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Selected aspects of the material and energy model assessment of onshore and offshore wind farms

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Abstract

The article presents a comparative analysis of wind farms equipped with V80 2 MW and V90 3 MW wind turbines. On the basis of these types of wind turbines and the example of two selected onshore and offshore wind farms a model was developed of material and energy inputs incurred for a given turbine in relation to the amount of electricity generated during its life cycle. Using this method it was possible to compare the two types of wind farms. The farms taken into consideration in the article correspond to each other in terms of installed capacity and the number of turbine units.

Keywords: offshore wind farms, onshore wind farms, wind turbine, LCA wind farm, Renewable Energy

1. Introduction

A wind turbine converts the kinetic energy of the wind into mechanical energy. A typical wind turbine consists of a foundation, tower, nacelle, rotor. The efficiency of the energy conversion process depends largely on the components and parameters of the device [1, 2]. Wind farms can be divided into onshore and offshore farms [3]. A comparative analysis method was used to assess the different types of farms. The analysis was conducted in respect of the calculated indicators, which are the material and energy inputs of the selected onshore and offshore wind farms throughout their assumed life cycle.

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2. Description of the selected onshore and offshore wind farms

The analysis covers four wind farms, two offshore and two onshore wind turbines. V80 2 MW and V90 3 MW turbines were installed on the farms. The farms have a similar number of installed turbines and occupy similar surface areas, as presented in Table 1.

Assuming peak power use at a maximum level and full load operation throughout the year (365 days×24 hours), the 4 farms are able to generate maximum annual energy as described by the following formula:

$$MEW_{1y} = P_{NH} \times 365 \times 24 \tag{1}$$

Thus, during their entire life cycle (20 years) the wind farms can generate a maximum amount of energy according to the following formula:

$$MEW_{LC} = MEW_{1y} \times 20 \tag{2}$$

Table 1: Installed capacity and wind farm area (based on data in [4])

	Type of farm	No. of turbines	Type of turbine	P, MW	A, km^2
North Hoyle	Offshore	30	V80 2MW	60	11,000
Kentish Flats	Offshore	30	V90 3MW	90	9,000
Cor-mainville/Guillonville	Onshore	30	V80 2MW	60	10,000
Salles-Curan	Onshore	29	V90 3MW	87	1,000

Table 2: Maximum MEW energy and overall ZEW energy balance (based on data in [4])

	MEW_{1y}, GWh	MEW_{LCA}, TWh	ZWE_{1y}, GWh	ZWE_{LCA}, GWh
North Hoyle	526	10.5	3,600	3,620
Kentish Flats	788	15.8	226	4,520
Cormainville/Guillonville	526	10.5	109	218
Salles-Curan	762	15.2	135	2,700

Source reports often claim that the amount of the generated energy measured in the turbine is highly inaccurate. A more accurate measure is the amount of exported energy EW measured at the transformer station. Exported energy should not be confused with the energy balance ZEW, which is the difference between the energy distributed to and derived from the wind farm. Exported energy is the value of already reduced losses WS in the internal grid of the wind farm (before the transformer) which for onshore farms is $WS=0$.

The final balance of wind farm energy is expressed by the equation:

$$ZEW = EW \times (1 - WS) - EI \tag{3}$$

For the entire life cycle, ZEW is as follows:

$$ZEW_{NH,LC} = ZEW_{NH,1y} \times 20 \tag{4}$$

3. Description of the material and energy inputs model and use of LCA methodology in wind energy

Based on the methodological requirements contained in [5], the analysis of the life cycle (LCA- Life Cycle Assessment) of a wind farm presented in this work shall be used to study the environmental impact of the farm: acquisition of raw materials, installation of wind turbines, 20 years of operational life, dismantling. Fig. 1 presents the groups of processes taken into account in the analysis of the wind turbine life cycle.

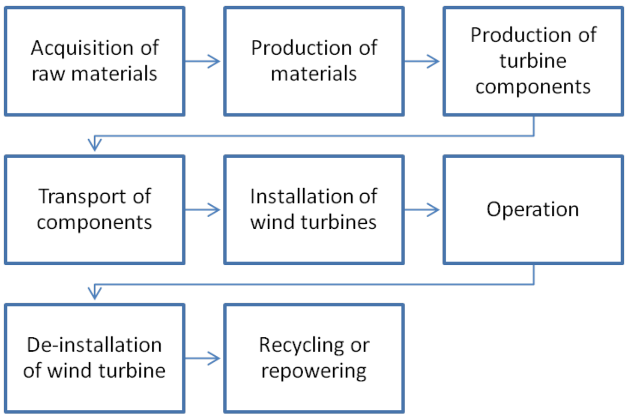

Figure 1: Groups of processes in the wind turbine life cycle analysis [5, 6]

In the LCA analysis, the material and energy inputs of the V80 2 MW and V90 3 MW turbines investigated includes the material and energy inputs used in the various stages in the life cycle of the farm.The material inputs during the operation phase are mainly greases and oils used in the servicing of the wind turbines, in rare cases individual components of the wind turbine may be exchanged. The worn parts are waste.

