Surplus Energy Economics

The home of the SEEDS economic model – Tim Morgan

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#247: The Surplus Energy Economy, part 2

THE ENERGY DYNAMIC

Introduction

As we have seen in part one of this series, underlying or 'clean' economic output, known here as C-GDP, has correlated remarkably closely with primary energy consumption over a period of more than forty years. This means that *we cannot "de-couple" the economy from energy use*. This conclusion is wholly logical, given that *nothing* which has any economic value whatsoever can be supplied without the use of energy.

In part two, our aim is to assess the outlook for the supply and cost of energy, because this will determine th

Following

prospects for economic output and prosperity. We conclude that, despite their unquestionable importance, alternative energy sources cannot provide a *complete* or like-for-like replacement for the energy *value* hitherto sourced from oil, natural gas and coal.

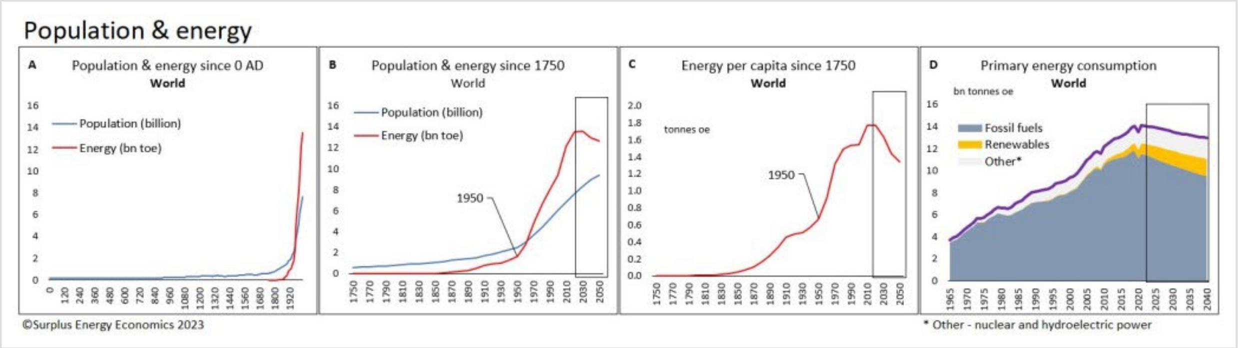
As is apparent in **Fig. 4** – charts in this series are being numbered consecutively – there has been a direct correlation between the exponential increases in, on the one hand, the use of energy and, on the other, population numbers and the economic means of their support. The exponential trends in both series started in the late eighteenth century, which was when the Industrial Revolution began, its symbolic commencement being James Watt's landmark completion of the first truly efficient heat-engine in 1776.

In short, Fig. 4A provides the clearest possible demonstration of the fact that **the economy is an energy system**, and that exponential expansion in population numbers and economic output was the direct result of discovering how to harness fossil fuel energy.

A second turning-point can be seen in the years after the Second World War. For much of the period since then, energy use (measured in billions of tonnes of oil-equivalent) has expanded *even more rapidly than* the population has increased.

This has meant that consumption of energy per capita has risen markedly, as shown in Fig. 4C. But the likelihood now is that the availability of energy will decline, both in aggregate (Fig. 4D) and in per capita terms. If this is what is happening, it means that both economic output and material prosperity **have started to contract**.

Fig. 4



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* Other - nuclear and hydroelectric power

Cost – the critical role of ECoE

The second of the three 'first principles' set out in part one is that energy is never 'free'. Whenever energy is accessed for our use, some of that energy is *always* consumed in the access process. This 'consumed in access' component is known here as the Energy Cost of Energy, or **ECoE**.

Trend ECoEs are on a relentlessly rising trajectory, and this is **the primary cause** of a process of deterioration which has seen growth in economic prosperity decline, stagnate and – now – go into reverse. Overall ECoEs (from all sources of energy) have risen from 2% in 1980 to 4% in 2000, and 10% now. The high-maintenance industrial economy cannot cope with double-digit ECoEs – and there's worse to come.

If ECoEs had stayed at 2%, the economy would still be growing robustly on the basis of abundant low-cost energy, and we wouldn't have stretched the financial system to breaking-point by piling on vast quantities of debt and other liabilities in pursuit of the chimera of credit-fuelled "growth".

If they had stuck at, say, 5%, growth would have been over in the West, but would be continuing in less complex EM (emerging market) countries. As it is, **ECoEs have reached levels at which global economic contraction has become inescapable**.

