of electricity) or "average" indicators (where the externalities in the power system are split equally on all kWh consumed).

Besides official standards, there are alternative methods on how to calculate externalities affiliated with electricity consumption. Most of them rely on the application of conversion factors for electricity. One example is the Greenhouse Gas Protocol (GHG Protocol) which is developed by the World Resources Institute (WRI) and the World Business Council on

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[1] Greenhouse gas metrics is a similar concept as CO2-factor

[2] Both standards are to be replaced by *ISO/DIS 52000-1 Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures*

Sustainable Development (WBCSD). Many consider the GHG Protocol to be a global standard on the reporting of emissions. According to the GHG Protocol, a CO2-factor for electricity for a specified geographic area shall be determined, based on average GHG emissions per kWh in the relevant grid area. In addition, a market-based CO2-factor shall be determined, taking into account the trade of environmental attributes of electricity (such a green certificates, guarantees of origin or other schemes where environmental attributes are sold separately from the physical delivery).

Today both PEFs and CO2-factors for electricity are applied in European energy policy regulations, statistics and environmental reporting, without being formally grounded in standards or widely accepted methods. Relevant energy policy regulations include the Ecodesign Directive, Energy Labelling Directive, Energy Efficiency Directive and the Energy Performance of Buildings directive.

2.3. Development of principles and the framework

2.3.1. Challenges in developing principles and the framework

Stipulating primary energy factors for electricity is complex because it often relies on a large number of assumptions and uncertainties. Examples on assumptions are the elasticity in demand and supply of power, production-mix and efficiencies of the different technologies, cross-border electricity trading, different time perspectives, etc. Moreover, a PEF may affect political and commercial interests because it can potentially change the attractiveness of electricity compared to its substitutes and therefore have an impact on end-user choices of energy carriers and energy solutions. For example, using a high PEF for electricity in a company's environmental strategy can push the company to switch to fuels with lower or no PEF.

As described in the previous section, no universally recognized approach or standard exist that will provide concrete guidelines on estimating PEF for electricity. In addition, existing standards do not give a sufficient base to establish a complete approach. For example, none of the standards indicate how policy instruments (e.g. emission trading) can affect the estimation of PEF. In addition, standards do not provide guidelines on how to separate externalities between the short- and long-term.

Establishing a PEF is complex and challenging, and the challenges are likely to subsist in the future. However, in this report we make an attempt at addressing these challenges by establishing transparent principles for the calculation of PEFs, as well as grounding the calculation choices in recognized references. In practice, we tried to supplement widely accepted principles in existing standards with strengthened guidelines grounded in economic theory.

2.3.2. Report's methodology structure and limitations

As described in the introduction, the aim of this report is to establish principles and framework for determining PEFs for electricity. Furthermore, the framework should be relevant and suitable to different goals and cases. In this respect, we define two general criteria concerning the determination of PEFs:

- The PEF shall be "accurate and goal-oriented"
- The calculation of the PEF shall have "sufficient precision"

By "accurate and goal-oriented", we mean that the PEF must be suitable for the concrete objective one aims at reaching. For example, if the goal is to reduce emissions of greenhouse gases, it may be more accurate to calculate a "CO2-factor" for electricity rather than a "primary energy factor". By "sufficient precision", we imply that the calculation of the PEF must not deviate much from its true value, making it insignificant. The PEF should be precise enough that it is representative and suitable for its indented application.

Based on the above, the framework for establishing PEF for electricity is divided in two parts:

PART 1: Attempts at making PEF "goal-oriented and accurate" through a number of principles. The description of these principles will primarily ensure that the PEF is suited to its indented application. Chapter 3 describes this part of the framework.

PART 2: Attempts to ensure that the PEF has "sufficient precision" via establishing guidelines for the calculations.

Figure 2.2 Structure in describing methodologies for calculating CO2-factors and primary energy factors for electricity

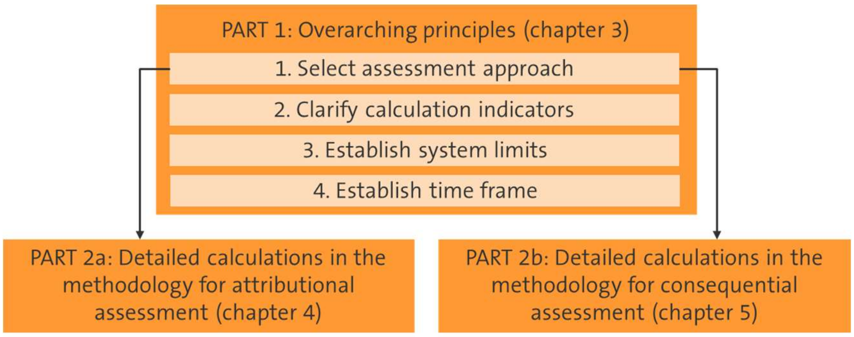


Figure 2.2 illustrates how this reports structures the two parts of the framework for establishing PEFs. The first step in part 1 is to clarify whether the conversion factors shall be used to 1) attribute primary energy consumption or 2) assess consequences. These two approaches require the use of different data, assumptions and calculation principles, such that it is natural to divide the second part of framework into two chapters.

Although this report seeks to establish principles and a framework for determining PEFs for electricity, the methodology is also suitable for calculating and highlighting other forms of externalities, such as GHG emissions, share of renewables, radioactive waste, etc.

3. Framework part 1: Overarching principles

Framework part 1 seeks to ensure that the PEF is "accurate and goal-oriented", through addressing a number of overarching principles.

The four principles in this part of the methodology are:

1. Select assessment approach
2. Clarify calculation indicators
3. Establish system limits
4. Establish a time frame

3.1. Step 1 - Select assessment approach

The first step is to select the appropriate assessment approach in the determination of the PEF for electricity. Two approaches are available:

- Attributional assessment
- Consequential assessment

The **attributional assessment** implies to allocate real (or expected) primary energy consumption associated with the production of electricity to the end-user consumption of electricity. This approach is suitable for various purposes, such as climate reporting and statistical benchmarking.

A **consequential assessment** requires the investigation of changes. This approach tries to uncover to what extent changes in the end-user consumption of electricity results in changes in the primary energy consumption. A relevant application for this methodology could be to investigate to what extent an electrification of European transport have an impact on overall European primary energy consumption. A consequential assessment is normally suitable for decision-making.

