Calculation of Environmental Profits with Weight Reduced Core Material in Rotor Blades

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Abstract

Construction of wind turbines has increased these recent years and is expected to escalate more in the nearest future. The expansion of wind power as an energy source requires specific and comprehensive transport, when production is far away from the installation site. Generally, the development of turbines has gone towards bigger turbines with longer rotor blades. As the blades grow in length, optimization of weight and sustainability will be more substantial. The turbine blades are subjected to high stresses and therefore the choice of materials for blade design is important. Weight and strength are two very important parameters to take into account. This article concludes the examination of the environmental profits of wind power with respect to different core materials in the sandwich construction used in the blades in the aspect of weight reduction.

I. Introduction

The task involves examining the environmental profits of wind power with respect to different core materials in the sandwich construction used in the blades. The environmental profits are defined as increased energy production for a wind turbine in the use of the products as well as reduced resource consumption in the transport and manufacturing of products to customers.
The wind turbine parameters and power output are chosen to represent an average onshore wind turbine from Vestas V112 3.0 MW, see Table 1.

Table 1: *Technical specifications of V112 [1]*

OPERATIONAL DATA	
Maximum rated power	3450 kW
Cut-in wind speed	3 m/s
Cut-out wind speed	25 m/s
ROTOR	
Rotor diameter	112 m
Swept area	9852 m^2
BLADE DIMENSIONS	
Length	54.7 m
Weight	11.9 tonnes

II. Methods

The work was initialised with a literature study to build up a base of understanding for wind turbines. Different calculations and data gathering was then made in order to achieve the final results.

i. Literature Study

The thesis work was initialized with a literature study in order to understand the function of wind turbines. With the help of the LCA [2], the scope for this thesis was defined. According to the assessment, there are three distinctive processes where there are environmental profits from decreasing the core material weight:

- Production of the core material of the rotor blade
- Transportation of turbine components to wind plant site
- Energy produced during wind plant operation

ii. Calculations

Calculations of the environmental profits has been made in three parts;

- CO_2 for the production of the core material
- overall power production
- transportation of rotor blades

The calculations for the power production are given in watt hours, Wh, which is converted to CO_2.

ii.1 Core Material Production

To calculate the amount of CO_2 that resulted when producing the different core materials, two things was needed: the volume of the materials and the emission factor for the materials. This information was provided by Diab, see Table 2.

Table 2: *Technical data for the core materials [3]*

	Density $[kg/m^3]$	Emission Factor
PN115	115	7.1
H60	60	6.6

ii.2 Transportation

The method chosen to calculate the greenhouse gas emission of a transport for this thesis was the method recommended by Naturvårdsverket, the Swedish Environmental Protection Agency [4]. In (1), E_{CO2} is the CO_2 emission in kg, C_{fuel} is the fuel consumption in m^3, H is the heat value defined in GJ/m^3 and E_f is the emission factor defined in kg/GJ.

$$E_{CO2} = C_{fuel} \cdot H \cdot E_f \tag{1}$$

ii.3 Electricity Production

The theoretical maximum power that can be extracted by a wind turbine is 16/27 or, approximately, 0.59 of the power of the free-flowing air in front of the rotor. This is usually described as Betz's Limit [5].

$$P_{max} = \frac{1}{2} A\rho \frac{16}{27} v^3 \tag{2}$$

In practice, usually only about 35% is utilized. The coefficient of power C_p of a wind turbine is a measurement in percent of how efficiently the wind turbine converts the energy in the wind into electricity. The wind power P can thus be estimated as

$$P = \frac{1}{2} C_p A\rho v^3 = \frac{1}{2} C_p \pi r^2 \rho v^3 \tag{3}$$

The kinetic energy in wind is converted to generate electricity or mechanical power. A lighter blade will require a lower wind speed to move and assuming that this difference in velocity can shift the power curve of the wind turbine to the left in Figure 1, more power will be generated.