It's vital, then, that we understand ECoE, the factor which, whilst it is ignored by orthodox economics, goes further than any other to explain why prior economic growth has gone into reverse. How do ECoEs evolve, and what effects do they have?

Coal, oil and natural gas are the sources of energy on which the modern economy has been constructed, and they continue to account for more than four-fifths of primary energy supply. This is where our consideration of ECoE needs to start.

Although data for earlier periods is not available, it's clear that the ECoEs of fossil fuels declined during most of the industrial era, probably reaching their nadir in the quarter-century after 1945.

Our use of fossil fuels began with small deposits, largely discovered on a happenstance basis, which were extracted, processed and delivered using rudimentary technologies.

Three processes contributed to a subsequent long decline in ECoEs.

First, as the energy industries expanded, they reaped continuing **economies of scale**. The relationship between fixed and variable costs dictates that a large oil, gas or coal field is less expensive to develop and operate in unit terms than a smaller one, and this applies to processing and distribution systems as well.

At the same time, the global search for lowest-cost energy supplies reduced ECoEs through the process of **geographic reach**. A notable milestone in this progression was the discovery and development of the vast petroleum resources of the Middle East. Despite the hopes that have been vested in various basins in more recent times, the industry has never found anything on a scale which compares with the enormous oil wealth of the Middle East. Whilst we cannot rule out the possibility that reserves of comparable size might yet be found elsewhere, we do know that any such discoveries would be remote, and technically challenging, meaning costly to access.

The third factor which has driven fossil fuel ECoEs downwards over time has been technical progress, at every stage of the chain from extraction to processing and distribution. This process has been gradual and, in an era in which excessive faith is often vested in technology, we need to remind ourselves that *the capabilities of technology are* *limited by the laws of physics*.

The 'shale revolution' is a case in point. The technological advances in fracturing made the extraction of shale energy more cost-effective than the extraction of **those same resources** would have been at an earlier time. But it did not – and **could not** – turn American oil and gas resources into the equivalent of Saudi Arabia, an outcome precluded by the differing characteristics of the resources in question. This is why shale has not been hugely profitable, despite many expectations to the contrary.

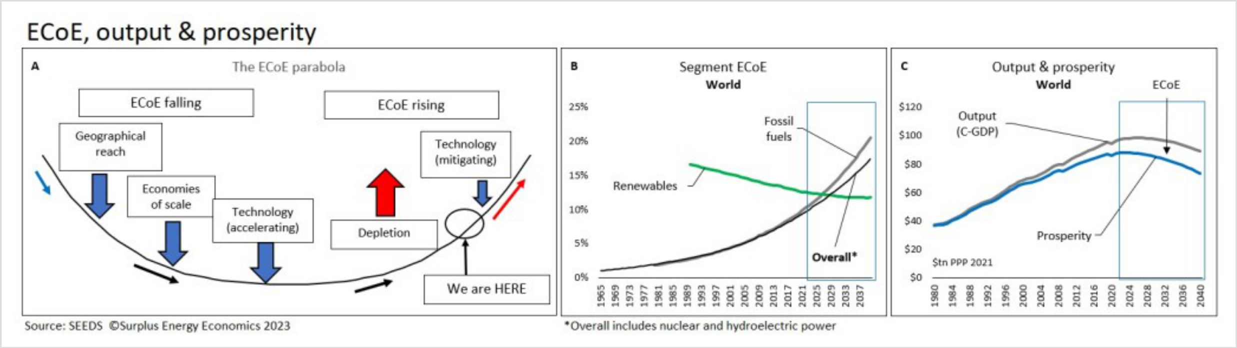
Technology accelerated the downwards trend in ECoEs, and can mitigate the upwards trajectory driven by depletion, but is limited by the physical characteristics of resources.

Once the benefits of *scale* and *reach* had been exhausted, a new factor became the driver of ECoEs. This factor is **depletion**, a term which describes the natural process whereby lowest-cost resources are used first, leaving costlier alternatives for later. Unlike reach and scale, depletion pushes trend ECoEs *upwards* rather than downwards.

We need to be clear that we are not going to 'run out of' oil, or, for that matter, gas or coal. Rather, what we are experiencing is a relentless increase in costs, as older (and generally larger and simpler) deposits are exhausted, and are replaced by resources which are higher-cost, and are often smaller, more remote and more technically challenging than previous sources.

