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Primary Energy Factor for Electricity Mix: The Case of Slovenia

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Abstract

According to the European energy policy, the energy use of technical systems in buildings is given at the level of primary energy. This calculation requires knowledge of the primary energy conversion factors according to their source; however, there is currently no single European-wide recognized method for their determination. The aim of this study is to present and compare three methods for determining primary energy factors, namely the method of partial substitution, the physical energy method, and calculation according to EN 15603 standard. For the case study, the electricity factor for Slovenia was calculated according to the aforementioned methods. The results of this study showed that the methods differ in the evaluation of individual primary sources, which has a significant impact on the PEF value. We found that with the partial substitution method, we do not get representative results about the PEF. The method of physical energy defines the efficiency of production from renewable energy sources as 100%. The question arises if we can truly assume that the use of PE is equal to the actual production of electricity. In the third method, defined in the EN 15603 standard, which provides two PEFs, a certain measure of criticality of the assumed factors for the different sources of energy is used.

Keywords: primary energy, primary energy factor, electricity mix, renewable energy sources

1. Introduction

The building sector in Europe is responsible for 40% of energy consumption and 36% of CO_2 emissions. Due to the high estimated energy saving potential of the building sector, the European Union (EU) set up a policy framework focused on reducing the energy of buildings which consists of policy actions, i.e., Energy Performance of Buildings Directive (EPBD) [1], Energy Efficiency Directive (EED) [2], EcoDesign Directive [3], Energy Labelling Regulation [4], and the Renewable Energy Directive (RED) [5]. The EED was prepared with the goal to achieve a 20% energy consumption reduction target across the EU. It establishes a number of important provisions to be implemented by the EU Member States, including the requirement to establish obligatory national energy efficiency targets, national building energy efficiency strategies, a requirement to renovate 3% of public sector buildings annually, the need to establish energy efficiency obligation schemes, and provisions for auditing and metering.

The evaluation of energy consumption, reduction, or efficiency on the building level is somehow problematic since different technical systems use various forms of energy to operate. Therefore, energy consumption and efficiency should be evaluated on a common basis. A single metric for combining different sources or types of energy is primary energy (PE). As the name indicates, PE evaluates different forms of energy based on the conversion of primary energy to useful energy. However, the concept does not differentiate between different energy forms. Therefore, exergy could be incorporated into the concept as it reflects the energy "quality" in terms of its capacity to do work. Although there are currently no requests, for such an approach, from energy practitioners, exergy analysis could gain significantly on importance in light of future resource scarcity to, for example, penalize the use of exergy-rich energy vectors for low-temperature applications.

The task of measuring energy efficiency may seem straightforward, contingent only on the choice of indicators for the input and output. In reality, however, both can be measured in numerous ways, and choosing one approach over another always leads to trade-offs [6–11]. Based on the input and output characteristics, three main indicator groups can be distinguished:

- Thermodynamic indicators—inputs and outputs represented in terms of thermodynamic quantities (e.g., the thermal efficiency of a heating system)

- Physical-thermodynamic indicators—energy inputs represented by thermodynamic quantities, outputs represented with physical units (e.g., building energy use intensity)

- Economic-thermodynamic indicators—products or services represented by market prices, energy represented by means of thermodynamic quantities (e.g., GDP energy intensity)

Each of these approaches has its advantages and disadvantages and should, thus, be defined with regard to the area of application, while considering environmental, social, economic, or other aspects of energy efficiency.

PE has become an important policy metric in the EU. Namely, the EPBD prescribes that the energy performance of a building shall also include a numeric indicator of PE, based on primary energy factors (PEF) per energy carrier, which may be based on national or regional annual weighted averages or a specific value for onsite production. A PEF connects primary and final energy. It indicates how much primary energy is used to generate a unit of electricity or a unit of useable thermal energy. The PEF describes the efficiency of converting energy from primary sources (e.g., coal, crude oil) to a secondary energy carrier (e.g., electricity, natural gas) that provides energy services delivered to end users. In the EU, the Member States can freely define its value. Consequently, this has become a political decision, with a direct impact on the actual energy consumption of a building.

Similar concept of analysis of the impact of building and appliance energy consumption is used in the USA. Compared to the more legislative-constrained EU approach the US approach is more market oriented. Full-fuel-cycle (FFC) metrics are used in building codes and appliance standards to evaluate the energy and environmental impact of consumer fuels and appliances [12].

To translate PE into final energy use, the PEF is applied in several EU legislative documents. In the EED and EPBD, the PEF is used to convert final energy consumption into PE consumption to monitor progress against targets. The EPB Directive aims at reducing the PE demand for buildings. Since technologies applied

in the building and improvements in the building envelope lead to savings in final energy, the PEF is applied to convert these savings into primary energy.

The latest version of the EPB Directive [13] claims that "the energy performance of a building shall be expressed by a numeric indicator of PE use for the purpose of both energy performance certification and compliance with minimum energy performance requirements." In addition, Member States may define additional numeric indicators of total nonrenewable and renewable primary energy use and of greenhouse gas emission. Member States have some flexibility in defining these metrics.

