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WIND ENERGY SCIENCE DISCUSSIONS

WESD

Interactive comment

Interactive comment on "Offshore and onshore ground-generation airborne wind energy power curve characterization" *by* Markus Sommerfeld et al.

Markus Sommerfeld et al.

msommerf@uvic.ca

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Response to referee 1 wes-2020-120

Markus Sommerfeld

January 2021

1 Author response

Dear referee 1, Thank you very much for your helpful comments to our manuscript, “Offshore and onshore ground-generation airborne wind energy power curve characterization”, wes-2020-120. Please accept my apologies for the delayed response.

A lot of time was spend on the revision of this paper including re-clustering WRF wind data, re-running optimizations, re-evaluating results and re-writing major sections of this manuscript. We added a reference section which compares optimization results to quasi steady-state (QSS) AWES and WT reference models. We agree with the criticism to the AWES power coefficient and removed it. Instead, we implemented a brief description and investigation using the harvesting factor **?**. Please find detailed responses below. I am looking forward to your comments to further improve this paper.

Sincerely, Markus Sommerfeld

2 Specific comments

- It depends on the purpose of your investigation. I would generally argue that higher resolution data results in better power and AEP predictions.
- WRF uses re-analysis data as boundary conditions and therefore also assimilates measurements.
- It depends on the purpose of your investigation. If you are not interested in the optimal trajectories an AWES would fly during non-monotonic / eccentric wind conditions than you would not simulate them. p5 and p95 are not necessarily more eccentric.
- The main contribution of this paper is to investigate AWES trajectories, power and AEP predictions based on more realistic wind conditions.
- Mapping high dimensional wind data onto 1D space is the standard approach for WT as well, even more as vertical changes in wind speed are just represented by a single average speed. We are trying to derive a simple, easy to understand representation for AWES power which can be communicated with industry, wind park developers and AWES designers. This is a complex problem which needs more investigation, but hopefully is a step into the right direction.

2.1 Abstract

Line 5 “A universal“ instead of “An ...“

- implemented

Line 5 What is the problem with power curves for log profile/power law wind conditions?

- Only log might not be enough to properly represent the complex wind resource and describe realistic AWES trajectories and operating conditions.

Line 6 “complex tether and drag losses” - why does this lead to a more problematic power curve description? Also WTs occasionally operate in wind conditions that are not covered by the assumptions made for determining their power curve e.g. low level jets

- rewritten

Line 7 The role of “rotor area normalization“ to the power curve description isnot clear. One can compare the harvesting efficiency of a WTs with differentscales by normalization, but normally the power curve just characterizes the(non-normalized) power.

- rewritten

Line 7 Not clear where “Therefore“ refers to

- rewritten

Line 14 put “with wind speed“ after “decreases“

- rewritten

2.2 Introduction

Line 20 WTs reach above 100 m

- Rewritten for clarity.

Line 22 Use acronym for wind turbines

– implemented

Lines 24 The list items are a bit random, suggestion: “3-bladed HAWT with con-ical tower“ - as to my knowledge you don’t find commercial HAWTs without nacelle and generator.

– removed nacelle and generator. Focus on main attributes of HAWT & it’s singular concept

Line 27 Replace “route“ by “concept“

– implemented

Line 29 Reel-in description is a bit simplistic: flexible kite is really pulled back in,whereas a rigid wing utilizes its gliding capabilities.

– Rewritten for clarity. This sentence is kept general for the introduction section and because it is not the focus of this paper.

Lines 34 State that power curves are in general only used for a preliminary analysis.

– Not implemented. It is expected that the reader already knows that.

Line 35 Not clear why the reference to Malz is needed here, does it belong to the previous sentence?

– implemented

Line 36 “wind speed magnitude” implies that the wind field in which an AWES operates can be described with one magnitude - needs some more explanation.

– I disagree. Both magnitude & profile shape including direction variation with height are clearly stated in the sentence.

Line 37 Ground-gen does not operate at a single altitude: “optimal trajectory” includes information about altitude

- Kept as is. Right, trajectory includes altitude information, but the point is that both the shape of the trajectory as well as altitude change.

Line 37 Suggestion: split sentence: “Simple ..“

- Kept as is

Line 41 “most ... studies”: it would be relevant to know which studies use an alternative approach.

- Basically every study I found uses simple log or exponential or global re-analysis model. Added an additional sentence and cited your paper.

Line 47 Discuss directly using measurements/LiDAR data for assessing wind resource (no weather modelling).

- Added an explanatory sentence

Line 48 Discuss your methodology (starting from “Results in ...“) in a separate paragraph. Also include here what exactly the contribution is of this paper. You already touch upon this in the paragraph starting at line 32, however it is not very concrete (probably you want to the content of this paragraph down here).

