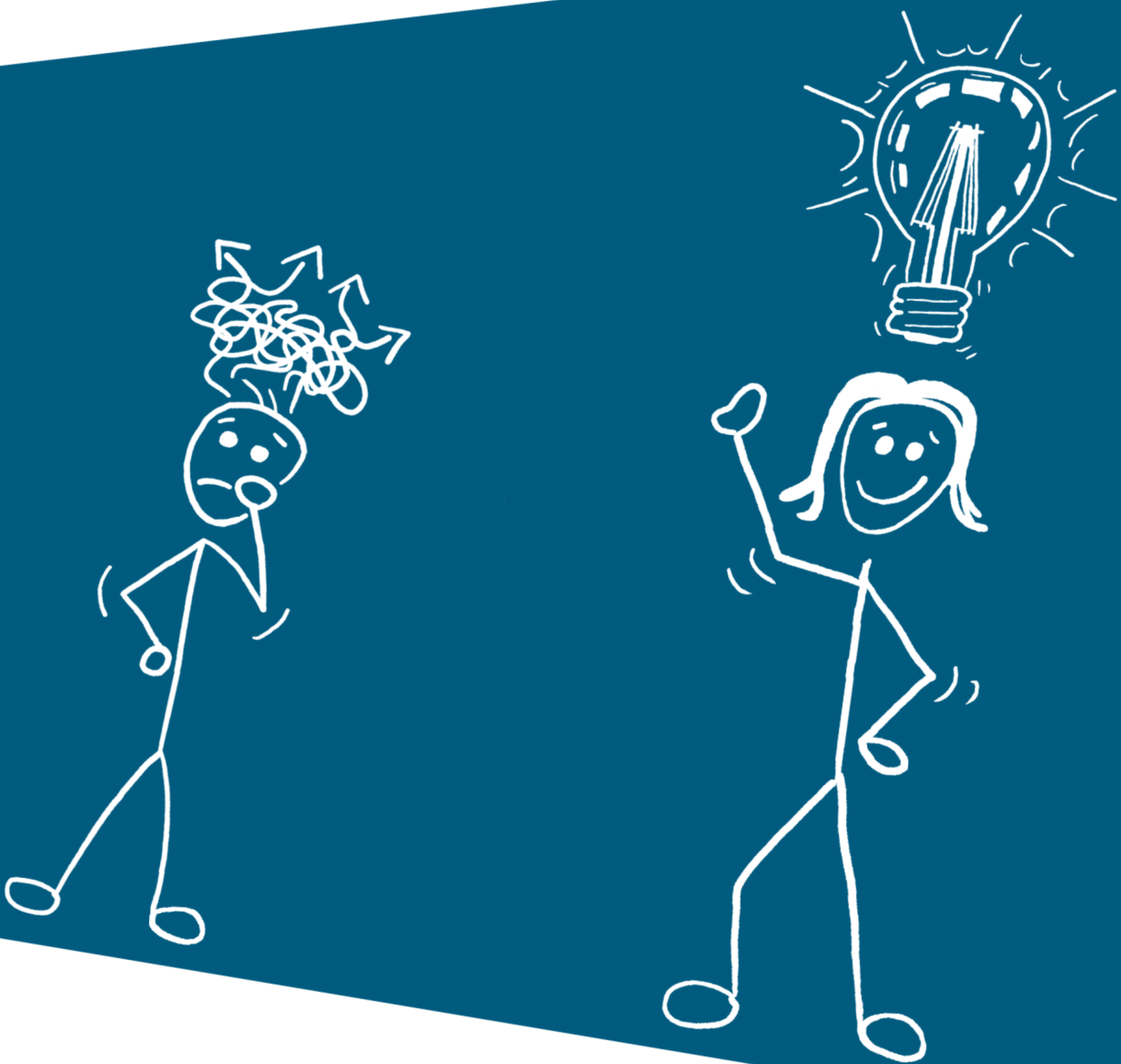
Fraunhofer ISI

ENERGY EXPLAINED

Primary Energy Factors



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In brief

Primary energy is energy that is available as an energy source in its natural form. However, before it can be used, primary energy is usually converted into **final energy** in one or more steps. The **primary energy factor** plays a crucial role in this context:

- Formally, a **primary energy factor** describes the ratio between primary energy use and final energy supply and thus the efficiency of the final energy supply.
- Against the background of the limited availability of fossil resources, **primary energy has been and still is an important indicator** for assessing the efficiency of an energy system.
- In particular, primary energy factors have been used in energy policy making **to illustrate the limited availability of fossil resources**.
- With the deployment of renewable energies and the need to define their primary energy factors, **primary energy factors are becoming less important than other metrics**, such as the shares of renewable energies in final energy supply or in final energy consumption as well as the greenhouse gas emissions.
- Primary energy is **very context-dependent**.
- For many energy carriers, there is **no single, correct primary energy factor**, but only one that is more or less appropriate for the objective in question.
- **Clarity of objectives and transparency** of system boundaries and conventions **are essential** for a meaningful interpretation of primary energy factors.