EED requires energy targets expressed in both primary and final energy form. PEFs are applied for conversion of final energy savings into primary energy savings. EPBD and EED both allow the Member States the option of choosing their own PEF values. Within the EcoDesign Directive and Energy Labelling Directive, the PEF value of 2.5 for electricity is prescribed to allow a comparison.

From the foregoing, it is evident that the PEF is defined on two different boundary conditions within the EU legislation. For instance, the boundary condition for energy-consuming appliances is defined at the appliance level. The next level of boundary is the building (or part of it), defined as a sum of all energy used by different appliances considering different energy sources. This boundary condition is important when on-site-produced renewable energy is used by building appliances.

The method for calculating the PE for fossil fuels is quite straightforward and consistent, while the calculation of PEFs for electricity or heat generated from renewable energies or grid-supplied electricity is more complex. First of all, the PEF for fossil fuels (also for combustible renewable fuels) does not change significantly over time. For electricity, especially grid supplied, the calculation of PEF involves different energy sources as well as different electricity generation technologies. The combination of various PE sources forms a so-called power generation mix, which is the share of different energy sources used to generate electricity. The share of energy sources changes over time depending on the availability of energy sources and the level of demand. However, evaluating this is a challenge especially in renewable energy sources and nuclear energy.

2. Methodology

PE sources are usually defined as inputs into energy systems (or conversion processes) which convert them into secondary energy carriers such as electricity, oil products, heat, or mechanical work. The EPBD [13] defines primary energy as the energy that has not been subjected to any (human induced) conversion or transformation process.

As mentioned before, PEF connects primary and final energy. It indicates how much primary energy is used to generate a unit of electricity or a unit of useable thermal energy, according to Eq. (1):

$$PEF = \frac{primary\ energy}{final\ energy} \tag{1}$$

PE is divided into renewable and nonrenewable energy [14]. The sum of renewable and nonrenewable energy is total energy. Energy extracted from sources that are naturally replenished on a human timescale is called renewable energy. The definition of renewable energy also includes some forms of energy carrier such as biomass and energy recovered from waste. For nonrenewable energy sources, the

extraction rate is higher than refill rate. Energy obtained from nonrenewable energy sources is called nonrenewable energy. This approach enables the determination of three primary energy factors for each energy carrier [14, 15]:

- Total primary energy factor (PEF_{tot}) (Eq. (2))

- Nonrenewable primary energy factor (PEF_{nren}) (Eq. (3))

- Renewable primary energy factor (PEF_{ren}) (Eq. (4))

$$PEF_{tot} = \frac{total\ \ primary\ \ energy}{delivered\ \ non-renewable + delivered\ \ renewable\ \ energy} \quad (2)$$

$$PEF_{nren} = \frac{non-renewable\ \ primary\ \ energy}{delivered\ \ non-renewable + delivered\ \ renewable\ \ energy} \quad (3)$$

$$PEF_{ren} = \frac{renewable\ \ primary\ \ energy}{delivered\ \ non-renewable + delivered\ \ renewable\ \ energy} \quad (4)$$

Energy sources can be further divided into combustible and noncombustible. Where primary energy is used to characterize fossil fuels, the embodied energy of the fuel is available as thermal energy, and typically around 70% is lost in conversion to electrical or mechanical energy.

In accordance with the laws of thermodynamics, the renewable PEF can be derived from the relevant energy conversion efficiency. For example, the electricity from a PV system with an overall efficiency of 20% can be considered to have a renewable PEF of 5. There is a similar 60–80% conversion loss when wind energy is converted to electricity. This also applies to nuclear energy, where only around 10% of the fuel's energy content is converted to electricity.

Although primary energy factors are thermodynamically universal, many different calculation methods exist. Moreover, there are also national variations. In order to calculate the PEFs, two approaches are mainly used, namely the partial substitution method and the physical energy method. They differ in the way how to calculate the PEFs from nuclear power plants and renewable energy sources such as hydroelectric power plants, solar energy, geothermal energy, etc.

The partial substitution method solves the aforementioned problem by concentrating on the theoretical energy content in traditional fossil fuels (coal, oil, and gas). The PEF for a mixture of electricity is calculated from these sources by dividing the energy content of the fuel as the input energy with the generated electricity. In the case of renewable energy and nuclear energy, this means calculating how much primary energy would be needed for such an amount of electricity if it were produced from fossil fuels.

The physical energy method differs from the partial substitution method in that it uses a different approach for the evaluation of primary energy in the production of electricity from hydro, wind, and nuclear power plants. The calculation of the PEF for the production of electricity from nuclear and geothermal energy is based on the thermal energy of the steam boiler that drives the turbine of the power plant. The efficiency of nuclear power plants is estimated at 33 and 10% for geothermal. For other renewable energy sources, such as hydro, wind, and solar energy, this is equal to gross electricity production.