- Added paragraph and contributions through summary of main findings

Line 48 As I understand, you previously corrected WRF with LiDAR for the Pritzwalk location. Therefore none of the mentioned reasons for not using apply LiDAR apply here. So how do you justify using purely WRF data?

- This comment is unrelated to this work. I did not use LiDAR because 1. only 6 mon of data available and that is not enough to generate annual statistics; 2. Data availability decreased significantly with height, making the combination of simulation and measurement necessary; Therefore, using WRF is the better approach here. Also, can be found in my previous papers.

Figure 54 Suggestion: Section 2 introduces the WRF model set-up and compares the onshore and offshore wind resource that follow from the WRF simulations.

- implemented

Line 55 Would be good to mention clustering before when introducing methodology

- added a sentence above

Line 59 Replace “derive“ by “produce“, replace “This includes“ by “These include

- implemented

Line 61 As I read it: the coefficient definition directly follows from the results, however I don’t think this is what is meant.

- Removed the power coefficient section and replaced with harvesting factor defined in “Airborne Wind Energy: Basic Concepts and Physical Foundations” (DOI: 10.1007/978-3-642-39965-7_1)

2.3 Wind data

Figure 64 Representative for what?

- added “onshore and offshore”

Line 67 AWE might be promising for other type of locations where it does not have to compete with WTs.

- No statement was made about where AWES might be deployed or are promising. This is rather a statement on the quality of the selected site, i.e. the location has good wind conditions.

Line 71 Why use different periods?

- For this study we make several generalizing assumptions, given the that this is not a site or time specific analysis. We assume that the periods are not important and the wind data are representative of not only that location, but also on- and offshore wind conditions in general. Generating these mesoscale data is costly. The simulated time for onshore location coincides with the measurement campaign. The offshore data was part of a different project.

Line 75 replace “in” with “with”

- implemented

Line 79 replace “on” with “in”

- implemented

Line 78 replace “The focus of this study is not on the detailed comparison between mesoscale models, but on AWES performance subject to representative onshore and offshore wind conditions determined based on clustered wind profiles (described on section 3). To that end“ by “For the assessment of AWES performance“

- Not sure what you mean

Line 80 What is adequate?

- it is adequate for our application: preliminary AWES performance assessment. It his not a specific site assessment for a particular AWES design. It is not important that both WRF models are slightly different. It is not important that we chose different time frames.

Line 80 remove “data“ in between sentences

- implemented

Line 82 Why use different data sources for boundary conditions

- Onshore WRF simulation was performed while ERA-Interim was still supported, i.e. before 31 August 2019.

Line 88 replace “h“ by “hours“

- implemented

Line 88 Why use different approaches to simulate 1 year?

- We are aware that this raises some questions. However, we believe that both WRF models provide adequate wind data for our purposes (As mentioned in line 75). This is solely the result of ongoing research, costly & time consuming simulations, collaboration with the awebox team and work on other projects.

Figure 1 It’s hard to assess the topography from this figure, leave out “topography“ in caption, or add information on color scale.

- removed “topography”

Line 91 “High-Performance Computing“ without capitals?

– implemented

Line 94 Wind directions without capitals

– implemented

Line 94 Dominant wind direction offshore is southwest for both 100 and 500 m.

– clarified

Line 94 Using “rotating“ is a bit strange here: the wind direction changes or the wind turns.

– implemented

Line 96 Start sentence with “The...”

– implemented

Line 97 “Offshore conditions ..“ is a bit vague. How does the 10 degrees relate to the 5 degrees of the preceding sentence? If the wind would always veer 10 degrees than so would the average wind direction.

– These 10 degrees relate specifically to wind direction above 500m as stated in the sentence. Clarified

Line 98 “the same westerly wind direction at high altitude“ - what do you mean? Figure 2 shows that offshore the wind is predominantly southwest.

– As mentioned in the sentence: “at high altitudes.”. Clarified

Line 99 Add point at end of sentence

– implemented

Line 99 Replace “The relative wind speed increase of“ by “The wind shear at“, and remove “and the already high wind speeds at lower heights“

- implemented

Line 102 replace “distribution“ by “distributions at each individual height level“

- implemented

Line 102 replace “These statistics give an insight into the overall wind conditions, but the actual profile shapes“ by “These distributions give insight into the wind speed statistics at the individual heights, but not onto the statistics of the wind profile shapes."

- implemented

Line 105 105: replace “have a fairly narrow range“ by “are relatively low“

- added “are relatively low” and kept “narrow range” as this necessitates the nonlinear color map

Line 106 replace “up to high altitudes“ by “for the full height range“.

