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Reply to 'The perils of automated fitting of datasets: the case of a wind turbine cost model'

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Abstract

Assessing the investment costs of wind power plants with different technological parameters is a challenging task. Previously, a cost model to predict specific investment costs using chosen technology parameters was created by fitting a function to cost data. The model, however, shows incorrect scaling behaviour with large installed capacity. A new model was tested with the original data, but it is difficult to estimate its quality without an extensive analysis.

Klöckl et al.[1] raised justified critique towards the wind power plant (WPP) cost model described in our previous article[2] on the effects of turbine technology development and land use on wind power resource potential. The cost model for predicting specific investment costs (EUR/kW) of a wind power plant consists of two parts. The site-independent part is described by the turbine rotor diameter and specific rating (generator capacity per rotor swept area, $\mathrm{W\,m^{-2}}$) as well as the tower height. The site-dependent part is described by the properties of the site: cost of building road and transmission grid connection to the wind power plant. Klöckl et al. argued that the site-independent part of the model exhibits a considerable generalisation error: the total cost of a wind power plant becomes negative with large amounts of installed power due to incorrect scaling behaviour of the model. As they stated, however, the flaw most likely did not impact the results of the article.

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Table 1: Wind power plant investment costs predicted using a regression model based on literature data. The hub height is fixed at 100 metres.

Turbine model	Rotor diameter (m)	Rated power (kW)	Specific rating ($W\,m^{-2}$)	Predicted cost (EUR/kW)
V90-3.0 MW	90	3,000	472	1,056
V90-2.0 MW	90	2,000	314	1,320
V117-3.45 MW	117	3,450	321	1,309
V136-3.45 MW	136	3,450	237	1,449

The aim of the site-independent part of the cost model was to differentiate only the chosen turbine models by terms of investment cost. Hence, the model was an application for calculating the economic potential in the case presented in the paper, and not a general one. In this regard, increasing only the installed power and keeping other parameters constant, which leads to implausible total costs as showed by Klöckl et al. (see Fig. 1 in ref.[1]), is a somewhat unfair exercise. They also calculated the total cost for many real turbine cases showing that our model fails for some technology configurations with high specific rating (high generator capacity per rotor swept area). We admit that the non-generalisability of the cost model should have been stated more clearly.

Specific rating and tower height were chosen as the technology parameters because of the recent development in both of them, as outlined in the introduction of the article. We do not argue that lower specific rating would lead to lower investment costs. Site-independent investment costs predicted using the cost model actually show increase in the cost with decreasing specific rating at a constant hub height, see Table 1. This was expected, and we previously showed that even with higher specific investment costs, the new (low-specific rating) turbine vintage of 2015 had higher economic potential in the presented case.

Alternative cost model

Fingersh et al.[3] presented a detailed bottom-up cost model for wind turbines. However, we originally decided not to use that methodology because of the need for extensive additional data on materials and labour costs. In addition, the model is already quite old being published in 2006, and recent development in wind turbine technology during the last ten years or so was the main driver of our article.

The cost model by Fingersh et al. can in principle be presented as a large polynomial function of turbine radius, rated power and hub height as well as their integer and real exponents. For this reply, we examined how this kind of polynomial could be fitted to the same cost data we used previously in ref.[2]. The coefficients of the polynomial were estimated using non-negative least squares regression to disallow negative correlation for any of the terms. The solution included non-zero coefficients for only some of the parameters: turbine rated power and its square as well as the product of hub height and turbine radius. The model can thus be expressed using the equation

$$I \approx 507P + 0.103P^2 + 59.9(hR)^{1.1736} + 621 \times 10^3, \tag{1}$$

where I is the total investment cost (EUR), P is the installed power (kW), h the hub height (m) and R the rotor diameter (m).

The errors of the model with this little data points were not normally distributed. The details of both the old (used in ref.[2]) and the new alternative cost model based on exponential polynomial are published as Jupyter Notebooks[4].

Conclusions

It is clear that the model we chose in ref.[2] is not suited for estimating the site-independent investment costs of WPPs in general. As stated in the article, the largest source of uncertainty in the economic potential was the site-independent (specific) investment cost given by the fitted cost model. Better estimates on the economic potential of wind power would require better data on the cost of wind power with different technology configurations. Creating a generalisable cost model for wind power with relevant technology parameters would help this task, but requires solid understanding of the model creation process. Since potential estimates are used to make decisions well into the future, a proper cost model should also include the time dimension.

Methods

Data availability Wind turbine investment cost data used in creating the cost model are available in Zenodo with the identifier doi:10.5281/zenodo.3362356 (ref.[4]).

Code availability The Jupyter Notebooks including Python code used to create the cost models are available in Zenodo with the identifier doi:10.5281/zenodo.3362356 (ref.[4]).

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Competing interests

The author declares no competing interests.

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Author contributions

E.R. conducted the analysis and prepared the manuscript draft for the reply. All authors participated in discussing the manuscript.