The calculation of the PEF can also be made using the method described in the standard SIST EN 15603:2008 [15]. The standard describes two alternative approaches for calculating the factor, namely, the total and nonrenewable PEF. The difference between these factors is that the latter does not include the use of renewable energy. In addition, the national PEF for the electricity mix is based either on the average electricity mix or on the marginal electricity production. The standard defines the default PEFs for different energy sources, including electricity. The values of the factors are given in **Table 1**.

We made a calculation of the PEF for the electricity mix in Slovenia, based on the three previously described methods, and conducted a temporal comparison. Statistical data on the generation of electricity from individual sources were obtained from the Statistical Office of Slovenia [16]. **Table 2** shows the produced electricity by years from various sources of energy.

The electricity mix in Slovenia is mainly composed of five sources of primary energy, namely nuclear, fossil, hydro, wind, and solar energy. Since Slovenia is a member of the EU, the directives stipulate that, by 2020, as much as 20% of the energy used is to be recovered from renewable energy sources as far as electricity is concerned. Therefore, in addition to calculating the factor for previous years, we have also tried to predict the generation of energy from individual sources, using linear regression, and then determine the resulting PEF for the electricity mix and the share of renewable sources. **Figure 1** presents the sources of energy, the share of energy sources in the production of electricity, and the share of energy from renewable sources.

Figure 1 shows that electricity generation from fossil fuels is somewhat lower, while production from solar energy and hydro resources is increasing. Generally speaking, the share of renewable resources is increasing. Wind energy represents a very small share; therefore, increasing the share is not noticeable from the figure, but if we look at **Table 1**, we see that production is slowly increasing from 2013 onward.

2.1 Calculation of primary energy factor by partial substitution method

In this method, the PE equivalent of the sources of electricity generation represents the amount of energy that would be necessary to generate an identical amount of electricity with conventional thermal power plants [17]. The PE equivalent is calculated using an average generating efficiency of these plants. This method has several shortcomings including the difficulty of choosing an appropriate energy conversion efficiency to determine the energy value of renewable energy

	PEF	
	Nonrenewable	**Total**
Fuel oil	1.35	1.35
Gas	1.36	1.36
Biomass	0.07	1.07
Hydro power plant (electricity)	0.5	1.5
Nuclear power plant (electricity)	2.8	2.8
Coal power plant (electricity)	4.05	4.05

Table 1.
Primary energy factors according to the Standard EN 15603:2008.

							Year									
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Nuclear	5528	5207	5459	5884	5548	5695	6273	5739	5657	6215	5528	5300	6370	5648	5715	6285
Fossil	5759	5657	5718	5772	5975	6082	6107	5945	6067	6073	5958	5661	4440	5081	5718	5610
Hydro	3313	2957	4095	3461	3591	3266	4018	4715	4703	3706	4087	4923	6366	4091	4782	4141
Wind	0	0	0	0	0	0	0	0	0	0	0	4	4	6	6	6
Solar	0	0	0	0	0	0	1	4	13	66	163	215	257	274	267	283

Table 2.
Yearly historical data on the electricity production in Slovenia (values in GWh) [16].
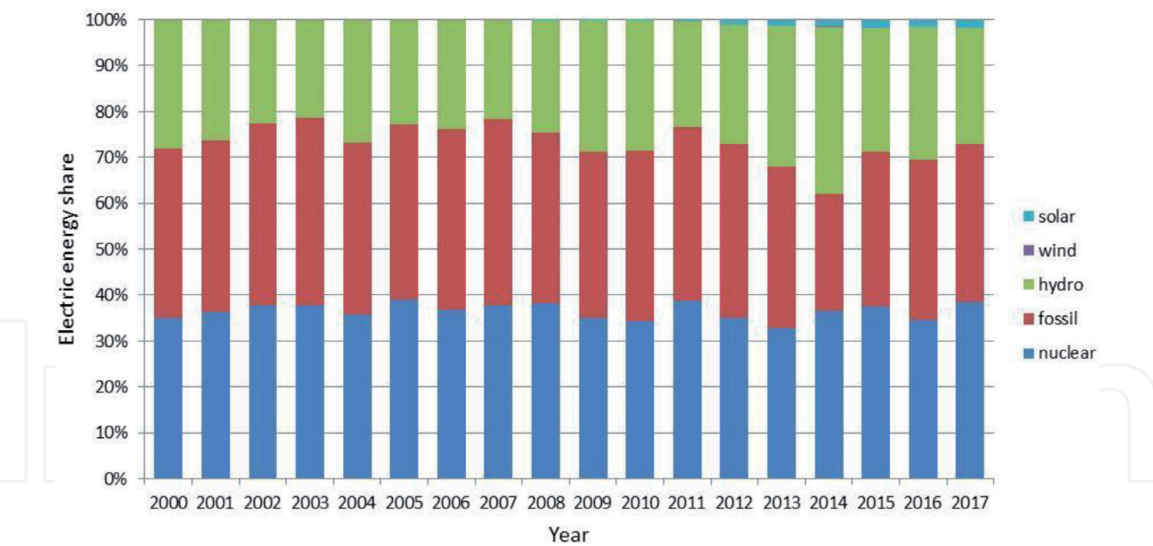
Figure 1.
Electricity mix in Slovenia.

and nuclear energy. For example, it may not be possible to quantify the energy content in the wind or the sun that serves as a fuel for wind and solar power plants. In conventional nuclear power plants, only 10% of the theoretical energy content in the fuel is converted to electricity. The partial substitution solves this challenge by focusing on the theoretical energy content of traditional fossil fuels (coal, gas, and oil). PEF for electricity produced from these sources is calculated by dividing the energy content of the fuel with the electricity production. For renewable and nuclear power, the partial substitution method calculates how much PE would be required if the electricity was generated from fossil fuels. Therefore, a conversion efficiency of 40% is assumed for these types of energy [18]. Also the efficiency of fossil fuel production is 40%. By means of these set values, we obtained for 2017 the results shown in **Table 3**.

