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An Evaluation of Primary Energy Factor Values of Wind Turbines †

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Abstract: In order to fulfil the European Energy Performance of Buildings Directive (EPBD) requirements regarding the reduction of energy consumption in buildings, much attention has been paid to primary energy consumption. Wind energy is one type of primary energy. The analysis of the literature has revealed that wind energy is evaluated by different methods. Therefore, the aim of this article was to calculate the effect of the parameters of wind sources on the primary energy factor of wind turbines. In order to achieve this aim, the primary energy factor of 100 investigated wind turbines and 11 wind farms operating in Lithuania was calculated. Investigation results showed that the difference of the non-renewable primary energy factor between wind turbines due to capacity is 35%. This paper provides a recommendation with regard to EU energy efficiency and renewable energy directives and regulations: All EU member states should use the same or very similar methodology for the calculation of the primary energy factor of renewable and non-renewable energy sources.

Keywords: primary energy; renewable energy; wind power; energy efficiency; auxiliary energy

1. Introduction

Directive 2010/31/EU recommends the use of renewable energy sources and reduction of the share of non-renewable energy in buildings by erecting energy-efficient buildings. One of the parameters of renewable energy sources is the primary energy factor (PEF) [1–3]. It is used for the setting of the demand of primary energy required to produce one unit of secondary energy. That means that the energy efficiency of a building is calculated as the balance of used and produced energy. The renewable primary energy factor ($f_{P,ren}$) is assessed, but the non-renewable primary energy factor ($f_{P,nren}$) depends on the additional energy consumed in the conversion device, which normally uses additional non-renewable energy, such as electrical energy, a common grid or fuel [4]. The investigation of wind turbine systems does not provide information due to the non-renewable energy in these systems [5]. However, wind turbine generators usually account for part of the energy used in wind farms from electricity grids, supplying common energy to buildings.

The PEF of electrical energy produced on-site/nearby or renewable energy supplied from the electrical grid has a direct influence on the calculation of the total PEF. There are two possibilities: To increase the share of electricity produced from renewable energy sources in electrical grids or to use electricity produced on-site/nearby from renewable sources, including wind turbines.

The analyzed literature did not give sufficient information on PEF value calculation; the obtained PEF values were very different for the same type of energy, and many different methodologies were used to calculate those values [6–8]. Only with sufficiently accurate data on wind renewable ($f_{P,ren}$) and non-renewable ($f_{P,nren}$) primary factors can the amount of renewable and non-renewable primary energy consumed in a building be objectively calculated.

Therefore, the aim of this article is to find the effect of wind energy parameters on the primary wind energy value and to calculate PEFs for wind turbines of different capacities.

2. Methods

Data for the investigation (for the period 2007–2014) were collected from 100 wind turbines and 11 wind farms operating in Lithuania. The data were collected by interviewing wind turbine owners/operators and by analyzing the reports of electricity transmission system operators in Lithuania [9]. In the end, six wind farms and eight wind turbines were selected for the study. Most of the investigated wind turbine or wind farm operators were unable to provide data on the main characteristics of wind turbines; because they do not collect and do not systemize the data, they do not have accounting tools or are connected to other electricity consumers. The wind turbines were classified into groups of different capacities ((>10) MW and (<10) MW) to determine their PEFs, and afterwards to compare the obtained values with the values provided in EN 15603:2014 [10]. The total primary energy may be calculated by Equation (1) according to the regulation of EN 15603:2014 [10]:

$$f_{P,tot} = f_{P,nren} + f_{P,ren}, \quad (1)$$

where $f_{P,tot}$ is the total primary energy, kW·h; $f_{P,nren}$ is the non-renewable primary energy, kW·h; and $f_{P,ren}$ is the renewable primary energy, kW·h.

It is assumed that all the energy supplied to the building is attributable to renewable energy because it is made from renewable wind energy. Accordingly, the renewable primary energy factor $f_{P,ren}$ is (Equation (3)):

$$f_{P,ren} = 1; \quad (2)$$

The value of the primary non-renewable energy factor $f_{P,nren}$ produced by wind turbines is given by the following formula (Equation (4)):

$$f_{P,nren} = \frac{E_{a,nren}}{E_{ren}};, \quad (3)$$

where $E_{a,nren}$ is the amount of additionally consumed non-renewable energy (from the electrical grid), apart from the produced electricity of the wind turbines, designed to be supplied into the building, kWh/year;

