<u>Reply to Reviewers</u>
Preprint wes-2024-124-R1
Title: Numerical Investigation of Regenerative Wind Farms Featuring Enhanced Vertical Energy Entrainment
Authors: YuanTso Li, Wei Yu, Andrea Sciacchitano, and Carlos Ferreira

Authors' reply to comments

We sincerely thank the reviewer for taking the time to evaluate our work and for recognizing its contributions. We have carefully considered the valuable suggestions provided and have revised the manuscript accordingly.

Regarding the inquiries posed, while they are indeed important and thought-provoking, some of them fall beyond the scope of the current study. However, to acknowledge their significance, we have explicitly highlighted those aspects in the manuscript as potential directions for future research.

Reviewer#3

General comments:

In this work, the authors examined the idea of regenerative wind farms using RANS simulations. Three configurations were tested, i.e., without-lifting, up-washing, and down-washing. Significant increases in power output were demonstrated. It is a very nice work, and the presented results are impressive. Comments are as follows:

Reply:
We sincerely thank the reviewer for acknowledging our work and expressing interest in the concept we have proposed. The comments given have been addressed in detail in the following responses.

Specific comments:

1. Accurately predicting the induced flow field using RANS methods is challenging. It is nice that the authors tested results from different RANS models. In addition to the contours shown in Figure B.2. It is beneficial to have some quantitative comparisons, such as the time-averaged streamwise, lateral, and vertical velocity profiles.

Reply:
We appreciate the reviewer's acknowledgment of our efforts in comparing results obtained using different turbulence models. We agree that contour plots in **Figure B2** primarily allow for qualitative comparisons. However, in **Figure B1**, we provide XY-plots illustrating the performance of MRSLs (Multi-Rotor System with Lifting Devices) predicted by employing different turbulence models. These plots offer a quantitative comparison, as the exerted forces and harvested power are directly derived from sampled velocity data, as detailed in **Section 3.4**. Since these output quantities are

closely linked to the flow field parameters, we believe that **Figures B1** and **B2** provide a sufficiently comprehensive assessment of the effects of different turbulence models.

2. The rotational flow motions caused by the rotor (especially for HAWTs) may also interact with the induced flow fields of the lifting device. In the RANS simulations, such an effect was not taken into account. How will it influence the conclusions of this work?

Reply:

We appreciate the reviewer for highlighting this challenging yet important aspect of MRSL aerodynamics. Indeed, with our current numerical framework, the rotational effects of the sub-rotors in the MRSL are not captured, as detailed in **Section 3.4**. However, we consider this aspect beyond the scope of the present study, and its influence is left for future investigations.

In response to the reviewer's comment, we have now explicitly acknowledged this limitation in the second paragraph of **Section 3.4**: "For instance, the supporting structures of the MRSL are not modeled, the rotational effects of the sub-rotors are not captured, and …". Additionally, we have emphasized this as a potential avenue for future research in **Section 5** (Conclusions and Outlook): "Also, modeling MRSLs with greater detail is desirable, as the effects of their detailed geometry and the rotational of the sub-rotors are omitted in the current work.".

That said, prior experimental work by Broertjes et al. (2024) provides valuable insight. They investigated an MRSL configuration with 16 rotating sub-rotors (vertical-axis wind turbines) and two wings, and their findings align with ours, showing that equipping MRSLs with lifting devices significantly improves wake recovery by enhancing advection. This experimental evidence supports that the secondary effects, including the rotational influence of sub-rotors, do not fundamentally alter the wake recovery mechanism of MRSL. This is now mentioned in the second paragraph of **Section 3.4**: "That said, it is worth noting that Broertjes et al. (2024) have already conducted experiments with an isolated MRSL equipped with rotating sub-rotors and supporting frames, demonstrating that the effectiveness of the lifting devices/wings is not significantly affected by these secondary effects, suggesting omitting them has limited impacts."

We believe these additions help clarify the scope of our study and reinforce the robustness of our conclusions. Moreover, the need for further exploration of secondary aerodynamic effects, including the influence of sub-rotor rotation and supporting structures, are also acknowledged.

3. Figure 12: it is suggested to add the profiles at several more streamwise positions.

Reply:
We appreciate the reviewer's suggestion. In response, we have added two additional streamwise positions for the lateral-averaged streamwise velocities profiles in **Figure**

12. With this adjustment, the evolutions of the lateral-averaged streamwise velocities along the streamwise direction are now more clearly illustrated.

4. Figure 13: people can only see the relative magnitude of the induced flow field. It is necessary to show quantitative comparisons of the lateral component of the time-averaged velocity.

Reply:

We appreciate the reviewer's valuable suggestion. In response, we have added a dedicated subsection, **Section 4.3.3**, to present and discuss the lateral and vertical velocity components in more detail. This subsection further examines the influence of the released tip vortices (CRVs, counter-rotating vortices) by analyzing the lateral and vertical velocity fields, particularly on how high the flow fields are influenced. Additionally, we now provide quantitative assessments of these velocity components.

To further aid interpretation, we have included absolute scales for the arrows illustrating the in-plane velocity of several plots (**Figures 13**, **14**, **B2**, and **D2**), facilitating a more quantitative evaluation.

We believe these additions enhance the clarity and completeness of our analysis.

5. It is seen in Figure 10 that the wake becomes larger and is located higher for the up-washing case, while it is split to the sides in the lateral direction for the down-washing case. Eventually, they will together interact with the atmospheric boundary layer. The question is, will the MRSLs remain efficient where there are many rows of them?

Reply:

We appreciate the reviewer for raising this important and practical question. However, the current study focuses on a specific wind farm layout consisting of five rows and three columns, aligned with the freestream direction. The effects of different wind farm layouts and larger farm sizes are beyond the scope of this work and are left for future investigations.

To clarify this limitation, we have explicitly stated in the last paragraph of **Section 4.3.1**: "However, although the significant potential of lifting-devices is presented, their effectiveness in regenerative wind farms with different layouts and sizes remains uncertain, necessitating further investigation in future studies.", and **Section 5** (Conclusions and Outlook): "Furthermore, exploring how the inflow directions, the layouts of regenerative wind farms, and the sizes of the regenerative wind farms impact the farm efficiency is also worth pursuing."

6. The lifting devices incur additional costs. Will the proposed MRSL still have advantages when considering the levelized cost of energy?

Reply:

We appreciate the reviewer for highlighting this highly relevant and practical concern. However, assessing the levelized cost of energy is beyond the scope of the current study, which focuses primarily on the aerodynamic aspects of MRSLs.

As noted in **Section 5** (Conclusions and Outlook), this question is left for dedicated upcoming investigations: "<u>Certainly, there are numerous other practical challenges beyond aerodynamics, such as the structural integrity of MRSLs, the control strategies and mechanisms of MRSLs (such as yaw control), **the economic feasibility of regenerative wind farms**, and others.</u>