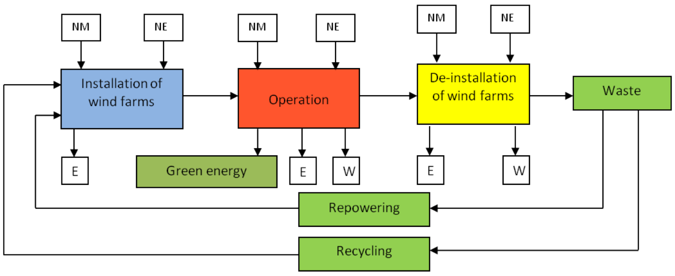

Figure 2: Block diagram of the wind farm LCA

Table 3: Volumes of material and energy inputs incurred for the turbine [4]

	V80 2 MW		V90 3 MW	
	On-shore	Off-shore	On-shore	Off-shore
Material inputs, Gg	8.82	13.1	8.78	14.4
Energy inputs, TJ	11.5	21.9	15.4	28.8

When performing the LCA, the particular phases of the farm life cycle should be indicated: installation of wind turbines, operating life and de-installation of the turbines. Then the analysis of the inputs and outputs in the particular phases should be made. In the model (Fig. 2) analysis of the inputs and outputs of the component production phase was included in the installation phase and the phase of preparing turbines for work.

The number of material inputs per one turbine is the sum of these inputs per individual turbine component, such as the foundation, tower, nacelle and rotor. It is calculated by the following equation:

$$NM_{WTG} = \sum_{i=1}^{n} F + \sum_{i=1}^{n} W + \sum_{i=1}^{n} G + \sum_{i=1}^{n} R \qquad (5)$$

Table 4: Weight of the individual components, Mg [7, 8]

V80 2 MW		V90 3 MW	
Onshore (60 m)	Offshore (78 m)	Onshore (105 m)	Offshore (80 m)
1,095	445	1,543	467

The material inputs at this stage, i.e., from production of the materials until the time of preparing the turbine for work, include in particular: water, oil, coal, aluminum. The energy inputs incurred for the turbine can be calculated in a similar way. The number of installed turbines of the model and the operating time (20 years), as well as the inputs to the model during its operation and dismantling phases should be borne in mind when assessing the entire cycle of the wind farm. Material inputs attributable to the V80 2 MW and V90 3 MW turbines are described in Table 3, while the weight of the individual components is presented in Table 4.

Demand for the material inputs related to the total energy transmitted to the grid in Mg/GWh is defined as the ratio of the sum of the material inputs incurred for all units of the wind farm of a given kind in the life cycle to the total energy transmitted from the wind farm to the grid during the life cycle.

$$nm_{ZEW} = \frac{\sum NM}{ZEW_{LC}} \qquad (6)$$

Whereas, the demand for the material inputs related to the total rated power in Mg/MW is defined as the ratio of the sum of the material inputs incurred for all units of the wind farm of a given kind during the entire life cycle to the rated power of the wind farm.

$$nm_P = \frac{\sum NM}{P} \qquad (7)$$

4. Selected results of the comparative analysis

The weight fraction of the individual components of wind turbines is shown by Fig. 3, while Fig. 4 and 5, respectively, present the demand for material inputs related to total energy transmitted to the grid and the demand for material inputs related to total rated power.

Demand for material inputs related to the work surface of the turbine in Mg/m^2 is shown in Fig. 6 and defined as the ratio of the sum of the material inputs incurred for all units of the wind farm of a given kind during the entire life cycle to the sum of the working surface of the installed turbines.

