Wind and wave farms could affect Earth's energy balance

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UPDATE, April 6: *This article has elicited a considerable amount of interest, and some criticism. We always welcome discussions of the stories we publish. Some readers felt the original headline (Wind and wave energies are not renewable after all) was misleading, so to address these concerns we have changed it. We have also been made aware of a wider debate about Kleidon's research that we did not address in the original article: we will continue to follow this issue and report back on what we find.*

Editorial: "The sun is our only truly renewable energy source"

The idea that we can draw endless supplies of clean energy from the wind and waves just doesn't add up

WITNESS a howling gale or an ocean storm, and it's hard to believe that humans could make a dent in the awesome natural forces that created them. Yet that is the provocative suggestion of one physicist who has done the sums.

He concludes that it is a mistake to assume that energy sources like wind and waves are truly renewable. Build enough wind farms to replace fossil fuels, he says, and we could seriously deplete the energy available in the atmosphere, with consequences as dire as severe climate change.

Axel Kleidon of the Max Planck Institute for Biogeochemistry in Jena, Germany, says that efforts to satisfy a large proportion of our energy needs from the wind and waves will sap a significant proportion of the usable energy available from the sun. In effect, he says, we will be depleting green energy sources. His logic rests on the laws of thermodynamics, which point inescapably to the fact that only a fraction of the solar energy reaching Earth can be exploited to generate energy we can use.

When energy from the sun reaches our atmosphere, some of it drives the winds and ocean currents, and evaporates water from the ground, raising it high into the air. Much of the rest is dissipated as heat, which we cannot harness.

At present, humans use only about 1 part in 10,000 of the total energy that comes to Earth from the sun. But this ratio is misleading, Kleidon says. Instead, we should be looking at how much useful energy - called "free" energy in the parlance of thermodynamics - is available from the global system, and our impact on that.

Humans currently use energy at the rate of 47 terawatts (TW) or trillions of watts, mostly by burning fossil fuels and harvesting farmed plants, Kleidon calculates in a paper to be published in *Philosophical Transactions of the Royal Society*. This corresponds to roughly 5 to 10 per cent of the free energy generated by the global system.

"It's hard to put a precise number on the fraction," he says, "but we certainly use more of the free energy than [is used by] all geological processes." In other words, we have a greater effect on Earth's energy balance than all the earthquakes, volcanoes and tectonic plate movements put together.

Radical as his thesis sounds, it is being taken seriously. "Kleidon is at the forefront of a new wave of research, and the potential prize is huge," says Peter Cox, who studies climate system dynamics at the University of Exeter, UK. "A theory of the thermodynamics of the Earth system could help us understand the constraints on humankind's sustainable use of resources." Indeed, Kleidon's calculations have profound implications for attempts to transform our energy supply.

Of the 47 TW of energy that we use, about 17 TW comes from burning fossil fuels. So to replace this, we would need to build enough sustainable energy installations to generate at least 17 TW. And because no technology can ever be perfectly efficient, some of the free energy harnessed by wind and wave generators will be lost as heat. So by setting up wind and wave farms, we convert part of the sun's useful energy into unusable heat.

"Large-scale exploitation of wind energy will inevitably leave an imprint in the atmosphere," says Kleidon. "Because we use so much free energy, and more every year, we'll deplete the reservoir of energy." He says this would probably show up first in wind farms themselves, where the gains expected from massive facilities just won't pan out as the energy of the Earth system is depleted.

Using a model of global circulation, Kleidon found that the amount of energy which we can expect to harness from the wind is reduced by a factor of 100 if you take into account the depletion of free energy by wind farms. It remains theoretically possible to extract up to 70 TW globally, but doing so would have serious consequences.

Although the winds will not die, sucking that much energy out of the atmosphere in Kleidon's model changed precipitation, turbulence and the amount of solar radiation reaching the Earth's surface. The magnitude of the changes was comparable to the changes to the climate caused by doubling atmospheric concentrations of carbon dioxide (*Earth System Dynamics*, DOI: 10.5194/esd-2-1-2011).

"This is an intriguing point of view and potentially very important," says meteorologist Maarten Ambaum of the University of Reading, UK. "Human consumption of energy is substantial when compared to free energy production in the Earth system. If we don't think in terms of free energy, we may be a bit misled by the potential for using natural energy resources."

This by no means spells the end for renewable energy, however. Photosynthesis also generates free energy, but without producing waste heat. Increasing the fraction of the Earth covered by light-harvesting vegetation - for example, through projects aimed at "greening the deserts" - would mean more free energy would get stored. Photovoltaic solar cells can also increase the amount of free energy gathered from incoming radiation, though there are still major obstacles to doing this sustainably (see "Is solar electricity the answer?").

In any event, says Kleidon, we are going to need to think about these fundamental principles much more clearly than we have in the past. "We have a hard time convincing engineers working on wind power that the ultimate limitation isn't how efficient an engine or wind farm is, but how much useful energy nature can generate." As Kleidon sees it, the idea that we can harvest unlimited amounts of renewable energy from our environment is as much of a fantasy as a perpetual motion machine.

Is solar electricity the answer?

A solar energy industry large enough to make a real impact will require cheap and efficient solar cells. Unfortunately, many of the most efficient of today's thin-film solar cells require rare elements such as indium and tellurium, whose global supplies could be depleted within decades.

For photovoltaic technology to be sustainable, it will have to be based on cheaper and more readily available materials such as zinc and copper, says Kasturi Chopra of the Indian Institute of Technology, New Delhi.

Researchers at IBM showed last year that they could produce solar cells from these elements along with tin, sulphur and the relatively rare element selenium. These "kesterite" cells already have an efficiency comparable with commercially competitive cells, and it may one day be possible to do without the selenium.

Even if solar cells like this are eventually built and put to work, they will still contribute to global warming. That is because they convert only a small fraction of the light that hits them, and absorb most of the rest, converting it to heat that spills into the environment. Sustainable solar energy may therefore require cells that reflect the light they cannot use.