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Investigation and Evaluation of Primary Energy from Wind Turbines for a Nearly Zero Energy Building (nZEB)

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Abstract: In order to fulfill the European Energy Performance of Buildings Directive (EPBD) requirements regarding the reduction of energy consumption in buildings, great attention is paid to primary energy consumption. Wind energy is considered a 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 is to calculate the effect of the parameters of wind sources and wind speed on the primary energy factor of wind turbines. In order to achieve this aim, the primary energy factor of investigated 100 wind turbines and 11 wind farms operating in Lithuania was calculated. The results of the investigation show that the difference in the non-renewable primary energy factors between wind turbines with regard to their capacity is 35%. In addition, primary energy factor (PEF) values depend on geographic location and climate conditions. This paper provides a recommendation that the EU energy efficiency and renewable energy directives and regulations of all EU member states should use the same or, at least, a very similar methodology for the calculation of the primary energy factors of renewable and non-renewable energy sources.

Keywords: primary energy; wind power; electricity production; electricity consumption; nearly zero-energy building

1. Introduction

Directive 2010/31/EU recommends the usage of renewable energy sources and a reduction in the share of non-renewable energy used in buildings by erecting energy-efficient buildings. Various energy sources can be used for the lighting, heating, cooling, ventilation of the building and the preparation of hot water: fossil energy sources such as oil and natural gas, or renewable energies such as solar and wind power, biomass or earth heat. The energy efficiency of a nearly nZEB is calculated as the balance of renewable and non-renewable energy. That means, supplied energy to the building boundary is a mixture of renewable and non-renewable energy (Figure 1). Renewable energy of a nearly nZEB building consists of more than half of the total energy; however, part of the energy is from a non-renewable energy source. This ratio between renewable and non-renewable energy can be estimated. Calculation methodologies are provided for this.

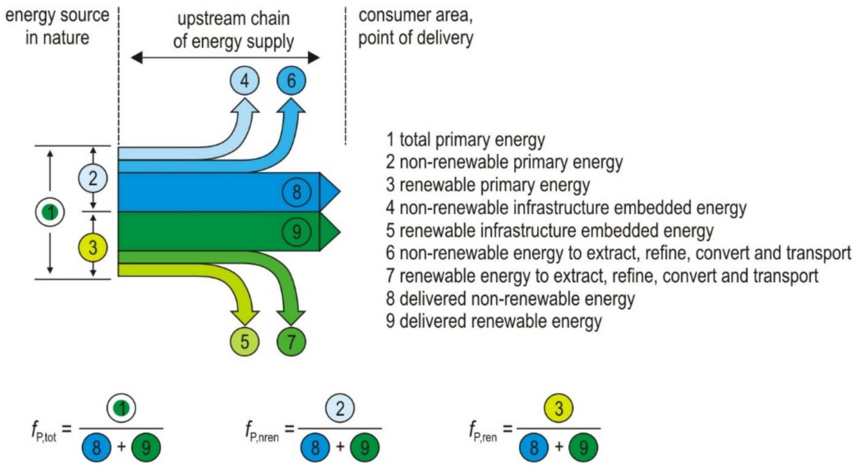


Figure 1. Primary energy factors and energy flows (own elaboration based on [1]).

However, one important factor that is not evaluated in the total energy balance of the nearly nZEB building but which still contributes is the primary energy factor (PEF), often referred to as a conversion factor, that it is required to calculate the total energy consumption including the chain of energy generation based on the final energy consumption data (Figure 2).

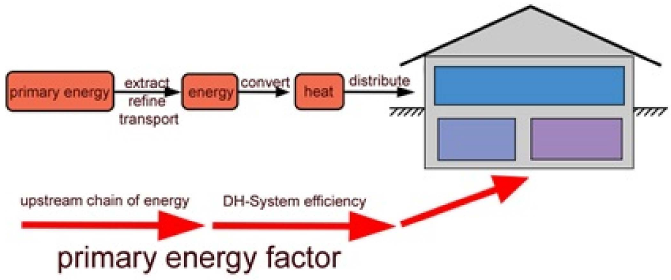


Figure 2. Supply chain of primary energy from renewable sources to building.

