Review of *Should wind turbines rotate in the opposite direction?* by Antonia Englberger, Julie K. Lundquist, and Andreas Dörnbrack

Reviewer: M. Paul van der Laan, DTU Wind Energy

The authors employ large-eddy simulations (LES) of a single actuator disk subjected to different stable atmospheric boundary layers to investigate the impact of the rotational direction on the potential downstream wind turbine power. The article has an interesting topic and I think it is worth publishing an in depth study about it. However, I have four main concerns with this work. First of all, the inflow is not a solution of the LES model, but simply set as an initial condition without any inflow turbulence. Secondly, the methodology of quantifying the impact of the rotational direction of the rotor on a downstream wind turbine is not sufficient and the reported gains in power are misleading because they only reflect a few specific cases that are rare with respect to all the flow cases that are typically present in an annual energy production calculation of a wind farm. Thirdly, the information provided in the article is not sufficient to redo the simulations and understand the presented results. Finally, I disagree with the main conclusion. I provided an Appendix where I have performed Reynolds-averaged Navier-Stokes simulations of two NREL-5MW wind turbines with 7D spacing subjected to an atmospheric inflow with a strong wind veer. I also see a relatively large impact of the rotation direction on the power output of the downstream wind turbine for a specific wind direction. However, my simulations suggest the opposite of the present paper, where a clockwise rotating wind turbine in the Northern Hemisphere performs better than a counter-clockwise rotating wind turbine (subjected to a strong wind veer). This is because the initial horizontal wake deflection for clockwise rotating wind turbine (without the effect of wind veer but including a wind shear) is clockwise (as seen from above). The counter-clockwise rotating wake brings fresh momentum from above towards the right side of the wind turbine, which results in a stronger deficit on the left side, and this causes the wake to deflect clockwise at seen from above, as shown by Zahle and Sørensen (2008). The addition of wind veer in the Northern Hemisphere deflects the wake even more clockwise, which is also shown in van der Laan and Sørensen (2017). Hence, I disagree with the authors conclusion. I have written a list of main and minor comments below. Since there are so many major concerns, I am afraid that I have to reject the article.

Main comments

1. Why do use a scaled down version of the DTU-10MW wind turbine? Wouldn't it be easier to either use the NREL-5MW wind turbine or the original DTU-10MW wind turbine (which is an upscaled version of the NREL-5MW wind turbine)? These reference wind turbines are made to make a comparison between scientific literature in wind energy more fair, and using a reference wind turbine allows other researchers to redo your simulations more easily.

2. Page 4, Line 26: Here you mention that you set different magnitudes of wind veer over the rotor area. How do you set these magnitudes? It seems that you specify them according to an initial profile from Eq. (6), without changing the physical parameters that actually influence the wind veer, i.e. the Coriolis parameter or geostrophic wind (for a constant inversion strength and atmospheric stability). If this is the case then all simulations will converge to the same wind veer if you run them long enough unless you have periodic conditions on all four lateral boundaries. You never mention the word *precursor* or which boundary conditions you use, so it is unclear to me how you make sure that inflow has reached a quasi steady-state before you apply the inflow to a wind turbine wake simulation. If you do not use a precursor simulation, then the inflow will develop downstream and you cannot isolate the wake effects from the imbalance of the inflow profile. If you do use a precursor simulation for each case, then please specify all the input parameters necessary to run each case. In addition, it would make sense to plot all inflow profiles and report the wind speed and turbulence intensity (for example based on the turbulent kinetic energy) at hub height. Furthermore, you seem to use a laminar

inflow (without a roughness length), which does not make sense when modeling a wind turbine wake subjected to an atmospheric inflow.

3. Eq. (9): What is η_{mech}? If you intend to calculate the electric (hypothetical) power from the mechanical (hypothetical) power, one would expect to have a 6% loss for a modern wind turbine, not 36%. In addition, it is unclear where the power in the other two dimensions are evaluated (y and z), you only mention the downstream distance. Furthermore, I would expect to the power to scale with U^3 and I would take the integral of U^3 over the rotor area. Please clarify. In addition, if you are not considering a second wind turbine, you are ignoring upstream effects of the downstream wind turbine. It is worth while to mention this simplification.