The broad ECoE situation is illustrated in **Fig. 5**. It must be emphasised that the left-hand diagram (Fig. 5A) is a stylized, explanatory representation of the "ECoE parabola", illustrating how ECoEs, initially driven downwards by scale and reach, then turn upwards as a result of depletion, with technology moving from an accelerating to a mitigating role.

Fig. 5



Source: SEEDS ©Surplus Energy Economics 2023

*Overall includes nuclear and hydroelectric power

The central chart (Fig. 5B) shows the projection that, with the ECoEs of fossil fuels on a sharply rising trajectory, neither renewables, nor increased contributions from nuclear and hydroelectric power, are likely to do more than moderate the rising trend in *overall* ECoEs.

In SEEDS analysis, ECoE defines the difference between economic *output* and material *prosperity*. As energy supply becomes more challenging, whilst ECoEs continue to increase, prosperity is in the process of declining **more rapidly**

than output measured as C-GDP (Fig. 5C). These are issues to which we shall return.

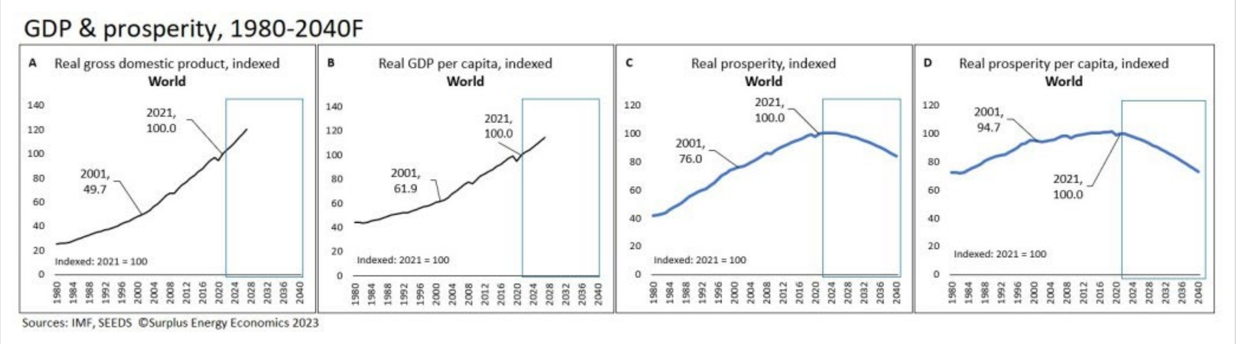
Matters at issue

At a later stage in this series, we'll look at the evolution of prosperity in detail, but it's helpful at this point to remind ourselves of what is at stake. The charts in **Fig. 6** are designed to put this into context. For comparison, each is indexed, with 2021 set at 100.

Conventional data informs us that GDP, generally – though mistakenly – assumed to measure economic output and prosperity, was 101% higher in real terms in 2021 than it had been back in 2001 (Fig. 6A). Population numbers increased over that period but, nevertheless, GDP per capita rose by 62% between those years (Fig. 6B). Both of these positive trends are, we are told, capable of continuing indefinitely.

Energy-based interpretation, conducted using the SEEDS economic model, presents a completely different picture. Growth in aggregate prosperity did occur between 2001 and 2021, but SEEDS puts this at only 32% (Fig. 6C), meaning that the world's average person was only 6%, rather than 62%, more prosperous in 2021 than he or she had been back in 2001 (Fig. 6D).

Fig. 6



Sources: IMF, SEEDS ©Surplus Energy Economics 2023

Needless to say, this average person's share of the world's aggregate debts has increased dramatically, real debt per capita having expanded by 125% between those years – and even this doesn't cover the broader liabilities embodied in the financial system.

More important still, SEEDS projects that aggregate prosperity is close to its point of inflexion, whilst prosperity per person *has already turned down*.

Here, then, is the point of contention. In stark contrast to the perpetual growth promised by orthodox economics, energy-based analysis informs us that prosperity can only expand, or even be maintained at current levels, if **two** conditions can be satisfied.

If aggregate prosperity is to be maintained, aggregate energy supply must not decrease, **and** we must find a way to stop further increases in trend ECoEs. Unless **both** conditions can be met, the economy gets smaller, with consequences that will be examined later in this series.

The outlook for supply

The ECoEs of fossil fuels are rising relentlessly, and will continue to do so. This means that volumetric supply of fossil energy is destined to contract.

