Manuscript ID: WES-2023-39 Turbine scaling for offshore wind farms

Authors: Mihir Kishore Mehta, Michiel Bastiaan Zaaijer, and Dominic von Terzi

In this work, using a wind farm cost model, the authors are demonstrating the possibility to find an optimum turbine scale for a given wind farm case. Cost and AEP gradients over rotor diameter and rated power are used to visualize the mutual effects within the wind farm. A sensitivity analysis on the model parameters (costs, farm characteristics) are presented. Lastly, different scenarios with respect to wind farm design constraints are investigated, which could be useful for wind farm developers.

The topic is of definite interest to the scientific community and is well written. I do have some comments and request of changes before the final publication.

General comments:

The title looks a bit too general; it could have been more specific.

- In general, the level of detail in the cost equations are low. But maybe this is fine. Authors have made the code public so the results should be reproducible, but maybe a short Appendix to the paper can help the reader to better understand some details.

Section 2.2:

- Line 101: T"he design space w.r.t. the two design variables, P and D, is **shown** in Fig. 2a, where the entire framework is run for the discrete set of points **shown**". Please review this sentence.
- Equation (2). The decommission costs C_{DECOM} introduced in this equation are not explained in the text of this section (even not mentioned). Please provide a short description about these costs as done for the other.
- More in general: a NOMENCALTURE table can be useful
- Figure 2.a & 2.b. I understand that in extreme cases like 10MW turbine with 300m diameter rotor and 20MW turbine with 180m, rated wind speeds are set very low and very high, respectively. Maybe this point needs to be further elaborated in the text, making a connection to Weibull distribution and dependency on average wind speed, as we see later in the paper. It could be that for high/low wind sites, the design space should be adapted accordingly.
- More in general , is not clear where the data of Fig2b come from. Which data and model have been used to extract these LCoEs?

Section 2.3.:

- Line 113. Is not clear why the model uses non-dimensional thrust LUT and dimensional power LUT (C_T and $P_{turbine}$).
- Line 116 & Eq. (3): "The ratio of the rated wind speeds (V_{rated}) compensates for any additional increase/decrease in the thrust due to a change in the rated wind speed for turbines with a specific power different from that of the reference turbine." This assumes that a linearly scaled aerodynamic and structural shape of the blade would result in the same thrust coefficient as the reference turbine. One can work with this assumption, but it needs to be clearly stated in the text.
- It is not clear to me if the rated wind speeds are changing when the rated power of the turbines are changed as they are scaled from reference. Even for two wind turbines with same specific powers, v_rated can be different if the resulting power coefficients are different. Finally, are

there some constraints on the maximum rotor speed, for instance to include some simplified noise-constraints) ?

Section 2.3.4 Support Structure

- Not very critical but it is not written which type of foundation is used in the model. The reader can presume that it is monopile, but I think it is better to make it clear.
- Line 157. The sizing is based on ultimate limit. Which are these limits? How the loads have been considered?

Section 2.5

- Cut-in cut-out wind speeds are not mentioned. It is not very critical, and they are probably kept constant, but it would be nice to add for completeness.

Section 3.1

- One could draw a line equivalent to the specific power 350 W/m2 investigated later in the paper, connecting the points calculated for that comparison. With that maybe it would also justify the selection of this specific power in section 3.1, showing that it coincides with the turbines investigated there. A separate figure LCoE vs specific power could also be added (like a scatter plot).

Section 3.2.

- A separate figure LCoE vs specific power could also be added (like a scatter plot). The points equivalent to the specific power 350 W/m2 investigated in Section 3.1 could be highlighted in this plot as well.
- Figure 8a: I think it is showing negative gradients, i.e. cost decrease per change in D and P.
- Equations 16, 17, 18. I honestly do not know this type of notation used to describe the derivatives. For example, the last one, $\frac{\partial AEP}{\partial D \partial P}$ looks wrong. From the right hand side of the equation it's clear that you are computing the FIRST derivative of AEP wrt ONE variable, so it should be $\frac{\partial AEP}{\partial D}$ and $\frac{\partial AEP}{\partial P}$, two different first order derivatives wrt to the two variables. Otherwise one should write $\frac{\partial^2 AEP}{\partial D \partial P}$ referring to the second derivative of the AEP wrt the two variables, i.e. $\frac{\partial}{\partial D}\left(\frac{\partial AEP}{\partial P}\right) = \frac{\partial}{\partial P}\left(\frac{\partial AEP}{\partial D}\right)$. But it's clear from the results of this derivate that the authors refer to the first case, i.e. the gradient wrt every single variable.

Chapter 4:

- Section 4.2 and 4.3 are a bit difficult to follow in general. A table where all these constraints and their impacts on major cost elements, AEP, wake losses etc. are summarized (with arrows going up/down etc.) could be nice.
- Figure 13: It seems graphically in Figure13b that the vector sum of gradients AEP' and Cost' from 'fixed-are-only' case would point to higher rated power and lower diameter. However, the new global optimum is located at higher rated power but also higher diameter. This shows that going in the direction of the gradient at baseline optimum would yield a local optimum. The explanations given in this section have different 'weightings' at every point in this design space. Maybe this point is worth emphasizing.

Chapter 5 Conclusion

- I am wondering if the presented results are sensitive (if yes, how sensitive) to the starting baseline design. We see that global optimum is found at 15MW rated power, which is equal to the rated power of the starting design IEA 15MW turbine with a smaller diameter. Can it be that Cp Ct curves, which are calculated using baseline design, are causing a bias towards 15MW?

- Line 586: “However, while the optimum specific power is fairly sensitive to particular project conditions, this shift is less sensitive to scale (first bullet point).” Second part of the sentence is not clear to me, rephrasing could be necessary.