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A Dynamic Function for the Energy Return on Investment (EROI) of Wind Energy

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Wind energy is one of the most promising source of energy for the future, as indicated by the increasing number of studies assessing its global or regional potential. Unfortunately, there is a large discrepancy in the results, leading to contradictory recommendations on the path to be taken for the energy transition¹. According to a large part of these studies, the technical potential would be several times the present world final energy consumption, so there seems to be no technical barriers to large scale deployment of wind energy. We show that these studies may be overestimating the global potential by ignoring physical limits to energy availability and accessibility.

We argue that the best way to evaluate the real potential of an energy source is to look at the net energy that is generated, via its Energy Return on Investment (EROI). This indicator is the ratio of the energy produced by an energy conversion device throughout its lifetime to all the energy inputs that were invested, from raw materials extraction to the end-of-life treatment of the facility. It has been shown that the EROIs of renewable energy sources are declining with their spatial expansion^{2,3}. A declining EROI may have significant impacts on economic activities and quality of life⁴, therefore it is crucial not only to assess the quantity of renewable energy that can be produced in the future, but also to estimate the associated embodied energy.

In this work we use a grid cell approach in order to estimate the evolution of the EROI of wind energy with cumulated annual production. First a suitability factor is associated to each cell, in order to take into account geographical and technical constraints. Then the theoretical potential in each cell is evaluated, by combining wind speed distribution and standard wind turbine specifications, and taking into account array efficiency. With a detailed life-cycle analysis the embodied energy of a typical wind farm is evaluated. It allows to estimate the energy generated and the associated EROI in each cell for an installed capacity that is optimized in order to maximize wind power production under constraints on the desired minimum value for the EROI.

Finally, these results are compared with a study of the kinetic energy available in the atmospheric boundary layer⁵. We show that in some cells the estimated technical potential in our model is greater than kinetic energy generation rate, therefore the optimized installed capacity is reduced accordingly.

With our methodology we are able to locate where wind farms can sustainably be installed, to optimize the installed capacity on those sites, and, by summing up local potentials, to derive an upper limit for the global wind potential as a function of the minimum EROI that is assumed as sustainable for the society.

As an example, for a minimum EROI of 12, the global potential on earth would be about 65 EJ/year, which is close to present world electricity consumption (74 EJ in 2015⁶), but only about 11.5 % of final energy consumption (561 EJ in 2015⁶). To reach that production, 8 TW of wind turbines should be installed on 3.6 million km².

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