This can be explained in terms of pricing which, for any energy source, has to meet two tests. First, it must cover suppliers' costs. Second, it must be affordable for the consumer.

This can be said of any product or service, but the difference with energy is that the affordability of the consumer *is determined by the energy to which he or she has access*. This isn't, then, the same kind of supply and demand equation that we might apply to non-energy products and services.

A person might or might not buy a cup of coffee or a refrigerator at its current price, but being unable or unwilling to make these purchases doesn't reduce his or her income. This is where energy is profoundly different – **a reduction in the supply of energy makes the economy poorer**.

When ECoEs rise, not only do suppliers' costs increase, but there is *a simultaneous decrease in the prosperity* (and hence in the affordability) of the consumer.

When costs are low, price-arbitraging the needs of producers and consumers is straightforward, because the available *value margin* is wide enough to satisfy both.

As costs rise, though, a point is reached at which volumes contract, because the costs of producers rise *at the same time as* the affordability of consumers declines. Far from being driven upwards by scarcity, fossil fuel prices might well decline in accordance with the decreasing prosperity (and hence affordability) of the user. This means that energy markets **cannot be relied upon to give us advance warning** about economic deterioration.

The SEEDS model uses a set of projections which sees the aggregate of fossil fuel supply falling by 18% between 2021 and 2040. Unless offset by increases from non-fossil sources, this would reduce *total* primary energy supply by 15% over that period.

It's certainly possible that the supply of nuclear power will increase, but this is expensive, and would require a major resource investment commitment from an economy which, from now on, isn't growing. The big problem here is scaling. As of 2021, the nuclear sector supplied only 4.5% of the world's primary energy and, taking not just resource needs but construction times as well into account, it's extremely unlikely that we can double, treble or quadruple nuclear generation in a comparatively short period of time. Nuclear fusion is plausible in theory, but has remained twenty-five years in the future throughout the lifetime of anyone reading this article.

Scenario assessment

What this means is that practical hopes for replacing dwindling fossil fuel energy are vested in renewables, with wind and solar power the renewable energy (RE) categories deemed to be capable of rapid expansion. In **Fig. 7**, we look at the demands that REs will be required to meet under four different scenarios.

In each instance, the focus is on the combined supply of energy from wind and solar power, which is shown in orange. For simplicity, it is assumed in all scenarios that fossil fuel supply declines by 18% between 2021 and 2040, and that there are modest increases in the availability of energy from nuclear and hydroelectric power.

In the first scenario (Fig. 7A), there is no increase in wind and solar from the 675 mm toe (tonnes of oil-equivalent) supplied in 2021. On this basis, and despite incremental contributions from nuclear and hydro, total primary energy availability is 12% lower in 2040 than it was in 2021.

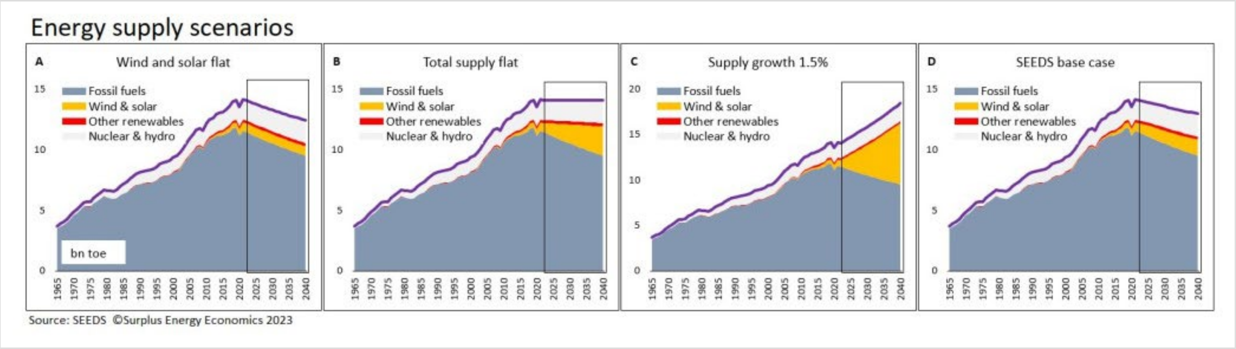
In the second scenario, the aim is to see what needs to happen to keep the total supply of energy unchanged throughout the forecast period (Fig. 7B). For this to happen, and with all other parameters unchanged, supply from wind and solar has to be 250% higher in 2040 than it was in 2021. This might be feasible – we'll look at the challenges shortly – but energy supply *per capita* would fall markedly, and the economic situation would be worsened by continuing increases in overall ECoEs.

