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LCA sensitivity analysis of a multi-megawatt wind turbine

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ABSTRACT

During recent years renewables have been acquiring gradually a significant importance in the world market (especially in the Spanish energetic market) and in society; this fact makes clear the need to increase and improve knowledge of these power sources. Starting from the results of a Life Cycle Assessment (LCA) of a multi-megawatt wind turbine, this work is aimed to assess the relevance of different choices that have been made during its development. Looking always to cover the largest possible spectrum of options, four scenarios have been analysed, focused on four main phases of lifecycle: maintenance, manufacturing, dismantling, and recycling. These scenarios facilitate to assess the degree of uncertainty of the developed LCA due to choices made, excluding from the assessment the uncertainty due to the inaccuracy and the simplification of the environmental models used or spatial and temporal variability in different parameters. The work has been developed at all times using the of Eco-indicator99 LCA method.

1. Introduction

Life Cycle Assessment (LCA) methodology [1,2] is useful for analysing the environmental impact occasioned by any type of product or process [3–7]. However, the results obtained with LCA present some uncertainties that have to be considered and assessed in an appropriate way. In general, these LCA uncertainties can be classified into, at least, five types: parameter uncertainty [8,9], model uncertainty [10,11], spatial variability [12,13], temporal variability [14–16], and life cycle scenario uncertainty [17–19].

LCA methodology has been frequently used to study the environmental impact occasioned by different renewable energy technologies [20–24]. The LCA of a multi-megawatt wind turbine [25,62,63] has been taken as a reference to develop this work, which is based on the Eco-indicator99 LCA method.

Moreover, studies of sensitivity analysis of LCA have been widely used in different areas, from the field of renewable energy [23] to the industrial field [26,27], including many different sectors such as residential construction [28], computers [29], and electronic boards [30]. For instance, [23] analyzes the impact of variations in the input material, the type of power considered in the manufacturing process, the transport, and the maintenance phase. In [28], a sensitivity analysis was carried out to find the impact of variations in life spans of the components, the need for extra room in micro-cogeneration plant, the efficiency of the auxiliary burner, and the electrical and overall efficiencies of the solid-oxide fuel cell plant.

Besides its practical application in several case studies, there also exists relevant literature on the development and analysis of the different methodologies used, from the analysis of different alternative scenarios to the statistical analysis of the uncertainty associated with the data used [31–34].

One of the purposes of this work is to analyse and assess the relevance of different choices that have been made during the development of the LCA. Four alternative scenarios have been studied. The first one (AS1) represents an increase in maintenance during the lifetime of the wind turbine. The second alternative scenario (AS2) analyses an increase in the needs of material and energy used. The third scenario (AS3) studies a change in the percentage of recycled materials during the disposal and waste treatment of the wind turbine. Finally, the fourth alternative scenario (AS4) analyses a change in the composite waste treatment of the blades at disposal time, from landfill to recycling.

These scenarios can facilitate to assess the degree of uncertainty of the developed LCA due to the choices made. Outside the limits of this work fall the uncertainty due to imprecise knowledge of the different parameters used in the Life Cycle Inventory (LCI), the spatial and temporal variability in different parameters of the LCI, or the uncertainty due to the inaccuracy and the simplification of the environmental models used.

2. Summary of the LCA of a multi-megawatt wind turbine

In order to facilitate the understanding of the work presented in this paper, a brief summary of the LCA that serves as the basis for the study is following presented [62,63].

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A LCA model of a wind turbine with Double Fed Induction Generator (DFIG) was developed [25] with the object of identifying the main types of environmental impact throughout the life cycle, in order to define possible ways of achieving environmental improvements for the particular type of wind turbine analysed or for similar ones. The wind turbine was a Gamesa onshore wind turbine, G8X model, with 2 MW rated power, and general dimensions: 80 m rotor diameter and 70 m height [35].

The final environmental effect of the wind turbine after a lifespan of 20 years and its subsequent decommissioning were studied, and the reduction in emissions and pollution due to the use of a clean energy source was also evaluated. It was analysed during the different stages of its life cycle, from cradle to grave, taking into consideration the production of each of its component parts, the transport to the wind farm, the installation, the start-up, the maintenance, and the final decommissioning, with its subsequent disposal of waste residues [36]. Outside the limits of the system under study fell the system of distribution of the electricity generated by the wind turbine (the medium-voltage wiring, the transformer substation, and the national electrical power network).

