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LIFE CYCLE ASSESSMENT FOR WIND TURBINES

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ABSTRACT: Tech-wise A/S has conducted a life cycle assessment of a 2 MW offshore wind turbine. A life cycle assessment (LCA), also known as a cradle to grave analysis, is an inventory of all environmental impact of a product, process or service within its complete lifecycle. An LCA includes a recovery of the resources used in the production through the utilisation to the dismantling and disposal of the product. As sample wind turbine a 2 MW offshore wind turbine placed at Horns Rev in the North Sea has been used, since this project is under development and Tech-wise A/S is the main consultant to this project. In this LCA assumptions have been made where there is information about certain materials. The assessment revealed - as expected - that the environmental impact is concentrated in the production and disposal phase. Mainly the use of normal and high-strength steel are contributors. This means that the main impact is found to come from the nacelle and the foundation.

Keywords: Environmental Aspects, Off-shore, Materials, Life Cycle Assessment, EDIP-method

The results of this LCA will be used to identify the most essential environmental impact in all life phases of a 2 MW offshore wind turbine. This project is the first step in an examination of the possible improvement of the environmental performance of that particular wind turbine and was finalised in spring 2001. The plan is to finalise the next project by the end of 2001.

1. METHOD

As basis for the LCA the Danish EDIP computer tool is used based on the EDIP method (EDIP stands for Environmental Design of Industrial Products. In Danish it is called UMIP). The development of the EDIP method has been supported by the Danish Environmental Protection Agency. Using that method it is ensured that the LCA follows ISO 14040.

The EDIP tool includes a comprehensive database covering materials, semi-manufactured components and working processes, but the aim is to identify processes and materials that need further description to achieve a more correct assessment. Data from the environmental management system of Vestas Wind Systems A/S and data from subcontractors are utilised for the LCA.

2. BACKGROUND

In 2000 Tech-wise A/S concluded an LCA project of the Danish heat and electricity production in 1997, which was conducted in collaboration with other partners from the energy sector. In that project the wind turbines where represented by an average 600 kW land-based wind turbine. The conclusions from that project were that wind turbines are amongst the most environmentally friendly power production techniques. The main impact from wind turbines was found in the production process of the wind turbines and not so much in the utilisation phase, as is the case for traditional coal and gas fired power plants. The results from that project are used as a basis for this LCA for a 2 MW offshore wind turbine.

This LCA focuses on an offshore wind turbine and as a sample turbine for the assessment it has been chosen to apply a 2 MW wind turbine as the ones to be erected in the Horns Rev Offshore Wind Farm in the North Sea. This allowed the project group to use the data from the actual project at Horns Rev, e.g. the size of the foundation.

The innovation of this project is primarily the combination of an environmental management system with the LCA tool. An LCA has previously been conducted for wind turbines, but with this new procedure for data collection the assessment is expected to be more accurate and detailed.

2.1 Description of Horns Rev Wind Farm

The planned offshore wind farm at Horns Rev is used as example for the 2 MW offshore wind turbine model in this LCA. The wind farm will be established by Elsam A/S.

The Horns Rev wind farm will consist of 80 2 MW Vestas offshore wind turbines. All turbines will be 3-bladed rotors placed on a tubular tower. The foundation will be monopile. The farm will be located about 15 km off the coast of Blåvands Huk. The average water depth at the site is about 10-13 meter. The wind turbines will be connected to an offshore transformer from which the electricity is transmitted via a submarine cable to the land-based transmission grid.

3. ASSUMPTIONS AND BOUNDARIES

The foundations and wind turbine are included in this LCA, while the grid connection is disregarded. It means that this LCA only deals with the wind turbine itself, and does not include the distribution of the generated electricity.

Not all materials are included, as this is unrealistic to achieve. The goal has been to include a certain amount of the materials, as follows:

- 80% of the weight of all materials for the nacelle

[1] All correspondence

- 95% of the weight of all materials for the tower
- 90% of the weight of all materials for the blades
- 90% of the weight of all materials for the foundations

In this study the nacelle is taken to comprise the generator, gear, transformer, control electronics, cables etc.

The above-mentioned goals have been reached. But for some materials/products the information has been inadequate, and here the information has been estimated from identical products.

The LCA is based on the following main assumptions:

- A production of 8 GWh/wind turbine per year.
- A wind turbine lifetime of 20 years.
- No replacement of main components during the lifetime.

4. DATA QUALITY

Data on the production of the tower, nacelle and blades have been collected from Vestas Wind Systems A/S, who has collected a valuable infinite number of data through their environmental management system. Data for the materials have been collected from suppliers.

Data about the production of the foundations have mainly been based on in-house information, since Tech-wise A/S is main consultant to the Horns Rev Wind Farm.

Information about transport, assembly, erection, installation, maintenance and decommissioning of the wind turbine has partly been acquired in-house from Tech-wise A/S, from contractors and from Vestas Wind Systems A/S' service department.

The data are of varying quality, and the focus has been on the areas where the greatest environmental impact originate.

