Review of:
"Data-driven optimisation of wind farm layout and wake steering with large-eddy simulations"
by Nikolaos Bempedelis, Filippo Gori, Andrew Wynn, Sylvain Laizet, and Luca Magri

General Comments:

The article present two different studies on optimization of wind farm performance, one on layout optimization and one on wind farm control using wake steering. The optimizations are performed using high-fidelity (LES) and low fidelity (FLORIS) wake modelling as well as multi-fidelity by combining results from both. The results are based on an impressive amount of LES, and provide interesting results. However, the article also show several shortcomings and several aspects, which lack important details for instance in terms of modeling choices, numerical blockage and uncertainties. Therefore, I recommend major revisions.

Specific Comments:

Lack of details:

Actuator Disc modeling and Power estimation:

The description of the actuator disc method is very inadequate, and Bempedelis et al. 2023 does not provide the necessary details. I can only assume that an uniformly loaded actuator disc is employed. If so, it is far from state-of-the-art and it has been shown several times to be insufficient, particular for more complex flows such as yawing turbines, see for instance [1], where a standard (uniform) actuator disc is compared to a BEM based actuator disc with rotation.

[1] also show how power production behind a uniformly loaded actuator disc is significantly overestimated compared to a slightly more advanced actuator disc model using BEM and rotation. Therefore, the authors should specify how the power is estimated, as this is particular important for yawing turbines. BEM has been shown to not give good estimates of power production in yaw, and this is further complicated if yawing turbines are operating in waked conditions, where power production can be overestimated, see [2]. I suspect the efficiencies in Figure 12 are a result of simplification, but it is hard to test/decipher as a reader. It would be beneficial to also report the actual power production (in [kW]), not only the efficiency. Furthermore, I have some concerns about the optimization angles shown in Figure 12. First, it is a general concern when optimizations consistently provides results at the admissible limit, as is the case where the first four turbines are yawing 30°. Second, several higher fidelity simulations have shown that there are secondary effects of wake steering. This means the turbines operating in wake will typically yaw less, see [3] for two turbines, where the second turbine yaws positively to increase production, and [4], where deep-row turbines should yaw relatively less. Such secondary effects are actually also visible in Figure 8.

Numerical blockage:

For the second study, the authors assess that the estimated efficiency would reduce from 4% to 3.3% by reducing the numerical blockage from $(\pi \cdot 80m^2)/(560m \cdot 1024m) = 3.5\%$ to $(\pi \cdot 80m^2)/(5 \cdot 560m \cdot 1024m) = 0.7\%$ (I assume it is a typo that line 282 states km, not m). This analysis is good and the results plausible. However, in the first study, the numerical blockage is up to $(16 \cdot \pi \cdot 100m^2)/(3340m \cdot 501m) = 30\%$ and even if the 16 turbines were arranged in a 4×4 it would correspond to 7.5%. For such layouts, the numerical blockage is significant and the impact clearly seen in the results with substantial speedups, where certain turbines have efficiencies of 110% (Figure 7). I am sceptical how realistic these speed-ups are, particular given the sensitivity mentioned for the second study. The article states that the impact is less than 1% when tested with a domain three times wider (line 230-231) and refers to Antonini et al. (2018) and King et al. (2017). I can not find the details in Antonini et al., which is also a 2D simulation, but King et al. have blockage ratio of 5.2% for worst case scenario and reference Chen and Liou to give a threshold of less than 10% for wind tunnel studies. I think the details of this analysis is required in an appendix.

Uncertainties:

- line 126: In principle, turbines should align themselves with the incoming wind direction. The reality is however, that unintended yaw misalignment is a very large uncertainty in normal operating wind farms, and it is a large challenge in order to actually apply wind farm control, where it is notoriously difficult to determine a wind direction and hence provide accurate estimates of how much to yaw, see for instance [5, 6].
- Section 2.1 and line 206: SLSQP is used to optimize FLORIS while LES is optimized with BO, but does the choice of optimization strategy not potentially affect the optimization results? Please motivate why different methods are used.
- There are significant uncertainties of wake steering related to the impact on structural loads, particular for large yaw angles, which is not addressed.

Unclear comments:

- Line 21: I think it is misleading to say that wind farms become increasingly less efficient as their size increase. First, many studies have shown how there an equilibrium between power extracted by turbines and the entrained energy from the atmosphere, see e.g. [7]. Second, wind farm layouts have historically developed from aligned/rectangular layouts to curved and finally more misaligned and "random" layouts. The authors use Horns Rev for the second study, and this development in layouts is very clear in the three different generations of wind farms at Horns Rev, see figure 1. The figure is reproduced from [8], where it can also be seen (Table 2) how the capacity factor has increased historically for these wind farms.
- line 34: Wake steering is still not generally applied on commercial wind farms, despite growing scientific evidence. The main reason is that the uncertainties related to wake steering remains very high, i.e. it is not given that overall power output will increase, see for instance the review paper [9] or the benchmark paper [10]. I think the article would benefit for including such considerations at least in the motivation and discussion.
- line 55: RANS is fully capable of modeling wake-to-wake interaction.
- Figure 6 and text: I find the text unclear related to the figure. First, in line 215 it says that 70% of the designs found by LES-BO produce more power than the designs found by FLORIS. Looking at Figure 6, LES-BO (black line) is alway above FLORIS (red line), i.e. 100%. The 70% seems to be that the combination of LF/LES outperforms LES-BO. Line 219 is also unclear as to which wake model outperforms LES-BO, but it appears to be LF/LES. It is not clear in the figure, but

have FLORIS and LF/LES been sorted independently or does design "n" of FLORIS correspond to design "n" of LF/LES? If not, it would be interesting to see a correlation plot of the two.
- Section 4: The two studies are somewhat disjointed, and could perhaps even have been clearer in two independent articles. Why not optimize for yaw angle on the optimal wind farm layout of Section 3?

