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WIND ENERGY SCIENCE DISCUSSIONS

WESD

Interactive comment

Interactive comment on "Reducing cost uncertainty in the drivetrain design decision with a focus on the operational phase" *by* Freia Harzendorf et al.

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Dear respected reviewer,

Thanks a lot for the helpful remarks on the manuscript. For a faster understanding of the changes made I allowed myself to copy the comments and type my response and changes made in the manuscript below, R stands for the referee and A for the authors answers.

R: This article compares the unplanned maintenance cost of 5 different drivetrain technologies for 3 MW, land-based turbines. The paper is well written and topic is of inter-

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Discussion paper

est. Here are some specific comments and suggestions:

A: Thank you very much for this constructive review. Your comments below are specific and have highlighted place for improvement of the paper. I have tried to implement all comments in the revised version of the paper.

R: The comparison will be more interesting if the cost of unplanned maintenance together with the probability of its occurrence are presented. Please comment on the probability of occurrence of unplanned maintenance for each concept over the life span.

A: In the authors eyes the presented expected value of drivetrain influenced unplanned operational effort is adding more value to the discussion than the probability of occurrence of unplanned maintenance. As the first incorporates the impact failure rate, failure severity as well as repair and downtime as uncertain factors have in combination on the result. Whereas unplanned maintenance indicates a happening of a failure but not the consequences this entails effort wise. The presented approach uses distribution functions which are based on literature values cited in the table in the bottom of Figure 2. Based on the distribution functions for failure rate respective mean time to failure it is possible to derive the probability of occurrence of unplanned maintenance for each concept. A table with the used literature values for deriving the distribution functions can be added into the supplementary material if requested.

R: It would be interesting to mention the share of such operational cost in the total cost (what portion of OPEX and what portion of CAPEX+OPEX). What is the CAPEX cost for each drivetrain concept?

A: Indeed, it would be interesting to see the share of unplanned operational drivetrain effort on the total cost of the drivetrain over the lifetime. Therefore, Table 4 (uploaded and see p. 12 in the revised manuscript) has been added showing the concept specific mean unplanned drivetrain influenced operational lifetime effort and the concept specific mean drivetrain component investment effort both in euro. The drivetrain component specific investment effort in euro is based on calculations from NRELs Drivetrain

Cost and Scaling model. Logistics and installation effort is not included as it cannot directly be assigned to the drivetrain. In literature it is usually assigned to the entire turbine. Finally the concept specific mean unplanned drivetrain influenced operational lifetime effort share on the total drivetrain lifetime effort is presented in the bottom of Table 4.

R: Literature review can be extended, in particular looking at relevant literature addressing total cost of drivetrain or over the life cycle (not only operation) - see for instance this https://doi.org/10.1002/we.2499 for drivetrains on offshore turbines.

A: The author intentionally limited the scope of this paper to the comparison on wind turbine drivetrain concepts with regards to unplanned operational drivetrain influenced effort. This uncertain topic has a high degree of complexity and needs a thorough analysis. Therefore, no literature addressing the total cost of drivetrain over the life cycle is added in the literature review. The suggested paper by the reviewer is well written, nevertheless it has a completely different focus, dealing with 10 MW offshore drivetrain technologies. Furthermore, it seems a bit strange, that the reviewer suggests a paper written by himself. Nevertheless, the authors did another literature research in the databases 'web of science' and 'scorpus'. They used the keywords "drivetrain" and "wind" in combination. Available literature analysing the drivetrain operational phase mostly deal with condition monitoring or very specific failure mechanisms as well as with different types of loading and dynamics which are not in the scope of this paper. Therefore, no further literature has been added.

R: Fig. 4: please comment on market share each concept has and what are their CAPEX estimates.

A: A source stating the market share of each drivetrain concept has been added to the table in Figure 4 (see p. 9). CAPEX estimates are included in Table 4, as stated in the comment above.

R: Fig 6: there is a point between year 2-4 where the mean value becomes almost steady and constant for most of the concepts, please provide explanation.

A: In order to explain the course of the graph in Figure 6 the combination of the failure behaviour of each component in the concept specific design should be kept in mind. Table 2 gives an overview about the modelled Weibull parameter for the failure behaviour of different drivetrain components. Concept A, D and E all show wear out behaviour (high level of mean unplanned operational effort at the end of the lifetime) which can be traced back to the used three stage gearbox. Furthermore, concept D and E both have a DFIG generator which also leads to the shown wear out behaviour. Interestingly random failure behavior is visible for these three concepts, as the DUOE stays at a constant level after its infancy. This is the authors explanation for the almost steady and constant course after year 2 – 4. Concept A, B and C all use synchronous generators where early failure behaviour is dominant. This is visible in the course of the graph in Figure 6, as it starts at a high level and decreases within the first years of operation. As visible in Figure 5 the chosen converter concept has a minor impact onto the mean unplanned drivetrain influenced operational lifetime effort modelled. Accordingly the impact on the course of Figure 6 is also negligible. This explanation is added in the paper.

R: It would be nice to have the mean and standard deviation figures together.

A: For better vividness the authors decided to plot mean and standard deviation indirectly in a figure for the yearly development (adjusted Figure 6 - uploaded). The introduced metric 'range of fluctuation' incorporates mean and standard deviation.

R: Page 14: "Despite the higher effort for their generator and converter designs they are superior as they can operate without a gearbox". "As the EESG investment is more expensive and heavier than the PMSG for the same application, a direct drive with a PMSG is the winner in this comparison." Comprehensive comparison of different designs is not the scope of this paper, therefore such these statements seems to be too general.