The entire supply chain boundary accounts for a total of renewables account for all direct and indirect energy transformations during the electricity generation process. The entire supply chain includes the energy spend on extraction, transportation, transformation, and considers the real share of renewables. Thereby, the efficiency of the wind turbine is related only to the process of resource combustion and does not account for the entire supply chain boundaries. It takes into account only the boundaries in the range of the wind turbine and does not consider energy losses related to the transportation, extraction, and conversion of energy [2] (Figure 2.). Therefore, the renewable primary energy factor ($f_{P,ren}$) is assessed; however, 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 generated from a common grid [3] (Figures 1 and 2).

One more related aspect to the energy produced in a wind turbine is the additional energy needed for the operation of the wind turbine. The operation of wind turbines (lighting, signaling, blade heating, using for the generator, etc.) requires additional energy, which is taken from the electricity grid [3]. That means that wind turbines use non-renewable energy in order to operate. The investigations of wind turbine systems do not provide information regarding the use of non-renewable energy in these systems. Although wind turbine generators usually obtain part of the energy used in wind farms from electricity grids, supplying common energy to the building, this is not integrated into the balance of total energy of nearly nZEB buildings. Although 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.

Despite the fact that wind energy is widely explored [4–10], there is a paucity of information on the evaluation of renewable energy for nearly nZEB buildings [11,12]. This issue is important because PEF characterizes the entire energy demand in the energy supply chain to the final consumer [3]. PEF values may be meaningful for the end user when making decisions related to which energy source should be used with the aim of meeting the requirements of a nearly zero-energy building (nZEB).The analysis of the latest scientific research results has revealed that wind energy is evaluated by different methods. The values of primary energy are most often obtained without taking into consideration wind speed, wind turbine capacity, conversion efficiency, and turbine-power consumption. No systematic research on this topic is currently available (Table 1).

Table 1. Parameters of different methodologies for the evaluation of primary energy produced from wind turbines.

	Method	Description of Primary Energy Evaluation	PEF	PEF Value	Reference
1.	Zero-equivalent method	Does not evaluate electrical and thermal energy production from renewable energy sources	Total primary energy $f_{P,tot}$,	0	[13]
2.	2a Direct equivalent	Evaluates electrical and thermal energy production from non-fossil renewable energy and nuclear energy sources	Total primary energy $f_{P,tot}$,	1.0	[14]
	2b Amount of physical energy	Evaluates the primary form of energy obtained in generation process	Total primary energy $f_{P,tot}$,	1.0	[15]
	2c Alternate	Evaluates the primary form of energy that is included into the statistical energy balance prior to conversion to the secondary or tertiary form of energy	Total primary energy $f_{P,tot}$,	2.5	[16,17]
3.	3a Effectiveness of technical conversion	Evaluates the entire energy production chain by separating the renewable and non-renewable energy	Non-renewable primary energy $f_{P,nren}$,	0.032	[16,17]
			Renewable primary energy $f_{P,ren}$,	2.5	
	3b Amount of physical energy	Evaluates the primary form of energy produced in the generation process	Non-renewable primary energy $f_{P,nren}$,	0.032	[15]
			Renewable primary energy $f_{P,ren}$,	1.0	

The data given in Table 1 show that different methodologies render different PEF values for the evaluation of wind energy; therefore, it is difficult to compare the values of primary energy or PEFs. The PEF for the same source of renewable energy may differ significantly depending on the type of primary energy and applied calculation method [18–20].

Data are given in Table 2 that also show that PEF values depend on the energy production and supply chain. The results presented in Table 2 show that different EU countries have provided different PEF values and many countries do not announce these values publicly. National standards and norms of many EU member states governing the construction field do not include or do not further specify the PEF values; therefore, it is not clear whether these values are valid for defining wind energy or are merely politically grounded values that are not meant for technical or scientific applications.

Table 2. The primary energy factor (PEF) values of wind energy used in construction work standards of EU countries.