Table 3.1: Characteristics of both assessment approaches

Attributional assessment	Consequential assessment
• Is able to account for the whole supply chain, for the production and distribution of electricity (cradle-to-grave) • Relies easily on averages, possibly alternative approaches to allocate primary energy consumption (e.g. guarantees of origin) • Appropriate for reporting of incurred primary energy consumption • Example: Calculating average primary energy consumption in European households	• Focuses only on the affected processes • Relies on data which reflects impact of changes • Takes into account physical constraints, market incentives and regulatory framework • Suitable as a decision-making tool • Example: Calculating changes in primary energy consumption resulting from an increase in the consumption of electricity

Table 3.1 provides an overview of the different characteristics of the two methodological choices.

An example from the transport sector can deepen the understanding of the differences between the two assessment approaches. The example stems from a person evaluating whether she will travel with her own private car or whether she will rely on public buses. Her overall goal is to minimize the total primary energy consumption.

Table 3.2 provides an overview of the primary energy consumption associated with the private car, a bus with five passenger and a bus with 30 passengers. The table is based on the assumption that the bus (and driver) consume 500 kWh/100km and that consumption is increased with 2 kWh/1100km for each passenger. The private car consume 50 kWh/100km.

Table 3.2: Example on primary energy (PE) consumption of a private car or a bus

	Private car	Bus with 5 passengers	Bus with 30 passengers
Total PE consumption	50 kWh/100km	510 kWh/100km	560 kWh/100km
Allocating PE per passenger	50 kWh/100km	102 kWh/100km	19 kWh/100km
Increase in PE when the person choose her mean of transportation (consequential assessment)	50 kWh/100km	2 kWh/100km	2 kWh/100km

According to the table above, the person should choose to travel by bus in order to minimize primary energy consumption. The bus will be out on the road, consuming primary energy, regardless of that one person's choice. If the person chooses to travel by bus, the total primary energy consumption will therefore only increase with 2 kWh/100km. If the person chooses to drive her private vehicle, the total primary energy consumption will increase with 50 kWh/100km.

On the other hand, if the person's goal to report her primary energy consumption according to the attributional assessment approach, we see that this will depend on the number of passengers on the bus. With fewer passengers, a larger share of the primary energy consumption is attributed to each passenger.

3.2. Step 2 - Clarify calculation indicators

A PEF for electricity reflects the relationship between end-use consumption of electricity and primary energy consumption. In some cases however, other calculation indicators may be more suitable. The second step is to clarify which calculation indicator that is best suited to the overall purpose. Table 3.3 show various indicators, which are relevant to account for different types of externalities.

Table 3.3: Externalities and choice of calculation indicators

Externality	Calculation indicator
Emission of greenhouse gases	gCO_2e/kWh
Consumption of primary energy	PEF (primary energy factor)
Renewable share	RES_{SHARE}
Energy cost	€/MWh
Emission of radioactive waste	mgRW/kWh

As mentioned in the above, the choice of indicator should reflect a defined purpose or objective. PEF and CO2-factors cannot be used interchangeably in order to meet multiple energy- and climate related goals. A PEF is not an indicator suitable to evaluate climate consequences associated with the consumption of electricity. The reason is that several technologies (e.g. nuclear power and power plants with CCS) combine high primary energy consumption with low GHG emissions. Retrofitting power plants with CCS will increase primary energy consumption, but GHG emissions will be reduced.

Table 3.4 categorizes various production technologies based on the following dimensions: low/high CO2-factor and low/high PEF. We see that several production technologies have low emissions, even though they require a large amount of primary energy. Similarly, some technologies release large amounts of greenhouse gases, while they require a small amount of primary energy.

Table 3.4: Comparison of the characteristics of various production technologies

	Low CO2-factor	High CO2-factor
High PEF	Geothermal energy Nuclear power Thermal energy with CCS Bioenergy	Coal-power Gas-power
Low PEF	Wind power Hydropower Solar energy Combined heat and power (bio)	Combined heat and power (coal) Combined heat and power (gas)

3.3. Step 3 - Establish system limits

The third step is to identify system limits for the determination of PEF. System limits should reflect the overall objective.

Establishing system limits primarily implies to delimitate the geographical area for which we want to investigate the relationship between the consumption of electricity and primary energy consumption. For example, a geographic delimitation can be national borders, regional borders, EU, or Europe as a whole.

3.4. Step 4 - Establish a time frame

The fourth step is to establish a time frame, which is a period of time over which primary energy consumption will be determined. Establishing a time frame is necessary to ensure that conversion factors are based on a mix of production technologies which is relevant for the time period in question.

Examples of different time frames relevant for various objectives requiring PEF-factors are provided in table 3.5.