As mentioned above, PE was obtained by dividing the energy produced by the production efficiency. This gave us the amount of PE needed to produce a certain amount of electricity. PE does not take into account the network losses; there-fore, we calculated how much the losses are and what is our consumption. From this data we could then directly calculate the PEF for the electricity mix. We assumed that the amount of losses was 10% of the energy produced [18]. If by this method the factors are calculated for all the years, we can see that the factors do not change, which is because we have assumed that the efficiency is always the same, so the ratio between the energy used and the electricity produced is constant.

	Production [GWh]	Efficiency	Primary energy [GWh]
Nuclear	6285	40%	14,288
Fossil	5610	40%	14,295
Hydro	4141	40%	11,955
Wind	6	40%	15
Solar	283	40%	668
Total	16,325		40,813

Table 3.
Calculation of PE by partial substitution method for the production of electricity in Slovenia in 2017.

2.2 Calculation of primary energy factor by physical energy content method

The energy content method distinguishes itself in the approach for evaluating renewable sources and nuclear power plants production [19, 20]. PE in this method is considered as the first practically utilizable energy flow. In the case of directly combustible energy carriers (e.g., coal, natural gas, oil, biogas, bio liquids, solid biomass, combustible municipal/industrial waste), PE is defined as the heat generated in the combustion process. For non-directly combustible energy sources, PE can be expressed with the produced heat (e.g., nuclear, geothermal and solar thermal) or produced electricity (e.g., solar photovoltaic, wind, hydro, tide, wave, and ocean).

A PEF value of 1 is assumed for fuels. For noncombustible renewables a conversion efficiency of 100% is assumed. In contrast, a conversion efficiency of 33% is assumed for nuclear power stations. For combustible renewables such as biomass, the conversion efficiency is calculated from [15]. The resulting PEF for electricity from the various sources are 1 for hydro, wind, and solar PV; 3–4 for biomass; and 3 for solar thermal and nuclear. The results for 2017 are shown in **Table 4**.

Just like at the partial substitution method, we took into account 10% losses in the network to obtain the PE shown in **Table 5**.

The calculated PEF for the electricity mix using the physical energy method for 2017 is 2.55. For this year, this value is similar to the value assumed for Slovenia, i.e., 2.5. In order to observe the temporal variation of PEF, the same calculations were also carried out for previous years, based on statistical data for Slovenia. The results are illustrated in **Figure 2**.

Figure 2 shows that the factor is constantly changing, but we can notice that from 2011 onward the factor has fallen slightly. The likely reason for this is that the share of renewable resources began to increase markedly in the meantime. Since this method assumes 100% conversion efficiency for electricity produced from renewable sources, the primary energy for production is the same as production itself.

2.3 Calculation of the primary energy factor according to the Standard EN 15603:2008

The last calculation was carried out by using the default PEFs prescribed by the standard SIST EN 15603 [15]. This methodology evaluates separately the nonrenewable part and the total part of PE. Solar energy (PV) was evaluated in the same way as water and wind energy. Therefore, the default factors are the same in this case. In this method, we used the fractions of individual energies which comprise the mixture of electricity from **Table 1**. The full calculation for 2017 is shown in **Table 6**.

	Production [GWh]	Efficiency	Primary energy [GWh]
Nuclear	6285	33%	19,045
Fossil	5610	40%	14,025
Hydro	4141	100%	4141
Wind	6	100%	6
Solar (PV)	283	100%	283
Total	16,325		37,500

Table 4.
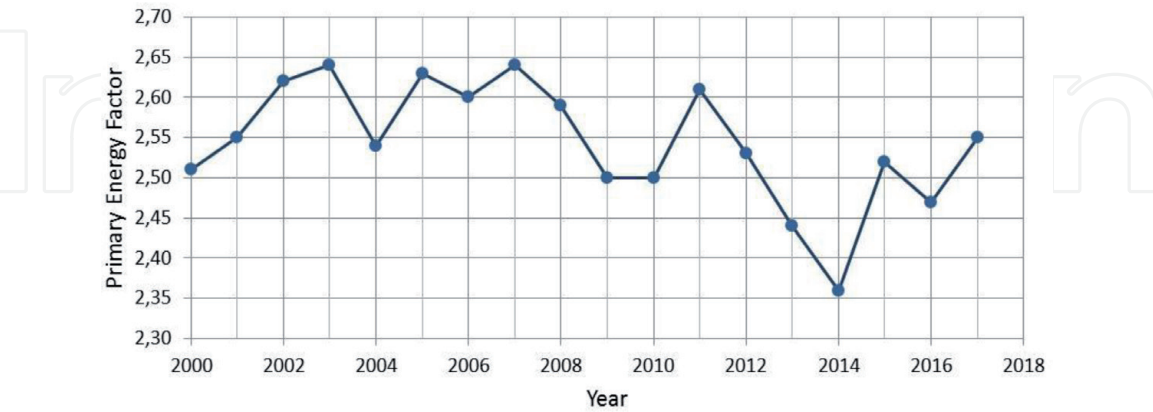*Calculation of PE by physical energy content method for the electricity production in Slovenia in 2017.*