Country	PEF	Total PEF, $f_{P,\ tot}$	Non-Renewable PEF, $f_{P,\ nren}$	Renewable PEF, $f_{P,\ ren}$	Literature Source
Czech Republic	-	-	-	-	[21]
Denmark	-	-	-	-	[22]
Estonia	-	-	-	-	[23]
Finland	-	-	-	-	[24]
France	1.00	-	-	-	[25]
Germany	-	1.03	0.03	1.00	[26]
Greece	-	-	-	-	[27]
Hungary	0	-	-	-	[28]
Italy	-	1.00	0	1.00	[29]
Poland	-	1.00	0	1.00	[30]
Slovakia	-	-	-	-	[31]
Slovenia	-	-	-	-	[32]
United Kingdom	1.00	-	-	-	[33]

Note: - not mentioned.

The results presented in Table 2 highlight the importance of this issue. Missing values indicate that these countries have not been included in an assessment of the PEF in the building efficiency methodology. The assumption was taken that the share of renewable energy in energy generated by wind turbines is 100%. However, as discussed above, this is not true. The power to the internal system of a wind turbine is supplied from batteries/condensers or from the electrical grid. Various pieces of equipment in wind turbines use electric power and energy consumption may reach up to 0.1% of the total produced energy, in other cases, it may be as high as 10–20% of the rated power of the wind turbine.

The conclusions from the literature review were, that when insufficient information was given regarding the calculation of the PEF value, the obtained PEF values were very different for the same type of energy, and various different methodologies were used to calculate those values. Only with sufficiently accurate data on wind renewable ($f_{P,ren}$) and non-renewable ($f_{P,nren}$) primary factors is it possible to objectively calculate the amount of renewable and non-renewable primary energy consumed in a nearly nZEB building. The methodology provided in EN 15603 [1] gives only one PEF value for wind turbines, irrespective of their capacity. The influence of the wind turbine capacity on the PEF value is unknown. Therefore, it would be useful to classify the studied wind turbines into groups of different capacities and to determine their PEFs using the real data of consumed and produced energy of the wind turbines/farms

Therefore, the aim of this research is to find the effect of wind energy parameters and wind speed on the primary wind energy value and to calculate PEFs for wind turbines of different capacity using the real data of consumed and produced energy of the wind turbines/farms. The paper addresses an issue which will be relevant to the policymakers. A detailed study of the wind energy of Lithuania can be used as a template for similar studies to be carried out elsewhere.

2. Methodology

2.1. Research Object

Data for 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 [34].

A total of six wind farms and eight wind turbines were selected for the study. The operators of the investigated wind turbines/farms were unable to provide data on the main characteristics of wind turbines. They have did not collected and systemized the data, they did have not provided reports regarding connecting to other electricity consumers. The operators of the Lithuanian electricity transmission system have reported only the amounts of electricity transmitted from all wind turbines/farms to the electricity grid in certain periods. The main characteristics of the investigated wind turbines/farms are presented in Table 3.

Table 3. The main characteristics of the investigated wind turbine.

Mark	Total Installed Power Capacity, MW	Turbine Capacity, MW	N_0 of Turbine in Farm	Blade Length, m	Tower Height, m	Produced Electrical Energy, MWh/year	Consumed Electrical Energy, MWh/year
1A	39.1	2	20	41	85	85298.1	30.6
2A	34	2	17	41	97	15695.1	2.3
3A	21.4	2	10	41	85	37496.8	212.7
4A	20	2	10	41	85	45591.2	254.0
5A	16	2.75–3	6	41	85	35780.3	225.0
6A	12	2	6	41	78	10751.9	37.2
1B	0.8	0.8	1	21	45	1842.0	0.4
2B	0.8	0.8	1	21	45	1321.3	4.6
3B	0.6	0.6	1	20	42	1637.8	5.7
4B	0.25	0.25	1	15	50	124.8	0.03
5B	0.25	0.25	1	15	50	394.7	0.06
6B	0.25	0.25	1	15	45	683.1	13.7
7B	0.25	0.25	1	15	55	366.9	4.8
8B	0.225	0.225	1	14	50	209.9	0.05

2.2. Climate Data

Lithuania is in the zone of the climate of the Atlantic–European continental zone. Lithuania has a humid continental climate (Dfb in the Köppen climate classification). Average temperatures on the coast are −2.5 °C (27.5 °F), on the center zone of Lithuania are −6 °C (21.2 °F) in January and 16 °C (60.8 °F) in July. Simply speaking, 20 °C (68 °F) is frequent on summer days and 14 °C (57.2 °F) at night. Temperatures occasionally reach 30 or 35 °C (86 or 95 °F) in summer. Winters, when easterly flows from Siberia predominate, are very cold, whereas winters dominated by westerly maritime airflows are mild with temperatures above freezing a normal occurrence. Winter extremes are −34 °C (−29 °F) at the coast and −43 °C (−45 °F) in the east of Lithuania.

