DTU Library

Simple model for assessment of energy production and costs of offshore wind farms

Sørensen, Jens Nørkær; Larsen, Gunner Chr.

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Wind Resource, Wind Farms and Wakes:

Simple model for assessment of energy production and costs of offshore wind farms

J.N. Sørensen[a] and G.C. Larsen [a,b]

Keywords: Offshore wind farms; energy production, levelized cost of energy; CAPEX and OPEX

Measured by the investments and efforts by the European wind energy industry to reduce the costs of offshore wind power, it is clear that offshore wind power will become a very important part of the future European wind power production. As an illustration of this, more than 105 offshore wind farms have been erected in Europe, contributing with an installed capacity of more than 18.000 MW, of which more than one third have been established within the past three years [1]. With respect to global installations of offshore wind power, 2019 was a year of record growth, with 6.1 GW of capacity added and cumulative global installations of 29.1 GW, and more than 205 GW of new offshore wind capacity is forecast through 2030 [2]. This rapid development demands access to fast and accurate predictive tools for assessing site-dependent energy production and costs.

The aim of the present work is to develop a simple, robust and reliable numerical framework that may aid developers and decision-makers in assessing the economic aspects of developing offshore wind power at a specific site. The idea is to have a tool to make initial cost analyses without the need of detailed technical information regarding the utilized wind turbines or the actual topology of the wind farm. Hence, ideally, the model only requires information on turbine size (rotor diameter and nameplate capacity), size of wind farm (number of turbines and wind farm area, or, alternatively, average distance between the turbines), and site Weibull parameters as well as water depths and distance to the coast. The output of the tool is the average annual power production, power intensity (power per unit area), installation costs (CAPEX), operation and maintenance costs (OPEX), and Levelised Cost of Energy (LCoE).

In the developed model, we employ the atmospheric wind farm boundary layer model of Frandsen [3] to assess the wind turbine array (wake) effect in the atmospheric boundary layer, and combine it with a wind resource model based on the site Weibull distribution adjusted for wake effects. This part of the model is important, as it determines the change of the Weibull parameters of the wind field within the wind farm due to wake effects. Furthermore, as the model of Frandsen [3] essentially is for an infinite wind farm, a simple correction is introduced that allows computations of the power production for wind farms of finite size. As cost model, we employ a set of simple parametrical expressions for the most essential wind farm cost elements, such as costs of wind turbines, support structures, cables and electrical substations, as well as Operation and Maintenance (O&M). To take into account the influence of wake effects on O&M expenses, a new expression has been developed that includes the spacing between the wind turbines, as well as the distance to the coast, as parameters. A description of the full model is given in Sørensen and Larsen [4], where

[a] Dept. Wind Energy, DTU, Kgs. Lyngby, 2800, Denmark
[b] Dept. Wind Energy, DTU, Roskilde, 4000, Denmark

the model is explained in detail and where it is validated on actual performance and cost data for a series of full-scale wind farms.

In Fig. 1 computed wind power production (GWh/year) are compared to actual production data for different wind farms (LG: Lillgrund; RS1: Rødsand 1; RS2: Rødsand 2; HR1: Horns Rev 1; HR2: Horns Rev 2; HR3: Horns Rev 3). It is here seen that the model is capable of computing the annual energy or power production within an accuracy of about 5%. Fig. 2 shows the wind power production per area unit (MW/km^2) for the different wind farms. Besides displaying the same accuracy as on Fig. 2, the figure shows the large differences in actual power production per area unit between the different wind farms. However, the expenses of having a high intensity of power yield, is that the levelized cost of Energy (LCoE) increases. In spite of its high power intensity, the LCoE for the Lillgrund wind farm is about double as big as for the other wind farms. It should be mentioned, however, that it is difficult to get actual LCoE data from the developers and therefore also difficult to validate the numerical predictions of LCoE. For the newly established Kriegers Flak wind farm in the Baltic Sea, the computed LCoE is found to be 51.4 Euro/MWh. The actual cost price of energy is, according to Vattenfall [5], anticipated to be 49.6 Euro/MWh (37,2 øre/kWh), which is within a difference of 4%. Fig. 3 shows a comparison in capital expenditures (CAPEX in M€) between actual and computed costs in 2019 prices. As for the energy production, we here get an accuracy within about 5%. Hence, in spite of its simplistic nature, the model is found to predict costs and power production of offshore wind farms with a surprisingly high accuracy.