	Production [GWh]	Network loss [GWh]	Useful energy [GWh]	Primary energy [GWh]	PEF
Total	16,325	1632.5	14,692	37,500	2.55

Table 5.
Calculation of PEF by physical energy content method for the electricity production in Slovenia in 2017.

Figure 2.
PEFs for the electricity mix in Slovenia using the physical energy method for the years 2000–2018.

2017	PEF [/]				
	Nonrenewable	**Total**	**Slovenia (average)**		
			Energy share [%]	Nonrenewable	Total
Nuclear	2.8	2.8	38.5	1.05	1.08
Fossil	4.05	4.05	34.36	1.39	1.39
Hydro	0.5	1.5	25.37	0.13	0.38
Wind	0.5	1.5	0.04	0.00	0.00
Solar	0.5	1.5	1.73	0.01	0.03
			Sum	2.61	2.88

Table 6.
Calculation of the PEF of electricity mix for Slovenia for 2017, using the reference values from the standard SIST EN 15603.

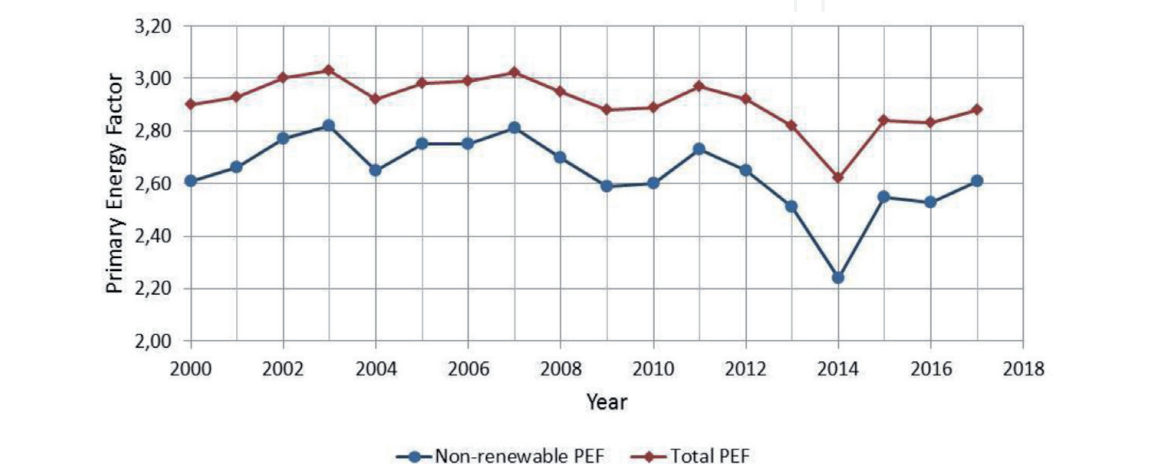—●— Non-renewable PEF   —◆— Total PEF

Figure 3.
Average PEFs for nonrenewable and total PE calculated in accordance with SIST EN 15603.

In **Table 6**, two PEFs for the electric mixture are calculated through the fractions of individual energies composing the electricity mix in Slovenia for 2017. We can see that the average PEF for nonrenewable is less than the total factor. The reason for this is that the default primary factors that take into account only the nonrenewable part of primary energy are lower than the total or total factor. The difference between the two average factors is almost 0.3, which is not negligible. As with previous methods, here again, the calculation was also performed for previous years, with the same default factors. The results are shown in **Figure 3**.

3. Results and discussion

By comparing the methods, we can find that the calculation after partial substitution yields the same results for each year. This is due to the default efficiency, which is based on certain default values. Since we get the same PEF for the electricity mixture in all years, we cannot see changes in individual years. It is also impossible to predict what will happen to the factor in the coming years. We can see that the factor is 2.78, which represents a higher value than the predicted factor for Slovenia, which is 2.5 [21].

In the case of the physical energy method, we can better categorize individual years, and from the calculations, we see the PEF fluctuation. Physical energy method assumes energy conversion efficiency of 100% for renewable sources (produced electricity equals primary energy). The highest value of the factor occurred in 2003, while the lowest value amounted to 2.23 in 2016. The reason for such a change in the last year is in the increased production of electricity from renewable sources.