- implemented

Line 106 replace “This leads to the development of“ by “The distributions show“

- implemented

Line 109 “Such multimodal distributions at higher altitudes are better described by the sum of two or more probability distributions“ - isn’t this the definition of multimodal?

- According to Wikipedia: In statistics, a bimodal distribution is a probability distribution with two different modes (The mode is the value that appears most often in a set of data values.) (...).

Line 113 “As mentioned above, the relative wind speed increase with height is less pronounced offshore than onshore.“ - why mention it twice?

- removed

Line 114 suggestion “Conventional WTs benefit from low wind shear offshore ..“

- Is the benefit that the shear is lower or the speeds are higher? kept as is

Line 115 replace “However, offshore AWES will also benefit from higher offshore winds and move offshore for other reasons such as safety or land use regulations“ by “Nevertheless, also AWES benefit from low wind shear. Among the reasons for placing AWES offshore are safety and land use regulations.“

- implemented

Figure 2 State that these results reflect single locations. Leave out “On average wind direction onshore rotates about 14 (symbol missing) while offshore winds rotate (symbol missing) about 5(symbol missing)between 100 and 500 m. Onshore shows a higher wind shear (symbol missing) due to higher surface roughness and relatively high wind speeds offshore.“ - this belongs in the text.

- implemented

Line 116 “Another benefit of offshore AWES in comparison to conventional WT is the smaller and cheaper support structure.“ - Statement is a bit misplaced in the wind resource discussion and needs a reference. Also the arguments are one-sided, there are many reasons why not to put AWES offshore.

- moved up to previous sentence together with “ safety or land use regulations”. I do not have a specific reference for this, but this argument (replacing tower with tether) has been made before.

Line 118 replace “categorized“ by “characterized“

- implemented

Figure 3 Clarify that this is not a 2D histogram, but independent histograms/distributions per height. State that these results reflect single locations.

- implemented

Line 126 Not clear if this is the classification as presented in the table.

- clarified

Line 129 Is the ocean always warmer? Remove “likely“

- I'd say generally warmer, yes. I would keep likely, as I did not specifically compare air and water temperature at the investigated location.

Line 131 Not sure what the use is of this paragraph: only covers literature without touching upon the results

- Point is to describe the wind conditions at the specific location and to justify the choice of location as well. Therefore, atmospheric stability and Obukhov length are introduced to the reader as they are later discussed in figure 8.

2.4 Clustering of wind conditions

Table 2 State that these results reflect single locations.

- implemented

Line 136 Statement is not very informative, rephrase to emphasize that it's not just time- and space-averaged wind velocities that effect the power output of wind energy systems, but also the variation in time and space.

- implemented

Line 138 Elaborate on excessive averaging

- rewwritten

Line 141 replace “proxy“ by “metric“, replace “a metric that“ by “, which“

- implemented

Line 143 Only one study is listed

- implemented

Line 143 Not clear what diverge with height means: large wind speed spread at high altitudes?

- yes, within each OL classification, while low altitudes did not show that spread

Line 144 Do you mean to say that there is no correlation between the wind speed profile over a high elevated layer and the surface-based stability?

- No, there still is some correlation. I am saying it is not enough to use surface data to describe wind conditions at hundreds or thousands of meter altitude. Atmospheric stability close to the surface might be different from the one aloft.

Line 146 Also grouping based on stability is “based on data similarity“: be more precise.

- added “their” similarity to clarify it is the similarity of “wind speed or velocity profiles”

Line 146 What does the reader need to see in the appendix? - Don't refer to results before the explanation of your methodology is finished.

- It is not a result. This figure visually shows the coherent / non-diverging clusters with all the comprising profiles. It is not a necessary result, but rather a visual addition. Moved to body of text

Line 148 Mathematical clustering is a vague term: explain. You use clustering, classifying, categorizing, and binning interchangeably: be more consistent.

- Point is that the clustering algorithm does not take physical conditions into account, but only relies on profile similarity. clarified

Line 154 The u-component is per definition along the x-direction. Explanation is not clear: also u_{main} and $u_{deviation}$ are not throughout this paper anymore - so why introduce them here?

- Which definition? You can define u & v or x & y as you wish! Such as along lat and lon lines or something else. Why anymore? It is important because this way it is easier to compare trajectories. Otherwise the wind speed profiles would just go in any direction.

Line 159 Replace “defined“ by “represented“

- implemented

Line 159 Suggestion: “The clustering finds the centroid positions that minimize ..."

- rewritten

Line 160 Distances between?

- “These centroids are arranged such that they minimize the sum of the Euclidean distances, to every data point within each cluster.”