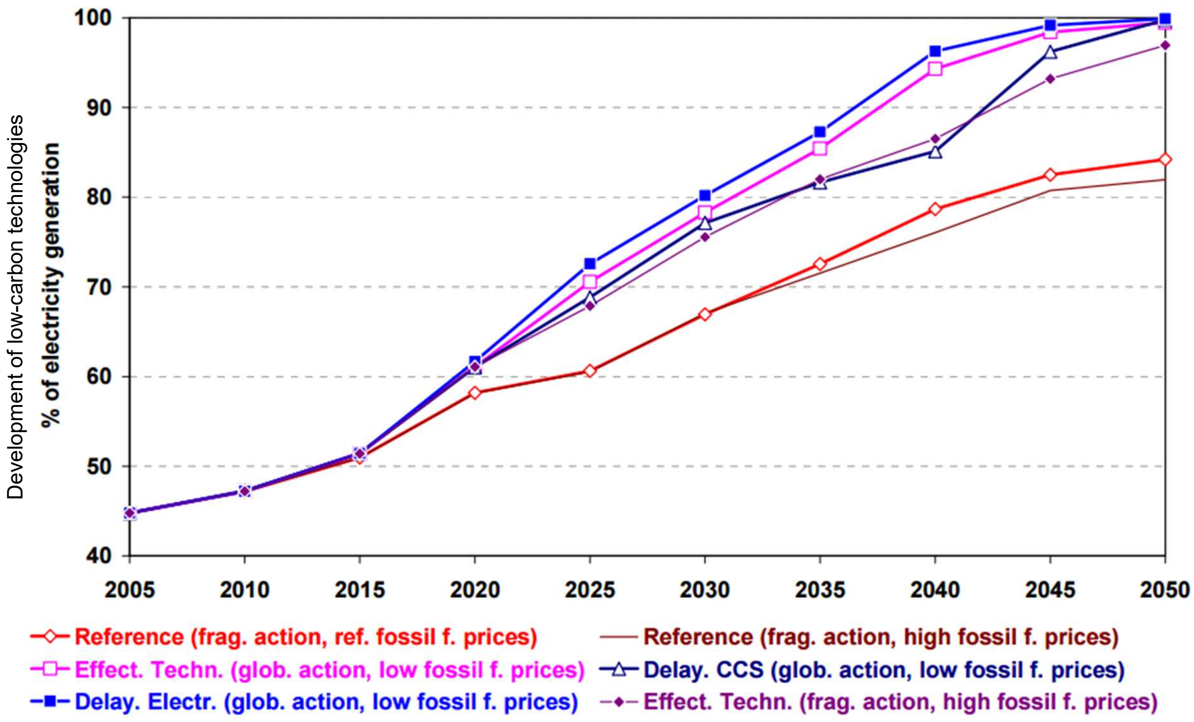
Table 3.5: Examples of time frames

Objective	Time period
Report annual energy statistics	Historical production data per year (e.g. year 2014)
Meet an energy efficiency target in 2020	Expected production data in 2020
Calculate energy performance of buildings with an expected lifetime of 50 years	2016-2065

When establishing a time frame, it is important to distinguish between historical or future time frames. The determination of a historical PEF may be based on historical electricity generation data. As the efficiency and share of electricity generation technologies in the generation mix change over time, historical electricity generation data cannot be used to identify future primary energy consumption associated with end-use of electricity.

When establishing a PEF that is to be applied to future electricity consumption, we must identify scenarios that represent expected developments in the production of electricity. An example is provided in figure 3.1, which shows six different scenarios representing the penetration of low-carbon technologies in the EU, provided that the EU achieves its long-term climate target[3].

Figure 3.1 Scenarios on the development of low-carbon technologies in the EUs electricity production mix (Source: EU-Commission)



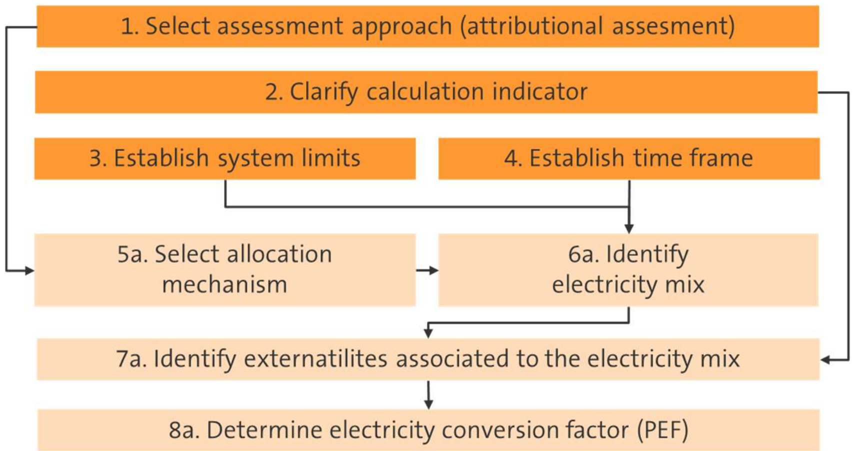
[3] Source: EU-Commission. *Roadmap for moving to a competitive low carbon economy in 2050 – Impact assessment* (2011)

4. Methodology part 2a: PEF-calculations in an attributional assessment

As described in chapter 2, the framework for determining PEFs for electricity consists of two parts. The overarching principles were described in part 1 (chapter 3). This chapter explains the implementation of detailed calculations under the attributional assessment approach.

Detailed calculations of a PEF for electricity within the attributional assessment methodology, is a multi-step process. The aim is to ensure that the PEF is precise, making suitable for its indented application. Figure 4.1 gives an overview on how the steps in the detailed calculations are interconnected. The figure also shows how the detailed calculations in part 2a is an extension of the principles defined in part 1.

Figure 4.1 Flowchart for calculating PEF in an attributional assessment approach



The following sections elaborates on how to conduct the calculations in each step of the process.

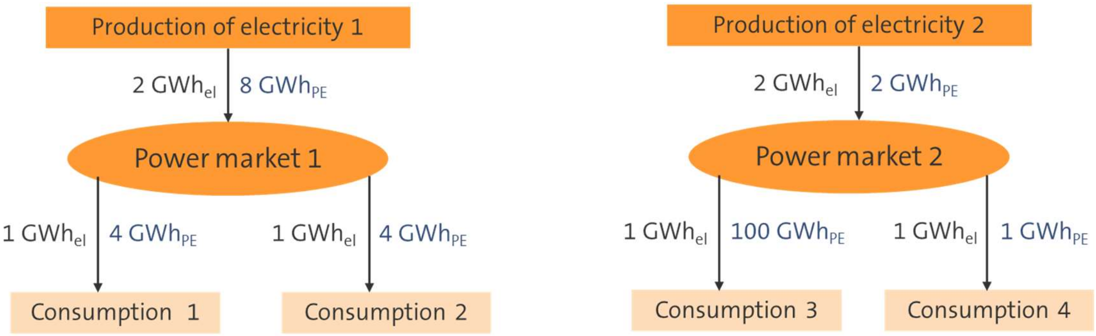
4.1. Step 5a – Select allocation mechanism

An attributional assessment involves allocating primary energy consumption in the production and distribution of electricity to the end-use of electricity. Therefore, a suitable allocation mechanism has to be selected. There are two main allocation mechanisms:

- Physical allocation mechanism
- Financial allocation mechanism

A physical allocation involves the allocation of primary energy consumption according to the physical flows of electricity. This allocation mechanism is illustrated in figure 4.2.