Find out more about

- *ENERGY EXPLAINED*
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Background

Given the limited availability of fossil resources, **primary energy** has been and remains an important indicator for assessing the efficiency of an energy system. As long as the energy supply was mainly based on energy carriers where the energy was stored by chemical bonds, this consideration was mostly straightforward. However, with the growing importance and diversity of renewable energies, the concept of primary energy is increasingly reaching its methodological limits. Only when you are aware of this, you can properly perceive the different uses of primary energy as an indicator.

The primary energy factor of renewables **is set** rather than calculated on a scientific and technical basis, unlike that of fossil fuels. The challenge of renewables in terms of availability is also different from that of fossil fuels. While the total amount of energy available from fossil energy carriers is finite, the energy available from renewables is "only" limited on a human scale by the capacity of the conversion equipment.

This can be illustrated, for example, by the German energy balance and the energy assessment of buildings in the context of the German Building Energy Act (GEG). The GEG only considers the consumption of non-renewable primary energy. This takes into account both the impact on the climate and the long-term scarcity of resources that only exists for fossil energy carriers. In contrast, the future availability of solar or wind energy is unlimited and is not considered as consumption. In the German energy balances, on the other hand, renewable energies are also assigned a primary energy factor to reflect their limited short-term availability.

In the following, different applications and possible pitfalls of using primary energy as an indicator are illustrated by six questions.

1 What is primary energy and what is a primary energy factor?

Primary energy factors - why and what for? **2**

3 How is a primary energy factor determined?

How does the system boundary affect the value of a primary energy factor? **4**

5 Which conventions are relevant in addition to the system boundary?

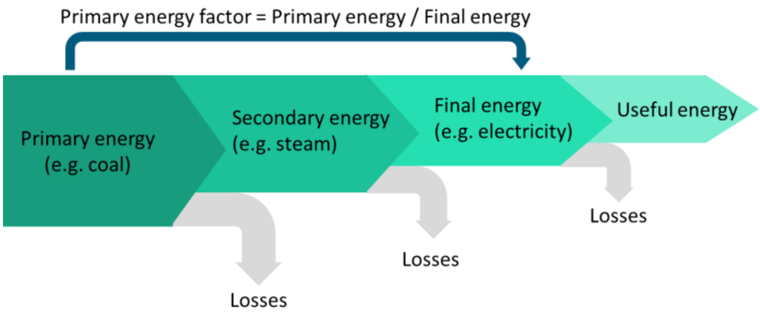
Which conventions are useful for which objective? **6**

1

What is primary energy and what is a primary energy factor?

Primary energy refers to energy that is available in its natural form as an energy source. This includes, for example, the kinetic energy of wind, the potential energy of water, the radiant energy of the sun, ambient heat, the chemically bound energy in coal or the nuclear energy from nuclear fuels.

To understand the term **primary energy factor**, the conversion chain must be kept in mind: primary energy (e.g. in the form of coal) cannot usually be used directly, but must first be converted into secondary energy (e.g. steam), possibly followed by further conversion steps (e.g. to electricity in the power plant) and transport before it is available to the consumer as final energy (e.g. electricity in a house). The final energy is then converted into useful energy (e.g. heat in the airflow of a hair dryer) as a last energy conversion step to meet the actual demand for an energy service (e.g. drying hair). Losses occur in every conversion process. Formally, a primary energy factor describes the ratio between the primary energy consumed and the final energy supplied and thus the efficiency of the supply of final energy.



A primary energy factor with a value > 1 means that more primary energy is required to provide the final energy. A value of 0 means that no primary energy is required at all, as may be the case if only renewable energy is used.

Primary energy factors - why and what for?