5. RESULTS

The main result of the LCA study is an improvement of the former LCA model for wind turbines. In an LCA the result is often presented as normalised environmental impact which is also the case here. A normalisation means that the contribution from 1 kWh of electricity is related to the average contribution from a normal citizen to the relevant environmental impact during one year. The results are reported in the unit milli-person-equivalent (mPE). If e.g. the greenhouse effect from 1 kWh of wind turbine electricity is 0.15 mPE it corresponds to 0.15‰ of a normal citizen's contribution from consuming 1 kWh electricity. The environmental impact of 1 kWh electricity produced by a 2 MW offshore wind turbine is presented in Figure 1.

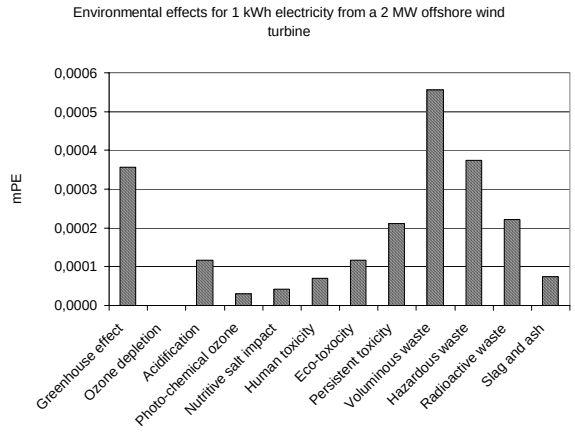

Figure 1.

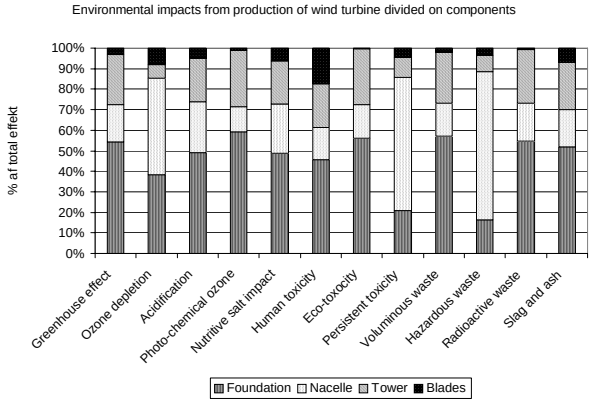

Figure 2.

Apart from the normalisation the result of the LCA can be an inventory of the consumed resources, as shown in Table 1. This inventory shows the main resources for 1 kWh electricity produced by a 2 MW offshore wind turbine. The dammed water is utilised for energy production at hydro power plants, and the 119 g of dammed water correspond to approximately 0.0002 kWh electricity.

To give an impression of the magnitude of the impact of 1 kWh from a 2 MW offshore wind turbine, this impact is compared to an average kWh of Danish electricity in 1997. See Figure 3 overleaf.

The composition of the electricity produced in Denmark in 1997 is shown in Figure 4 overleaf.

The comparison to the average Danish electricity in 1997 reveals that the wind generated electricity is much more clean than the average electricity.

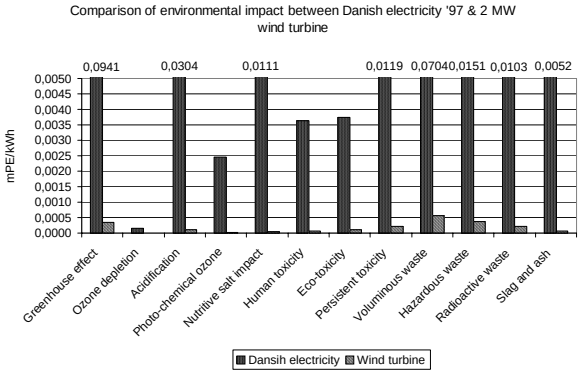

Figure 3.

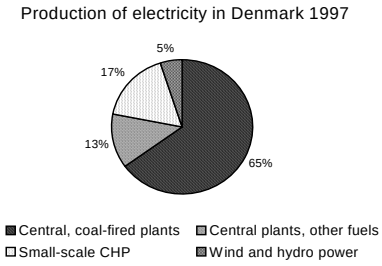

Figure 4.

6. CONCLUSION

One of the main conclusions of this LCA project is that the model for a wind turbine has been improved since the LCA for the Danish heat and electricity in 1997 was conducted. One of the main reasons for this improvement is the improved data available for this assessment.

A not very surprising conclusion is that the impact mainly originates from the production and disposal. It is found that the disposal scenario is very important to the environmental profile of the wind power.

The foundation/tower and the nacelle are found to give the greatest contributions to the most impact. The foundation and tower are the two heaviest components in a wind turbine and primarily made of steel. The nacelle contains quite a lot of high-strength steel which contributes considerably to the total impact from the wind turbine.

To continue this LCA work a new project is ongoing where the model will be even more refined and a comparison between a land-based and an offshore wind farm will be conducted. Furthermore the possibilities of using LCA results for environmental product optimisation and for Environmental Product Declarations will be investigated and tested.

The project reported in this paper has been conducted jointly by Tech-wise A/S and Vestas Wind Systems A/S and is supported by the PSO funds 1999.

Table 1.

Resource	**Amount [g/kWh]**
Dammed water	119
Other water	23
Coal (pit)	0.77
Iron	0.40
Natural gas	0.27
Oil	0.18
Calciumcarbonate ($CaCO_3$)	0.11
Lignite	0.08
Petrol	0.04
Aluminium (Al)	0.01

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