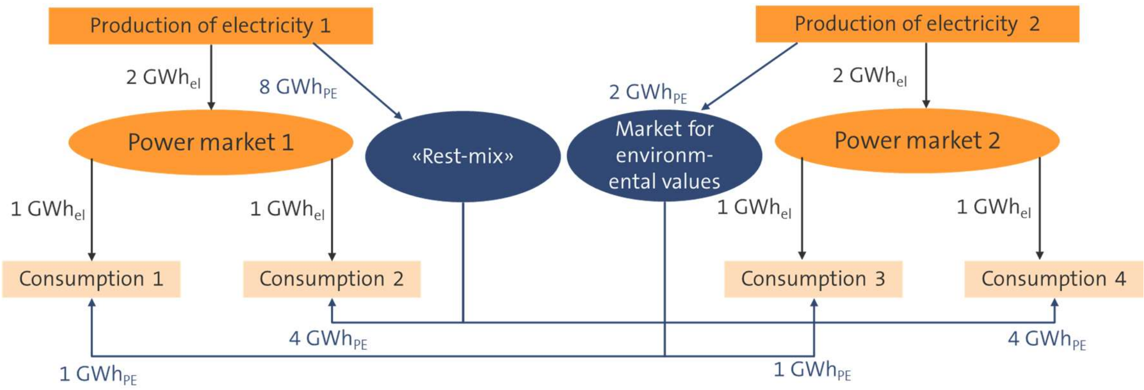
Figure 4.2 Physical allocation of primary energy (PE) consumption



The second allocation mechanism, the so-called financial allocation, detaches the allocation of primary energy from the physical distribution of electricity. The allocation may instead be conducted according financial flows of financial papers (guarantees or certificates) that describe the primary energy consumption associated with the production of electricity. This document can be traded in a financial marked for, e.g. environmental values (across the grid and separate power markets).

In Europe, a market for trading environmental attributes of electricity production has been created, based on guarantees of origin. The market is illustrated in figure 4.3. We see from the figure that consumers may influence their primary energy consumption via the purchase of guarantees of origin.

Figure 4.3 Financial allocation mechanism



4.2. Step 6a - Identify electricity mix

As shown in figure 4.1, the following step is to identify the share of different electricity production technologies in the electricity mix. The identification of the electricity mix should be based on the previous clarifications:

- Step 3 – Establish system limits
- Step 4 – Establish time frame
- Step 5a – Select allocation mechanism

As discussed in chapter 3.3., system limits indicate the geographical delimitation for the calculation of PEF. This can for example be a specific country, a region or Europe as a whole. Also the time frame is important to identify the electricity mix. The aim is to identify the mix of electricity production that takes place at the same time as the consumption of electricity for which the PEF is to be applied. Also, the time frame resolution may be relevant for the calculation of the PEF in some cases. Examples of possible time frames can be as follows:

- Average electricity mix 1990-2005
- Average electricity mix in 2014
- Average electricity mix in winter months
- Average electricity mix during weekdays at 9:00 a.m. to 4:00 p.m.

Finally, it is necessary to correct the physical electricity mix for possible trade of environmental values (e.g. in the form of guarantees of origin), if one chooses a financial allocation mechanism as explained under chapter 4.1.

4.3. Step 7a- Identify externalities associated to the electricity mix

Next step in the process is to identify the primary energy consumption associated with different production technologies in the relevant electricity-mix. Hereunder, it is necessary to whether the focus shall solely be on primary energy losses in the production of electricity, or whether primary energy losses in a wider life-cycle perspective also should be considered. The life-cycle phases that may be included are as follows:

- Recovery, preparation and transport of the fuel to the site for production of electricity
- Electricity production
- Distribution of electricity
- Building, maintaining and decomissionning of production and distribution facilities

I may prove challenging to determine values for different life-cycle phases with a high level of precision, mainly due to lack of data or the complexity of the calculations. For example, consumption of primary energy during the production phase of coal power will depend on a number of additional parameters such as:

- Average efficiencies in power plants during the relevant time frame
- Average characteristics of the fuel which is used at the time of production
- Grid losses
- Allocation of externalities between the production of power and heat from co-generation

The level of precision in the calculations should be adapted to the objective for which the PEF is established. Average values from publicly available statistic may be sufficient to calculate the externalities associated to the production of electricity in many instances.

4.4. Step 8a - Determine electricity conversion factor (PEF)

The last step in the process is to calculate the PEF. Primary energy associated with each electricity production technology should be multiplied with its share in the total electricity mix.

5. Methodology part 2b: PEF-calculations in an consequential assessment

A calculation of PEF with a consequential assessment as methodical approach seeks to identify how changes in the end-use of electricity has an impact on primary energy consumption. We seek to establish a causal link between the use of electricity and primary energy where the principle of additionality is fulfilled (triggering effect in terms of changes in primary energy consumption). This approach is therefore suitable as a basis for decisions, where one seeks to assess the consequences of changes in electricity consumption.

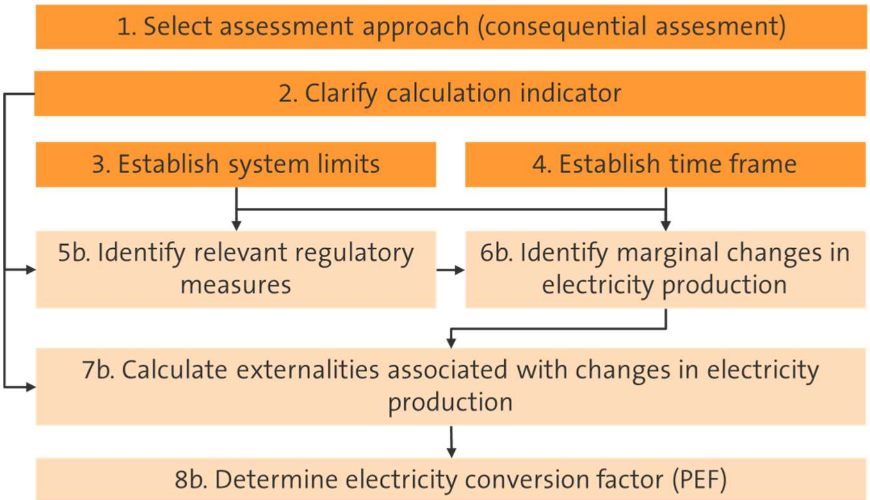
When assessing changes in electricity production due to changes in the consumption of electricity, it is important that we manage to establish a complete understanding of all the elements that influence the behaviour of power generators. Changes in the consumption of electricity is only one of several elements that influence power production. Elements that may influence or restrict power producers' behaviour are as follows:

- Changes in consumption (which triggers a change in energy price)
- Changes in production costs
- Changes in the regulatory framework

A consequential assessment must take into account all of these elements. When trying to assess electricity production consequences caused by changes in electricity consumption, we have to consider how production costs and regulatory framework influence power producers' response to changes in consumption.

Calculations of conversion factors in a consequential assessment is a process that consists of a series of steps, similar to the attributional approach. Figure 5.1 provides an overview of the steps involved.

Figure 5.1 Flowchart for calculating CO2-factors and primary energy factors in a consequential assessment approach



The following sup-chapters discuss the data requirements and calculation principles for each step in the process.