If prosperity is to stand any chance of being maintained at current levels – taking into account rising ECoEs – aggregate energy supply needs to grow by at least 1.5% annually (Fig. 7C). For this to happen, we would need a 900% increase in the supply of energy from wind and solar power. This is roughly the set of projections which corresponds to the lower end of consensus expectations, and we're not jumping too far ahead if we state here and now that this is extremely improbable.

The final scenario (Fig. 7D) is the one actually used in SEEDS analysis. By 2040, fossil fuel supplies are 18% lower than they were in 2021. Wind and solar power, taken together, have increased by 90%. There has been a 21% rise in the combined contribution of nuclear and hydroelectricity, and a modest increase from renewable sources other than wind and solar.

In this scenario, the aggregate supply of primary energy falls by 8%, and *energy availability per capita is 20% lower in 2040 than it was in 2021*.

Fig. 7


Energy supply scenarios

Source: SEEDS ©Surplus Energy Economics 2023

The limits to transition

Simply stated, the consensus view is that the supply of energy from wind and solar power will increase so dramatically in the coming decades that we can reduce or even eliminate the use of climate-damaging fossil fuels *without experiencing any contraction in the economy*. There can be no question about the importance of the environmental imperative contained in this view.

But the orthodox line doesn't just postulate the attainment of environmental sustainability through like-for-like transition to renewables, let alone suggest that we can attain sustainability by making some economic sacrifices, which might be a reasonable point of view.

Rather, it holds out the bold promise of "sustainable *growth*".

We're told, for instance, that most of the world's vehicles – totalling close to 2 billion, and including 1.1 billion cars – can be replaced with electric vehicles (EVs). The aggregate of global prosperity will carry on growing indefinitely, perhaps by between 3% and 3.5% annually, meaning that the economy will be somewhere between 75% and 90% bigger, in real terms, in 2040 than it was in 2021. Needless to say, there won't have to be significant sacrifices made by the public, who will carry on driving, flying and consuming at ever-increasing rates.

All of this **depends absolutely** on dramatic expansion in the energy supplied by renewables, which really means by wind and solar power, as these are the two categories which are capable, at least according to the orthodox narrative, of major increases in scale. The ability of these sources of supply to increase is not a matter of dispute. The question is whether they expand by **enough** to take over from fossil fuels.

It has to be said that the consensus scenario of seamless transition owes almost everything to assumption, and virtually nothing to a realistic appraisal of what is achievable within available resources and the parameters set by the laws of physics. The latter is a good place to start an investigation of what might be possible for energy transition.

There are, broadly speaking, two ways in which the supply of any material product can be increased. One of these is to increase the technical efficiency of the supply process, and the other is to expand production capacity. If a manufacturer wants to double his output of widgets, he can either find machinery which is twice as efficient as what he is using now, or double the size of his factory.

Where efficiency is concerned, the harnessing of energy is subject to the laws of physics, which set limits to what is possible. This is certainly true of renewables. The potential efficiency of wind power is determined by Betz' Law, which states that a maximum of 60% of the kinetic energy of wind can be captured by a turbine. The equivalent for solar is the Shockley-Queisser Limit, which is 34%.

For practical purposes, two observations need to be made here. First, we cannot expect to lift conversion efficiency all the way to the Betz and Shockley-Queisser maxima, because no technology can attain perfect theoretical efficiency.

Second, and more importantly, current best practice *is already close to theoretical maxima*. The conversion ratios of solar panels (where the limit is 34%) already exceeds 26%. The efficiency of wind energy conversion, where the maximum is 60%, is already above 40%.

In short, and whilst technical progress is likely to continue, **there can be no quantum leap in conversion efficiencies**, a conclusion well stated here.

If we are to attain very large increases in the supply of wind and solar power, the heavy lifting will have to be done by capacity expansion.

The cost of transition to renewables has been calculated, and is known to be enormous, well in excess of USD 100 trillion. What matters, though, isn't the financial cost, but what that cost means in terms of *the material inputs to be purchased with it*.

Rapid expansion (and maintenance) of wind and solar generating capacity and distribution will require vast amounts of concrete, steel, copper, plastics, lithium, cobalt, nickel, graphite, rare earths and numerous other raw materials. It is by no means clear that these materials even exist in the requisite quantities – and the environmental and ecological effects of accessing them are likely to be severely adverse.

