LCA_WIND_DK: temporally, geographically and technologically-sensitive life cycle inventories for the Danish wind turbine fleet

Romain Besseau, Romain Sacchi, Paula Perez-Lopez, Isabelle Blanc

LCA_WIND_DK: temporally, geographically and technologically-sensitive life cycle inventories for the Danish wind turbine fleet

Romain Besseau[1], Romain Sacchi[2], Paula Pérez-Lopéz[1], Isabelle Blanc[1]

[1] Centre Observation, Impacts, Energie (OIE), MINES ParisTech PSL Research University
[2] Department of Planning, Aalborg University
E-mail contact: romain.besseau@mines-paristech.fr

1. Introduction

The environmental performance of a wind turbine is usually calculated as the ratio of the life cycle impacts occurring during the manufacture, installation, maintenance and dismantling of the plant, to the electricity it produces during the use phase [1]. The modelling of the life cycle inventory in each phase should ideally cover the temporal, geographical and technological dimensions of the product system under study, since parameters that relate to the country of manufacture, the location of use or the technology govern the performance of the wind turbine [2]. Assumptions are commonly used to simplify and handle variable aspects of the inventory often know *a posteriori* [1]. While this approach provides generic one-size-fit-all inventories, it may disregard important characteristics of the wind turbine leading to biased end-results. As these assumptions are prone to differ from one study to another, the results become hardly comparable [1]. With more than 1,500 wind turbine models on the market and a high variability of locations and manufacture periods of the different installations, it makes the environmental assessment of wind turbine fleets a daunting task.

It is the case notably for Denmark, where the wind power penetration rate stood at 45% of the gross production in 2016 [3]. Despite the predominance of wind power, the LCA model of the Danish Transmission System Operator relies on generic wind turbine inventories and conditions of use from the Gabi LCI database [3]. There has been since then, an attempt to model detailed projections of the Danish electricity system with increasing shares of renewable energy sources, based on observed production data provided by the national TSO [4] and the wind turbines were modelled here again from generic ecoinvent inventories, via the life cycle assessment energy-modelling tool EASETECH Energy [5]. The issues of transferability and comparability of models from one site to another with a parametrized model that considers the location of use and the technological characteristics of the evaluated plant have been addressed by Zimmerman [6] and such modelling do represent a major step towards site-specific modelling for wind turbines fleets.

Current available life cycle assessment studies of regional or national wind turbine fleets are based on generic average values site and do not consider time-specific inventories. In light of the current state of the art, this study aims at a comprehensive fleet modelling based on spatial, technological and site specific LCAs.

2. Materials and methods

LCA_WIND_DK is an on-line tool that provides the environmental footprint of Danish wind turbines based on systematic individual cradle-to-grave life cycle inventories that are temporally, geographically and technologically sensitive. Information of all wind turbines installed in Denmark since 1980 have been collected by the Danish Energy Agency [7] including their geo-localisation, dimensions, model and yearly measured production.

The technological aspect has been included in the inventory by linking wind turbine models and dimensions to a manufacturer’s database containing the specific weights of wind turbine components. The temporal context is considered through the evolution of the electricity mix used for manufacturing the wind turbines as well as the evolution of the recycled content in materials over time. In the past, the electricity mix had a higher carbon footprint and steel had a lower content of secondary steel [3, 8]. The spatial dimension is also accounted through geographical parameters such as the distance to the coast and sea depth for offshore installations. Such distance and depth will determine the length of cables and the amount of materials for the foundations. The geographic context is also considered for the supply chain with the selection of relevant material and energy suppliers (e.g. use of German steel market [8]).

Finally, the Danish fleet, known in detail from 1980 to 2016, has been projected from 2017 to 2030 based on national objectives for onshore and offshore installed capacity and a list of pre-approved offshore park projects [7]. The approach considers the registered electricity production for past and present wind turbines, and allows the estimation of the future production of each wind turbine based on its power curve and geo-localized wind time-series provided by the MERRA-2 weather reanalysis model.