Line 161 Rephrase: the centroid will at best coincide with a data point by chance

- added

Line 161 Explain what a data point consists of. Also not clear that each data point is assigned to the closest centroid.

- added

Line 162 I misunderstood at first: I thought you were talking about the labels assigned to each data point. Leave out mentioning the initialization as it is confusing. Just mention that the label number that each cluster gets is rather random and does not have any mathematical meaning.

- implemented

Line 164 replace “Later evaluation uses clusters sorted by average wind speed up to 500 m.“ by “As presented, the resulting clusters sorted by average wind speed up to 500 m.“

- implemented

Figure 4 Use the same color scheme for the clusters as for figure 5. It’s unclear from the right column of figure 4 what is plotted on the y-axis as there is no grid/ticks.

- improved the clustering and implemented consistent coloring scheme

Line 168 "inertia reduction becomes marginally small with increasing number of clusters" - this is not completely true: above all the elbow method says that kinks in the inertia trend indicate sensible choices for k. It’s hard to observe them with evaluating so little values of k. Best to just use a step size of 1

- That is one definition and approach.

Line 169 that doesn't make inertia meaningless

- removed

Line 170 add space after hyphen

- implemented

Line 171 table 1 doesn't show any difference between the vertical levels (grid) of the two analyses. How different are they? I would not expect the vertical grid to have a large effect. More probable is a larger spread of the centroids.

- removed

Line 172 replace membership by a more precise explanation

- added explanation

Line 176 also if you would use a fixed (not random) initialization the cluster would not be arranged in a logical order, suggested: "Note that the order of the clusters is random and does not follow any logic."

- implemented

Line 176 It's still on the y-axis.

- clarified

Line 178 Too many I don't find very likely. At least the mean silhouette score always decreases with k. Do you have a reference?

- Added citations, also see: https://www.mathworks.com/help/stats/silhouette.html and https://medium.com/analytics-vidhya/how-to-determine-the-optimal-k-for-k-means-708505d204eb.

Line 179 Not clear what you mean with “the continuous nature of wind which results in a high cluster proximity“ and how this effects the silhouette scores - please expand.

- removed

Line 180 For readability I would suggest not to jump to the conclusions of the next section.

- removed

Line 181 Replace “intersect ..“ by “are grouped together with monotonic wind profiles“

- Clarified. I want to say that these non-monotonic profiles are closer to one cluster at low altitudes and then closer to another at higher altitude.

Line 182 closing parenthesis missing

- added

Line 184 Is there a reason for using first wind speed and after velocity? If not, rephrase.

- I only used wind speed profiles (magnitude over height) for visualization purposes in this paper. The actual code uses 2D wind velocity profiles (u_{main} & $U_{deviation}$ component over height)

Line 185 replace “comprising ..“ by “WRF-simulated wind speed profiles that are input for the clustering"

- clarified

Line 185 suggestion: “Within a cluster, the wind speed profiles span..“

- implemented

Line 189 False statement: this explains the higher inertia, not the silhouette score. Also the onshore clusters are distinct.

- removed these parts of the sentence

Line 191 I don’t see why “directional differences“ result in a decrease of wind speed with height - explain.

- removed

Line 192 What about small-scale weather phenomena?

- added

Line 192 Why too many clusters (in which context)? I think it is very insightful to find these type of cluster mean wind profiles. Them having a lower probability makes it even more interesting to evaluate why the clustering gives these clusters as a result as normally k-means clustering tends to produce equally sized clusters.

- removed

Line 195 Is the wind speed inversed or the wind shear?

- implemented

Line 197 replace “determining“ by “dominant“ and replace “stacked“ by “ordered“

- implemented

Line 200 Suggestion: add reference to Schelbergen

- added

Line 204 For which application/analysis are long term averaged wind speed profiles considered? Using a averaged profile **shape** is commonly done for AEP calculations, but that’s a somewhat different approach.

- An error would occur if using a simple log-profile and low reference wind speed at low heights. Extrapolating this to higher altitudes might over-predict wind speed.

Figure 5 The wrf-simulated wind profiles only show as a filled area, so not very informative - but I suppose it doesn't hurt either.

- It's hard to display ~ 52.000 profiles. Just supposed to give a feel for the range of profiles

Line 220 The name of the "other" category suggest to me that these conditions are exceptional/not often occurring, however your analysis shows the opposite. How should I physically interpret this category?

- These clusters exhibit Obukhov lengths close to zero (likely caused by very low friction velocity u_*) and are classified as "other" because they do not fall within one of the other atmospheric stability classes according to Floors et al. (2011) (see table 2).

Line 220 What do you mean with wind power assessment? Why is the impact of low wind conditions low? I don't understand the comparison.