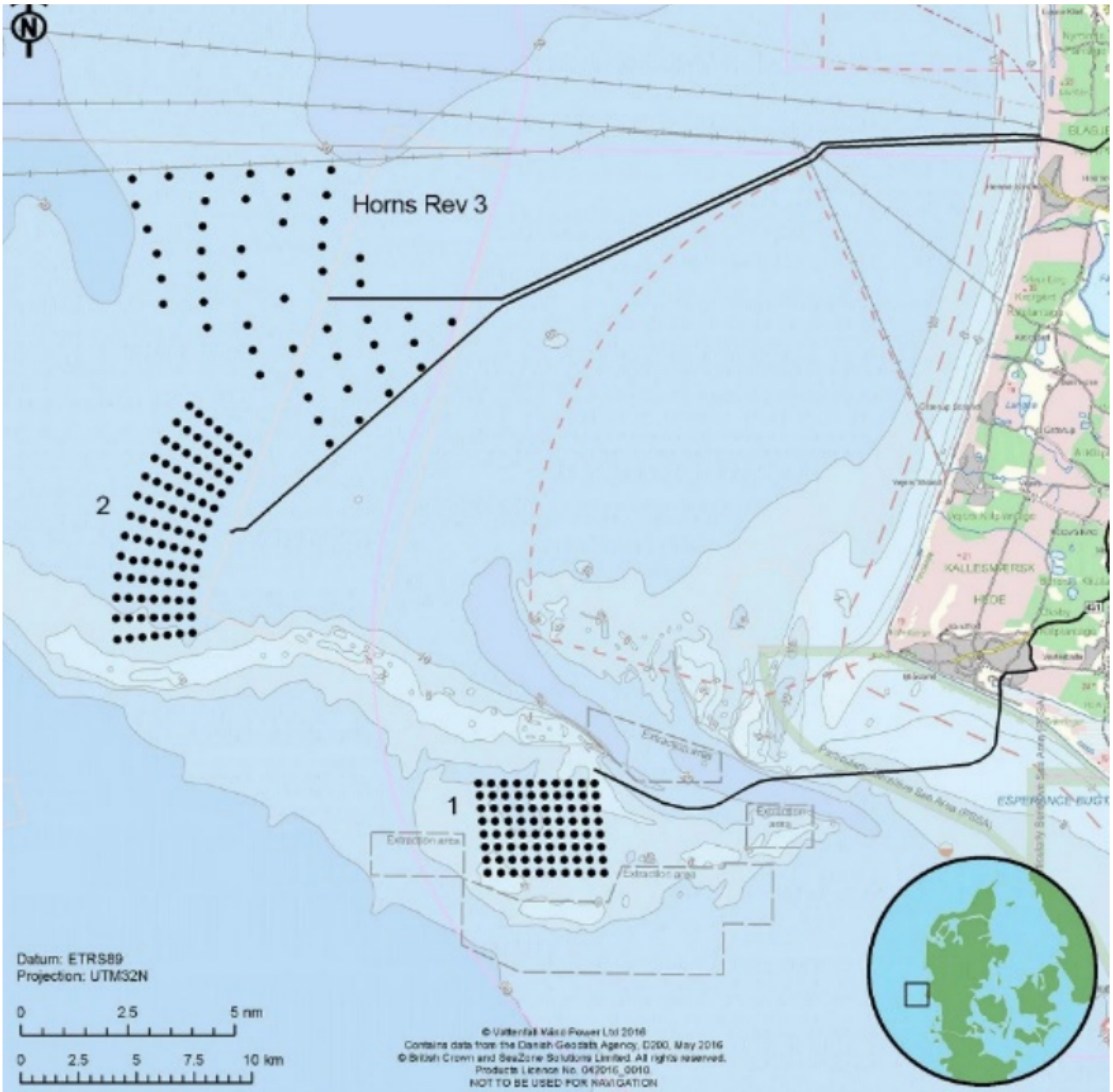

Figure 1: Layout of three generations of wind farms at Horns Rev.

Minor Comments and Technical Corrections:

- Figure 5: Please define "f" (y-axis)
- Figure 9: Please add turbine numbers.
- Figure 10: What does the hatched bars indicate?

References

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[5] Quick J, Annoni J, King R, Dykes K, Fleming P and Ning A 2017 *Journal of Physics: Conference Series* **854** 012036 URL https://dx.doi.org/10.1088/1742-6596/854/1/012036

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[10] Göçmen T, Campagnolo F, Duc T, Eguinoa I, Andersen S J, Petrović V, Imširović L, Braunbehrens R, Liew J, Baungaard M, van der Laan M P, Qian G, Aparicio-Sanchez M, González-Lope R, Dighe V V, Becker M, van den Broek M J, van Wingerden J W, Stock A, Cole M, Ruisi R, Bossanyi E, Requate N, Strnad S, Schmidt J, Vollmer L, Sood I and Meyers J 2022 *Wind Energy Science* **7** 1791–1825 URL https://wes.copernicus.org/articles/7/1791/2022/