5.1. Step 5b - Identify relevant regulatory measures

In order to identify changes in externalities arising from changes in electricity consumption, it is necessary to take into account relevant regulatory framework for electricity production. In fact, energy policy measures and regulations are often designed with the aim to influence or limit the scope of externalities. Therefore, it is important that we both identify and take account of energy policy measures aimed at electricity producers that are relevant for the externalities we want to highlight.

An example of a relevant regulatory measure is concession procedures for electricity generators. Legislation can set requirements for the type of production facilities you can establish in a market in the long term. Another relevant regulatory restriction may be criteria to obtain emission permits.

As an example of how energy policy measures influence power production, we elaborate in section 5.2.3. on the relationship between changes in electricity consumption within the boundaries of electricity quota systems (often referred to as “tradable certificate systems”).

5.2. Step 6b - Identify marginal changes in electricity production

Next step in the process is to identify marginal changes in electricity production caused by changes in electricity consumption, based on the following previous clarifications:

- Step 3 – Establish system limits
- Step 4 – Establish time frame
- Step 5b – Identify relevant regulatory measures

The system limits determine the geographic area where we will consider changes in primary energy consumption. This may be a specific region, country or EU as a whole. As production costs (including distribution costs, fuel prices, taxes, etc.) vary between different areas, marginal changes in electricity production caused by changes in electricity use will vary as well.

When trying to identify marginal changes in electricity production within the established time frame, we also have to consider whether the change in electricity consumption is permanent or temporary. If the change in consumption is permanent (e.g. caused by strengthened energy performance requirements in building regulations), it will have a long term impact on the demand for electricity, and thus affect producers' behaviour in the energy market in the long term. If the change is temporary (e.g. increased electricity consumption caused by a short-lived heat wave), power producers will not make long-term adjustments to consumption change. Section 5.2.1 and 5.2.2. elaborates on the difference between consequential assessments in the short- and long-term perspective.

When we seek to identify the marginal production changes we must also consider the relevant regulatory framework as discussed in chapter 5.1. As an example, section 5.2.3. discuss how electricity quota systems influence marginal production of electricity.

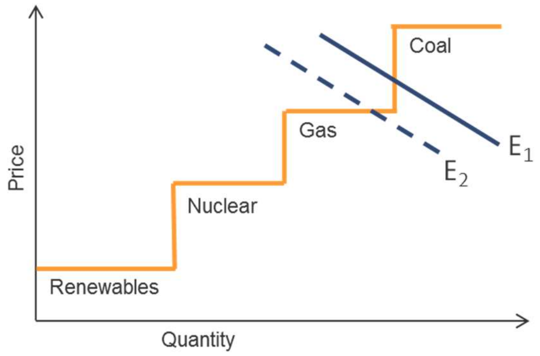
The calculation of marginal production changes caused by changes in electricity consumption is characterised by a high level of complexity. In addition to the prerequisites discussed in the above, the calculation also depend on access to data on demand elasticity, generation capacity, production costs, cross-border trade, electricity prices in the neighbouring electricity markets, etc. Complexity increases along with the degree of required precision in the calculations. However, software that simulate electricity market adaptations are able to perform these calculations.

5.2.1. Short-term marginal changes in electricity production

If the change in the consumption of electricity is temporary, it will influence generation of electricity in the short term only. In the short-term, power producers may not invest in increased generation capacity to meet demand change. Therefore, production response will only affect existing production plants.

Figure 5.2 illustrates an example of marginal changes in electricity production in the short term. When electricity demand decreases (a change in demand from E_1 to E_2) only the production of gas power is reduced. The production of renewable electricity and nuclear power are unaffected, as they do not rely on high electricity prices (lower marginal costs).

Figure 5.2 Marginal changes in electricity production in the short term



5.2.2. Long-term marginal changes in electricity production

If the change in the consumption of electricity is permanent, it will be appropriate to identify marginal production changes over the long term. In the long term, power producers are able to invest in new installations to accommodate consumption growth. For instance, there are no technical limitations on how much the supply of wind and solar power can be increased in the long-term. This means that producers' marginal production curve will change completely when we shift from a short term to a long term perspective.

The example in figure 5.3 illustrates the difference between electricity producers' short- and long-term price elasticity. Wind power production is in the short term limited by production capacity in existing plants. As wind energy has no fuel costs, producers are willing to produce at maximum capacity almost independent of the power price. Temporary changes in consumption will therefore only lead to changes in the production of gas power. In the long term, however, wind power producers may invest in new power plants if the power price over time will pay for the investment costs. Therefore, the long-term marginal production may very well be wind power.

Figure 5.3 The difference between electricity producers' short- and long-term price elasticity

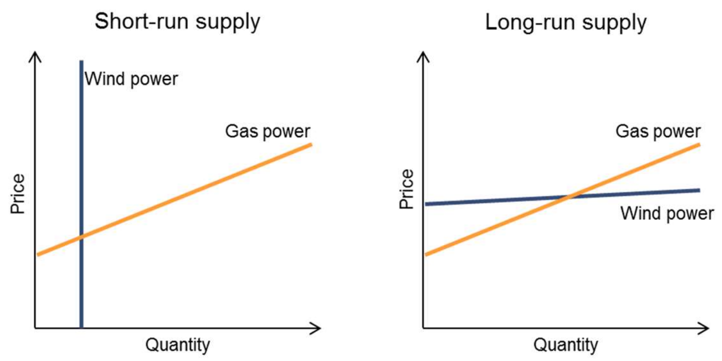
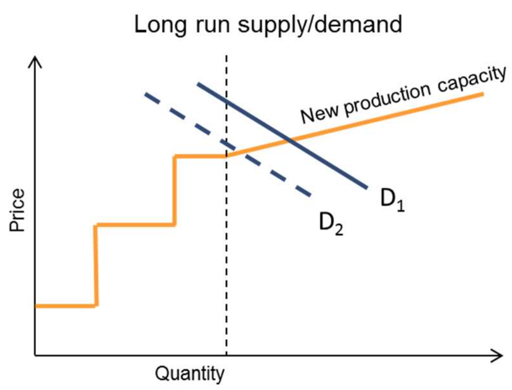


Figure 5.4 illustrates an example on how the long-term dispatch curve for electricity producers may be. In the long term, some of the existing production facilities will be phased out because they reach the end of their technical lifetime or they lack profitability (e.g. due to increased prices in production costs or emission allowances). In addition, long-term demand will be met by new capacity investments. In the figure, an expected decline in electricity consumption from D_1 to D_2 will cause a decrease in the installation of new plants in the long-term. In this perspective, marginal production changes will consist of the technologies representing new investments in the market.