- Removed. Meant that they do not contribute a lot to the power curve as they are just around cut-in wind speed.

Line 221 Basically what you're saying is that how often wind conditions occur (the wind speed distribution) has a large effect on the AEP? - I would say that the reader is familiar with this.

- Removed.

2.5 AWES trajectory optimization

Line 231 Very technical start of the section - readability would benefit from further introduction.

- added a short paragraph

Line 232 Which unstable dynamics are you referring to?

- The tethered AWES dynamics are unstable.

Line 233 Which multiple inputs, multiple outputs?

- input: tether & aircraft control inputs, control surface deflections etc; outputs: tether speed, tension, aircraft position, speed etc

Line 238 Which simulated profiles? Aren't you using the cluster means?

- No, I am not using cluster means, but actual (5th, 50th, 95th percentile) wind velocity profiles

Line 239 replaced "during" by "of"

- rewritten

Line 247 What is the main wind direction?

- clarified. u_{main} as defined by the average wind direction up to 500 m, compare section 3

Line 252 Suggestion: "We use the aerodynamic model of the Ampyx AP2 (Malz et al., 2019; Ampyx)"

- implemented

Line 252 The footnote is confusing as you mention that no other data is available while you are referring to a source.

- clarified

Line 259 Introduce kappa and bring equation 2 forward.

- moved and rewritten.

Line 260 “This results in an overestimation of output power and lower cut-in speed in comparison to a heavier aircraft.“ - unclear how you come to this conclusion.

- Aircraft mass delays cut-in and reduces average power.
- κ was changed to 2.4.

Line 263 Mentioning focus of paper is a bit misplaced, better save that for the outlook.

- This is more to justify the unrealistic mass scaling.

Figure 9 Why mentioning Loyd in caption?

- Because that is where $c_\mathrm{L}^3/c_\mathrm{D}^2$ comes from

Line 264 rephrase

- How and why?

Line 265 Leave out or mention how you would estimate it.

- Included a reference calculation on AWES power and AEP estimation using Loyd’s formula including tether drag.

Equation 2 Position at related text and introduce properly.

- implemented

Line 270 mention conditions for which this is valid.

- iplemented

Line 270 Last part of sentence is confusing. Suggestion: “.. , thereby the reelout speed is expected to remain below 10 m/s as the wind speed hardly exceeds 20 m/s.

- implemented

Line 271 Implies that the ratio is fixed, however I don’t think that’s what’s meant. - example values 10/15 is superfluous.

- clarified

Line 272 I would not discuss this pre-optimization step. As you mentioned yourself: this paper is about assessing performance metrics and not system design. Consider the tether diameter as a given.

- removed

Line 280 No need to state subsection number, table number suffices.

- removed

Line 281 why "or"?

- replaced by and

Line 282 add “coefficient“ - why do you use a linear relation?

- added and clarified

Line 285 replace “prevailing“ by “can be adapted to“, replace “dynamically“ by “continuously"

- than there would be 2 “adapt” in the same sentence. “continuously” implemented

Line 286 replace “AWES“ by “AWESs"

- implemented

Line 290 Isn’t 19 m/s a bit low? - this is equivalent to a mild storm

- 19 m/s at 10 m height would be quite extreme.

Line 293 Explain what a p-value is: add a figure to explain.

- p-value stands for percentile. Profiles are chosen based on percentile of average wind speed distribution. Sentenced added, no figure added

Line 294 Why average wind speed up to 500 m?

- Added an additional sentence. Previous analyzes showed that AWES mostly operate within this range

Line 294 On line 176 you mention that a representative k is 10. Better to choose k already at section 3, instead of quickly mentioning it here.

- These are actually 2 different things. Line 176 is just showing silhouette score for k=10 (could also be 20,30, 1000). Added sentences in section 3.

Line 296 Rewrite “cluster centroids.. implemented"

- not sure what you mean, but “to estimate AEP” was moved to the end of sentence

Line 297 Not clear when you use the p5,50,95 and when you don't and how you use them if you do. Please rewrite paragraph. So you only use these p-values for determining the power curve? I would say this is the most important part of this study so it should get more explanation

- implemented

Equation 3 Move to the related text.

- implemented

Line 304 Would the analysis benefit from running the optimization using multiple starting points?

- Yes, ideally you want to compare multiple initialization (tether length, radius, elevation angle, etc.), but that is extremely costly. We initialized different tether length depending on system size and reference wind speed

Line 306 remove hyphen: "inequality"

- implemented

Line 306 Which equality constraints? You only mentioned inequality constraints.

- e.g. tether diameter, wind speed profile for each optimization

Line 307 As far as I know, an optimal control problem always uses discretized control intervals, irrespective of if direct collocation is used or not.