$$nm_{Aw} = \frac{\sum NM}{\sum Aw} \qquad (8)$$

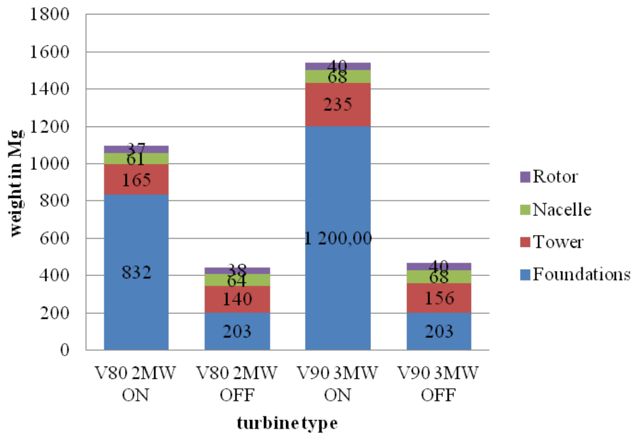

Figure 3: Weight fraction of the individual components of the wind turbine

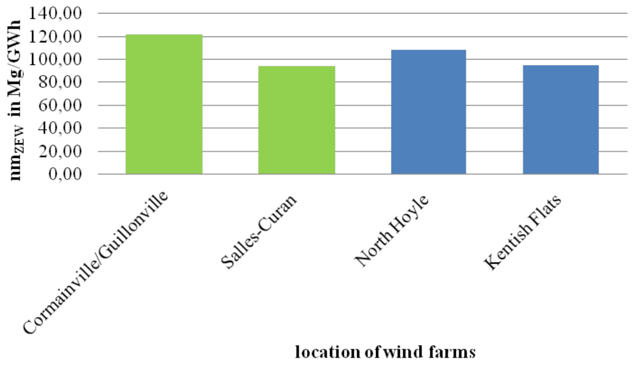

Figure 4: Demand for material inputs related to total energy transmitted to the grid

Demand for energy inputs related to total energy transmitted to the grid in GJ/GWh, as shown in Fig. 7, is defined as the ratio of the total energy inputs incurred for all units of the wind farm of a given kind in the life cycle to the total energy transmitted from the wind farm to the grid throughout the life cycle.

$$ne_{ZEW} = \frac{\sum NE}{ZEW_{LC}} \tag{9}$$

Demand for energy inputs related to total rated power in GJ/MW (see Fig. 8) is defined as the ratio of the total sum of the material inputs incurred for all units of the wind farm of a given kind during the entire life cycle to the rated power of the wind farm.

$$ne_P = \frac{\sum NE}{ZEW_P} \tag{10}$$

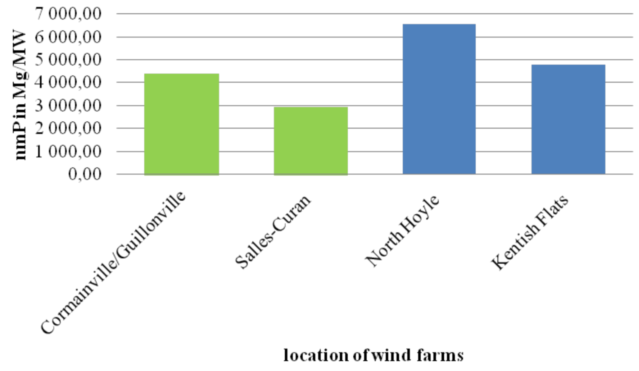

Figure 5: Demand for material inputs related to total rated power

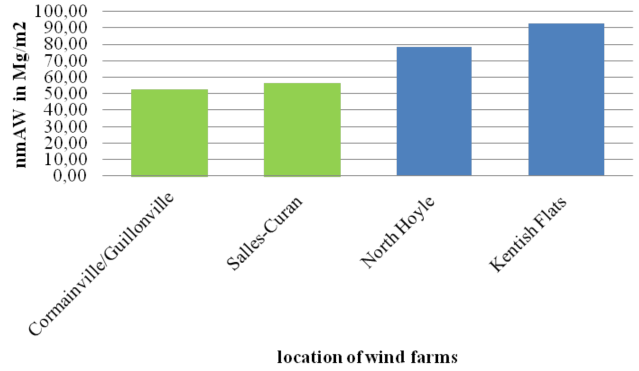

Figure 6: Demand for material inputs related to the working surface of the turbine

Demand for energy inputs related to the sum of the working surface of the turbine GJ/m^2 (see Fig. 9) is defined as the ratio of the total energy inputs incurred for all units of the wind farm of a given kind in the life cycle to the total energy transmitted from the wind farm to the grid during the life cycle.

$$ne_{Aw} = \frac{\sum NE}{ZEW_{Aw}} \tag{11}$$

5. Conclusion

With the developed model it is possible to compare onshore and offshore wind farms in terms of material and energy inputs incurred for each of the wind turbines in relation to the amount of electricity produced, installed capacity and total working surface. The analysis was made taking into account the 20-year operational lifespan of the turbines.