2

A key purpose of primary energy factors is to provide a **common reference** for calculating and comparing the quantities of different energy carriers. If only a single energy carrier is considered, its quantity can also be expressed in its 'natural' unit. Primary energy factors allow bringing different energy carriers such as coal, natural gas, electricity, biomass and uranium 'to a common denominator'. To achieve such a comparability, conventions need to be established (cf. #4: How does the system boundary affect the value of a primary energy factor?) which depend on the objectives of the common reference. There are several of them:

- **Assessing technical efficiencies:** Based on the knowledge of both primary and final energy consumption, conclusions can be drawn about the efficiency of the energy conversion or on conversion losses and the associated potentials for improvement.
- **Benchmarking:** Benchmarking can be used to compare different technologies or applications of energy supply and demand on the basis of their specific primary energy demand.
- **Determining the environmental impact:** When determining the environmental impact, primary energy factors serve as a starting point to compute primary energy demand as an indicator to understand the environmental burden of using energy carriers.
- **Designing energy systems:** Historical and/or projected trends in primary energy use provide be a basis for planning future energy supply capacity.
- **Determining ranges:** The aim of range determination is to predict how long the energy supply can be guaranteed with finite energy resources and reserves.

- **Assessing import dependency:** Import dependency assessments relate primary energy demand to imports of energy carriers from third countries, for example to understand the importance of geopolitical areas for in energy supply.
- **Monitoring:** The aim of the monitoring is to show progress over time in the development and composition of the energy supply. Under certain conditions, conclusions can also be drawn on achieved savings, e.g. through energy efficiency measures, or additional consumption.

3 How is a primary energy factor determined?

In the case of chemically bound energy, the primary energy content of the energy carriers can be unambiguously determined by the calorific value and the conversion and transport losses to the final energy. Therefore, in this case, the determination is based **on physical-technical properties**.

A special role is played by all forms of renewable energy, where the ratio between the primary energy used and the final energy supplied cannot be easily determined. For this reason, **conventions** have been established **as a workaround**. For example, a conversion efficiency of 100% is internationally used for solar, wind and hydro power. Nuclear energy has always been a special case: a general efficiency of 33% is used for it, even though the actual share is much lower.

The determination of primary energy factors **varies according to the objectives**. Conditions are set accordingly, but despite their relevance, they are often mentioned only implicitly or in passing. Due to the wide range of possible definitions, primary energy factors are therefore **not necessarily unambiguous**, but may be more or less appropriate for a given objective. Some of these determinations result from the definition of the considered **system boundaries** (cf. #4: How does the system boundary affect the value of a primary energy factor?), others simply from **conventions** (cf. #5: Which conventions are relevant in addition to the system boundary?).

4 How does the system boundary affect the value of a primary energy factor?

The choice of the system boundary is a key factor influencing the value of a primary energy factor. The following aspects can be distinguished here:

- **Geography:** The region under consideration plays an important role in determining the primary energy factors. Depending on the geographical definition, the primary energy factors can vary considerably due to the local energy conversion facilities (power plants) and their specific use. The higher the share of fossil fuels in a region, the higher usually the primary energy factor.

> **EXAMPLE** *The primary energy factor for electricity generation in the coastal region of Nowheresville is 1.2, due to the extensive use of offshore wind power. This is significantly lower than the corresponding value of 1.8 for the inland coal region of Camelot. For the identical amount of electricity, the average of 1.5 for the two regions together differs from their individual values.*

- **Time frame:** Energy supply is influenced by fluctuating energy demand, variable availability of renewable energy sources and technical constraints (e.g. start-up times, minimum operating times). As a result, the chosen length and definition of the period under consideration influences the value of the primary energy factor.

> **EXAMPLE** *On cloudy, windless 12 December, the hourly primary energy factor in Camelot at 13:00 is 2.1. This is thus well above the annual average of 1.8 and due to a transitory dominance of coal-fired power stations and low levels of wind and solar generation.*

- **Upstream processes:** Before energy carriers can be converted, machinery, equipment and labour must be used to locate, extract, process and transport the required energy carriers. The more of these upstream activities and their respective upstream processes are included in determining the primary energy factor, the higher its value.

> **EXAMPLE** *The power plant at Nowheresville uses coal from Camelot to generate electricity. In the usual narrow interpretation of the upstream process, the electricity delivered by the power station's transformer reflects the average calorific value of the hard coal, giving a value of 2.4. A broader view includes the marine diesel used to import the coal and the energy used to extract it at the overseas lignite mine Backwater. This increases the primary energy factor to 2.6.*

- **Life cycle phases:** The primary energy factor also depends on which phases of the energy conversion life cycle are considered. Usually, only the use phase of the energy carriers is considered, i.e. the energy conversion itself. If other phases are included, the primary energy factor increases.

