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Global Wind Power Potential

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Topic: Alternative energy
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This is a guest post by Carlos de Castro, a professor of Applied Physics in the University of Valladolid in Spain. Carlos is the lead author of an article that was recently accepted by Energy Policy called, "Global wind power potential: Physical and technological limits." The article is behind a pay wall, but Carlos was kind enough to write a summary of the article for us.

Global wind power potential: Physical and technological limits

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Abstract:
This paper is focused on a new methodology for the global assessment of wind power potential. Most of the previous works on the global assessment of the technological potential of wind power have used bottom-up methodologies (e.g. Archer and Jacobson, 2005, Capps and Zender, 2010, Lu et. al., 2009). Economic, ecological and other assessments have been developed, based on these technological capacities. However, this paper tries to show that the reported regional and global technological potential are flawed because they do not conserve the energetic balance on Earth, violating the first principle of energy conservation (Gans et al., 2010). We propose a top-down approach, such as that in Miller et al., 2010, to evaluate the physical-geographical potential and, for the first time, to evaluate the global technological wind power potential, while acknowledging energy conservation. The results give roughly 1TW for the top limit of the future electrical potential of wind energy. This value is much lower than previous estimates and even lower than economic and realizable potentials published for the mid-century (e.g. DeVries et al., 2007, EEA, 2009, Zerta et al., 2008).

Our calculations:

We use a top-down methodology based on six stages. The base data is the kinetic energy contained in the atmosphere, and this amount is restricted by several constraints that subtract the energy that cannot be transformed into electricity. These constraints are:

1. The energy of the lowest layer of the atmosphere, f_1, $P_0(h < 200) = f_1 \cdot P_0$

Estimates of the total kinetic energy dissipation in the atmosphere vary from 340 TW to 3600 TW. We take an intermediate value of P_0 = 1200 TW as our starting point. The fraction of that energy that is available in the lowest 200m, f_1, can be estimated via different methods taking into consideration 1) changes in energy density with height; 2) residence time of surface air masses or 3) dissipated power of the Atmospheric Boundary Layer. All three methods yield similar values near f_1=0.083. Thus the power dissipated in the lower 200m of the atmosphere (accessible to windmills) is calculated as: $f_1 \cdot P_0(h < 200) = 100$ TW.

2. Reachable areas of the Earth (geographical constraint), f_2. $P_G = f_1 \cdot f_2 \cdot P_0$

The Earth's surface is not uniformly suitable for kinetic energy extraction. Deep sea areas (more than 200m deep), areas permanently covered by ice, etc., can be excluded as uneconomic. Thus ¾ of the Earth's surface is not suitable for wind farms. On the other hand, the windiest continent is Antarctica, and wind has a lot more energy over the deep seas than on the ground. We could, therefore, easily estimate that less than 80% of the energy will be lost because of these geographical restrictions.
$f_2 < 0.2$

3. Percentage of the wind that interacts with the blades of the mills, f_3

We estimate than a farm could catch less than approximately 30% of the kinetic energy that goes through it (considering the space among mills, a wind front of 200 meters high and mills of 100 meters in diameter), because the rest will simply never interact with the blades of the mill. Therefore:
$f_3 < 0.3$

4. Areas with reasonable wind potential, f_4

Even in locations accessible for wind parks, we consider that the mills will be situated in areas of class 3 or higher. Approximately half of all the kinetic energy of the geographically accessible areas are in areas of class 3 or higher, then we have: $f_4 = 0.5$

5. Percentage of energy of the wind speeds that are valid to produce electricity (not too little or too much velocity), f_5

Wind turbines do not perform equally efficiently at all wind speeds. On average, modern wind turbines have an energy conversion efficiency of < 50%. We estimate that future designs will be able to improve this ratio and use three quarters of the energy that interacts with them, but not much more, therefore: $f_5 = 0.75$

6. Efficiency of the conversion of kinetic energy into electric energy, f_6

The maximum theoretical efficiency of a wind turbine (power output)/(power in wind) is known as the Betz limit and has a value of 0.59. If we assume than in the future the losses relative to the Betz limit (front kinetic energy to net electric energy) will only be 15% (at present losses are >30%) then: $f_6 = 0.5$

Therefore: $P_T = f_1 \cdot f_2 \cdot f_3 \cdot f_4 \cdot f_5 \cdot f_6 \cdot P_0 \sim 1$TWe

Our conclusions:

The global assessment of the technological potential of wind power to produce electricity, based on the top-down approach, shows quite different results to those of previous works. The technical assessment potential that has been obtained is one or two orders of magnitude lower than those estimated by other authors. This means that technological wind power potential imposes an important limit on the effective electric wind power that could be developed, against the common thinking of no technological constraints by economic, ecological or other assessments.

According to the World Wind Energy Association, the electrical wind power produced today is ~0.045 TW and this type of energy is growing at an annual rate of > 25%. If the present growth rate continues, we would reach the 1 TW we estimated in less than 15 years. Therefore, probably in this decade, we will see less growth than we saw in the previous decade.

This limit poses important limitations to the expansion of this energy. Since the present exergy consumption of all energies is ~17 TW, it implies that no more than 6% of today's primary energy can be obtained from the wind.

Furthermore, if the electric wind power of the world were to approach 1TW, we could generate a new class of "tragedy of the commons" with the necessity of the international regulation of rights to winds. Without an effective regulation, in a medium-term future, we will see "wind park effect and wake effect" on a global scale, making new and old installed parks less efficient.

Global assessment of potential energy based on bottom-up methodologies has been used for renewable energies such as tidal, wave or geothermal.

A top-down review of the global assessment of potential energy from these renewable sources may be necessary in order to obtain the best estimation for the top limit of primary energy that our society is able to use in a sustainable

Some of our References

These two papers use bottom-up methodologies being criticized:

Archer C. L., M. Z. Jacobson, 2005. Evaluation of global wind power. Journal of Geophysical Research, vol. 110, D12110.
doi:10.1029/2004JD005462

Capps S.B., C.S. Zender, 2010. The estimated global ocean wind power potential from QuickScat observations, accounting for turbine characteristics and sitting. Journal of Geophysical Research. Vol 115, D01101, 13PP, doi:10.1029/2009JD012679

These two papers calculate the power of the wind in the atmosphere that we use for our top-down approach:

Peixoto, J. P., Oort, A. H., 1992. Physics of climate. American Institute of Physics, 1, 379–385, 1992. 109

Sorensen, B., 2004. Renewable energy: its physics, engineering use, environment impacts, economy and planning aspects. Elsevier Acad. Press.

This paper gives a theoretical discussion of why bottom-up methodologies violate the first principle:

Gans, F., et al., 2010. The problem of the second wind turbine—a note on a common but flawed wind power estimation method. Earth System Dynamics Discussion 1, 103–114. doi:10.5194/esdd-1-103-2010.

This paper discusses why the "solution" is not the hypothetical energy transfer of wind from the upper layers of the atmosphere:

Wang, C., Prinn, R.G., 2010. Potential climatic impacts and reliability of very large-scale wind farms. Atmospheric Chemistry and Physics 10, 2053–2061.

This paper discusses the wake effect on a local scale:

Christiansen, M.B., Hasager, C.B., 2005. Wake effects of large offshore wind farms identified from satellite SAR. Remote Sensing of Environment 98 (2–3), 251–268 15 October 2005.

More Information

More details and more extensive references can be found in the original copyrighted version of the paper, Global wind power potential: Physical and technological limits, available from Energy Policy.