4. It would be nice to report the tip speed ratio, the thrust coefficient and the power coefficient, for each case. This information is necessary to replicate your simulations.

5. Table 1: This table is confusing. Why do you have both clockwise and counter-clockwise at the same row? I also get confused with the amount of cases and labeling. You also use these labels all the time in the article and it makes it hard to follow the text. Couldn't you simplify the cases and pick those that are really important for your conclusions?

6. Table 1: How is it possible to get a negative and positive wind veer for the same Coriolis parameter? This seems to me that your inflow profile is not in balance with your equations because these kind of effects are typically caused by (unsteady) meso-scale phenomena, which you are not modelling, as far I can understand.

7. I would expect the wake deflects differently for different rotor rotation directions or the wake deflects simply more for a certain rotor direction. Is this correct? It might be worthwhile to discuss and show this (for example with a wake center tracking method). In addition, if you had a downstream wind turbine in unfavourable staggered position, then the additional wake deflection could reduce the power of the downstream wind turbine.

8. Figure 1, why not just plot wake deficit profiles as function of the cross coordinate at different downstream distances? Now you are only looking directly behind the wind turbine, while the wake has deflected laterally (and possible vertically as well), so you are missing a lot of important information.

9. The stream-wise velocity contour plots presented of Figures 3, 5 and 6, do not seem to resemble converged statistics. If you have converged statistics, then I expect smooth plots, see for example the low turbulence intensity case in van der Laan and Andersen (2018), where 1 hour LES results are presented. This could indicate that your LES data set is not large or long enough, or your simulation has not converge to a (quasi) steady-state, but keeps changing instead.

10. Conclusion and abstract: You have to mention that the simulated power increase of 23% only reflects a specific wind direction. In other words, if you would consider multiple wind directions, then the impact of rotor rotation direction on the power (deficit) is much smaller than you report. In addition, if a full wind farm is considered, I expect that the effect of rotation direction is reduced further downstream in the wind farm because of an increase in turbulence level. Finally, if one would look at the effect of the rotor rotation on the wind farm annual energy production, which also consists of many flow cases, where rotor rotation has no influence, you might find that the effect of rotor rotation direction is far less than 1%. Such the study would be necessary in order to answer the question raised in the title.

    If your title is *Should wind turbines rotate in the opposite direction?* then I expect to find a thorough answer in the article. The presented simulations cannot answer this question because we need an estimate of the rotor rotation direction on the annual energy production.

Minor comments

1. Page 2, Line 20. Remove (SH) at the end of the sentence.

References

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Appendix A: Reynolds-averaged Navier-Stokes simulations from reviewer

I have performed Reynolds-averaged Navier-Stokes (RANS) simulations of two NREL-5MW wind turbines (Jonkman et al., 2009) with 7D spacing. The wind turbines are aligned for a wind direction of 270°and 90°. The wind turbines are represented by actuator disks, where the forces are based on airfoil data. The wind turbine force controller is described in van der Laan et al. (2015b). The turbulence is modeled by the limited-length scale k-ε model of Apsley and Castro (1997) coupled with the k-ε-f_P model of van der Laan et al. (2013), the latter has been developed for wind turbine wake simulations. The model setup is described in more detail in van der Laan et al. (2015a); van der Laan and Sørensen (2017). The inflow is generated by a precursor simulation and it represents a stable atmospheric boundary layer, where a maximum turbulence length scale of 5 m is set and geostrophic wind speed of 8.4 m/s is chosen. Buoyancy source terms and a temperature equation are not included, the effect of the stability is solely modeled by setting a maximum turbulence length scale, as described in detail in Apsley and Castro (1997). The Coriolis parameter is 10^{-4} 1/s and the roughness length is set to a typical offshore value of 10^{-4} m. This results in wind speed and turbulence intensity at hub height of 8 m/s and 3%, respectively. The wind veer over the rotor diameter is approximately 12°. The inflow is plotted in Figure A1.

