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WIND ENERGY SCIENCE DISCUSSIONS

Interactive comment on "Polynomial chaos to efficiently compute the annual energy production in wind farm layout optimization" *by* Andrés Santiago Padrón et al.

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Thank you for taking the time to thoroughly review the manuscript and for your insightful comments. We have updated the manuscript to reflect your comments as detailed below under each specific comment. In general, we included many of the comments in a new Discussions and conclusions (DC) section that greatly expanded our previous Conclusions section.

RC2 - Comment 1: "PC is interpolating/regressing figure 5, the power as a function of wind-speed (y) and direction (x), which shows a highly irregular pattern in the x. I suggest polynomials may be quite a poor choice for approximating this function. This

could be verified by the authors if they plotted the implied response surfaces of PC-R and PC-Q and compared with this reference - oscillations may be present, as well as high sensitivity to the sample locations (hence perhaps their 10 runs with varying samples). In contrast the rectangle rule is just "pixellating" Fig 5. Given the periodicity of and shape of x, I would use combination of a Fourier series in x, and a polynomial in y. An equivalent integral approximation can be built, and since the underlying representation better matches the response, the AEP should be better."

We agree that one could potentially build a better approximation in the x-direction, especially using more samples, but we are not sure that for the same number of samples it could provide a better estimate of the AEP. We've included a couple of sentences with your suggestions and to encourage future research to look into other approximations at the end of the third paragraph of the new Discussions and conclusions (DC) section. One of our goals of this work is to encourage people to look into better ways to approximate the AEP than the rectangle rule, and we will be happy to see others try to improve the results shown here.

Also, we have included a paragraph (paragraph 4 of DC) discussing why polynomial chaos is a good choice for this problem. We have also emphasized the fact that we show how to compute the gradients of the statistics with polynomial chaos. The gradients are novel for the case of the polynomial chaos based on regression. These changes have been made in a couple of places including modifying a sentence in the abstract and adding a sentence in the introduction, among other places (see the pdf marked up with the differences).

During our work, we have visualized the polynomial approximations and the rectangle rule approximations to the power response (figure 5), they indeed do not exactly match the power responses shown in figure 5. However, the approximations do get better as the number of samples used to construct the approximation increases, as can be seen in figure 8. The power response is a complicated function, and the approximations we build with only a couple hundred samples are not going to be able to capture all the high-frequency oscillations, but they can give good estimates of the AEP as we have shown. For reference, Figure 5 was constructed using 32,400 samples (a grid made by 360 wind directions (every degree) and 90 wind speeds). Also, as mentioned in the paper, even using 200,000 MC samples to estimate the AEP only ensures with 99 % confidence that the true AEP is within $\pm$ 1 % of estimated AEP.

RC2 - Comment 2: "The fact that PC is perhaps not a good choice here, is additionally suggested by that fact that it performs only very slightly better than the rectangle rule (I don't agree with the authors interpretation of significant improvements in Figures 6-8). Rectangle should be 2nd-order while PC should be spectral. I suggest the lower variance of PC-R in Fig 9 is most likely the effect of PC-R filtering noise with regression. PC is likely not significantly improving the representation of Fig 5, compared to the under-sampling of the rectangle rule."

We believe that reductions of up to an order of magnitude in the number of simulations are significant. As mentioned above, we have included a paragraph (paragraph 4 of DC) discussing why polynomial chaos is a good choice for this problem, in addition to that of computing the AEP more efficiently than the rectangle rule. You are correct in your observation of Fig 9. We have added this to the caption of Fig 9.

RC2 - Comment 3: "The authors should not underestimate the effect non-independence of wind-speed and direction may have on the AEP. In my experience (in unrelated problems) dependence relationships in inputs are significantly more important than non-Gaussianity (skewness, kurtosis, etc.) of 1d-marginals. This makes the careful choice of Weibull potentially irrelevant for the purposes of comparing layouts. Please plot the 2d distribution in Fig 3, so we can see how strong the dependence is. Mention how PC could be generalized to allow for this (there is some literature on the subject). Computing the effect of this on the AEP would also be a very nice addition."

We have made it clearer that we constructed the wind direction and wind speed to be independent. We use the NoordZeeWind meteorological mast data, which is depen-

dent, as inspiration to create the probability distributions (see the modifications in 5.1 Probability distributions of the uncertain wind conditions). In the paper, we provide a reference that shows a plot of the experimental correlated data we used as a base to construct the independent distributions.

We have added a paragraph (paragraph 5 of DC) discussing different methods to generalize PC for dependent variables, and we have stated that an interesting extension to the paper would be to study the effects of different wind distributions, including correlated distributions, on the convergence of the AEP.

RC2 - Comment 4: "Justify why wind-speed is fit with a distribution, but direction not."

Both, the wind speed and wind direction distributions are specified by histograms containing 50 bins of equal width. We have clarified this in the updated section 5.1 Probability distributions of the uncertain wind conditions. We created the histogram data for the wind direction by linearly interpolating the experimental data. For the wind speed, we did a two-step approach. First, we fitted a Weibull to the experimental data, then we truncated the Weibull and used its likelihood values to create the histogram. We fitted the Weibull to smooth the data and because this is commonly done for the wind speed (we have included a couple of citations referring to this in section 5.1 as well). Granted, we could have constructed the speed histogram without fitting the Weibull, but we followed the wind industry standard of fitting the wind speed with a Weibull.

RC2 - Comment 5: "Justify why computing time of this problem is relevant. This is a one-off optimization for a farm that might last 20 years."

The final optimization would be a one-off optimization. However, to get to the final optimization, many optimizations are required during the design phase. For example, designers may need to explore scenarios with different turbine types, different sites, larger farms with a different number of turbines and possibly even systems of wind farms. Also, the presence of local optima would require many optimizations with different restarts to find the best layout. And, furthermore, there is a desire to increase the fidelity of the models used to simulate the wind farm, which will increase the time and computational cost of the optimizations. Thus reducing the computational time is relevant as it will enable the use of higher fidelity models and also facilitate the exploration of many different and larger wind farm designs. In the paper, we have included this justification of why the computing time is relevant in the first paragraph of the Discussions and conclusions section.

RC2 - Comment 6: "Given your results it seems that the layout problem could have a very large subspace of close-to-optimal designs - all essentially equivalent. Do you agree? Please comment."

We agree. We have commented on this in the new Discussions and conclusions (DC) section. Specifically, at the end of paragraph 6 of DC section.

RC2 - Comment 7: "I have a personal interest in wake-deflection, which is mentioned in connection with FLORIS. Could the authors comment on how the layout problem would change if optimal wake deflection were allowed?"

We have commented on this in the last paragraph of the Discussions and conclusions section.

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