- yes, but there are different methods and we use direct collocation

Line 307 missing space after dot

- fixed

Line 307 Is this the input you give to awebox for generating an initial guess? Explain estimated aircraft speed - this will vary between reel-in and reel-out and also within the reel-out phase over one loop.

- Aircraft speed is estimated from the circumference (2 pi radius) divided by estimated time of 1 loop. Clarified in text

2.6 Results

Line 317 Shouldn't it be "average wind speeds for different height ranges"?

- I also compare average between height ranges to a single reference height. I therefore believe that my formulation includes these as well and is formulated more generally.

Line 320 "Rayleigh distributed log-profiles" is not very precise

- What would you add? I understand that this is how wind conditions are defined in the IEC standards and in sub-section 'Wind boundary conditions'

Line 323 "representative" does not fit the context, list which profiles you have chosen.

- The point here is that these are not specific, special trajectories. They are supposed to give the reader an impression of typical optimal trajectories based on representative onshore and offshore wind conditions that have been chosen as written in brackets: 'chosen because of different wind speeds and profile shape'. Removed brackets and clarified in text

Line 325 missing closing parenthesis, replace "figures" by "figure"

- removed

Figure 10 In caption list which profiles are plotted. Also describe what is highlighted using the colors in the left column. Remove “The deviation of the colored lines is caused by the approximation of discrete data points with Lagrange polynomials.“ - too much detail for caption.

- Wind profiles chosen to represent typical low (blue, orange), medium (red) and high wind speeds (green).Removed

Line 328 replace “optimization“ by “modelling"

- it’s for optimization though because we need 2 times differntiable functions for the used solver

Line 328 Wind speed vs wind velocity profiles is a bit confusing. Just mention that only the wind speed is plotted and that changes in wind direction with height can be seen in the lower left plot.

- removed

Line 330 Didn’t you introduce the “rotated u and v component“ as u_{main} and $u_{deviation}$? - then also use them here

- changed labels

Line 330 replace “wind velocity components as experienced by the AWES in color“ by “with the part of the profiles corresponding to the height range swept by the kite in color

- changed

Line 332 not clear which are the onshore and which the offshore profiles.

- removed

Line 333 first should be x-z plane

- implemented

Line 335 perpendicular to x is both y and z-direction

- removed

Line 335 What is unrealistic about them?

- probably unrealistic than anyone will want to fly such crazy trajectories and will probably take a less optimal, but safer / easier to fly trajectory. removed

Line 338 Can you identify whether the system is de-powering or not? If so than you can differentiate between the two.

- I don't think that is possible. The system de-powers when it would exceed any constraint, e.g. tether force constraint

Line 338 What about de-powering by increasing the reelout speed?

- that is possible, but the optimizer does not chose to do so when looking at figure 10. Possible that that would increase the tether length too much and increase reel-in losses.

Line 342 So for an elevated path, you don't want to fly at maximum cl3/cd2? This is not what we observe in figure 10: the most elevated path has the lowest angles of attack during reelout

- But lowest α does not mean optimal α. α here was (wrongfully) estimated without tether drag. Including tether drag optimal α would be higher. It can be seen that the aircraft reduces α to stay within force constraints and optimal α is higher as all other α have similar values during reel-out. Section removed as c_L^2/c_D^2 did not include tether drag and the α value was off.

Line 347 So you're relating this observation in the reel-in phase (reaching max reel-in speed) to an observation in the reel-out phase (de-powered loop)? Isn't it more likely that the de-powering is triggered by reaching max tether force during reel-out?

- I believe the phrase 'in these cases' was not clear. rewritten

Line 355 Which previous analyses?

- unpublished analyses done by the awebox developers

Line 356 Not completely: zero would probably not give you the best performance.

- agreed, hence 'almost' zero

Line 363 Clarify that you're not just using the 4 profiles that were treated in the previous subsection.

- see line 359: 'The data is based on the p5, p50, p95-th wind profiles of k=20 onshore and offshore clusters...'

Line 363 What is $z_{operation}$? I would expect a height range, not a single value.

- Not sure what you mean: 'frequency distribution of operating altitude $z_{\mathrm{operating}}$'

Line 364 Replace "emerge"

- with what? I want to keep the sentence in active language, don't want to write: become visible or can be seen.

Line 365 add comma after onshore, correct for this in the rest of the paper

- added

Line 365 remove “and typically higher winds offshore“ from end of sentence and mention in a different sentence that generally tether length increases with wind speed

- Yes, tether length increases with wind speed, but comparing the the tether lengths for the same reference wind speed at both locations show different tether lengths with must be due to wind speed profile shape. Clarified

Line 369 "on the other hand“ - comparison is not clear

- removed

Line 372 “This also has implications for tower-based..“ - Leave the WT discussion out. It’s well known that offshore turbines have lower towers than onshore.