South-westerly and westerly winds prevail in the major part of the Lithuanian territory, with westerly and south-easterly winds common in the coastal zone [35,36]. Katinas [37] investigated the wind climate conditions in the coastal area of the Baltic Sea and other regions of Lithuania.

A researcher created the Lithuanian wind speed atlas (Figure 3) and decided that the western part of the country is the most suitable location for wind turbines because of prevailing wind velocities and more developed transmission networks. The average wind speed at a height of 50 m ranges from 4 m/s to 6.5 m/s. The highest wind speed is in the coastal zone, where it reaches 5–6.5 m/s and decreases moving away from the coast eastwards. Therefore, the investigated wind turbines are located mostly in the western part of the country (Figure 3).

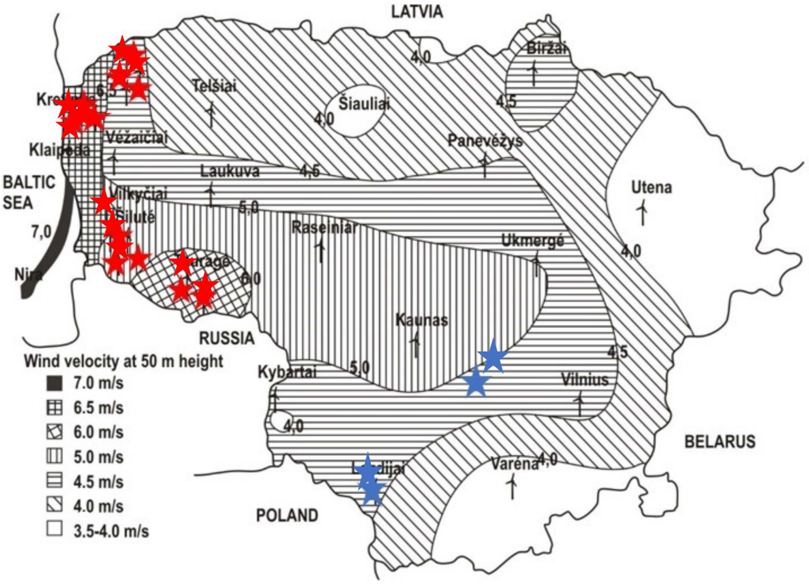


Figure 3. Lithuanian wind atlas (own elaboration based on [37]) The investigated wind turbines are located in the area marked (red stars in the western part of the country, blue stars in the south and middle part of the country)**.**

The highest wind speeds recorded in the center of Lithuania are observed in November–January and in October–December in the coastal zone (the extreme gust was 36 m/s in the 1993 year); the lowest wind speed is observed in June–July. In June and July, Lithuanian wind turbines produce about two times less energy compared to that which is produced in December and January. In the summertime, the highest wind speed is between midnight and 06:00. In the morning, it increases until noon and reaches a peak at about 14:00. The peak wind speed persists until 18:00 and afterwards, begins to decrease reaching the minimum observed values at about midnight. In the wintertime, the changes in the value of wind speed are less due to the lower fluctuation of air mass temperatures influenced by the smaller amounts of solar radiation energy. The wind class is IV according to IEC Standard 61400-1 [38]. Wind energy resources in Lithuania were evaluated based on the measurement data from meteorological stations, as well as measurements obtained from various research centers in the regions.

The Lithuanian terrain is extremely flat (all the country is under 300 m), meaning there are no altitude-induced climate differences. The slopes within a radius of 100 meters from the all investigated turbines were less 10°. The terrain of investigated wind turbines/farms was the open space with single trees at a distance of 500–1000 m from wind turbines/farms.

The turbulence of single wind turbines is not significant because of the annual average of wind speed is low (Figure 3). IEC Standard 61400-1 [38] provide the turbulence may be lower than 16%. in this case. The turbulence of wind farms depends on the layout type of turbines. The turbines of operating farms in Lithuania was placed in one row because the prevailing wind is south-westerly and westerly. The distance between the wind turbines is 360 m.