References

1. Wind Europe: Offshore Wind in Europe: Key trends and statistics 2018. Published in February 2019 by WindEurope.org. https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2018.pdf
2. GWEC: Global Offshore Wind Report 2020. https://gwec.net/wp-content/uploads/2020/12/GWEC-Global-Offshore-Wind-Report-2020.pdf
3. Frandsen, S.T. (1992) On the Wind Speed Reduction in the Centre of Large Clusters of Wind Turbines. Journal of Wind Engineering and Industrial Aerodynamics, 39, pp. 251-265.
4. Sørensen, J.N. and Larsen, G.C. (2021) A minimalistic prediction model to determine energy production and costs of offshore wind farms. Energies, 14, 448. https://doi.org/10.3390/en14020448
5. Vattenfall homepage: https://group.vattenfall.com/dk/vores-forretning/vindprojekter-i-danmark/kriegers-flak

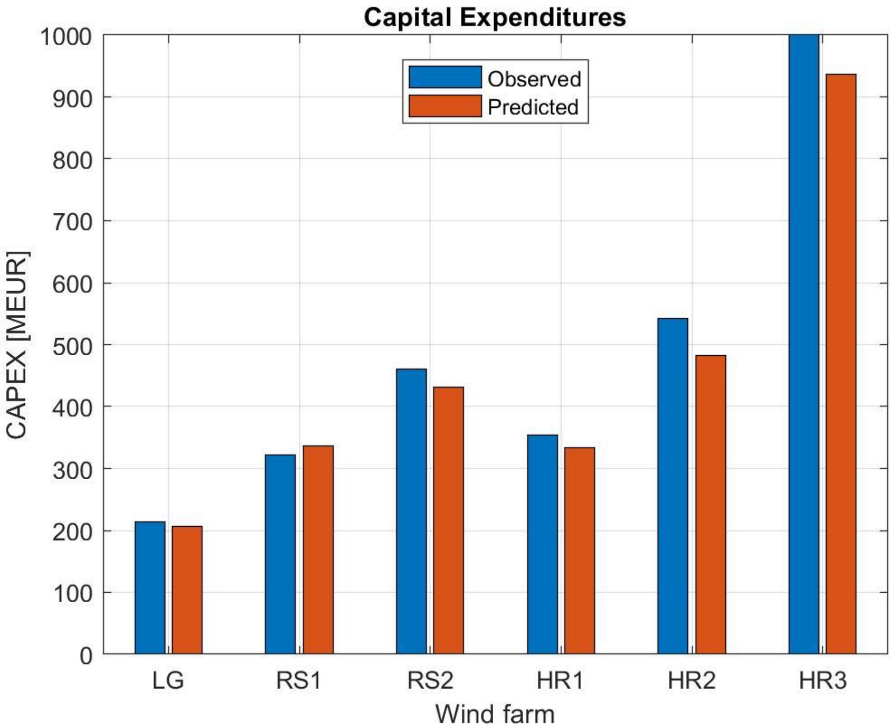

Figure 1. Comparison between computed and actual production data for different wind farms