In the last method proposed by the standard SIST EN 15603, which computes two factors, we can see that in the case of the total factor, the value is higher than the average PEF, which takes into account only the nonrenewable part of energy. This is the case for renewable energy sources where PEF values are lower by threefold in comparison to nonrenewable energy sources. What is logical is that we do not consume any energy for the generation of hydro, wind, and solar energy. Likewise, we can also notice here that both factors are the highest in 2003, while they are the lowest in 2014. The reason for this is that the share of produced electricity from fossil fuels is the lowest, and the share of water energy is the highest, which means that due to the low share of energy from fossil fuels and high energy from renewable energy, the factor of PE has decreased.

3.1 Forecast of electricity generation and impact on PEF

By analyzing statistical data and calculating the PEF, we can predict the change of PEF for the electricity mix of Slovenia. The total production of electricity for the coming years and the annual growth of production were calculated by adding the individual quantities of electricity that were calculated by linear regression for each source separately. This means that we added the predicted production of electricity from nuclear power, fossil fuels, hydroelectric power, wind energy, and solar energy. With this simple linear regression, we predicted the amount of energy produced from different sources and how it affects the PEF. The predictions were made for 2020, 2030, and 2040 (**Table 7**). The share of individual sources and the total share of renewables are shown in **Table 8**.

In **Table 8**, we see that the nuclear energy share will decrease over time as well as for fossil fuels, whose share will decrease by more than 5% by 2040. In the case of hydro energy, the share will increase by just over 7%. Wind energy already

Year	2017	2020	2030	2040
Nuclear	6285	6147	6574	7001
Fossil	5610	5592	5524	5455
Hydro	4141	5350	6384	7418
Wind	6	9	14	25
Solar	283	475	894	1312
Total	16,325	17,574	19,392	21,211

Table 7.
Forecast of total electricity production [GWh].

Year	2017	2020	2030	2040
Nuclear	38.5	35.0	33.9	33.0
Fossil	34.36	31.8	28.5	25.7
Hydro	25.37	30.4	32.9	35.0
Wind	0.04	0.1	0.1	0.1
Solar	1.73	2.7	4.6	6.2
Total share of renewables	27.1	33.2	37.6	41.3

Table 8.
Prediction of energy shares in the production of electricity.

represents a very small share in electricity, so in the future it is not expected to grow significantly. The share of solar energy will also increase; by 2040, we can expect an almost 5% increase. As we can see, Slovenia already generates a large share of electricity from renewable sources; by 2040, we can expect that this share will grow by almost 15%.

3.2 Forecast of the primary energy factor for Slovenia

For the partial substitution method, we used the same production efficiency as given in **Table 3**. The only difference is that in this case we carry out the calculation for 2020, 2030, and 2040. In **Table 9** we see an example of the calculation for 2020, where we used the previously predicted quantity of produced electricity.

The PEF calculated according to the method of partial substitution method does not change over the years. The reason why the factor remains the same is that the method assumes the same production efficiency for all energy sources.

For the physical energy method, we used the same production efficiency as in Chapter 2.2. The predictions for 2020, 2030, and 2040 have been recalculated, taking into account the energy production predicted by linear regression. In this method we also considered 10% network losses in the network. The forecasts of the PEF are listed in **Table 10**.

	Production [GWh]	Network loss [GWh]	Useful energy [GWh]	Primary energy [GWh]	PEF
Total	17,574	1757.4	15,816	43,934	2.78

Table 9.
Calculation of predicted PEF by partial substitution method for the production of electricity in Slovenia in 2020.

Year	Production [GWh]	Primary energy [GWh]	PEF
2020	17,574	38,442	2.43
2030	19,392	41,024	2.35
2040	21,211	43,607	2.23

Table 10.
Forecast of the PEF for the electricity mix in Slovenia using the physical energy method.

We can see that the PEF will decrease over time. This result is logical, since the share of renewable energy sources will increase substantially over time. Hence, the PEF is expected to decrease. For better transparency, the PEF calculated by the physical energy method is depicted along its forecast in **Figure 4**.

Calculation of PEF according to the standard SIST EN 15603 was carried out as described in Chapter 2.3. In this method we use the proportions of individual sources determined by linear regression. Two PEFs are proposed, namely, the average PEF-nonrenewable and average PEF-total. The PEFs for 2020 are given in **Table 11**. The average PEF for the electricity mix with predicted values is illustrated in **Figure 5**. It can be noticed that by 2040, the average PEF for nonrenewable energy will decrease to a value of 2.17, while the average PEF-total will be 2.58.

According to the conversion factors of PE, discrepancy between nonrenewable and total PEFs for the electricity mix can be significant. From **Figure 6**, we can see the annual progress of all the PEFs, calculated with all three evaluated methods, for electricity in Slovenia.