Figure 5.4 Example on a long-term marginal cost curve for electricity supply



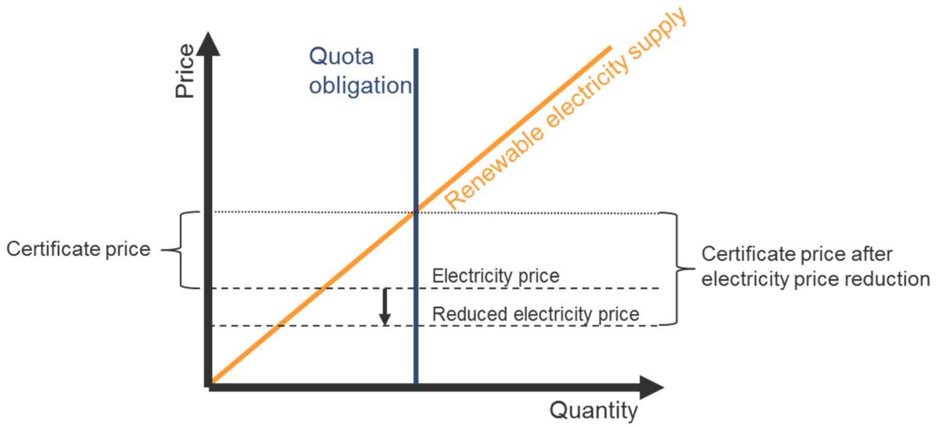
5.2.3. *Electricity quota systems – an example on the significance of regulatory and energy policy measures*

European and national regulatory and energy policy measures influence power producers' response to consumption variations in both a short- and long-term perspective. In order to identify changes in electricity production due to changes in electricity, one must take into account the incentives and disincentives provided by the regulatory framework. This section elaborates on how electricity quota systems influence or determine marginal production of electricity.

Many European countries have introduced electricity quota systems in order to increase the generation of electricity from renewable sources. In a quota system, an obligation to buy electricity certificates is imposed on a suitable party such as electricity suppliers and large electricity consumers. The quota obligation is often set as a percentage of total electricity sales/consumption. The certificates are issued to renewable electricity producers, thus creating an extra financial incentive to generate renewable electricity.

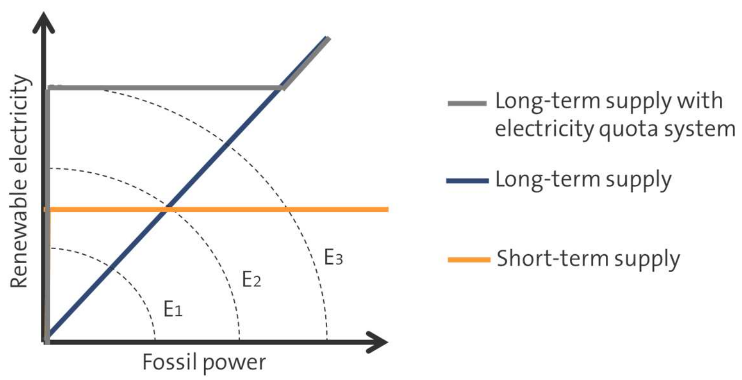
Figure 5.5 illustrates how changes in electricity market prices (caused by changes in electricity demand) influence renewable electricity production subject to an electricity quota system. As the electricity quota regulates the demand for renewable electricity, changes in electricity prices will only result in changes in the price of electricity certificates. The supply of renewable electricity is constant and independent of changes in consumption.

Figure 5.5 Changes in renewable electricity production in markets regulated by electricity quota systems



Electricity quota systems affects producers' market adaptations. The system ensures the supply of a specific amount of renewable energy, regardless of the consumption variations and changes in electricity prices. Figure 5.6 illustrates three examples of supply response to consumption variations. The dotted lines labelled E_1, E_2, E_3 represent different scenarios for consumption of electricity, where power consumption is constant along each dotted line. The coloured lines represent changes in the production composition due to changes in consumption.

Figure 5.6 Changes in supply as a response to consumption variations



The orange line illustrates the production composition in the short term, depending on short-term or temporary consumption variations. Increased consumption will primarily trigger increased renewable electricity production, as long as there is available capacity in existing production facilities. This is because renewable electricity in this example has no marginal production costs (no ongoing fuel expenses relating to water, wind or sun). When the capacity of the existing renewable production facilities are fully utilized, consumption increases lead to increased production of fossil power.

The blue line in Figure 5.6 illustrates how changes in production composition in the long term. In the long term there are no limitations on how much renewable production capacity that can be installed. In this perspective, total average costs (consisting of both CAPEX and OPEX) for each production technology will determine the production composition for each consumption scenario.

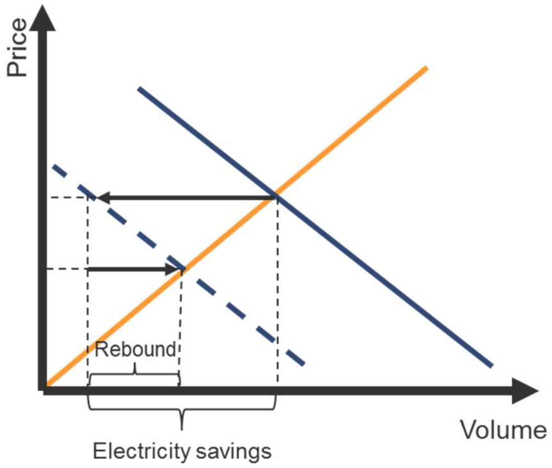
The grey line in figure 5.6 illustrates changes in production composition in the long term in a market regulated by an electricity quota system. The quota obligation will ensure a specific amount of renewable production capacity within the systems duration. Long-term consumption increases will thus lead to increased production of renewable electricity, as long as consumption can be covered by the renewable production capacity that is provided by the system. If consumption increases beyond the renewable production capacity, this could trigger an increase in the production of fossil power.

5.2.4. Price elasticity of demand and rebound

Changes in electricity demand will cause a change in electricity supply. However, we cannot expect that a specific amount of energy savings will result in an equal decline in electricity production. This is due to rebound effects.