2.3. Primary Energy Calculation Methodology

From the net delivered energy, a numeric indicator of the primary energy can be calculated and used to define the performance level of a nearly nZEB building. The primary energy indicator (called also often referred to also as the primary energy rating) sums up all the delivered and exported energy (electricity, district heat/cooling, fuels) into a single indicator with primary energy factors. Therefore, the PEF of wind turbines shall be calculated using the methodology described in EN 15603 [1], where is included energy calculation framework specifying how to define the various energy flows and how to establish the energy boundaries ion the building is specified within the energy calculation framework.

The total primary energy of the nearly nZEB building was calculated (Equation (1)):

$$E_p = \sum_i \left(E_{del,i} f_{P,del,i}\right) - \sum_i \left(E_{exp,i} f_{P,exp,i}\right) \tag{1}$$

where E_p—the primary energy, kW·h; $E_{del,i}$—the delivered energy for energy carrier i, kW·h; $f_{P,del,i}$—is the primary energy factor for the delivered energy carrier i; $E_{exp,i}$—is the exported energy for energy carrier i, kW·h; $f_{P,exp,i}$—is the primary energy factor for the exported energy carrier i.

The total PEF was calculated from Equation (2):

$$f_{P,tot} = f_{P,nren} + f_{P,ren} \tag{2}$$

where: $f_{P,\ tot}$—the total primary energy factor; $f_{P,\ nren}$—the non-renewable primary energy factor; $f_{P,\ ren}$—the renewable primary energy factor.

It was assumed that all the energy supplied to the building was attributable to renewable energy because it was produced wind turbines. Accordingly, the renewable primary energy factor $f_{P,\ ren}$ is given by Equation (3):

$$f_{P,ren} = 1; \tag{3}$$

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

$$f_{P,nren} = \frac{E_{a,nren}}{E_{ren}}; \tag{4}$$

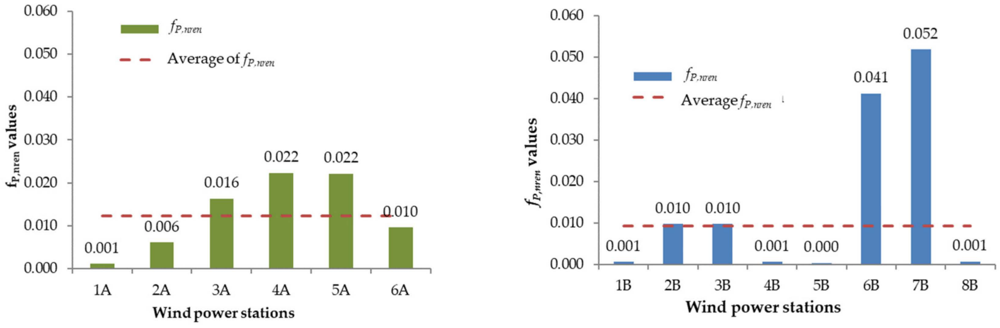
where $E_{a,nren}$—the amount of additionally consumed non-renewable energy (from the electrical grid) regarding the produced electricity of the wind turbines, designed to supply into the building, kWh/year; E_{ren}—the amount of electrical energy, which is produced in wind turbines and supplied into the building, kWh/year.

The calculation of the value of the primary energy factor of the electricity produced by wind turbines was performed according to the data provided by the power plants (Table 3).

3. Results

3.1. The Estimation of the PEF of the Wind Turbines

The non-renewable primary energy factor $f_{P,nren}$ was determined after classifying the studied wind turbines into groups of different capacities. Figure 4 presents the results of the calculation of $f_{P,nren}$ of >10 MW and <10 MW capacity wind turbines/farms.



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

Figure 4. Relationship between $f_{P,nren}$ and wind power in wind turbines/farms: (**a**) in >10 MW capacity of the wind turbines; (**b**) in <10 MW capacity of the wind turbines.

The data presented in Figure 4a shows that the average value of the $f_{P,nren}$ factor in the wind turbines/farms of >10 MW capacity is 0.012 kW·h (the dashed line). The wind turbine 1A has the lowest $f_{P,nren}$ factor, which has a value of 0.001, the wind turbines 4A and 5A have the highest factor, which is the value of 0.022 kW·h.

