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Earth System Dynamics Discussions

Interactive comment on "The problem of the second wind turbine – a note on a common but flawed wind power estimation method" *by* F. Gans et al.

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We would like to thank the reviewer Daniel Kirk-Davidoff for his constructive criticism on our manuscript which helped to improve this revised submission. From his review, we selected the critical points and will respond to them individually here.

Regarding the potential increase of atmospheric power generation after installing wind turbines

According to Kirk-Davidoff, the potential for the global atmosphere to generate more kinetic wind energy in the presence of wind turbines *"... is intuitively unlikely and has never arisen in any simulation of the impact of surface roughness on the atmospheric ïňĆow. In fact, all simulations of total wind power generated by a practically maximal distribution of wind turbines that have included the additional roughness due to wind turbines themselves have demonstrated reduced wind power in regions where roughness is increased, relative to a control (e.g. Kirk-Davidoff and Keith, 2008; Barrie and Kirk-Davidoff, 2010; Wang and Prinn , 2010)."*

We argued the same points throughout our manuscript and thank the reviewer for their support on this topic.

Concluding remarks that do not suit the scope of the paper

As stated by Kirk-Davidoff,*"... the conclusion of the note, that estimates of wind power that are based on the simple approach of applying prevailing winds to typical turbine power curves, may result in 'worthless and possibly dangerous policy advice' is not remotely justified by the work presented. Policy makers are a long way from bumping up against these limits. [...] The world is thus in no danger of bumping up against the fundamental limits of wind power production any time soon."*

We agree with the reviewer. We have reformulated the conclusions accordingly to address these concerns.

Relation to other published work (*e.g.* Wang & Prinn, (2010))

According to Kirk-Davidoff, *"Since state-of-the-art estimates of the ultimate wind resource (e.g. Wang and Prinn, 2010) already address the concerns that Miller et al. [assumed here to instead mean Gans et al.] raise, it seems*

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unlikely that any terrible policy mistakes will be made by over-reliance on the first order estimates of the total wind resource made without regard to the synoptic scale reduction of winds due to the turbines themselves."

We disagree. Many scientists involved in policy advice do not appear aware of these fundamental limits of extraction and the applicability of related first order estimates. For example, (Jacobson and DeLucchi, 2010) quantify the global surface wind power potential to be 1700TW — an estimate which, according to our first order estimates, is unachievable with any wind power extraction technology. If the method used in Kirk-Davidoff & Keith (2008); Barrie & Kirk-Davidoff (2010); Wang & Prinn (2010) represented the majority of the published work regarding large-scale wind power estimates, we would instead agree with the reviewer. However, there is a significant list of recent publications that do not consider the fundamental limits of wind power generation on large-scale wind power extraction (Jacobson & Masters (2001); Archer & Jacobson (2003, 2005); Acker et al. (2007); American Wind Energy Association (2007); Liu et al. (2008); United States Department of Energy (2008); Archer and Caldeira (2009); Lu et al. (2009); Santa Maria & Jacobson (2009); Capps and Zender (2010); Dvorak et al. (2010); Jacobson & Delucchi (2010)). We would particularly draw the reviewer and editor's attention to the respective publication dates — methodologies similar to that illustrated in this submitted manuscript are becoming more and more common.

South Dakota as an illustrative example

As stated by Kirk-Davidoff, "*... the state of South Dakota has an area of 200,000 km^2 . Assuming an average dissipation of 1.5 W/m^2, this would indicate an upper limit of about 150 GW of wind power (dividing by two to account for the Betz limit) that could be generated over South Dakota. The current installed wind power capacity over the whole United States is about 30 GW.*

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We recognize the contribution of the reviewer and agree with its relevance. Nevertheless, we also note that in Lu et al. (2009), they quantify the wind power potential of South Dakota to be 440GW. This is nearly 3-times the reviewer's estimate based on fundamental limits for this particular state. We are using this example, not to disagree with the reviewer, but to illustrate that such varied estimates have been published in such journals as *The Proceedings of the National Academy of Sciences* and what may appear trivial to the reviewer, may not be immediately apparent to other scientists or reviewers.

Concluding remarks

The main message of our paper remains the same — one cannot extract more energy than is generated. We also recognize that this argument may initially appear trivial to some researchers and scientists. This paper was written to address other researchers who are not yet aware of the fundamental limits of of the wind power generation rate within the atmosphere and how it applies large-scale wind power estimation. This disparity is apparent based on the differences of scientific opinion, visible both in this paper's open discussion, and in a similar topic discussion by the same authors (Miller et al. (2011) - Discussion paper). This demonstrates the need to use this basic 'tunnel experiment' to bridge this knowledge gap.

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