> **EXAMPLE** *Energy is also needed to build the lignite-fired power plant at Nowheresville, to build the ships to transport the coal and to build the mine. Energy is also needed to dismantle or recycle the systems. The consumption required for this can be added to an extended primary energy factor, which increases from 2.6 to 2.9.*

- **Type of consideration:** In addition, a distinction can be made between the average approach and the displacement approach when determining the primary energy factors. The average approach uses all the energy supply capacities currently in use. The displacement approach, in contrast, takes into account only those capacities that would be next switched on or off in the event of a change in energy demand. If there are no other factors influencing the value, the average ('total mix') approach is useful to assess the impact of a change in demand on the total primary energy demand. In contrast, the 'marginal mix' approach is used to understand the impact of the change in demand.

> **EXAMPLE** *At 14:00 on 12 December, 42 powers plants with an average primary energy factor of 1.9 were in operation in addition to the coal-fired power plant at Nowheresville. A local gas-fired power station with a primary energy factor of 1.7 is about to be taken off the grid due to a predicted decline in electricity demand.*

5

Which conventions are relevant in addition to the system boundary?

In addition to the definition of system boundaries, there are a number of conventions for specific energy carriers that depend, in particular, on the objectives. Challenges include how to account for energy provided by the environment and how to determine the typical primary energy factors of the energy carriers.

- **Biomass:** The assessment of biomass as an energy carrier can vary depending on whether a shorter or longer horizon is chosen. In the short term, it can be argued that biomass cannot be replaced because it takes time to grow again. Accordingly, it is assigned a primary energy factor above 1. In the long term, however, it can be argued that biomass will be compensated by plant growth. In this case, a value of 0 can be justified.
- **Solar, wind and hydro power:** In this case, it is also important to clarify how they are considered. If these energy carriers are seen as inexhaustible in terms of resource availability, a value of 0 may be appropriate. If the efficiency of the technical system is taken into account (e.g. the efficiency of a photovoltaic module), a value greater than 1 may be appropriate.
- **Fossil energy carriers:** For these energy carriers, the physical net or gross calorific values of typical market products are generally used.
- **Nuclear energy carriers:** When using nuclear energy, only a fraction of the actually available energy is put to use. Following the reasoning used for the energy balances, the use of primary energy would be extremely high in relation to the final energy provided. Therefore, a value of 0.33 is set by convention for nuclear energy carriers.
- **Ambient heat:** Another specific case is accounting for ambient heat, especially in connection with the use of heat pumps. If the ambient heat input is not considered in the balance, the primary energy factor in heating mode results from the ratio between the heat output provided and the electricity input is much lower than 1. In case the input of ambient heat is included in the calculation with a factor of 1, then the primary energy factor of the heat pump exceeds 1.
- **Energy storage and synthetic energy carriers:** If energy storage systems (e.g. batteries, flywheels, gas storages, tanks or pumped storage power plants) and synthetic energy carriers (e.g. hydrogen, ethanol or ammonia) are to be taken into account to any significant extent, the case is not clear-cut. For physical reasons, intermediate storage or conversion is always associated with losses. Depending on whether and to what extent the originally stored energy is to be included, the primary energy factor for the use of energy from such sources may vary. In principle, however, the factor should be chosen consistently with the values of the originally used energy carriers.

Which conventions are useful for which objectives?

Depending on the objectives (cf. #2: Primary energy factors - why and what for?), different conventions can be selected for specific energy carriers. Some suggestions are given in the table. A value of 0 means that no consideration is required.

6

Primary energy factors by objectives and energy carriers	Biomass	Solar, wind and hydro power	Fossil energy carriers	Ambient heat	Energy storage and synthetic energy carriers
Technical efficiency	> 1, since information about conversion efficiency				consistent with other conventions
Benchmarking	depending on the specific objective of the benchmark				consistent with other conventions
Environmental burden	> 1 in short term, =0 in the long term	= 0	> 1	= 0	consistent with other conventions
Energy system design	>1, since information about available capacities				consistent with other conventions
Range	= 0, since renewable in the long term	= 0, since virtually inexhaustible	> 1, since limited	= 0, since virtually inexhaustible	consistent with other conventions
Import dependency	depending on the origin of the biomass	= 0, since available at the place of energy supply	depending on the origin of the energy carriers	= 0, since available at the place of energy supply	consistent with other conventions
Monitoring	> 1, since analysis of overall developments				consistent with other conventions

Imprint

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ENERGY EXPLAINED

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