Imagine households that install heat pumps. They should experience lower heating costs, which in turn inspire them have a higher indoor temperature throughout the heating season. This is called the rebound or the 'take-back' effect. Now consider this in an electricity market perspective. Changes in demand trigger changes in power prices, which in turn leads to changes in electricity consumption for other applications/sectors. This effect is often referred to as the direct rebound. Figure 5.7 illustrates the direct rebound effect. When the blue demand curve shifts to the left because of energy savings, it leads to lower electricity prices. Lower prices will in turn increase the consumption of electricity. It is this increase in consumption that we call "rebound".

Figure 5.7 Rebound effects



Changes in electricity consumption may also trigger "indirect" rebound effects, either positive or negative. It is likely that households, who invest in profitable energy efficiency measures, spend the money they save on other energy services (e.g. family vacation by airplane). However, other households might use their increased funds on measures that reduce primary energy consumption (e.g. purchase of an electric vehicle). Furthermore, households who go through with an unprofitable energy efficiency investment (e.g. due to building regulations), we might expect a reduction in the household spending on other energy intensive services.

5.3. Step 7b - Calculate externalities associated with changes in electricity production

The next step in the process will be to identify primary energy consumption associated with the production technologies that respond to consumption variations. It is necessary to decide on whether the focus shall be on primary energy consumption resulting from the production of electricity itself, or whether primary energy consumption in a wider perspective also should be taken into account (e.g. cradle-to-grave). The life-cycle phases which can be included in the calculation may be same as in an attributional assessment. The difference, however, is that we seek only to identify changes in externalities arising from a change in the consumption of electricity.

It may prove difficult to obtain necessary data in order to calculate precise values for primary energy consumption associated to changes in electricity production. The level of precision in the calculations should therefore reflect the overall objective and data availability.

5.4. Step 8b - Determine electricity conversion factor (PEF)

The last step in the process is to calculate the PEF. It is achieved by multiplying the primary energy per kWh for each production technology with the share each technology has in the marginal electricity production mix.

6. EU application of the principles and framework

In 2009, the EU set a 20% energy savings target by 2020 when compared to the projected use of energy in 2020. In order to meet the savings target, the EU has adopted a series of legislative acts that will improve energy efficiency in Europe.

In this chapter, we discuss how the principles and framework for estimating primary energy factors might apply for the following EU energy policy framework:

- Energy Efficiency Directive (EED)
- Ecodesign Directive and Energy Labelling Directive
- Energy Performance of Buildings Directive (EPBD)

6.1. Electricity conversion factors in the Energy Efficiency Directive

The 2012 Energy Efficiency Directive (EED) introduced a series of binding energy end-use measures, aimed at reaching the 20% energy efficiency target by 2020. EU countries were required to transpose the directive's provisions into their national laws by 5 June 2014.

According to the directive, all Member States must set a national energy savings target for 2020. The targets should be set taking into account the overall EU target of 20% primary energy savings. However, the national target may be expressed in terms of primary energy savings, final energy saving or a targeted change in energy intensity. Furthermore, the directive requires Members States to introduce a series of measures, including:

- Every three years, Member States shall submit a national energy efficiency action plans
- At least 3% of buildings owned and occupied by central government should be renovated each year
- EU governments should only purchase buildings which are highly energy efficient
- Implementation of an energy efficiency obligation scheme
- EU countries must draw-up long-term national building renovation strategies which can be included in their National Energy Efficiency Action Plans

As the directive aims to increase efficiency in final energy consumption, the use of conversion factors is not mandatory. However, Member States may adopt a national primary energy savings target. A conversion factor for electricity may be applied to determine primary energy savings achieved through electricity savings.

In annex 4 to the directive, there is a table showing the energy content of various fuels. A footnote to the table states that Member States may use a coefficient of 2,5 for the electricity, reflecting an estimated 40 % power generation efficiency in the EU. Other coefficients may also be used if member states can justify it. The text is reproduced here:

For savings in kWh electricity Member States may apply a default co-efficient of 2,5 reflecting the estimated 40 % average EU generation efficiency during the target period. Member States may apply a different co-efficient provided they can justify it.

6.2. Electricity conversion factors in the Energy performance of buildings directive

The revised EPBD entered into force in EU in June 2010, repealing the previous directive from 2002. The revised directive imposes a series of requirements on Member States, including

- The adoption of a methodology for calculating the energy performance of buildings
- Setting minimum energy performance requirements for new buildings and for major building renovations
- Establishing a system of certification of the energy performance of buildings
- Establishing inspection schemes for heating and air conditioning systems
- Ensuring that all new buildings must be nearly zero energy buildings by 31 December 2020 (public buildings by 31 December 2018)

Annex 1 to the Directive set specific requirements for methodology for calculating the energy performance of buildings. The methodology should be able to calculate the building's primary energy consumption through the use of primary energy factors. The annex has the following wording:

The energy performance of a building shall be expressed in a transparent manner and shall include an energy performance indicator and a numeric indicator of primary energy use, based on primary energy factors per energy carrier, which may be based on national or regional annual weighted averages or a specific value for on- site production.

According to wording above, the methodology for calculating the energy performance of buildings shall include a primary energy indicator. However, Member States are free to decide which indicators they wish to apply in the minimum requirements for energy performance and in the energy performance certificates.

Regarding minimum energy performance requirements, Member States shall ensure that minimum energy performance requirements for buildings are set with a view to achieving cost-optimal levels. In January 2012 the Commission published Regulation 244/2012, laying down principles for the calculation to define the cost optimal level of energy performance requirements. According to this Regulation, primary energy factors should be determined at national level.

The only specific requirement for regulatory use of a primary energy factor is laid down in article 9, regarding nearly zero-energy buildings. According to the article, Member States should develop a national plan to increase the number of nearly zero-energy buildings. Article 9 contains the following wording:

The national plans shall include, inter alia, the following elements:
(a) the Member State’s detailed application in practice of the definition of nearly zero-energy buildings, reflecting their national, regional or local conditions, and including a numerical indicator of primary energy use expressed in kWh/m 2 per year. Primary energy factors used for the determination of the primary energy use may be based on national or regional yearly average values and may take into account relevant European standards;

The definition of nearly zero-energy buildings should be expressed in terms of primary energy consumption, calculated with the use of primary energy factors. However, Member States are free to adopt national primary energy factors for different energy carriers.