- removed

Line 376 The distributions for 25 and 50m2 are not that much different and is worthwhile mentioning.

- That is also a finding that needs to be communicated.

Line 378 Figure 11 shows only onshore 1% exceeding 600 m for 20m2 and offshore 0%

- This sentence refers to $A_{wing} = 50m^2$. Clarified

Figure 11 Differentiate between p5, p50 and p95 using for example different markers. Put occurrences on the horizontal axis. If I understand correctly your only plotting the results of 60 optimizations: this would be more clear by plotting occurrences.

- These are the results of 100 time steps (added information in text) for each of the 60 optimizations. The percentile of each profile does not add any information, but would just be a distraction. These are are 60 representative wind conditions.

Line 384 replace “unanimously accepted“ by “consensus“

- replaced

Line 385 replace “wind speed probability distribution“ by “wind resource model“

- implemented

Line 387 I would just mention that AWESs generally operate in a larger height range

- implemented

Line 389 So this leaves you with a non-linear grid on the x-axis? Also the order is different for every reference height range? - If so, mention this. I would expect the p5 and p95 causing a lot irregularities in the power curves and wind distributions. Would it be possible to show data points represent p5, p50 and p95 powers? About using the power curves for integrating: basically you're trying to map this high dimensional space describing the wind profiles (60*2=120 dimensions?) to a 1D space. By doing so you loose a lot of information on the wind profiles. How would you justify integrating over only this 1D space? How accurate would this be? Do you also use p5, p50 and p95 wind profiles to the frequency distributions? Is the area underneath your frequency distributions 100% in that case?

- Recreated this figure with new data . The point of using p5, p50 and p95 within each cluster is to better represent the entire spectrum of simulated wind conditions and not to isolate their effect. No, this does not result in a non-linear grid on the x-axis. The x-axis is linear, but the points are scattered at a different location on the abscissa. The purpose of this analysis is to derive a SIMPLE power curve (+ investigating a good reference height x-axis) that can easily be understood and communicated. Therefore, it it necessary to simplify the wind profiles to a single value. Yes, the frequency of wind speeds adds up to 100%.

Line 393 “respective AWES operating altitude“ - why using 60 - 629 m and 59 -551 m? Not all trajectories fly over this full range.

- That’s right. Added: The height ranges displayed in the legend represent the minimum and maximum operating altitude.

Line 394 “black“ instead of “red“

- implemented

Line 395 ‘The power curve shows a varying c_p^{WT}

- added ’up to rated wind speed’

Line 397 what is the value of the rotor disc area?

- added

Equation 4 U^3

- implemented

Line 400 What do you mean with limit specific designs?

- removed

Line 405 Isn’t this just due to your choice for the rotor disc area?

- The point here is to show that reference wind speed shifts the power curve and AWES power curves don’t always align with typical WT power curves.

Line 406 Explain more precisely: if wind speed is monotonically increasing with height $u_{100m} \leq u_{100-400m}$. So the data points move to the when plotted against $u_{100-400m}$ with respect to when they are plotted against u_{100m}.

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Discussion paper

– Implemented

Line 409 replace “overlap“ by “lie on top“

– implemented

Line 409 Not clear why 200m ref would be better, since you mention in the previous sentence that every reference height gives roughly the same power curve.

– removed

Line 410 with divergence you mean large difference?

– I mean that the power curves diverge from each other with increasing reference wind speed.

Line 411 Also c_p^{WT} is lowered after the rated wind speed

– sentence removed

Figure 12 On y-axis is the energy contribution: not E average

– changed to E. Also change legend of operating height

Line 414 That the flight trajectory influence mean cycle power should be clear from the literature study.

– That is true, but these results nonetheless highlight this fact.

Line 415 An overkill to use a separate plot when only adjusting the cp. What if you change the rotor disc area?

– Which is why the plot is only in the appendix. Added a comment, assuming the same rotor diameter.

Line 416 Leave out “A better .. future study.“. Mention in the outlook at the end of paper.

- Left in "A better...", but removed "This however ..."

Line 418 Rephrase “integral multiplication"

- removed "integral"

Line 419 replace “Its total“ by “The area underneath the distribution "

- implemented

Line 420 Rewrite “shifts towards higher wind speeds due to .. higher wind speeds"

- rewritten

Line 421 How is that similar?

- removed

Line 426 Which effect scales with size? - Isn’t this specific to your methodology, i.e. the integration of the equivalent 1D wind profile space.

