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Life cycle assessment of a multi-megawatt wind turbine

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ABSTRACT

At the present moment in time, renewable energy sources have achieved great significance for modern day society. The main reason for this boom is the need to use alternative sources of energy to fossil fuels which are free of CO_2 emissions and contamination. Among the current renewable energy sources, the growth of wind farms has been spectacular. Wind power uses the kinetic energy of the wind to produce a clean form of energy without producing contamination or emissions. The problem it raises is that of quantifying to what extent it is a totally clean form of energy. In this sense we have to consider not only the emissions produced while they are in operation, but also the contamination and environmental impact resulting from their manufacture and the future dismantling of the turbines when they come to the end of their working life. The aim of this study is to analyse the real impact that this technology has if we consider the whole life cycle. The application of the ISO 14040 standard [ISO. ISO 14040. Environmental management – life cycle assessment – principles and framework. Geneva, Switzerland: International Standard Organization; 1998.] allows us to make an LCA study quantifying the overall impact of a wind turbine and each of its components.

Applying this methodology, the wind turbine is analysed during all the phases of its life cycle, from cradle to grave, with regard to the manufacture of its key components (through the incorporation of cut-off criteria), transport to the wind farm, subsequent installation, start-up, maintenance and final dismantling and stripping down into waste materials and their treatment.

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1. Introduction

At the present time, renewable energy, and particularly wind power energy, is becoming increasingly relevant in the world's electricity market. Over the last few years renewable sources of energy have won the legislative support of governments in several countries [2–6]. This support has taken the form of various legal frameworks with stable and lasting premiums. If we look at the current scene in the implementation of renewable energy, we can see the rapid advance made by wind power and its significant contribution to the electricity supply network in several countries, both at European and world level (see Fig. 1). Wind power supplies less than 1% of electricity now [7]. In the EU, 4% of the power installed originates from wind power and in Spain the figure is 9% [8]. Current forecasts predict that wind power will contribute 12% of the global demand for electricity by 2020 [9]. This huge boom in implementation and forecasts for wind power installation makes clear the need to increase people's understanding of this power source [10,11]. Although there are several analyses about environmental impact of renewable energies [12–15], not many life cycle assessment studies exist for current wind turbines with high rated power [16–18]. So an LCA model has been developed with the purpose of being able to assess the wind energy and the related emissions to produce current wind energy production technology. Furthermore, the LCA model can be used to define the energy payback time.

2. Life cycle assessment of a wind turbine

2.1. Goal, scope and background

The LCA model which has been developed seeks to identify the main types of impact on the environment throughout the life cycle of a wind turbine with doubly fed inductor generator (DFIG). The study has specifically focussed on the Gamesa onshore wind turbine model G8X with 2 MW rated power installed in the Munilla wind farm. This wind farm is located in the autonomous community of La Rioja, in northern Spain. This is a complex terrain located at 1200 m altitude. The general dimensions of this wind turbine are 80 m rotor blade, 5027 m^2 sweep area and a height of 70 m. This project is the first phase of a more wide-reaching one which seeks

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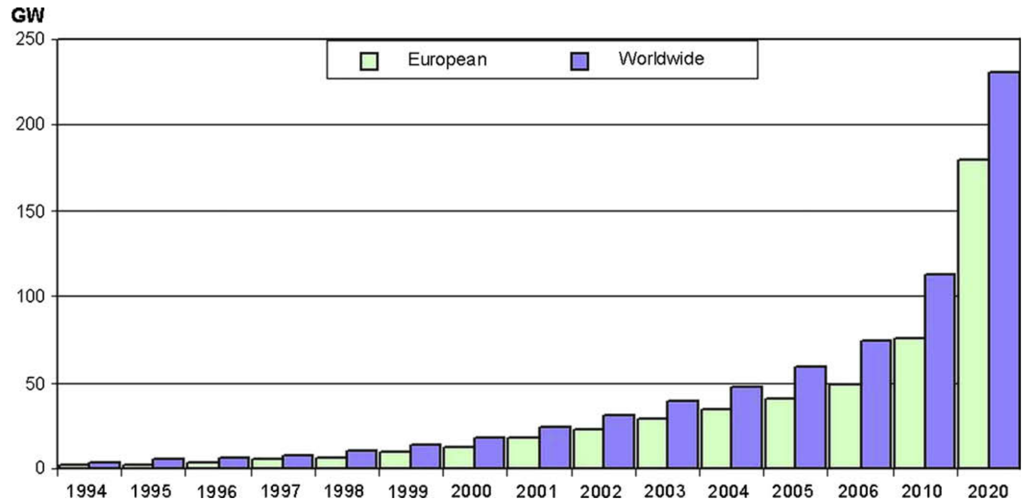