6.3. Electricity conversion factors in Ecodesign and Energy Labelling

In 2009 the EU adopted the revised Ecodesign Directive. The directive establishes a framework for determining minimum energy, climate and environmental performance of energy-related products in households, industry and service sectors. The definition of an energy-related product is any product that affects energy consumption, directly or indirectly. The directive lays down principles for the design of requirements, while the actual product requirements are laid down in EU regulations for each relevant product group.

The revised Energy Labelling Directive was adopted in the EU in 2010. The directive requires that appliances are labelled according to their energy performance in such a manner that it is possible to compare the efficiency with that of other models. The product categories regulated by the energy labelling are also regulated by ecodesign. Specific product-related information requirements are laid down relevant product-specific regulations.

The objective behind the directives is to contribute to the overall 20% primary energy efficiency target by 2020. Ecodesign and energy labelling regulations use a common calculation methodology to assess the energy performance of products.

Some product categories that are subject to ecodesign and energy labelling requirements can use different energy carriers, e.g. gas or electricity. This is the case for heating systems, boilers, water heaters, ventilation and cooling, washing machines, dishwashers and dryers. In order to compare the energy efficiency of products that use electricity with products that use other energy carriers, a 'conversion coefficient' is applied in the energy performance assessment. The conversion coefficient has the following definition in the relevant regulations:

'conversion coefficient' or 'CC' means a coefficient reflecting the estimated 40 % average EU generation efficiency referred to in Directive 2012/27/EU of the European Parliament and of the Council; the value of the conversion coefficient is CC = 2,5;

When calculating the energy performance of products subject to the regulations, electricity consumption is multiplied 2,5. As a result, the calculated energy performance of electrical products will be significantly higher than alternatives that use other energy carriers. Although the regulations does not use the term "primary energy factor", the explanation of the conversion coefficient is similar to primary energy calculation principles; the coefficient should reflect the average energy loss that occurs when primary energy is converted into electricity.

6.4. EU application of the principles and framework

Chapter 6.1. – 6.3 describes EU application of electricity conversion factors. Although conversion factors are applied in several legislative acts, only the Ecodesign Directive and Energy Labelling Directive require Member States to implement regulatory use of a common conversion coefficient of 2,5. This is not the case for the EPBD and the EED. Either member States may choose not to apply a conversion factor for electricity or the conversion factors may be determined at a national level.

The EU Commission or other EU authorities have not given any specific explanation for the application of the conversion coefficient in ecodesign and energy labelling. Some stakeholders claim it is far more efficient to use gas directly in products, rather burning gas in a power plant and send it to end-users in the form of electricity. Based on this claim, one can argue that it is appropriate to assess each product's consumption of primary energy. As mentioned in the above, both Ecodesign and Energy Labelling seek to reduce EU primary energy consumption.

Others consider the application of the default conversion coefficient of 2,5 as controversial, as it stimulates end-users to switch from electricity to other energy carriers. This incentive may create a number of challenges for EU in their attempt to reach other energy objectives in the energy- and climate policy, such as improved security of supply and greenhouse gas abatements. As conversion factors stimulate a switch from electricity to gas, it may trigger investments in gas infrastructure, thus creating a lock-in of long-term European gas imports. 65 % of EU gas consumption stems from imports. Therefore, reduced end-use of gas is vital in order to reduce import dependency.

In addition, the EU is committed to cut 85% of its emissions by 2050 (compared to 1990-levels). According to the EU's roadmap for the realization of a low-carbon society, all end-use of gas must be replaced with carbon neutral energy carriers (such as electricity) in the future.

It is outside the scope of this report to investigate if the use of electricity conversion factors in the EU should be abandoned. In the following sections we discuss how the EU "conversion coefficient" of 2,5 could be reviewed, following the principles and framework that is presented in chapter 3-5 in this report.

6.4.1. Assessment approach

The conversion coefficient of 2,5 reflects an estimated 40 % average EU generation efficiency. Thus, the EU has chosen to apply the attributional assessment approach in the determination of the coefficient.

The attributional approach should not be considered appropriate for ecodesign and energy labelling purposes. Being part of the EU energy efficiency framework, the conversion factor for electricity should contribute to reduce primary energy consumption in 2020. Thus, we need to assess how changes in the end-user consumption of electricity results in changes in the primary energy consumption. According to chapter 3.1., the EU should select the consequential assessment methodology in the determination of the conversion factor.

6.4.2. Calculation indicator

The EU has chosen "conversion coefficient" as the calculation indicator. This indicator reflects average EU generation efficiency. The indicator does not include energy losses occurring in other parts of the electricity value chain, such as during transmission and distribution. It would be more in line with the overall purpose of the directives to include such losses by selecting a PEF as a calculation indicator.

6.4.3. System limits

The system limits for the current conversion coefficient reflects EU borders in 2004. In the following years, the union has expanded. Also, as the ecodesign and labelling requirements are implemented in the European Economic Area (EEA). It would be appropriate to alter the geographical delimitation so that all countries in the EEA is included.

6.4.4. Time frame

The EU conversion coefficient is based on a time frame set to 2004. Generation statistics from 2004 serve as the basis for the calculation of average EU electricity generation efficiency.

EU generation mix in 2004 is not representative for the generation mix in 2020, which is the year we seek to reduce primary energy consumption by 20 %. It would be appropriate to change the time frame from 2004 to 2020.

6.4.5. Detailed calculations

Sections 6.4.1.–6.4.4. give recommendations to changes in EUs current adaptation to the overarching principles that are described in chapter 3 in this report. Table 6.1. summarize the recommendations.

Table 6.1: Recommendations on changes in the EU electricity conversion factor determination

Overarching principles	EU conversion factor	Recommended conversion factor
1. Assessment approach	Attributional	Consequential
2. Indicator	Conversion coefficient	PEF
3. System limits	EU25	EEA
4. Time frame	2004	2020

We recommend that detailed calculations following the clarification of principles in table 6.1. should be done with the aid of power market model simulation software. According to chapter 5 in this report, the market model must reflect relevant regulatory measures implemented throughout the EEA, such as:

- Planned investments in new renewable generation capacity due to national RES-targets in the Renewable Energy Directive.
- Changes in the use of gas and coal for electricity production due to emissions trading (EU ETS)
- Other planned commissioning and the decommissioning of power plants within 2020.

The power market model will allow us to assess how permanent changes in electricity consumption (due to Ecodesign and Energy labelling requirements) results in changes in electricity generation within the EEA. The results of this analysis will allows us to determine an appropriate PEF for electricity, relevant to the overall objective.

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