A climate for discussion

Climate science is a contentious field, as everyone knows. New research tends to be pounced upon by people convinced, if they don't like its conclusions, that it must be propaganda spewed by nefarious forces — those behind the vast 'climate change conspiracy', perhaps, or their oil-soaked enemies the climate change deniers.

I stumbled blindly into this gallery of indiscriminate bludgeoning last month when I had the idea to cover some recent research on Earth system dynamics for *New Scientist* magazine. The topic was non-equilibrium thermodynamics and its potential implications for future energy use. It seemed innocuous enough to me. Not so.

Within days, a popular climate blog had likened my article to one of the rants of American actor Charlie Sheen. After all, I had reported on some analyses — completely insane, apparently — that take the second law of thermodynamics seriously for the Earth system, and consider how much energy we might feasibly extract from various sources, including the winds. Some people, it seems, just can't stand this kind of research.

In a series of recent papers, physicist Axel Kleidon of the Max Planck Institute for Biogeochemistry in Jena, Germany, has argued that consideration of the free-energy flows through the Earth system — as opposed to total-energy flows — helps to clarify important issues. For example, the total energy used by humans (per year) is a piddling one part in 10,000 of that coming in from the Sun. So, naively, it seems unlikely we could really have an important effect on the environment. But separate out all the energy lost more or less immediately to useless heat, and compare our energy use to the total free energy produced per year by the atmosphere and biosphere, and you find that we use a legitimate fraction of the total amount, perhaps as high as 5–10%. Now our influence isn't so puzzling.

That alone is an important point, but it's also just a beginning. Kleidon argues (in a paper to appear in *Philosophical Transactions of the Royal Society*) that climate scientists and others studying potential responses to climate change have largely overlooked this distinction between energy and free energy, and have therefore misjudged (and often overestimated) just how much energy is available in resources

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such as wind. He makes the assertion — patently ridiculous to those who know the right things — that careful consideration of the various ways that free energy comes to be available on Earth can inform our long-term energy strategies.

Here's why. As Kleidon points out, there are essentially two distinct ways that natural processes turn solar energy into free energy. First, the Sun heats different parts of the Earth differently (more in the tropics than at the poles, for example) and the resulting temperature gradients drive all kinds of physical flows — winds, water vapour and so on. Second, solar energy also gets converted directly into electronic energy through photochemistry — in biological organisms or solar-harvesting technology.

Kleidon's main point is that there is a fundamental difference in our harvesting of free energy from these two distinct channels. We can and probably should tap into the first one as an alternative energy source on a fairly large scale, but we will face limits on what is possible. In particular, we will by necessity reduce the total free energy being generated in that channel. This follows from thermodynamics. By contrast, the second channel doesn't present the same kinds of limits, and our efforts to harvest it could actually increase the total free energy available on Earth.

The limit on the first channel arises because the total rate of free-energy production in this channel is fixed — it's just determined by the size of the temperature gradients that drive the various flows. In other words, all the available free energy in this channel comes about through the action of an enormous heat engine. We can link up some devices to this heat engine — some big wind farms, for example — and convert some of its free energy into other forms such as electricity. But this free energy has to come from those flows. Our generators can't be perfectly efficient, so the overall rate of free energy being generated on Earth through this channel will have decreased.

That doesn't mean there's not lots of energy we could harness from this channel, but that it's not the perpetual motion machine it's often taken to be. Indeed, in earlier work (*Earth Syst. Dynam.* **2,** 1–12; 2011), Kleidon and colleagues tried to estimate the maximum extractable energy from winds, finding a value in the range of 18–68 TW (we currently get about 17 TW from burning fossil fuels). These are rough values estimated by various means ranging from back of the envelope calculations to large-scale computational simulations of atmospheric circulation, and the values are up to 100 times lower than optimistic engineering estimates. All of this of course requires much further research.

But Kleidon's point about the finite capacity of this channel is beyond dispute. And this is important because the second channel of free energy — through photochemistry or other ways of changing light energy directly into electrical energy — doesn't face this fundamental limitation. The key is that solar energy driving this channel doesn't first get changed into heat at the Earth's surface. We can skip that step and harvest it directly from low-entropy light. Consequently, we can get usable energy out of this channel without in any way decreasing its overall free energy content. We can even increase it, because lots of that free energy is currently just being absorbed at the Earth's surface in heat.

Hence, Kleidon argues, sensible analyses of the prospects for shifting to various different energy sources should consider flows of free energy, not just energy. Doing so suggests that more sustainable strategies will aim to increase the overall capacity of the Earth system — us plus the biosphere — to produce free energy from sunlight. That means more efficient direct harvesting of solar energy and more complete covering of the Earth's surface with light-harvesting bio-matter.

Is everything he says right? I certainly don't know, and probably not. These are complex issues. But Kleidon's appeal to fundamental principles is refreshing and the potential importance of his points is surely worth considering. ❐

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