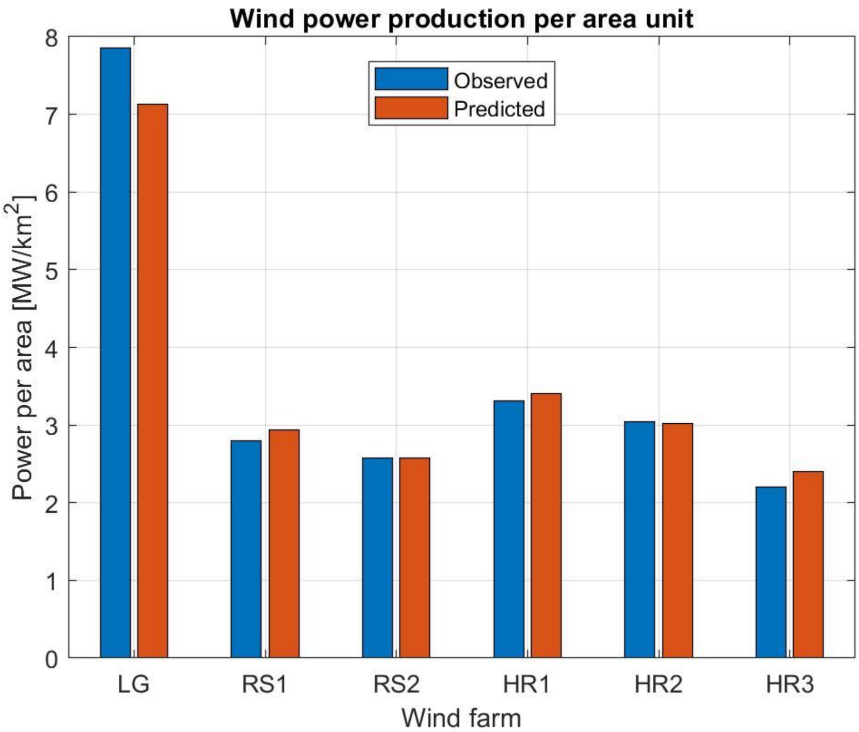

Figure 2. Comparison between computed and actual power intensities for different wind farms

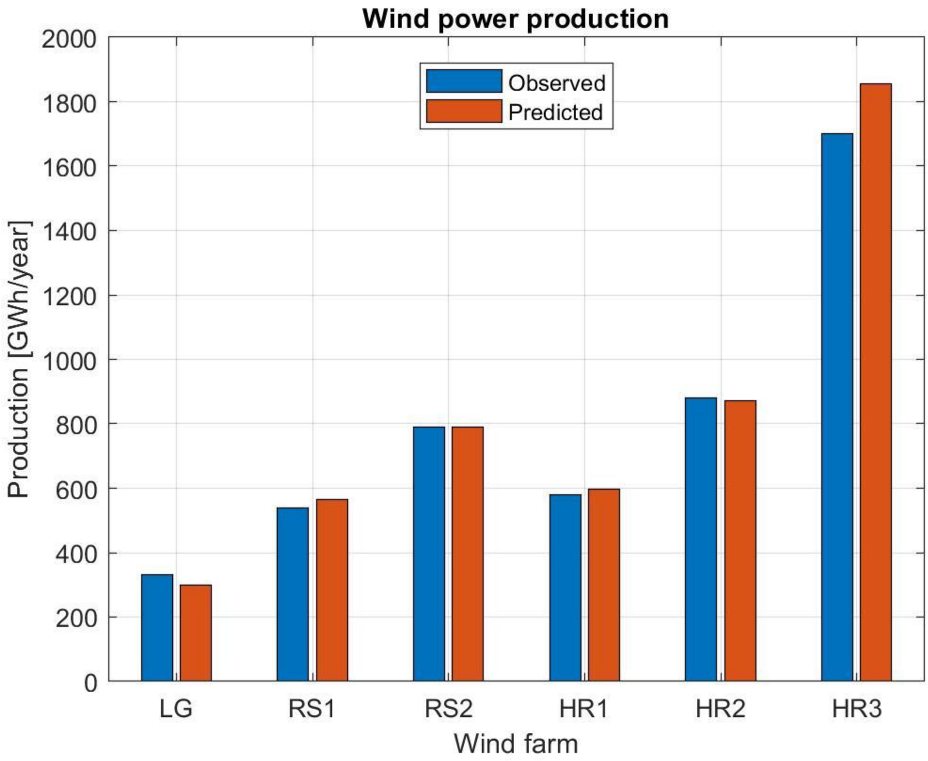

Figure 3. Comparison between computed and actual CAPEX for different wind farms