With the partial substitution method, we can see that the PEF for electricity does not change over the years, i.e., it remains 2.78. The reason for this lies in the assumption about the efficiency of production from renewable energy sources and nuclear energy, where 40% efficiency is taken into account. Furthermore, the same efficiency is also used for fossil fuels. Therefore, the efficiency of production from all primary sources is 40%. This is why we get the same PEF for all years. This means that according to this method, we do not get the correct representation of the PEF for the electricity mix, or the assumptions are not applicable for the case of Slovenia. In the event that Slovenia produced part of the electricity from biomass, whose production efficiency is estimated with 30% in this method, the PEF would be more volatile. However, Slovenia does not use biomass for the production of electricity; therefore, this method does not give us the useful values of the factor. We also notice that the factor 2.78 is quite high in terms of other methods.
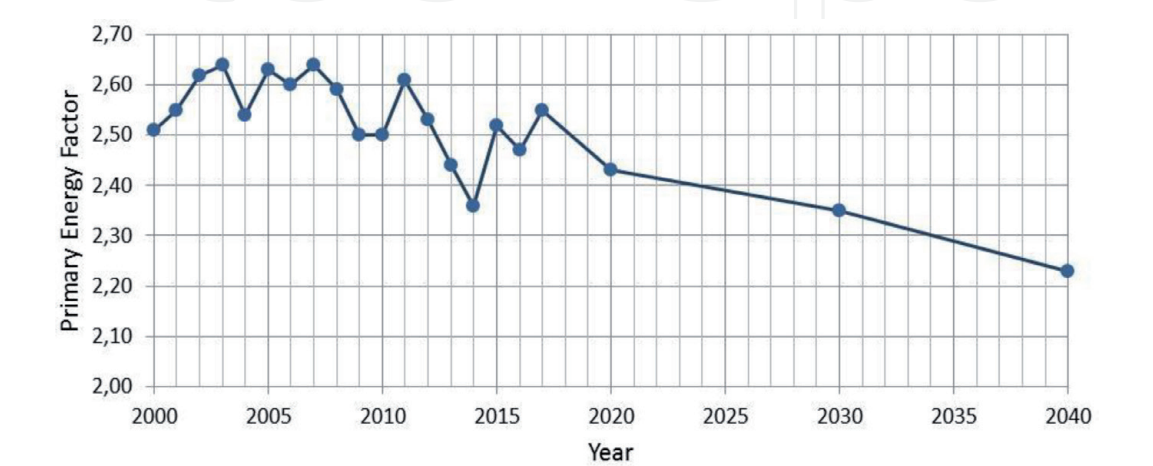

Figure 4.
PEF of electricity calculated according to the physical energy method.

2020	PEF				
	Nonrenewable	Total	Slovenia (average)		
			Energy Share [%]	Nonrenewable	Total
Nuclear	2.8	2.8	34.98	0.98	0.98
Fossil	4.05	4.05	31.82	1.29	1.29
Hydro	0.5	1.5	30.45	0.15	0.46
Wind	0.5	1.5	0.05	0.00	0.00
Solar	0.5	1.5	2.70	0.01	0.04
			Sum	2.43	2.77

Table 11.
Forecast of the PEF for the electricity mix in Slovenia for 2020, using the reference values from the standard SIST EN 15603.
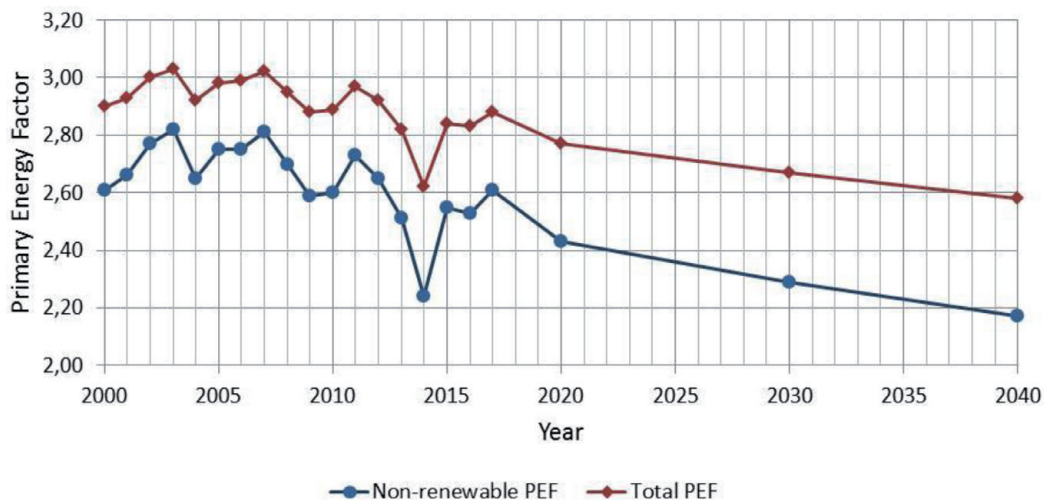
Figure 5.
Average PEF for electricity mix according to the SIST EN 15603 method with predicted values.
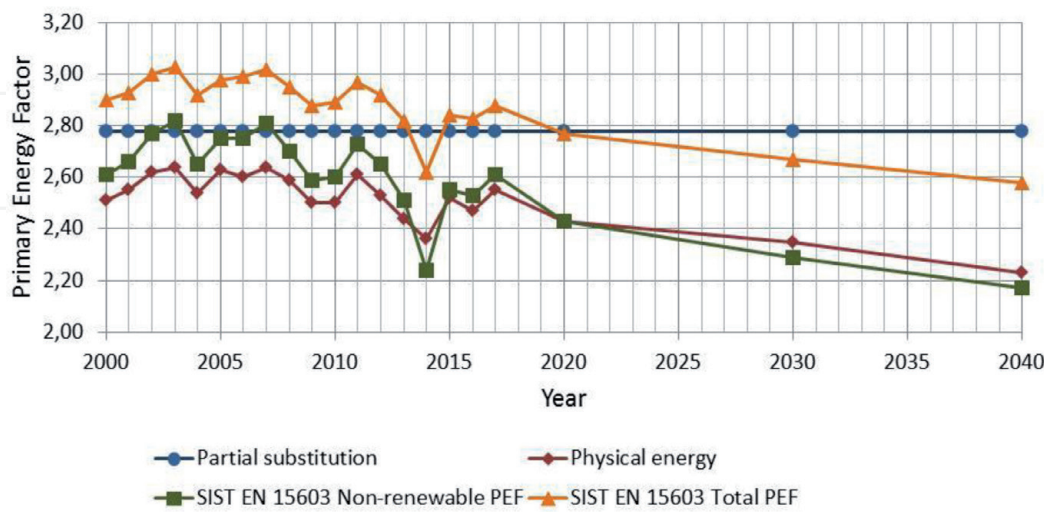