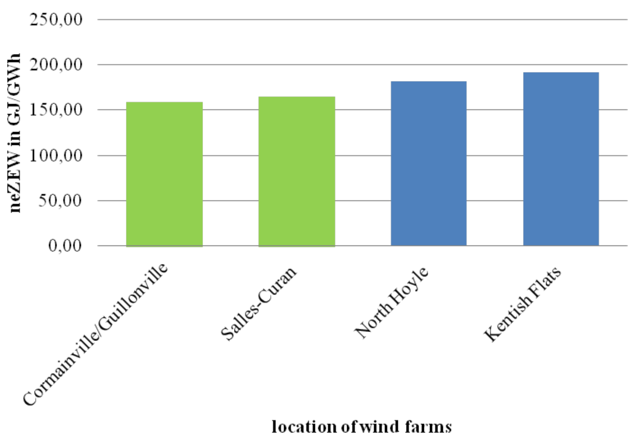

Figure 7: Demand for energy inputs related to the total energy transmitte do the grid

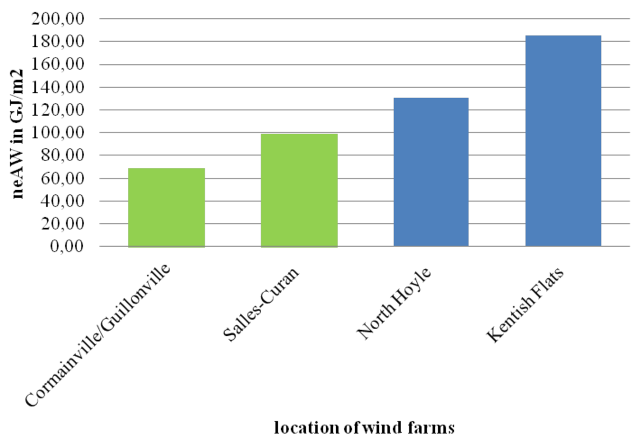

Figure 9: Demand for energy inputs related to the sum of the working surface of the turbine

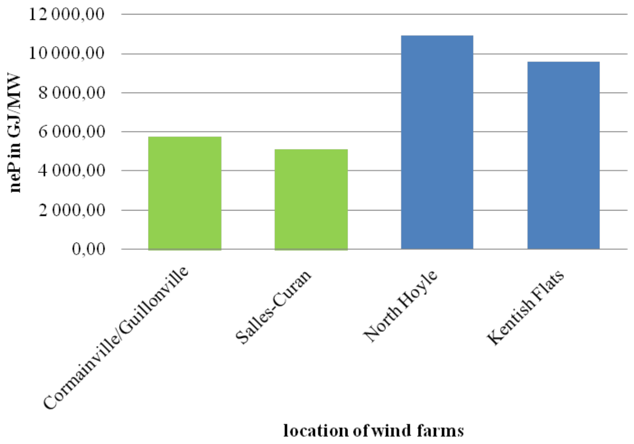

Figure 8: Demand for energy inputs related to total rated power

The examined volume of material inputs calculated per single wind turbine is about 35% higher in the case of the offshore wind turbines. However, the tested volume of the energy inputs is about 47% higher, as shown in Table 3. The volume of the calculated material and energy inputs is inversely proportional to the weight fraction of the various types of turbines (see Table 4).

As is shown in Fig. 3, the elements that make up a wind turbine are mostly steel, aluminum, other metals and polymeric materials. As regards the weight fraction of the turbine, the greatest weight is evidently the foundation. In the case of the onshore wind turbines the foundation is built of concrete and rebar, and accounts for 76% of the weight for a unit with a capacity of 2 MW and 78% for a turbine with a capacity of 3 MW. In the case of offshore wind turbines, monopile and jacket foundations are the most commonly used types; they are steel structures, so they make up only about 45% of the weight. The tower accounts for 15–30% of the wind power plant weight, the difference in weight is dependent on the height of the tower.

Demand for material inputs for the onshore farms is comparable with the demand for the offshore wind farms, as seen in Fig. 4 to 6. Demand for material inputs related to installed capacity is comparable for both types of farms, but the volumes of these inputs depend on the types of turbines used. The lower the turbine power, the greater the demand is for material inputs (see Fig. 5). Similarly, with an increase in power of the whole wind farm, the demand for material inputs increases. As seen in Fig. 6, the demand for material inputs in relation to the turbine working surface is about 35% higher in the case of the offshore wind farms.

Fig. 7 presents the demand for energy inputs related to total energy transmitted to the grid. Demand for energy inputs for the onshore wind farms is comparable to the volume of energy inputs for the offshore wind farms. A clear difference in the demand for energy inputs can be seen in Fig.s 8 and 9. The offshore wind farms have a greater demand for energy inputs, in relation to both total installed capacity and working surface of the turbine. There is a 47% difference in demand for energy inputs between the onshore and offshore farms.

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