A: The reviewer is totally right. The paragraph is changed in the following way: "The application of this approach on five state-of-the-art drivetrain concepts for a 3 MW, 120 m rotor diameter turbine shows that for all concepts and components the material expenses have the highest influence on mean DUOE followed by labour expenses. Equipment expenses, if modelled in the way presented, are less influential. Overall direct drive concepts lead to the lowest mean DUOE over the lifetime. This indication is confirmed when looking on the inherent risk of deviations from these estimated mean values."

R: There are some typos, e.g. in duction instead of induction, and some grammar mistakes which needed more careful proofreading.

A: The grammar and typos in the paper were revised. Please excuse the previous mistakes. R: The definition of variables in eqs must be improved. The variable (a) is not defined in eq. 1. It is also not explained why s, j and d are taking those values. I assume "a" in figures 4 and 6 refers to annual.

A: Thanks to the hint of the reviewer Formula (1) has been changed and includes now a variable h which indicates the number of hours a calendar year has. Furthermore, examples for s, j and d are given for improving the understandability of these variables.

R: It would be interesting if the authors could comment the same study on different power ranges.

A: Thanks to the reviewers comment the manuscript is now expanded to a look at possible future developments. The application for future turbines is characterized by a rated power of 5 MW and a rotor diameter of 150 m, being the average wind OEMs announced in 2020 for onshore application. The order of advantageousness is not changed due to the change in the application requirements, without taking technological development into account. Though the authors are not able to anticipate future development with certainty they can utilize the presented method to give indications about possible trends. Exemplarily the possible impact of higher torque density in gearboxes, a change to moment bearings and adjusted coil design in electrically excited generators is incorporated. It shows, that the superiority of synchronous generator concepts manifested in historic data is not entirely certain in future application.

R: The concept stated by the statement “Having included component specific mass and cost makes this approach scalable in rated power and rotor diameter.” In lines 137 and 138 needs more elaboration and justification.

A: More elaboration and justification is added in line 148 ff on page 5 of the manuscript. Both component design specific weight and component design specific investment cost scale with rated power and rotor diameter and therefore with the application. They are calculated based on the NREL Cost and Scaling Model (Fingersh et al., 2006), which is a cost and mass regression model based on industry data. As visible in Formula (2) these two variables have an impact on the material expenses as well as on the equipment expenses and though a high impact on DUOE. This way the use of these inputs makes this approach scalable in rated power and rotor diameter.

I hope all remarks are taken into account to your satisfaction.

With best regards, Freia Harzendorf

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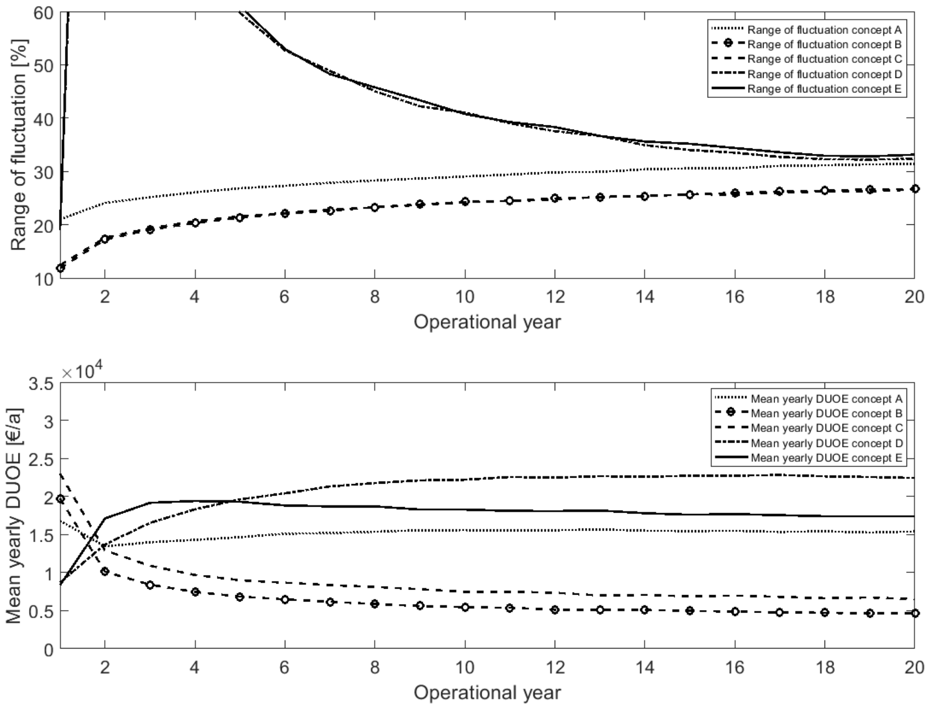

Fig. 1. Figure 6 from the manuscript: Mean unplanned yearly DUOE and yearly range of fluctuation of DUOE for different drivetrain concepts based on 1,000,000 iterations for a 3 MW 120 m rotor application

Table 1: Concept specific DUOEs lifetime impact on the total drivetrain lifetime effort for the 3 MW 120 m rotor application

Concept	A	B	C	D	E
3 MW and 120 m rotor diameter application					
Mean lifetime DUOE [€]	305,160	131,620	174,800	410,610	354,270
Calculated drivetrain specific investment cost [€]	748,800	874,700	1,143,700	861,300	861,300
Total drivetrain lifetime effort [€]	1,053,960	1,006,320	1,318,500	1,271,910	1,215,570
Share of mean lifetime DUOE on total drivetrain lifetime effort [%]	28.95	13.08	13.26	32.28	29.14

Fig. 2. Table 4: Concept specific DUOEs lifetime impact on the total drivetrain lifetime effort for the 3 MW 120 m rotor application