The software used in the environmental analysis was SimaPro 7.0 by Pré Consultants (SimaPro 2006). The procedures, details, and results obtained were based on the application of the existing international standards of LCA [2]. In addition, environmental details and indications of materials and energy consumption provided by the various companies related to the production of the component parts (specifically the foundation, the tower, the nacelle, and the rotor) were certified by the application of the environmental management system ISO14001 [37]. The LCA model included both the turbine and the foundations that support it, but not the system for connection to the grid (medium voltage lines and transformer substation). According to the requirements of the standard ISO14044, allocation was avoided, since in the study only the production of electrical power was considered as the function of the system.

LCA methodology was based on Eco-indicator99, and the functional unit was defined as the electric energy produced by the wind turbines during its lifespan. A series of cut-off criteria was established in order to develop the study in practice, by defining the maximum level of detail in the gathering of data for the different components of the wind turbine. The main cut-off criterion chosen was the weight of each element in relation to the total weight. This limitation in data collection did not mean a significant weakening of the final results obtained, but allowed us to streamline, facilitate, and adjust the LCA study to make it more flexible.

The characterisation of each component was obtained from the most important basic data of the manufacture, which are: the raw material required, the direct consumption of energy involved in the manufacturing processes, and the information of transport used. The information published by Risø National Laboratory [38] was used when it was not possible to obtain the energy cost of the manufacturing process directly. This information for specific substances included the primary energy consumption use related to the production, transportation, and manufacture of 1 kg of material.

Thus, the LCA was performed under the following conditions, due to limitations of time and cost:

- The cut-off criterion used was the weight of the components. The elements that were taken into account, altogether, made up 95% of the foundations, 95% of the tower, and 85% of the nacelle and rotors.

Table 1
LCA results of the base scenario in ecopointss (pt).

	Basic scenario					
	Maintenance	Tower	Foundation	Rotor	Nacelle	Total
Impact category						
Carcinogens	1457.5	97.4	3.3	153.9	1492.9	47,224.7
Respiratory organics	2.5	3.8	2.1	4.0	2.1	3205.0
Respiratory inorganics	1055.9	1011.4	798.0	3961.0	3172.8	14.5
Climate change	114.4	441.9	507.7	854.9	227.6	9999.1
Radiation	2.3	20.9	8.6	20.0	9.2	2146.5
Ozone layer	0.1	0.2	0.1	0.3	0.1	61.1
Ecotoxicity	3093.4	2796.5	529.9	249.9	3467.7	0.9
Acidif/Eutrop	131.4	204.4	177.1	568.1	340.0	10,137.4
Land use	293.5	194.0	99.7	88.6	696.8	1421.0
Minerals	429.7	1139.2	300.3	26.9	1211.2	1372.5
Fossil fuels	1259.5	3387.7	1930.7	7369.5	1812.1	3107.2
Total	7840.0	9297.4	4357.5	13,297.2	12,432.5	15,759.5

Table 2
LCA results of the base scenario in the characterisation phase.

	Basic scenario					
	Maintenance	Tower	Foundation	Rotor	Nacelle	Total
Impact category						
Carcinogens (DALY)	7.51E−02	5.02E−03	1.72E−04	7.93E−03	7.69E−02	1.65E−01
Respiratory organics (DALY)	1.29E−04	1.97E−04	1.07E−04	2.09E−04	1.08E−04	7.49E−04
Respiratory inorganics (DALY)	5.44E−02	5.21E−02	4.11E−02	2.04E−01	1.63E−01	5.15E−01
Climate change (DALY)	5.89E−03	2.28E−02	2.62E−02	4.40E−02	1.17E−02	1.11E−01
Radiation (DALY)	1.19E−04	1.08E−03	4.45E−04	1.03E−03	4.75E−04	3.15E−03
Ozone layer (DALY)	4.18E−06	1.19E−05	7.31E−06	1.54E−05	5.16E−06	4.40E−05
Ecotoxicity (PAF∗m2yr)	3.17E+05	2.87E+05	5.43E+04	2.56E+04	3.56E+05	1.04E+06
Acidif/Eutrop (PDF∗m2yr)	1.35E+03	2.10E+03	1.82E+03	5.83E+03	3.49E+03	1.46E+04
Land use (PDF∗m2yr)	3.01E+03	1.99E+03	1.02E+03	9.08E+02	7.15E+03	1.41E+04
Minerals (MJ surplus)	1.28E+04	3.39E+04	8.94E+03	8.02E+02	3.60E+04	9.25E+04
Fossil fuels (MJ surplus)	3.75E+04	1.01E+05	5.75E+04	2.19E+05	5.39E+04	4.69E+05