Meanwhile, the average value of the $f_{P,nren}$ factor in the wind turbines/farms of <10 MW capacity is 0.009 (the dashed line in Figure 4b). The wind turbines 1B, 4B, 5B and 8B have the lowest $f_{P,nren}$ factor (value is 0.001), and the wind turbine 7B has the highest factor, with a value of 0.052.

The obtained results lead to the conclusion that the $f_{P,nren}$ factor value is influenced by the capacity of the wind turbines. A trend is observed in which this indicator decreases with a higher installed power capacity of the wind turbines for wind turbines with >10 MW capacity. The PEF calculation results are presented in Table 4.

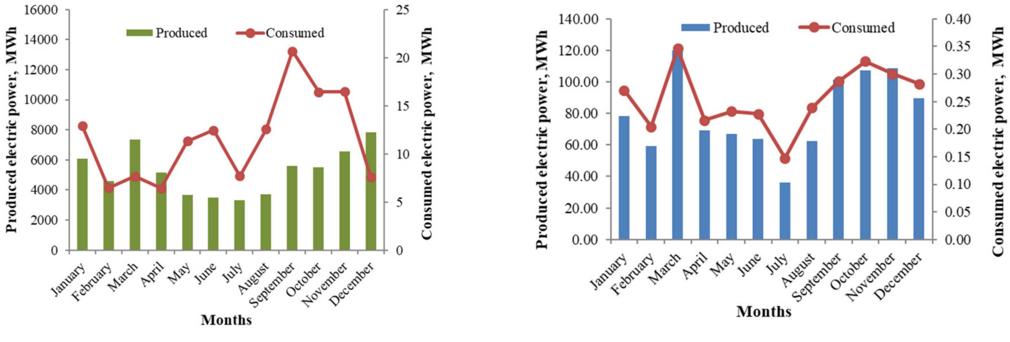
Table 4. The result of the PEF calculation.

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

Comparing the determined values of the $f_{P,nren}$ factor, the scattering of data of the results is greater for wind turbines that possess a greater wind power capacity (<10 MW). The reason for this might be the location of the wind turbines. The 6B and 7B wind turbines, for which the value of $f_{P,nren}$ factor is determined to be the largest, are located in the south and middle of the country, that is to say, these are further from the coastal zone, where the value of the wind speed is less (Figure 3, blue stars).

3.2. The Estimation of the Produced and Consumed Electric Power

In order to determine the influence of wind speed on the primary energy factor of wind turbines, first of all, the balance of the produced and consumed electric power was investigated in the mentioned wind turbines. The results of the investigation of the average distribution of produced and consumed electric power in >10 MW and <10 MW wind turbines/farms by month are presented in Figure 5.



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

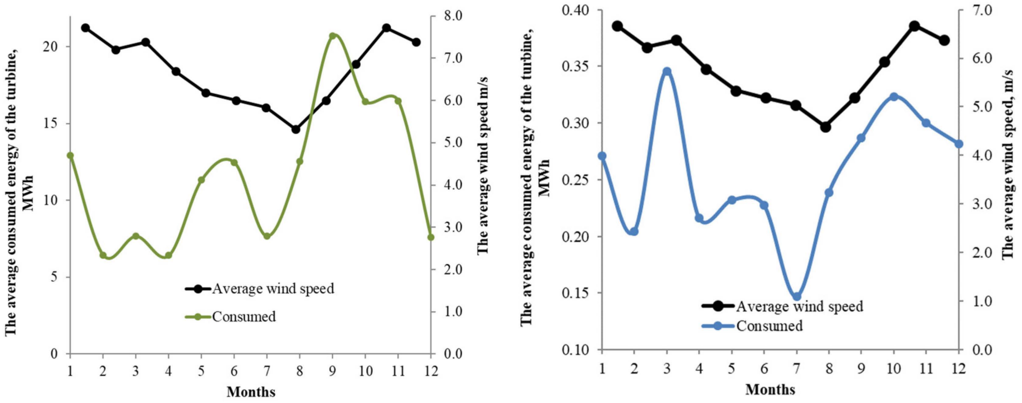
Figure 5. The average values of the balance of the produced and consumed electric power per year: (**a**) in >10 MW capacity of the wind turbines; (**b**) in <10 MW capacity of the wind turbines.