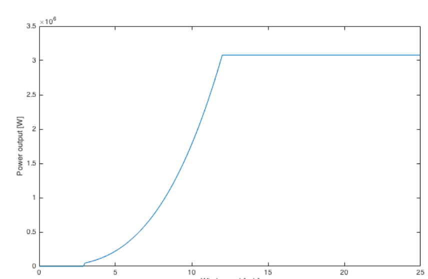

Figure 1: *Power curve for Vestas V112*

The aerodynamic forces are used to calculate the reduced wind velocity needed to move a lighter blade. The incoming air creates a lift force on the rotor blade airfoil which results in a torque. The lift force L is perpendicular to the direction of the oncoming air flow. This force is a consequence of the unequal pressure on the upper and lower airfoil surfaces. The drag force D is parallel to the direction of the oncoming air flow. This force is due both to viscous friction forces at the surface of the airfoil and to unequal pressure on the airfoil surfaces facing toward and away from the oncoming flow [6]. Lift and drag forces are illustrated in Figure 2, C_L denotes the lift coefficient, C_D denotes the drag coefficient. The aerodynamic loads are expressed in (4) and (5). B denotes the area of the orthographic projection of the object.

$$L = \frac{1}{2} B \rho v^2 C_L \tag{4}$$

$$D = \frac{1}{2} B \rho v^2 C_D \tag{5}$$

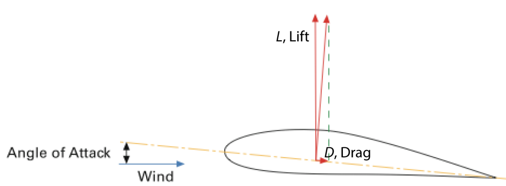

Figure 2: *Lift and drag forces on airfoil*

ii.4 Break-even Time

The break-even time after which the power production outweighs the power required over the lifetime of the V112 wind plant is 8 months, or 0.67 years [2]. This was derived by using following relation,

$$\frac{E_{life}}{E_{year}} = \text{Break-even Time (year)}$$

E_{life} = Energy requirement for the life cycle (GWh)

E_{year} = Energy produced in one year (GWh/year)

By using the results in this thesis for the savings in production and transportation of H60 instead of PN115, CO_2 converted to energy in GWh, the break-even time for the lighter blades are given.

III. Results

i. Total Environmental Profit

Calculations resulted in an environmental profit of 2096.7 tonnes CO_2 after a wind turbine's lifetime of 20 years by using core material H60 instead of PN115. The largest contribution of environmental profit came from the electricity production.

Table 3: *Total environmental profit in CO_2*

	CO2 [tonne]
Core Material Production	6.728
Transportation	0.013
Electricity Production	2090
Total:	2096.741

ii. Break-even Time

The break-even time, amount of time when the power production outweighs the power required over the lifetime, is 7.87 months compared to 8.04 months with the heavier core material. This corresponds to a reduction of 2%. This is around 5 days sooner than the break-even time with the heavier core material.

IV. Discussion

Factors that could have affected the results are the assumptions that were made. Annual electricity production according to Arise [7] is 8.5 GWh but the result was 5.1 GWh. Site placement was chosen to be Gubbhögen as it was rather close to Havsnäs which was used in the calculations made by Trafikverket [8]. 8.5 GWh is produced annually at the wind farm site

Skäppentorp which is much closer to the coast than Gubbhögen. Based on the placements of wind turbine plants that are owned by Arise, the mean wind speeds at Gubbhögen is maybe more suitable for a 2 MW turbine that has a lower wind speed range for power production. There is also uncertainty in the wind data used to calculate the electricity production as the adjusted wind speeds with the wind gradient is constant to the wind speed measured at the height of 10 m.

Lighter rotor blades would probably result in less wear and tear for the turbine which would require less replacement parts for turbine, less transports for maintenance and service, etc. The environmental profit (excluding end-of-life) in fact is probably larger than the result given by this thesis. This due to the restrictions made in the scope of this study.

Calculations of transportation was performed with a method given by Naturvårdsverket [4]; this part could have been performed with other methods. For example the method used by Trafikverket, which used the relation of 2621 g CO_2 per litre of fuel. The assumptions made for the transportation simplified the calculations which, of course, affected the given result. However, since the environmental profit given by the reduced weight during transportation was so extremely small, this wouldn't have given a big impact to the total result of environmental profit. The electricity production was calculated based on a theory which implicated a shift in the power curve, as a lighter blade requires a lower wind speed to move. This method was not that complex and a more advanced method involving simulations would probably be more accurate.

References

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