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Interactive Comment

Interactive comment on "Estimating maximum global land surface wind power extractability and associated climatic consequences" *by* L. M. Miller et al.

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Renaissance of the Perpetuummobile

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In their comment, Jacobson and Archer (JA2010) introduce an energetic concept, in which energy(-reservoirs) and time-rates of energy transfer, i.e., power are not clearly distinguished. That distinction is not just physicists' caprice, but an absolutely necessary conceptual requirement. A brief demonstration:

The reservoir of kinetic energy in a given volume is volume multiplied with energy density, KE = V rho/2 v2, [m3] [J/m3]. In putting a turbine of power P and swept area A into that volume, the reduction of the reservoir is maximal if it is positioned at the up-stream end of the volume, and the reduction of the reservoir is zero if the turbine is positioned at the down-stream end. This example demonstrates that the reservoir is not the relevant quantity, simply because local energy is permanently being transported downstream.

Therefore, the relevant quantity is the cross-sectional power density (energy-flux density) of the flow, rho/2 v3, [W/m2] = [J/(m2s)]. Independent of the position of the turbine, the flow's power density in the swept area is reduced by P/A downwind of the turbine and the turbine extracts the power P from the flow. With a good turbine, P/A in the wake is half the initial value (turbine's mechanical efficiency 50%). Without replenishment of the wake, the reservoir-reduction downwind the turbine is simply proportional to distance. Thus, a definite power extraction causes an indefinite reservoir-reduction. That demonstrates very clearly, why reservoir-considerations of that type make no physical sense.

Replenishment of the power density downwind the turbine

JA2010 mentions the following processes:

- Turbulent diffusion of kinetic energy into the wake

- Increased dissipation of kinetic energy due to turbines leads to increased heat generation, which is transformed to additional potential energy, which in its turn transformed to additional kinetic energy that re-fills the kinetic-energy reservoir of the atmosphere.

Turbulent diffusion of kinetic energy into the wake is only available at the price of additional dissipation, and the wake cannot be re-filled to the initial power density by diffusion in finite time, see Bergmann (2010) for details. Nevertheless, Archer, Jacobson and Sta. Maria (2010) claim complete regeneration of power density after a definite wake length in their comment on the precursor article by Gans, Miller and Kleidon (2010).

The second process, which is supposed to re-fill the kinetic-energy reservoir (being tapped by the diffusion process), represents a veritable perpetuummobile. Even if it is built on the wrong premise that turbines increase total dissipation, let us analyse its energy-chain:

Frictional heat (internal energy) from dissipation of kinetic energy produces potential energy. This potential energy is transformed to kinetic energy, extracted by the turbines, dissipated to heat, and so on.

This energy-chain is flawed for several reasons. If it were correct, natural atmospheric flow without turbines would not need any external mechanical energy supply because all mechanical energy is being recycled. The atmospheric pressure fields would be there forever, independent of global circulation (differential heating). That would represent a perpetuummobile of the second type, which is impossible due to the second law of thermodynamics: Heat-energy can only be transformed to mechanical energy at Carnot-efficiency T2/(T2 - T1). Introduction of turbines spins up the chain, but only under the condition that extracted mechanical energy is immediately dissipated (which is not the case in reality, see below).

Presentation of the energy-"regeneration" in JA2010 is not really clear. The only definite quantitative statement is: "In equilibrium the total PE (potential + internal) energy will have to increase by the same amount as KE decreases." The statement does not say anything about the time-rate of energy-"regeneration" (power). Also, energy-extraction by turbines is not possible under this condition because turbine-extracted energy is not necessarily transformed to heat (internal energy of the atmosphere at turbines' locations): Extracted energy is utilised at far-away locations and can even be stored (e.g., as chemical energy), thus not participating in JA2010's energy-chain.

JA2010's quantitative statement on power is based on postulates, but not on specified

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physical processes: “In addition, to maintain the KE balance and compensate for the increased KE dissipation, the atmosphere must convert PE into KE (KE generation via adiabatic processes) at the same rate as the KE dissipation. In sum, enhanced KE dissipation ultimately must cause enhanced KE generation at an equal rate.” However, as there is no physical process that generates KE at that rate (second law of thermodynamics!), the entire concept is obsolete and all the postulates as well.

In summary, if the natural dissipation rates are not a good proxy for the availability of wind power, as claimed in JA2010 as central argument, the consequence would be that the atmosphere would have to destroy the amount of mechanical energy, which could be extracted additionally due to JA2010. That is, slightly said, not really physical.

The present author also commented very critically on the article by Miller, Gans and Kleidon, but the natural dissipation rates as proxy for wind power availability are recognised as a sound basis, simply for energy-conservation reasons.

References

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