The tool generates a life cycle inventory and impact assessment for each of the 11,000 wind turbines that compose the Danish national fleet over the 1980-2030 period. The open-source LCA-library Brightway2 was used for the calculations and Ecoinvent 3.3 cut-off was used as the source of background data. Environmental impacts were calculated for a selection of impact categories recommended by the ILCD Handbook.

3. Results and discussion

Denmark, where modern wind turbines were first installed in the 80s and contributed to 45% of the gross annual electricity production in 2016, is a prominent choice to demonstrate the benefits of such spatial, technological and site specific LCA model associated to an on-line tool. The results are showcased as a map where the individual performance of each past, present and future wind turbine can be consulted, as well as the performance of the whole fleet at a given year, as shown in Figure 1.

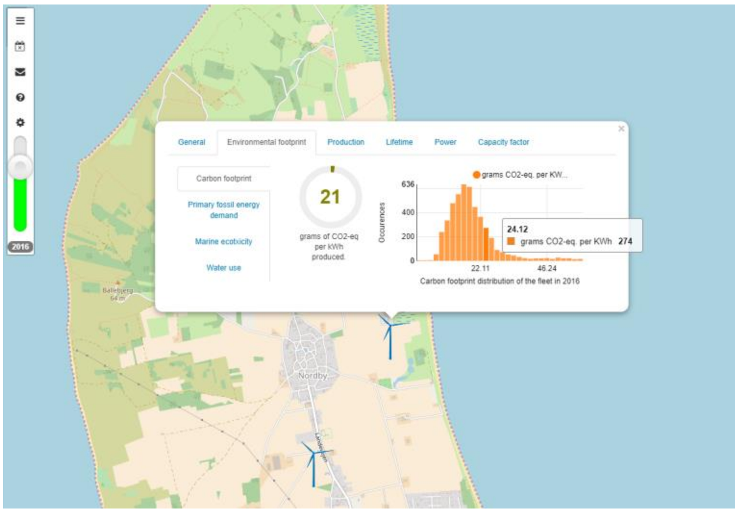

Figure 1: Screen capture of LCA_WIND_DK for the carbon footprint in 2016

The comprehensive analysis of the Danish wind turbine fleet performance between 1980 and 2030 highlights the long-term reduction of the carbon footprint. The environmental performances for most of the other evaluated impact categories are correlated with the carbon footprint. This is not the case, however, for offshore turbines in impact categories where copper has a high contribution to the total impact. In these categories, the impacts are also correlated with the weight of the cable to reach the coast.

Environmental improvements from 1980 to 2030 are mainly explained by a higher electricity production per power output, which results of larger wind turbines and a progressive deployment of offshore installations with better wind resources. The increasing share of renewable energy supply in the electricity mix used to manufacture the wind turbines and a higher recycled content in the steel also contribute to the environmental improvements of the fleet over time.

4. References

[1] Asdrubali et al. 2015. Life cycle assessment of electricity production from renewable energies: Review and results harmonization. Renewable and Sustainable Energy Reviews. 42:1113–22.

[2] Lenzen, Munksgaard. 2002. Energy and CO2 life-cycle analyses of wind turbines—review and applications. Renewable Energy 26:339–62.

[3] Energinet, https://en.energinet.dk/Electricity, 2017.

[4] Turconi et al. 2014. Environmental impacts of future low-carbon electricity systems: Detailed life cycle assessment of a Danish case study. Applied Energy. 132:66–73.

[5] Christensen et al. 2013. EASETECH - A Dedicated Waste Management LCA-Model. Proceedings Sardinia. CISA publisher.

[6] Zimmermann. 2013. Parameterized tool for site specific LCAs of wind energy converters. The International Journal of Life Cycle Assessment. 18:49–60.

[7] Danish Energy Agency, https://ens.dk/service/statistik-data-noegletal-og-kort, 2017.

[8] German Steel Federation, http://en.stahl-online.de/index.php/statistics/, 2017.