On one point there is no scope for dispute – making these raw materials available on a huge scale will require the use of correspondingly vast amounts of energy.

Two further considerations exacerbate the input problem. The first is the intermittency of wind and solar power, and the second is the intrinsic difficulty of storing electricity when compared with the storage of fossil fuels. In the absence of fossil fuel back-up, intermittency requires both surplus capacity (for use when the sun is shining and the wind is blowing) and large and efficient methods of storage.

Both of these considerations leverage the necessary quantities of material inputs. Battery weight is about 60X higher than the weight required for the storage of an energy-equivalent quantity of fossil fuels, and between 50 and 100 tonnes of raw materials are needed for each tonne of batteries produced. In some applications, hydrogen might be a viable alternative storage technology, but hydrogen does not exist in its natural state, and its manufacture is energy-intensive.

This is why systemic capacity for the storage of electricity remains very small indeed. Inventories of petroleum are customarily recorded in days, weeks or months, but electricity reserves are calculated in *minutes*. In the report cited above, it was stated that "[t]he annual output of Tesla's Gigafactory, the world's largest battery factory, could store three minutes' worth of annual U.S. electricity demand. It would require 1,000 years of production to make enough batteries for two days' worth of U.S. electricity demand".

It needs to be noted, too, that capacity expansion targets need to take account of the ageing and replacement, not just of batteries, but of wind turbines and solar panels as well.

The second compounding factor is the shape of planned application. It is, for example, one thing to use renewable electricity to power trams or electric railways, but quite another to supply huge numbers of EVs.

What we are trying to do is to transition vehicles – and numerous other systems created on the basis of fossil fuels – to a completely different source of energy. *This isn't how energy-using technologies develop*. The Wright Brothers didn't invent the aeroplane and then sit around waiting for someone to discover petroleum.

Rather, technologies need to be developed *in accordance with the energy available*. But there is no preparedness to accept that trains and trams might make more sense than cars in a transport system powered by electricity rather than by petroleum. Even the humble bitumen used in road surfaces is sourced from oil.

Serious though these problems are, we have yet to come to the clincher on seamless transition. Even if we assume that all necessary materials for renewable transition exist in the required quantities, they still need to be extracted, processed, manufactured and delivered, and this requires massive quantities of energy that can only come from the legacy energy of fossil fuels. This, in turn, **ties the ECoEs of renewables to those of oil, gas and coal**.

Even if supplies of fossil fuel energy could be relied upon to continue at current levels, nobody has yet postulated the current uses of this energy that will be relinquished to free up energy for the purposes of transition. Are we prepared to drive less, fly less or consume less, in order to make energy available for the extraction and processing of steel, copper, lithium and cobalt?

A rocky road ahead

The situation, in summary, is that (a) fossil fuel supplies can be expected to decrease more rapidly than alternatives can be expanded, and (b) that the material connection between renewables and fossil fuels *makes it implausible that the relentless rise in ECoEs can be stemmed, still less reversed, by renewables expansion*. As we have seen, decreasing energy availability reduces economic output, whilst rising ECoEs leverage the adverse consequences for prosperity.

The Surplus Energy Economics project concentrates on the analytical rather than the prescriptive, and the foregoing should not be taken as disputing the imperative of transition to renewables.

On the contrary, renewables offer our best chance of mitigating economic decline. If we decided to stick with fossil fuel energy and back-pedal on renewables, the economy would contract under the combined pressures of decreasing energy supply **and** relentlessly rising ECoEs.

There is not, as is so often assumed, any necessary contradiction between our economic and our environmental best interests, which means that transition is imperative for economic **as well as** environmental reasons. If we tried to carry on with reliance on fossil fuels, we *might* wreck the environment but would *definitely* wreck the economy, as supplies of fossil energy decline, and their ECoEs soar.

But there really is no justification for techno-optimism around transition, and claims that “sustainable *growth*” is assured are starkly at odds with reality. The fact of the matter is that fossil fuels offer energy density, flexibility and portability that no other source of primary energy can match.

We cannot circumvent the laws of physics, nor sever the necessary connection between energy use and economic output. Neither can we reverse the rise in ECoEs by switching to lower-density sources of energy supply.

With this understood, we can move on to assess the outlook, first for economic prosperity, and then for the financial system.

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