I have run two cases where:

1. Both wind turbines rotate clockwise.

2. Both wind turbines rotate counter-clockwise.

Figure A2 show the power of the downstream wind turbine for the two cases, for a range of wind directions between 240° and 300° with an interval of 2°. Figure A3 shows the relative difference in power of the downstream wind turbine for the two cases. The RANS simulations indicate that the downstream wind turbine has more power when the upstream wind turbine is rotating in the clockwise direction for most wind directions, with a maximum difference of 26%, for a wind direction of 274°. A clockwise rotating wind turbine deflects the wake slightly clockwise (as seen from above) due to the interaction with the shear, as shown by Zahle and Sørensen (2008). The wind veer (in the Northern Hemisphere) also deflects a wind turbine clockwise (as seen from above), as shown in van der Laan and Sørensen (2017). Hence, a clockwise rotating wind turbine and the wind veer in the Northern Hemisphere compliment each other to increase the clockwise wake deflection, which result in an increased power output of the downstream wind turbine for a small range of wind directions. This is the opposite conclusion of the present article.

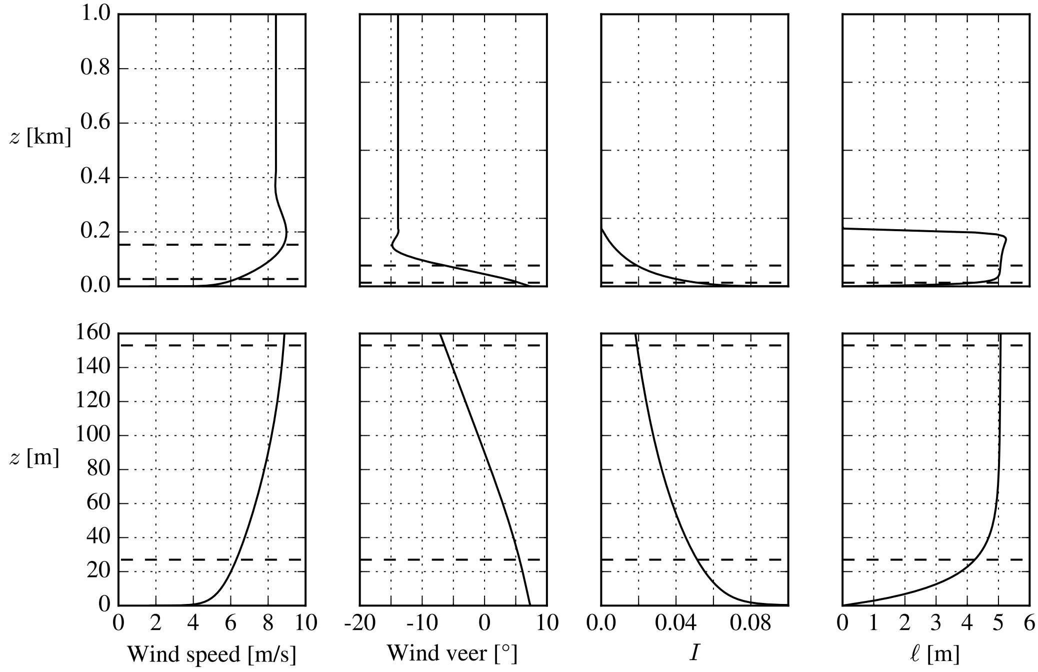

Figure A1. Inflow profiles of wind speed, wind veer, turbulence intensity (I) and turbulence length scale (ℓ). Bottom plot is a zoom of the top plot. Dashed lines represents the boundaries of the rotor plane.

