The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Renewable Transition 2: EROEI Uncertainty

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In the first part of this series, I discussed the practicality of a future transition from fossil fuels to renewable energy sources—specifically renewable sources of electricity such as solar and wind power. One little-discussed hurdle is the fact that, because we must invest energy in renewables up front, a rapid transition threatens to greatly impact near-term demand for energy resulting in unwanted economic and political effects. Another is that, because we will initially use fossil fuels to build our renewable infrastructure, the transition to renewables will result in a short-term increase in carbon emissions. The extent to which both of these impacts will be significant, even their potential to foreclose the possibility of such a transition, will turn on the net energy, or Energy Return on Energy Invested (EROEI), of available renewable energy technology.

As I alluded to last time, while there are many EROEI numbers floating about for solar, wind, etc., these numbers are far less accurate or verifiable than is, I believe, commonly assumed. I'll argue that our measurements of EROEI are fundamentally flawed, at least for some purposes. Most EROEI studies serve as a tool to compare different technologies or to gauge advances in technology--a role for which they are generally well suited. However, when viewed from a complete systems perspective, current EROEI figures fail to provide an inclusive measurement. I'll argue that, for purposes of planning a civilizational transition, a meaningful meansure must be inclusive of all energy inputs. Finally, I'll propose a possible proxy-measurement to address the methodological issues surrounding EROEI.

"Conventional" EROEI vs. "systemic" EROEI measurements: I've been fairly candid with my critique of conventional EROEI measurements, even suggesting that many such measurements are more accurately characterized as marketing copy than empirical, verifiable measurements. This is perhaps a bit unfair--the core of my critique is that these conventional EROEI measurements, while valuable and perhaps even accurate for some purposes, are wholly inadequate to measure the systemic implications of a transition to these alternatives. Here, to assist this critique, I've divided EROEI measurements into two broad categories.

What I'm calling "conventional" EROEI measures use an artificial boundary to simplify their accounting by excluding energy that, while certainly an input, is several steps removed from the direct manufacture of the renewable. This includes standard input-output analysis, process analysis, and hybrids of these two. This type of EROEI estimate (as it must fairly be called) seems to have utility in two areas: 1) comparing the relative EROEI of similar renewables (for example, two different turbine designs), and 2) measuring the progress of design advances (for example, the effect of improving the design of one given type of turbine).

The second type of EROEI is what I'm calling "systemic" EROEI. While I think this terminology is self-explanatory, here I mean a complete system-wide measure of all outputs compared to all inputs. The value of such a measure is in determining the viability of such technologies to support human civilization as a whole, to sustain certain levels of growth (or contraction), etc.

The problem with calculating EROEI: Why the need for two sets of EROEI calculations? Why not just use one fundamentally "true" measurement methodology and call it a day? The answer is that measuring EROEI is far more challenging than is commonly presumed because of (among several reasons) the following question: how attenuated an energy input is necessarily included in our calculations? Certainly the electricity and natural gas used in a turbine manufacturing plant must be included. What about the energy used to build that plant? What about the energy used to build the machinery used to build that plant? What about the energy used to build the plant to build *that* machinery, ad infinitum? This is just the tip of the iceberg, but already you can see where this is going: we must draw an artificial boundary if we hope to *actually count* these energy inputs, but by so doing we necessarily exclude a portion of the actual energy inputs—inputs the significance of which are unknown and unknowable (because we can only know their significance by actually counting them—which brings us back to our initial problem). The outcome of these methodologies, while admittedly the result of actual counting of measurable inputs and outputs, remains but an estimate.