Fig. 1. Evolution and future objectives for wind power installments.

to define possible ways of achieving environmental improvements for this particular type of wind turbine. To achieve this goal we have started by analysing the wind turbine during the various stages of its life cycle, from cradle to grave, taking into consideration the following: the manufacture of each of its component parts, transport to the wind farm, installation, start-up, maintenance and final decommissioning with its subsequent disposal of waste residues.

2.2. Functional unit

As the functional unit for the system, we have selected the kWh produced by the wind turbine in such a way that it has been possible to obtain a relationship between the environmental impact of the turbine and the electricity generated. In this way it is possible to make a posterior comparative study with regard to other kinds of energy producing technology.

2.3. Life cycle inventory

Fig. 2 shows an outline of the model used for assessing the environmental impact of a wind turbine during its whole life cycle.

A wind turbine consists of many electrical, electronic and mechanical parts and components. The components of a wind turbine, such as the nacelle, also comprise many sub-components and/or electrical parts. It is difficult to gather all the information on all the

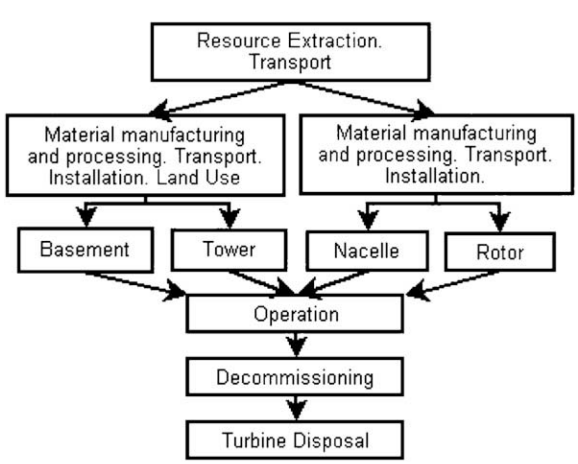

Fig. 2. LCA model of the wind turbine.

parts and components from suppliers. We focused on compiling the LCI data on important components such as the base, the tower, the nacelle and the rotor. However, in the few cases in which the data found were not sufficiently reliable and proven, we used quasi-process information from commercial SimaPro software. The materials and energy used in the various components were incorporated into the model using data provided by Gamesa and the commercial databases of SimaPro.

When considering transport, distances have been calculated from specific maps as far as the real emplacement of the Munilla-Lasanta wind farm. During the operational phase, all the maintenance operations have been taken into account. These maintenance operations are performed by the owner company of the wind farm and recorded in its environmental management system according to the ISO 14001 standard. Among the maintenance tasks programmed we can check quantities of oil and grease used, replacement of filters and transport, among others.

Below we briefly describe each of the components analysed.

2.3.1. Foundations

The base has a volume of 270 m^3 of concrete and a total weight of 700 t and uses 25 t of iron for the reinforcing bars (see Table 1). The steel ferrule used to connect and support the turbine tower weighs 15 t (see Table 1). During the lifespan of the wind turbine the possible emissions from the foundation into the environment have not been considered. In the decommissioning process it has been assumed that the foundations will be left in place and covered with a layer of 20–30 cm of organic soil [19].

2.3.2. Tower

In the study conducted only the processes of shaping and welding steel have been considered. The surface treatment was considered as irrelevant with regard to the final result of the analysis. Once the whole tower is erected it measures 67 m and weighs 143 t (see Table 1). During the operation of the wind turbine no maintenance work on the tower is provided for. In the decommissioning process of the tower, the material undergoes a recycling process in which losses of material are estimated at 10% [20]. An average material loss rate of 10% has been assumed for recycling process.

2.3.3. Nacelle

The structure of nacelle consists of a bed frame and a nacelle cover made of composite material (prepreg). Inside nacelle are the

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