Please note that the RANS simulations presented here use a coupled turbulence model that has not yet been validated thoroughly and might need a re-calibration. However, I expect that the model can predict the qualitative difference between the two cases (clockwise and counter-clockwise rotation) accurately. I have checked that my simulations produce a counter-clockwise wake rotation for a clockwise rotating wind turbine and a clockwise wake rotation for a counter-clockwise rotating wind turbine. I have also checked that the inflow wind veer is rotating clockwise while going up in height. In addition, the RANS setup represent an idealized ABL, which means that the model cannot represent a wind profile with backing.

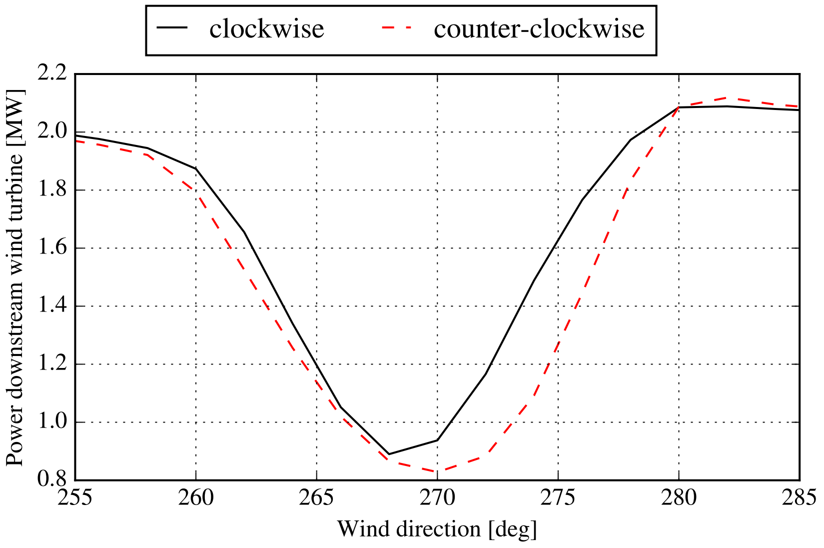

Figure A2. Power of downstream wind direction for clockwise and counter-clockwise rotor rotation using an atmospheric boundary inflow with a strong wind veer for the Northern Hemisphere.

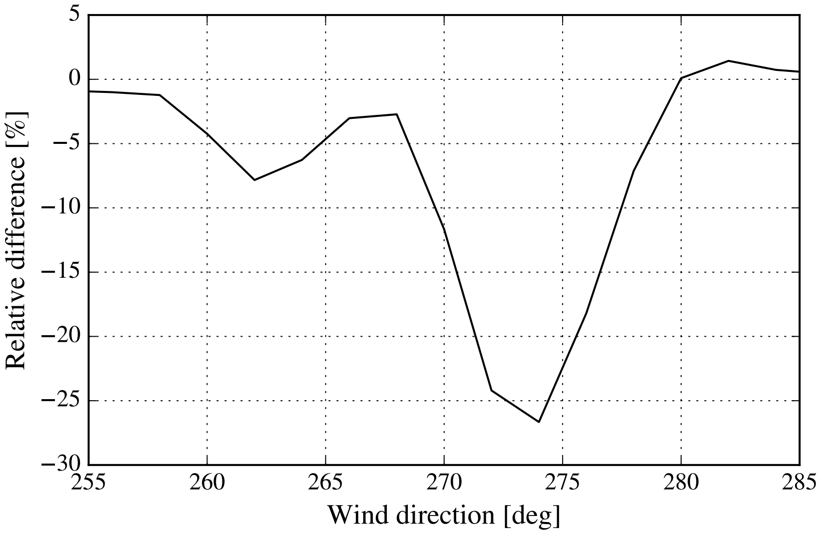

Figure A3. Relative difference in power of downstream wind direction for clockwise and counter-clockwise rotor rotation using an atmospheric boundary layer inflow with a strong wind veer for the Northern Hemisphere. Negative difference means more power for the clockwise rotating wind turbine.