Are these excluded inputs inconsequential? Do we really need to count the energy used to harvest the grains used to feed the longshoreman that loaded the component ores on a dock in Asia as an energy input to the turbine parts that were produced from that ore? And what is the aggregate impact of these attenuated inputs? First, I suggest that we do not and cannot know, as argued above. See the figure below:

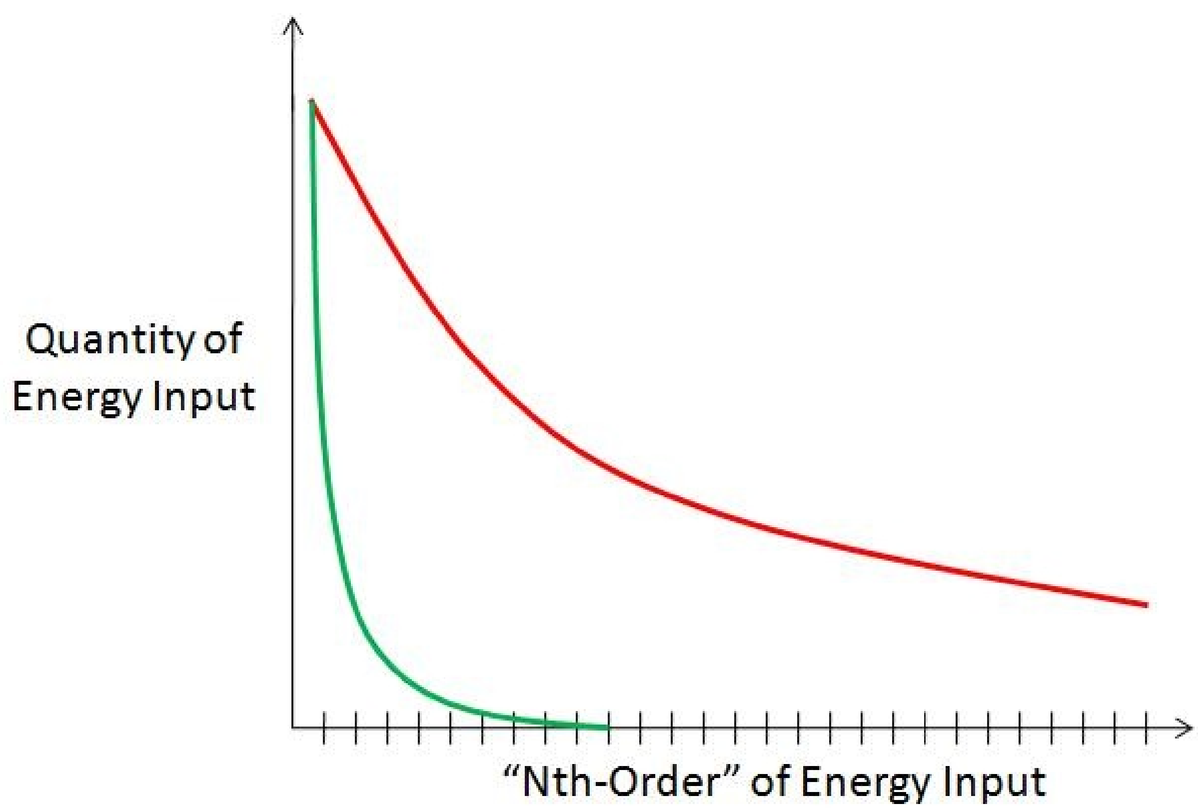

Figure 1: The different theories about the importance of "long-tail" inputs are compared above. In both cases (red and green lines), the total energy input is represented by the area under the curve. In the green line model (the view reflected by most current EROEI figures), the vast majority of energy input is accounted for in very proximate use (e.g., the energy consumed in the turbine assembly line, the energy used to transport the finished turbines, etc.). In the red line model (an inclusive view that I advance here), attenuated energy inputs are much more significant (e.g., the proportion of energy used to build the mining machinery to mine the ore for the metals used in the machine tools in the turbine assembly line). If, as I argue, the red line model is at all accurate, then the inability of current EROEI calculation methodologies is a fatal flaw, at least to the extent that we are looking for an inclusive number to answer systemic questions.

Only one empirical study, to my knowledge, has attempted to calculate an inclusive EROEI, and even that study assumes that, where 10% of our economy spent on energy is used to fuel the other 90%, that this other 90% is in no way a prerequisite to the energy production. See What is the Minimum EROI that a Sustainable Society Must Have? by C. Hall, et al. This study suggests that, where the initial "well-head" EROEI is 20:1, after the necessary supporting infrastructure of society is accounted for the EROEI drops to 3:1. This is a drop from "conventional" to "systemic" EROEI of nearly an order of magnitude.

