

Fully parameterized LCA tool for wind energy converters

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Abstract Wind energy is supposed to provide the world with “clean” and almost carbon neutral energy, reducing the emission of anthropogenic greenhouse gases and other environmental impacts. While the energy produced in the use phase of wind energy converters (WEC) is as good as carbon neutral there are environmental impacts coming from production, transport and disposal of the WEC. Here the question about the WEC's energy balance and actual CO₂-savings comes up. To find answers to this and other questions a project in cooperation between ENERCON GmbH and the University of Bremen has been carried out. Within this project a fully parameterized LCA Tool for ENERCON WECs has been developed. This tool uses about 330 partly predefined parameters and allows to assess the environmental impacts and to calculate the harvest factor and the energetic payback time of different converter types at different sites.

1 Introduction

Wind energy plays a key role in the energy supply of the future and has even today a share of around eight percent of the total energy consumption in Germany [1]. WECs with a total wattage of between 1,550 and 3,150 MW have been installed annually for the past ten years [2]. This rapid expansion of wind energy is not only caused by a growing demand from customers for green energy, it is also promoted by the federal government through the renewable energies act (Erneuerbare Energien Gesetz, EEG).

The essential hope that is connected with wind energy is that it will make a major contribution to the efforts of limiting climate change by providing comparably clean energy. However, there is only limited data on the environmental performance of WECs available and at least some of the existing studies prove to be more or less based on assumptions and estimations instead of primary data. Furthermore the overall environmental performance strongly depends on the site

of the WEC and other site specific factors as well as the inherent technological aspects of the converter. Site specific parameters are for example the wind conditions that are crucial for the energy production or the condition of the soil that determines what foundation needs to be laid. On the technological side there are aspects like the tower that can be of concrete as well as steel or a combination of both, the material of the nacelle, or a design with or without a gear. Even converters from the same manufacturer can vary strongly from each other in terms of used materials, production processes etc.

In contrast to this difficulty WEC producers experience an increasing demand for environmental figures like carbon footprint, CED, energetic payback time or harvest factor from customers. These figures show how environmental friendly wind energy actually is and how big its potential to save CO₂ is.

In order to answer these questions, to calculate the energetic payback time and the harvest factor and to analyze other environmental impacts of WECs a project in cooperation between ENERCON GmbH and the University of Bremen has been carried out. Within this project a fully parameterized LCA Tool for ENERCON WECs has been developed, allowing conducting LCAs for different converter types at different sites.

2 Development of the tool

For the building of the LCA tool an extensive collection of primary data has been carried out. This data has been completed with data from PE databases and literature and was transferred into a parameterized material flow model in the LCA software GaBi 4. A more detailed description of the proceeding for data collection and modeling can be found in [3].

As it was a requirement to the tool to allow to examine a WEC's energy balance as well as to perform complete life cycle assessments only complete LCA datasets have been used.

The collection of primary data has been carried out directly in the manufacturing sites of the various WEC components like rotor blades, generator, nacelle, electronics and tower. As ENERCON has a comparatively very high in-house production depth the required data about materials, production processes and wastes as well as construction and maintenance had been available at first hand. This data has been completed with datasets from PE databases [4][3]. PE datasets have mainly been used to model raw material production, energy supply and waste treatment.

Based on an analysis of the product system 330 relevant parameters that vary depending on the site and the converter type and that are important for the environmental performance of the WEC have been identified. These parameters are partly pre-defined based on the collected primary data.

The parameters can be divided into production parameters, use phase and site specific parameters and end-of-life parameters. The production parameters are mostly pre-defined based on the primary data for the different converters and tower types. Here the user simply has to choose the respective converter-tower combination he wants to assess. The respective materials and production processes are configured accordingly and automatically.

The use phase and site specific parameters depend on where the WEC is located and therefore are most likely to be different for most assessments. Figures like the wind conditions, the size of the foundation, the length of the access roads and the number of service trips per year belong to the use phase and site specific parameters among others. These aspects will usually be available to the user when a particular converter shall be assessed. They can then be entered manually into the tool. However, there are recommendations available in case some of these parameters are unknown or not available at the time.

For the end-of-life the user has several options, too. Besides a cut-off approach and a basis scenario that is based on the state-of-the-art for the recycling of WECs the user can select an optimistic as well as a conservative scenario with different recycling rates and credits. Additionally it is possible to choose for every component between recycling and re-use with value adjustment.

The following table shows a selection of several parameters of the LCA tool that need to be entered by the user.