Figure 6.
Comparison of the methods of calculating the PEF for the electricity mix in Slovenia.

The other method used to determine the PEF for electricity is the physical energy method. With this method we evaluate the efficiency of production from renewable energy sources as 100%, while the default efficiency of nuclear power

generation and fossil fuel is 33 and 40%, respectively. The PEF calculated according to this method is very low, as shown in **Figure 4**. The reason is in the assumption that the efficiency of production from renewable sources is 100% and Slovenia has a large share of renewable sources in its electricity production, mainly from hydropower sources. In the previous analyses of individual years and forecasts, we also noticed that the share of renewable resources is increasing over time. For this reason, from **Figure 4** decreasing trend for the future is clear. This means that a PEF determined by this method will slowly decrease with respect to the increase in renewable energy sources in electricity generation.

With calculation according to the standard SIST EN 15603, we calculated two different primary energy factors: the average PEF for nonrenewables, which takes into account only the nonrenewable part of the energy of individual primary sources, and the PEF, which takes into account the total share of primary energies. We used the default values of the individual factors determined by the method for each primary source separately. We can see that the average PEF for nonrenewable energy is much lower than the total. The reason for this is that the default values of the factors that we use to calculate the nonrenewable and total factor are different. The greatest differences occur in renewable energy sources. This is because renewable energy sources have a very small share of nonrenewable energy. Therefore, the factors for calculating the individual PE sources are low in the case of hydropower, wind, and solar energy. When calculating the total factor, the factor value for these types of energy is 1.5. Moreover, a different calculation approach is used in this method, i.e., the PEF is calculated through the shares of individual energy sources in the total electricity.

4. Conclusions

PEFs are used to describe the conversion efficiency from primary energy sources to secondary energy sources, which are supplied to end consumers. PEFs are, therefore, used for comparing necessary quantities of primary energy to the final energy demands. At EU level as well as national levels, PEFs are used for converting final energy to primary energy consumption, for comparing efficiency of devices with different energy sources as well as to benchmark building energy performance. As it stands, the EU Member States can autonomously determine national PEFs, which in turn can skew the evaluation process of primary energy use in buildings.

We analyzed the three most commonly used methods used to determine the PEF for the electricity mix. We examined what are the assumptions of the individual methods and the individual default values that the method assumes. Then, using these methods, the value of the PEF for electricity in Slovenia was determined. We also recalculated with all the methods how the PEF changed over time at an annual level. All calculations were made using statistical data about produced electricity from various primary energy sources and individual assumptions determined by the methods. In addition, a statistical analysis using linear regression was carried out in order to predict the future PEF values for all three considered methods.

We have found that the methods differ in the evaluation of individual primary sources, which has a significant impact on the PEF value. In addition, we observed that the factor is also changing in terms of the electricity production from different sources, which means that the factor depends on the amount of energy that is produced either from nonrenewable sources of energy or from renewable energy sources. If the annual production of electricity from renewable energy sources is higher, we can expect a lower PEF and vice versa. We also noted that the share of renewable resources increases over time, which is also noticeable in the predicted values of production from renewable energy sources.

We also found that with the partial substitution method, we do not get representative results about the PEF, since it remains constant over the years. This means that this method does not provide a proper representation of the PEFs and, hence, is not applicable for the case in Slovenia. The method of physical energy gives the efficiency of production from renewable energy sources as 100%. Here, too, the question arises as to whether the evaluation is completely correct and if we can truly assume that the use of PE is equal to the actual production of electricity. In the third method, defined in the standard SIST EN 15603, which provides two PEFs, a certain measure of criticality of the assumed factors for the different sources of energy is used.

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