This calculation of a truly inclusive, systemic EROEI for renewable energy sources stands at the very core of our society's ability to transition to renewable energy. Compare, for example, results of input-output vs. process-analysis EROEI figures from existing studies of wind EROEI at Meta-analysis of net energy return for wind power systems by Kubiszewski, et al. Two brief quotations are in order, first at pp. 2-3:

> The choice about system boundaries is perhaps the most important decision made in net energy analysis, and, for that matter, in other analytical approaches as well. One of the most critical differences among the diverse studies is the number of stages in the life cycle of an energy system that are assessed and compared against the cumulative lifetime energy output of the system.

and at p.7:

> Studies using the input-output analysis have an average EROI of 12 while those using process analysis an average EROI of 24. Process analysis . . . may be prone to the exclusion of certain indirect costs compared to the input-output analysis.

Input-output studies (which tend to be "more comprehensive," including more attenuated inputs, but certainly still only the “front” of the long-tail) averaged only 50% the EROEI figure of the process-analysis EROEI figures for similar technologies under roughly similar conditions. If inclusion of a small portion of this long-tail can reduce EROEI by as much as 50%, it is at least possible--I would argue likely--that inclusion of the full "long tail" will make “systemic” EROEI as much as an order of magnitude lower than “conventional” EROEI measures.

Ultimately, energy can neither be created nor destroyed. As a result, in any closed system, the energy flows within that system must come into unity. The more pertinent question here may be "what artificial boundary to draw when considering questions that affect human society as a whole?" I argue that, ultimately, we must draw the boundary at our planet, a system that, at least on human-relevant time scales, tends to operate in relative stasis given the continuous input of solar energy. As a result, EROEI of civilization must balance out to roughly 1:1 + the rate of growth of human society. While that may seem like a tautology at first, and is used by some to argue that "systemic" or "inclusive" EROEI measures such as those I suggest here are pointless, I think the reverse is true--while 0.8 or 1.2 may seem like minor differences, they fundamentally represent the difference between a shrinking global civilization (and quite possibly a declining foundation of ecological support and resiliency) or one that is growing.

We have been able to expand and grow our global civilization based, recently, on savings of "ancient sunlight" accumulated over geological time. We have empirical proof that the EROEI of these sources was significantly greater than 1 due to the sustained growth of human civilization. Now, any attempt to replace that vast inheritance with renewable technologies must address that same *systemic* question: when ALL the energy inputs are considered, will civilization have the energy to expand energy, maintain, or reduce the energy consumed per capita? The answer to that question will largely guide the future of humanity--as such it is critical for us to understand if the "systemic" EROEI of modern renewable energy technologies are actually, as I suggest, an order of magnitude lower than advertised.

As a quick thought exercise--and even if you only consider it a slight possibility that systemic EROEI is actually an order of magnitude lower than the numbers floating around--consider the impact on the transition from issues raised in the first post in this series (boot-strapping burden and carbon front-loading) . . .

I would also like to address one attempt to reconcile this problem: Howard Odum's "emergy" concept. While I applaud his recognition of this problem, and his efforts to address it, "emergy" really doesn't address the accounting impossibility highlighted above. While "emergy" recognizes the need to account for all energy inputs, it provides no methodology to get around the process of actually counting them, as we regress infinitely step-by-step back from the assembly line itself. As a result, "emergy" calculations must either draw an artificial boundary somewhere (resulting in the same long tail of unknown significance) or must resort to mere guesses about the inputs. (I recognize that Odum's "emergy" also addresses the cost of transformation between different energy qualities--this doesn't eliminate the problem caused by the "long tail" of energy inputs where such transformation must be considered, and where Odum presents no accounting theory or proxy measurement methodology to measure these inputs in aggregate.)