- removed. I don’t expect that this is because my method, but rather due to the more realistic wind conditions which result in a wider range of profiles

Line 428 Leave out “This indicates that onshore wind conditions favor higher operating altitude due to higher wind shear.

- removed

Line 429 What reduction? The AEP goes up

- it’s the energy relative to system size.

Line 432 “This main difference“ - which difference is explained exactly?

– removed

Line 433 The cp is very much dependent on the area you chose, which you haven’t justified. Also, the onshore 20m2 curve for reference height 100m lies on top of that of the wind turbine.

– removed

Line 434 “wind speed along the actual AWES trajectory“: this is a varying property - how would you use it as a reference?

– added ’average’

Line 436 Figure 11 shows that the operational height range of 100 m are common. Why would a 500m height range be a good reference in that case?

– It is the average wind speed between 100 and 600m not a single height.

Line 439 How would you use this power coefficient in practice for power estimation? I think it’s still a rather challenging task as you still need to determine the relation between lpath and the wind speed. More importantly, for WTs cp is often used to quantify the efficiency of the energy conversion. I don’t think the given formulation is a good metric for AWES efficiency. Take for example the (hypothetical) situation where we have a uniform wind field and let’s neglect the variation of the air density. As you implied earlier (line 356): the mean cycle power is not very sensitive to the flight path length. So for the same kite size, a shorter and longer pumping cycle with the same mean cycle power will give me completely different values for cp while the AWES efficiency did not change.

– Agreed, removed sub-section

Line 441 You mean average wind speed?

- removed

Line 442 Air density at which height?

- removed

Line 444 $z_{operation}$ suggests a single height, but probably needs to be a height range? Change throughout the paper.

- removed

Line 451 cp is not truly “velocity profile independent“: especially at low wind speeds you see a vertical spread for fixed wind speed. How sensitive is power output to the wind profile shape?

- removed

Line 452 sentence does not explain any difference. Rewrite “The difference .. remains almost constant (see sub-section 5.1 and 5.2)“ - unclear what you’re saying.

- removed

Line 457 Dividing cp by c is the same as having the area of the kite multiplied by the path length in the denominator of equation 5 - why not use the wing area instead of the swept area in the first place and leave out the path length?

- removed

Line 459 Fit looks poor for larger wind speeds. Why do you only plot the line up to 18 m/s?

- removed

Line 462 “contrasts“ replace by “compares“

- implemented

Figure 13 The markers are not connected by the lines. Why is this?

- because these are individual data points and connecting them would result in zig zag lines. Instead, the lines are the curve fit. Figure removed

Equation 7 leave out h/year

- removed

Line 472 remove “static“

- removed

Line 473 use “probability distributions“

- but it is the cluster frequency and not the probability distribution derived from a model

Line 475 replace “justified“ by “justify“

- implemented

Line 480 I think it is a bit bold to say that they are averaged out. You could reason that they are underrepresented. Also show with a figure similar to 12 how both computations are different

- I think my point here is that high wind speeds contribute more to power than low speeds because of the cubic relation between power and wind speed. If you instead just use the average wind speed you lose this non-linear relationship.

2.7 Conclusions and outlook

Line 490 replace “characterized“ by “evaluated“

- implemented

Line 492 replace “deduced“ by “uses“

- rewritten

Line 493 replace “Representative wind velocity profiles based on k-means clustering were chosen to reduce computational cost.“ by “A representative wind resource model is deduced using the results of clustering wind profiles“ - and place after discussing WRF

- implemented

Line 494 Do you need this high resolution if you drastically simplify the wind model in the end?

- I still used actual profiles rather than cluster-means. I guess it depends on the purpose of the analysis. For the purpose of analysing trajectories and considering the non-linear relation between wind speed and power, I would argue yes.

Line 497 “acceleration“?

- ’increase’

Line 511 replace “implemented“ by “given as input“

- implemented

Line 514 replace “fast“ by “high“

- implemented

Line 517 See earlier comments on WT power coefficient

- removed

Line 519 remove part about social acceptance: not touched upon in body of paper

- True, but kept in to motivate moving offshore for other reasons than beneficial wind conditions

Line 522 replace “collapse ..“ by “yields a location and size independent metric“

- removed

Line 526 You did not evaluate the AEP for 10 clusters and the p5, p50, p95 profiles if I'm not mistaken. So how do you get to this conclusion? If the AEP is higher than for all other calculations I wouldn't expect it to be the most realistic.

- rewritten

Line 529 I don't see this back in Figure 14, it shows quite a large bias between the log and cluster AEP.

- rewritten

Line 536 Why do you expect this?

- removed

Line 538 Be more general in this paragraph

- implemented