The results, which are presented in Figure 5, reveal the inverse relationship between the produced and consumed electric power capacity of wind turbines/farms. Thus, it is known that the operation of the wind turbine a fraction of the energy [39]. therefore, the results reveal that the average annual turbine-energy consumption is as high as 0.22% of the total produced electrical energy in the case of >10 MW wind turbines. Meanwhile, this fraction is even higher (up to 0.32%) in the case of <10 MW wind turbines.

Furthermore, the relationship between the consumed amount of electrical energy and the season was determined; typically, it was higher in the warm season and lower in the cold season, i.e., in wintertime it may reach 0.10% in >10 MW wind turbines and 0.28% in <10 MW wind turbines. In the summertime, the consumed amount of electrical energy may reach 0.36% in >10 MW wind turbines and 0.41% in <10 MW wind turbines. The differences between the consumed amount of electrical energy regarding the season are related to the power and frequency of the wind.

3.3. The Estimation of the Influence of the Average Wind Speed

The influence of the average wind speed to the average turbine-power consumption in the analyzed wind turbines/farms can be seen from the results, which are presented in Figure 6.

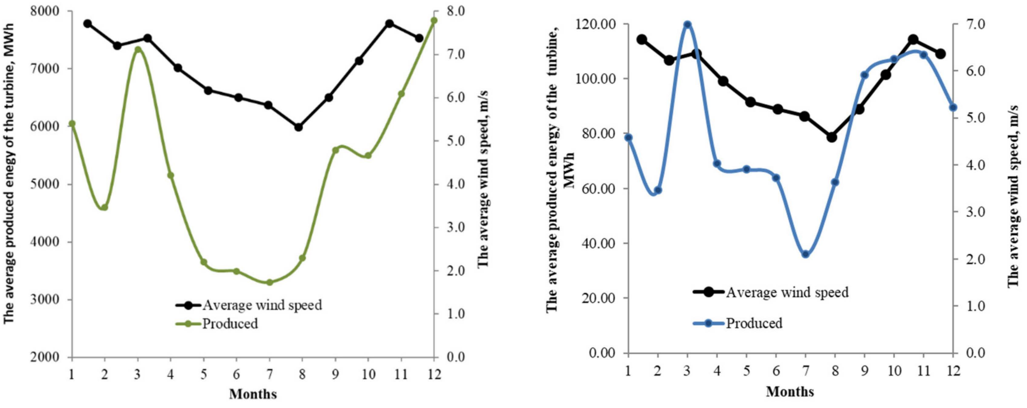


(**a**) (**b**)

Figure 6. The relationship between the average consumed energy by wind turbines/farms and the average wind speed: (**a**) in >10 MW capacity of the wind turbines; (**b**) in <10 MW capacity of the wind turbines.

The obtained results (Figure 6a) reveal that the relationship between the energy consumed by >10 MW capacity wind turbines/farms and wind speed is indirectly proportional, i.e., wind turbines consume more energy at lower wind speeds. Meanwhile, the relationship (Figure 6b) between the energy consumed by <10 MW capacity wind turbines/farms and wind speed is closer to a linear relationship, i.e., wind turbines consume more energy at higher wind speeds.

Figure 7 illustrates the results of the relationship between the average amount of energy produced by wind turbines/farms and the average wind speed.



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

Figure 7. Relationship between the average produced energy by wind turbines/farms and the average wind speed: (**a**) in >10 MW capacity of the wind turbines; (**b**) in <10 MW capacity of the wind turbines.

The data presented in Figure 7 show that the quantities of energy produced by the wind turbines/farms increase with higher wind speeds. The capacity of wind turbines is not significant.

The obtained results lead to the conclusion that the quantities of energy produced are directly related to wind speeds. The resulting fluctuations may be explained by technical factors related to the equipment.