To show that a clockwise rotating wind turbine induces a clockwise wake deflection (as seen from above), and to show that a counter-clockwise rotating wind turbine induces a counter-clockwise wake deflection (as seen from above), I have performed additional RANS simulation for neutral surface layer inflow conditions (logarithmic law), using a wind speed and turbulence intensity of 8 m/s and 6%, respectively, at hub height. No Coriolis forces and wind veer are present and only the k-ε-f_P model is used as described in van der Laan et al. (2015c). The results are presented in Figures A4 and A5.

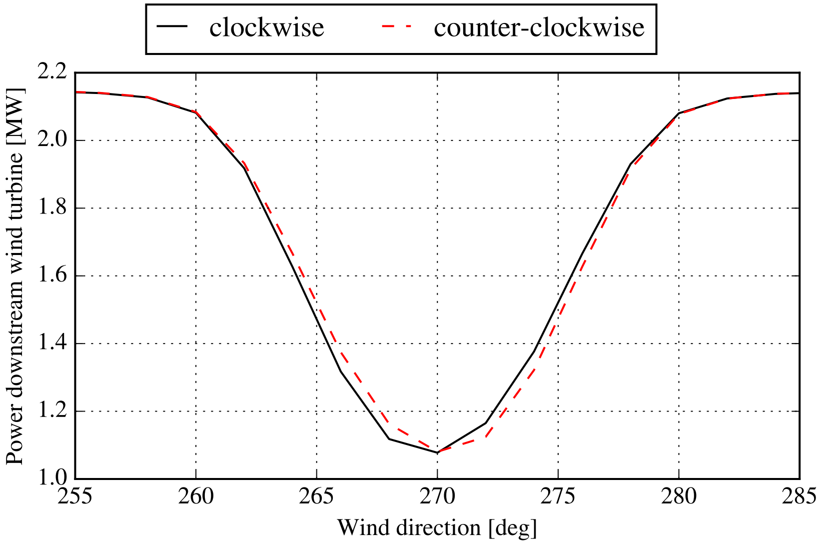

Figure A4. Power of downstream wind direction for clockwise and counter-clockwise rotor rotation using an atmospheric surface layer inflow without wind veer.

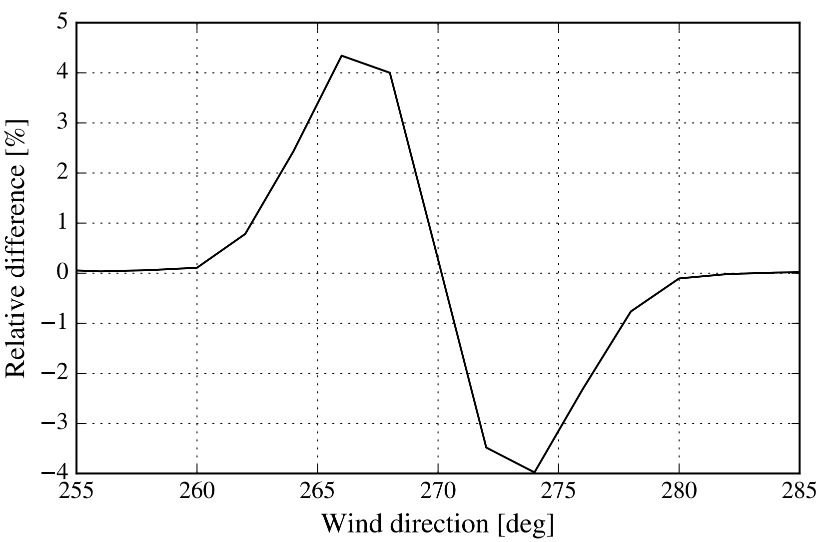

Figure A5. Relative difference in power of downstream wind direction for clockwise and counter-clockwise rotor rotation using an atmospheric surface layer inflow without wind veer. Negative difference means more power for the clockwise rotating wind turbine.