Tab.1: Selection of LCA tool parameters

Parameter	Description
converter type	allows to choose between different converter types, e.g. E-70 or E-82 E2
tower type	allows to choose between different tower types, e.g. 107m pre-cast concrete tower or 77m steel tower
production waste	allows to choose between different scenarios for the treatment of the production waste
transport	allows to define distances for transport by truck, train, ship (inland) and ship (ocean)
life span	allows to define the WEC's life span in years
full load hours p.a.	allows to define the expected number of full load hours

	per year, depending on the specific wind conditions
power consumption	allows to define the amount of energy that the converter obtains from the grid
service trips per year	allows to define the number of service trips per year
distance to service station	allows to define the distance to the nearest service station
length access roads	allows to define the length of the access roads that need to be built for the WEC
EoL scenario	allows to choose between several EoL scenarios

After entering the parameter values the WEC's life cycle inventory is calculated and the impact assessment can be carried out. Technically the user is free to choose between different methodologies and impact categories here. Nevertheless the following results have been considered as the key figures in accordance with ENERCON's requirements:

- Cumulated energy demand (CED)
- Net energy production
- Harvest factor
- Energetic payback time
- Global Warming Potential/ Carbon Footprint

The CED is the sum of the primary energy used over the converter's life cycle, e.g. for production, use and disposal. The net energy production is the amount of energy that is produced minus the energy that the converter obtains from the grid over its life cycle. The harvest factor indicates the ratio between the energy fed into the grid by the WEC and the CED. The energetic payback time is the time after which the WEC fed an amount of energy into the grid that equals the CED.

For identifying the global warming potential the CML methodology is used (see for example [5]). In addition to the global warming potential over the entire life cycle the carbon footprint per kWh is calculated. This makes it easier to draw a comparison to other power generating technologies.

3 Exemplary results

As described before the LCA tool can be used to perform specific assessments of any included combination of converter, tower and site. To demonstrate this capability an assessment for the ENERCON E-82 E2 at three different sites is described in the following (see [3]). The E-82 E2 is a WEC for medium wind

speeds with 2.3 MW rated power. For this analysis a 97 meter precast concrete has been chosen. This results in a total height of the WEC of about 140 meters. The three different sites under assessment are a coast-site, a near-coast site and an inland-site. The main differences between them are the wind conditions. The wind conditions result in 3,100 full load hours per year at the coast-site, in 2,500 full load hours at the near-coast site and 2,170 full load hours at the inland site. For the three different scenarios the converter's life span has been assumed to be 20 years. For the end-of-life the basic scenario that is based on today's state of the art has been chosen.

3.1 Cumulated energy demand

The CED depends mainly on the production and disposal phase is therefore alike for the different scenarios. It amounts about 2,880 MWh. The main contribution arises from the production phase with more than 80 percent while the operation of the WEC including service and maintenance contributes only little (<8 percent).

3.2 Net energy production, harvest factor and energetic payback time

As the main differences between the scenarios are the wind conditions, the net energy production varies accordingly. At the inland-site there is a net energy production of 101,990 MWh, at the near-coast-site 117,500 MWh and at the coast-site 147,000 MWh. Based on this, the harvest factor for the inland-site is 35.4, for the near-coast-site 40.8 and for the coast-site 51. That implies that at the different sites under assessment the WEC feeds between 35.4 and 51 times more energy into the grid than it consumes primary energy throughout its life cycle. Fig. 1 shows the energy production in the different scenarios and the CED in comparison.

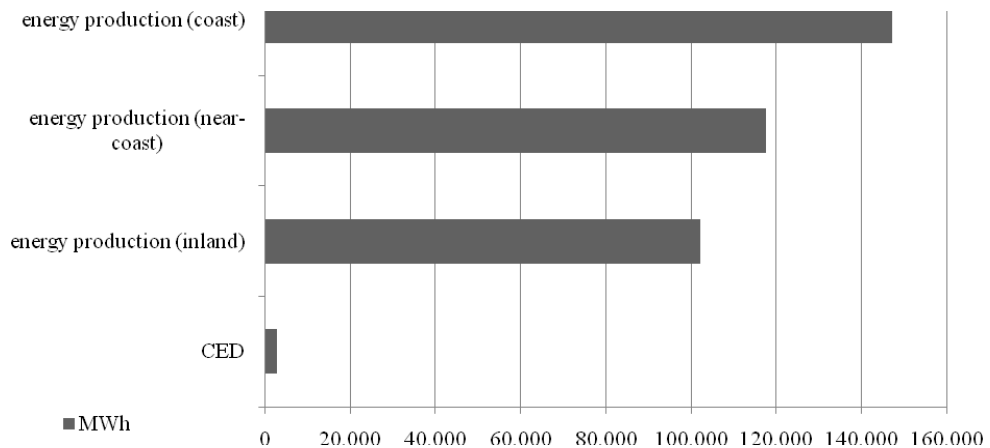


Fig. 1: Energy production and CED in comparison

The energetic payback time that results from the CED and the net energy production is 6.8 months for the inland-site, 5.9 months for the near-coast-site and 4.7 months for the coast-site. So, after between 4.7 and 6.8 months depending on the site the converter produced an amount of energy that equals the energy it consumes over its entire life cycle.