4. Discussion

In order to meet the requirements set forth in Directive 2010/31/EU [39], the primary energy factor value for wind turbines is calculated following the methodology described in EN 15603 [1]. However, any reference conditions and criteria used to determine the value of the non-renewable primary energy factor are not given in the mentioned standard. Although a few EU countries, which have investigated PEF, obtained similar results for PEF (Table 2). The values of total PEF of the wind turbines operated in Lithuania are similar (the average $f_{P,tot}$ = 1.01) (Table 4) as those obtained in Germany, France, Italy, Poland, and the United Kingdom (Table 2). However, the data show that not all the mentioned EU countries obtained similar results for PEF, e.g., Hungary (Table 2). The influencing conditions and criteria for PEF determination of the countries mentioned are unclear.

The investigation has shown that the value of non-renewable PEF of the wind turbines/farms of >10 MW capacity is larger ($f_{P,nren}$ = 0.012) than that of the wind turbines/farms of <10 MW capacity ($f_{P,nren}$ = 0.009, Table 4). This is a difference of 35%. Accordingly, the total value of PEF may depend on the number of different wind turbines/farms with regard the capacity of the wind turbines. The methodology provided in EN 15603 gives only one PEF value for wind turbines irrespective of their capacity. The primary investigation shows that this aspect regarding the capacity of wind turbines should be assessed for the determination of PEF. This is a primary outcome and draws attention to the need for further research.

Another factor which influences the value of PEF is the geographic location. The investigation was shown that the value of the non-renewable PEF of the wind turbines located in the middle of a continent might be bigger than in the coastal areas. All kinds of continent obstacles in the form of buildings or trees affect the roughness of the terrain. This translates into a significant reduction in wind speed and increased turbulence. According to the classification of terrain roughness [40,41], wind farms should be located in a large, open space, i.e. in cultivated areas or on the open sea [40–43]. In order to prove this outcome, there need to be more comprehensive investigations. In addition, the data of total PEF of Hungary (Table 2) yield the opposite outcome. The information regarding the methodology of the PEF determination of Hungary is not given. Consequently, the reason for a different outcome is unclear.

One more observation is related to climate conditions—the consumed amount of electrical energy was higher in the warm season than in the cold season. This means, that the European latitude is significant: the value of PEF might be greater in the southern part of the EU and lower in the northern part of the EU.

Many researchers report that wind speed is the most significant factor in terms of the amount of wind power produced [40,44,45]. The investigation confirms this outcome. However, the investigation determined that in >10 MW capacity wind turbines the turbine power consumption increases with decreasing wind speed, whereas in <10 MW capacity wind turbines the opposite is true, i.e., the turbine power consumption increases with increasing wind speed. The obtained results lead to the conclusions that turbine consumption is compensated for by the energy produced by the wind turbine. When wind turbines stop working or do not operate at full capacity, energy is taken from the power grid. The resulting fluctuations may be explained by technical factors relating to the equipment. This is a detailed study of the wind energy of Lithuania and can be used as a template for similar studies to be carried out elsewhere.

The results of the research will help to more precisely evaluate the energy efficiency of nearly nZEB buildings in Lithuania. PEF values will help the end user when choosing decisions regarding which energy source to use with the aim of meeting the requirements for nearly nZEB buildings.

Overall, the findings of this work indicate that a number of parameters can influence the value of PEF. This study provides 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 the PEF values. However, PEF is important for setting precise primary energy values, which are used in energy policymaking, in defining energy-saving goals or energy consumption efficiency in international and national energy 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 climate (wind speed, wind turbine capacity, conversion efficiency, turbine-power consumption etc.).

5. Conclusions

These investigations has shown that PEF may depend on the capacity of the 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. For the wind turbines/farms of <10 MW capacity, the value was 0.009. This is a difference of 35%. Therefore, the total value of PEF depends on the number of different wind turbines/farms with regard to the capacity of the wind turbines.

The study results revealed that in >10 MW capacity wind turbines, the turbine consumption increased with decreasing wind speed, whereas in <10 MW capacity wind turbines, the opposite was true, i.e., the turbine consumption increased with increasing wind speed.

Furthermore, the investigation revealed that the value of the non-renewable PEF of the wind turbines depends on both the geographic location and climate conditions. The wind turbines located in the middle of a continent might have a larger non-renewable PEF than that in coastal areas. The consumed amount of electrical energy was higher in the warm latitude/season than in the cold latitude/season. 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, at least, a very similar methodology for the calculation of the primary energy factor of renewable and non-renewable energy sources.

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