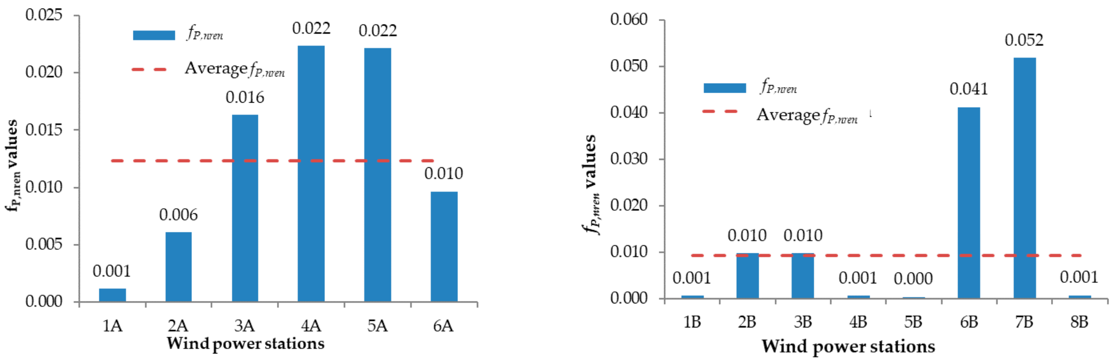
E_{ren} is the the amount of electrical energy which is produced in wind turbines and supplied into the building, kWh/year.

The calculation of the value of the primary energy factor of the electricity produced by wind turbines was done according to the data provided by the power plants [9].

3. Results and Discussion

The calculated $f_{P,nren}$ factors of the analyzed wind turbines/farms are presented in Figure 1.

The data presented in Figure 1a show that the average numeric indicator of the $f_{P,nren}$ factor in wind turbines/farms of (>10) MW capacity was 0.012 kW·h (the dotted line). The wind turbine 1A had the lowest $f_{P,nren}$ factor, whose value was 0.001; the wind turbines 4A and 5A had the highest factor, whose value was 0.022 kW·h.



(**a**) (**b**)

Figure 1. Relationship between f_{Pnren} and wind power in wind turbines/farms: (**a**) In (>10) MW wind turbines; (**b**) in (<10) MW wind turbines.

The average numeric indicator of the $f_{P,nren}$ factor in wind turbines/farms of (>10) MW capacity illustrated in Figure 1b was 0.009 (the dotted line). The wind turbines 1B, 4B, 5B, and 8B had the lowest $f_{P,nren}$ factor (value is 0.001), and the wind turbine 7B had the highest factor, whose value was 0.052.

The obtained results lead to the conclusion that the $f_{P,nren}$ factor value is influenced by the capacity of wind turbines. A trend is observed that in wind turbines of (>10) MW capacity this indicator decreases with a higher installed power capacity of wind turbines.

The results of the PEF calculation are presented in Table 1.

Table 1. The result of the primary energy factor (PEF) calculation.

Indicators	**The Values of the Capacities of the Wind Turbines Operated in Lithuania**		**Weighted Average**
	(>10) MW	**(<10) MW**	
$f_{P,nren}$	0.012	0.009	0.01
$f_{P,ren}$	1	1	1
$f_{P,tot}$	1.012	1.009	1.01

The investigation showed that the value of non-renewable PEF of wind turbines/farms of (>10) MW capacity was bigger ($f_{P,nren}$ = 0.012) than that of the wind turbines/farms of (<10) MW capacity ($f_{P,nren}$ = 0.009). This was a 35% difference. Accordingly, the total value of PEF may depend on the number of different wind turbines/farms regarding the capacity of wind turbines. The methodology provided in EN 15603 provides only one PEF value for wind turbines irrespective of their capacity. The primary investigation showed that the aspect of the capacity of wind turbines should be assessed for the determination of PEF. This outcome is primary, which drew attention to the need for further research.

Overall, the findings of this work indicate that a number of parameters can influence the value of PEF. This study has provided guidelines for PEF determination; nevertheless, each case should be carefully examined on an individual building basis, especially when there is no exact methodology for determining PEF values. However, PEF is important for setting precise primary energy values, which are used in energy policymaking and in defining energy-saving goals or energy consumption efficiency in international and national energy statistics, scenarios, environmental impact assessments, directives, and standards. Every European Union member state should define the primary energy in wind turbines as well as the statistical parameters of wind turbines and the climate (wind speed, wind turbine capacity, conversion efficiency, turbine-power consumption, etc.).

4. Conclusions

The investigation showed that PEF may depend on the capacity of wind turbines. The value of the non-renewable energy factor $f_{P,nren}$ of the wind turbines/farms of (>10) MW capacity was 0.012 and it was 0.009 in the wind turbines/farms of (<10) MW capacity. This was a 35% difference. Therefore, the total value of PEF depends on the number of different wind turbines/farms and the capacity of wind turbines.

In order to achieve the goals set forth in EU energy efficiency and renewable energy directives and regulations, all EU member states should use the same or very similar methodology for the calculation of the primary energy factor of renewable and non-renewable energy sources.

Author Contributions: All authors contributed equally to this work. All authors designed the calculations, discussed the results and implications, and commented on the manuscript at all stages. R.T. and P.B. calculated various primary factor values of non-renewable energy of wind power turbines of different capacities and interviewed wind turbine owners/operators. D.A.K. and J.Š. analyzed climate data and prepared the report of electricity transmission system operators. J.Š. wrote the paper.

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Conflicts of Interest: The authors declare no conflict of interest.

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