3.3 Global warming potential and carbon footprint

Just like for the CED, the global warming potential is about the same for the three scenarios. About 901 tons of CO₂ equivalents are emitted over the WECs life cycles. The figures per kWh are however varying. Here the WEC at the inland-site comes to 8.9 grams of CO₂e per kWh. The WEC at the coast-near-site has a carbon footprint of 7.7 grams of CO₂e per kWh and the coast located WEC has a carbon footprint of 6.1 grams of CO₂e per kWh .

Over the life cycle this means considerable CO₂ savings compared to the grid mix (here, the PE dataset for the German grid mix has been used [4]). These savings amount to 58,611 tons of CO₂e for the inland-site, 67,678 tons of CO₂e for the near-coast-site and 84,893 tons for the coast-site.

...Comparison with coal and photovoltaics?...

3.4 Parameter variations

Besides performing assessments for fixed parameter settings the LCA tool allows to analyze the effect of parameter variations. This capability will be demonstrated in the following by varying two parameters that have a significant impact on the net energy production - the average number of the full load hours and the life span. These parameters have been varied for the near-coast scenario. The number of full load hours has been varied from 2.000 to 4.800, the life span from 10 to 30 years.

For the full load hours this resulted in a range of 30 to 72 for the harvest factor and an energetic payback from 8 to 3.3 months. Fig. 2: Variation of full load hours Fig. 2 shows these results.

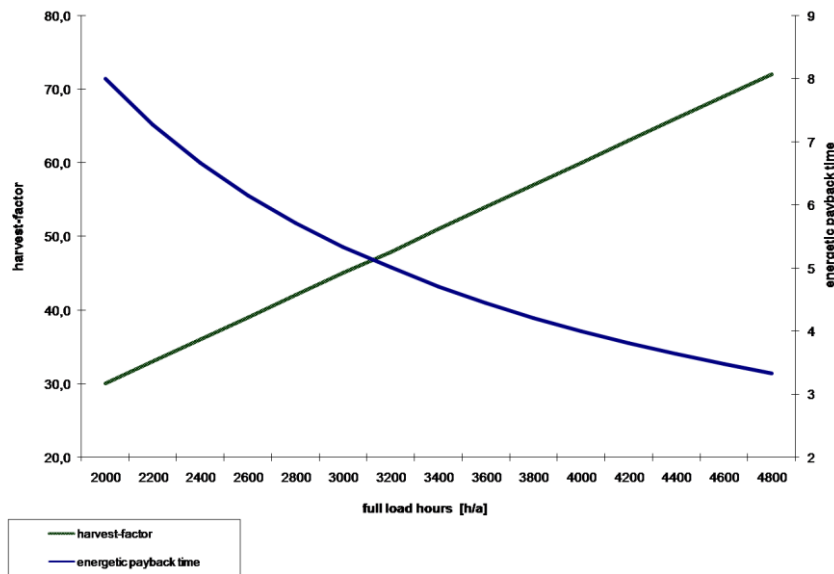


Fig. 2: Variation of full load hours

The variation of the life span has only marginally impact on the CED, while net energy production and harvest factor are heavily influenced. The harvest factor ranges between 21 for a life span of ten years and 56.5 for a life span of 30 years. The impacts of a variation of the life span on CED, harvest factor and energy production are shown in Fig. 3.

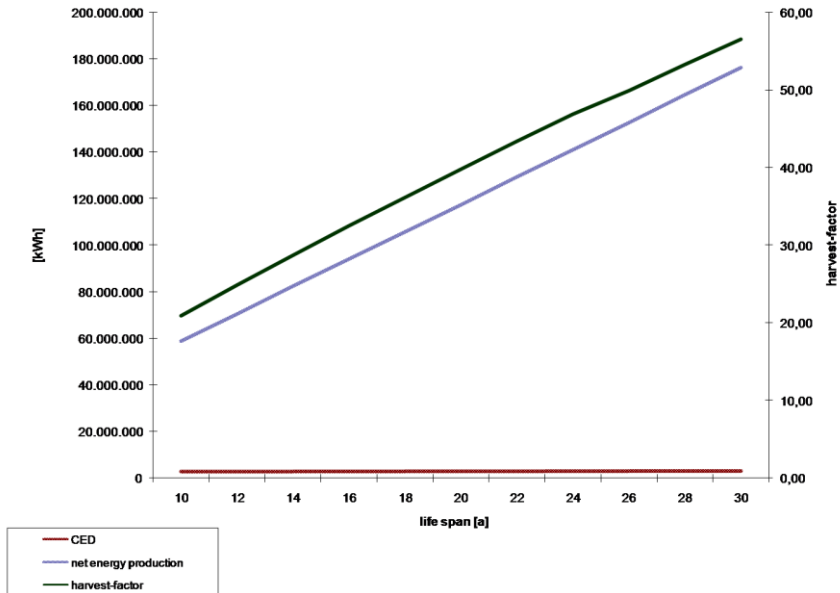


Fig. 3: Variation of life span

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