Energy costs

The economic and political history of humanity has been shaped by our access to energy. Our conquest of fire, shift from hunting and gathering to farming, and then later exploitation of fossil fuels vastly multiplied our per capita use of energy. Ample energy resources have changed the shapes of our brains and digestive tracts, and let us spread over the entire globe. Modern technological society is the result.

Today, energy remains central to all politics and the competition among nations, which helps explain why, even as we face an existential crisis in global warming and need sharp cuts in fossil fuel use, nations are simultaneously racing to open the Arctic to search for new fuel deposits. The Chinese, to take one example, are building a fleet of nuclear-powered icebreakers in an effort to pursue the estimated 2 trillion cubic feet of natural gas and nearly 100 billion barrels of oil under the Arctic ice.

Exploiting any resource requires effort and the expenditure of energy — to find it, gather it and process it into useful forms. It requires energy to produce energy. Indeed, how much energy it takes to produce and use energy in different physical forms could be among the most decisive determinants of how we manage — or fail to manage — the necessary transition to a more sustainable future. As Marco Raugei of Oxford Brookes University explores in a recent article, however, even getting accurate numbers for this quantity isn't as easy as it may seem (*Nat. Energy* **4**, 86–88; 2019).

The key technical term is known as energy return on investment (EROI) — essentially the ratio of how much energy we get from some energy production process to how much energy we had to expend in carrying it out. We may develop farmland, grow plants and then process the product into biodiesel. Or, we may drill, pump, transport and refine oil, design and construct wind turbines or hydroelectric generating stations. For any particular source of energy, the EROI is a dimensionless quantity reflecting the energy density and ease of access of that source.

Previous efforts to estimate EROI numbers, Raugei points out, suffer from many inconsistencies. For example, some researchers focus on the EROI considered from the point where the energy resource is extracted — the well head, in the case of crude oil. But this tends to inflate the EROI, because most of the energy in producing usable heavy fuel oil or petrol comes further downstream in the refining process. Include this energy expenditure, and the EROI figures become much smaller. In contrast, an energy source such as solar power comes out of panels as electricity, and the energy expended in further processing are minimal. Any realistic comparison of EROI for different sources has to take such differences into account.

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For any energy source, the EROI may change over time as the resource grows more scarce, or as technology makes new sources available. Such changes can exert a strong influence on economic activity. After all, the energy used up in extracting energy doesn't create any real economic output, but merely goes to providing the energy that can then be used to produce economic output. Hence, if other factors remain fixed, a temporary drop in EROI, for any reason, means we need to use up more energy in producing energy, and therefore have less to spend on real economic activity — on this logic, economic growth should then falter.

Indeed, this seems to be the case empirically. Over the past 150 years, periods of low EROI — implying a temporary decrease in energy available for useful economic activity — have been correlated with lower rates of economic growth (D. J. Murphy and C. A. S. Hall, *Ann. NY Acad. Sci.* **1185**, 102–118; 2010).

This relation may have some implications for economic growth in the future, as the EROI figures for our most important fuels have been declining for some time. The EROI for oil and gas in the United States has fallen from more than 100 in 1919 to around 5–10 in the 2010s. Global figures are fairly similar. Unsurprisingly, alternatives to traditional fossil fuels such as tar sands and shale oil have even lower EROIs, as it takes a great deal more processing to produce usable fuels this way. It may well be true, as economists suggest, that there's lots of oil left in the ground, and higher oil prices will encourage its extraction. This happened in the past two decades, as the shale oil boom has brought a surge in US oil production. But it is also true that ever more energy is being spent in delivering this fuel.

This trend is not likely to reverse, as renewable and non-conventional energy alternatives also have substantially lower EROI values than the fossil fuels used decades ago. A study of values for photovoltaic cells over several decades puts the EROI at around 10. Electricity generated from wind seems to be a little higher at 18 or so, but the amount of energy achievable with this technology is strongly limited. The potential for energy production from biofuels, at least away from the tropics, is even lower — probably less than 5. Estimates of the EROI for nuclear energy range anywhere from 1 up to 90, but many are almost certainly biased by the political views of those making the estimates. A meta-study considering all such estimates, and trying to compare their different methods, came up with a most likely value of around 5, averaged over the entire fuel cycle (M. Lenzen, *Energy Conversion and Management* **49**, 2178–2199; 2008).

Hence, across the globe, we should expect declining EROI values to place difficult demands on economic organization and activity. An increasing proportion will need to be channelled toward obtaining more energy, leaving less for the kind of activity that drives meaningful growth. A disturbing reality — typically referred to as the 'net energy cliff' — is that the fraction of the economy devoted to energy gathering grows very rapidly as EROI falls toward 1. If a drop from 20 to 10 implies a doubling of this part of the economy, a further drop of EROI to 5 puts fully 20% of the economy into the energy gathering sector. A drop to 3 would mean 33% of all energy being used only to get more energy — our societies would change profoundly.

We appear to be well along a trajectory approaching that point. This EROI trend is fully consistent with the empirical observation (S. Lange et al., *Ecological Economics* **147**, 123–133; 2018) that the growth of mature economies appears to be more linear than exponential, or equivalently, that rates of exponential growth are decreasing over time. No one knows the cause. Energy may be part of it. ❒

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