Price-Estimated EROEI: I have proposed that, in order to calculate "systemic" EROEI, we must use some sort of proxy-calculation that gets around the accounting impossibility highlighted above. While I've reviewed several options, the only one that seems workable is what I've called the price-estimated EROEI method.

In the price-estimated EROEI methodology, we attempt to use the price mechanism to account —by proxy—for this long tail of energy inputs. The basic calculation is quite simple: convert the financial cost to build and maintain the system into units of the same energy produced by the system and then compare to the amount of energy that the system will produce over its expected lifespan. I've gone through two applications of this methodology below. I'd like to be the first to recognize that there are very significant concerns with this methodology. Just to name a few: inaccuracy caused by the differing energy value of the input energy type actually used compared to the output energy type; price distortions caused by currency fluctuations, market inefficiencies, and market failures; the unaccounted for externalities of the actual inputs, especially fossil fuels, compared to the often fully internalized equivalent in the clean renewable energy produced.

While there are many legitimate criticisms of the price-estimated EROEI method (some listed above), one of the more frequent criticisms is, in my opinion, unfounded, and should be rebutted. Many people have suggested that the energy used, for example, to feed and house a person involved in the production of, say, wind turbines, shouldn't be counted because that person would need to be housed and fed whether or not she was involved in turbine production. This critique is overly simplistic: the reason that this energy input must be counted is because of the concept of opportunity cost. If our wind turbine worker was not involved in that process, she could be involved in another energy-producing activity. Therefore, because she must give up these alternatives in order to work on wind turbines, this energy is accurately accounted as an input in wind-turbine production. Additionally, because price-estimated EROEI is an attempt to calculate the systemic EROEI, we must consider that, if this energy is not accounted for, we may be assuming that society can support a component worker that, in fact, cannot be supported and will be "cut" through population shrinkage ("die off") and economic contraction.

Example price-estimated EROEI calculation for solar photovoltaics: LA Solar PV Installation: This 2009 installation is my example for price-estimated EROEI calculation. I think it's a good example (no example is perfect) for several reasons: at 1.2 MW, it's modest in size, but large enough to reap economies of scale; because it is installed on an existing roof space, there is no land cost associated with the installation (that, in some circumstances, could present acquisition costs or environmental compliance/impact statment costs not truly representative of net energy issues); because it is in California, where the average cost of electricity (and especially peaking "sunny day" electricity that solar provides) is higher, it will provide a more conservative estimate; because it is located in the downtown of a major metropolitan area it will not require significant transmission investment to provide a true measure, and is therefore also more conservative. Finally, there are good cost and output numbers available for the site. Basic data: 1.2 MW array installed 2009 in Los Angeles, cost $16.5 million up front (ignoring rebates/tax credits/incentives), projected financial return of $550,000 per year. At the rough California rate of $.15 per KWh, that's about 4 GWh per year (conservative). Price-Estimated-EROEI Calculation: The $16.5 million up-front is, at $0.09/KWh (here using national average, as there's no reason to think that manufacturers would use primarily California peaking power to build this system), an input of 183 GWh through installation (I'm ignoring the realtively small maintenance costs here, which will also make the figure more conservative). If we assume a life-span of 40 years, then the energy output of this system is 160 GWh. That's a price-estimated EROEI of 0.87:1.

Example price-estimated EROEI calculation for wind: I've had a more difficult time finding a recent wind project where clear data (on both cost and actual, as opposed to nameplate, output) is readily available. As a result, I've chosen a 2000 Danish offshore wind project at Middelgrunden. While up-front expenses may be higher off-shore (making the resulting EROEI here more accurate for offshore projects than on-shore), I think this is a relatively modern installation (2MW turbines). If readers have more current projects with full data, please provide in the comments--another point for investigation is whether the price-estimated-EROEI of solar and wind have been improving or if they are holding relatively stead. Basic data: Cost of $60 million, annual energy ouput 85 GWh. Price-Estimated-EROEI Calculation: At the US national average rate for electricity ($0.09/KWh), the $60 million up-front energy investment works out to 666 GWh. Using a life-span of 25 years (and assuming zero maintenance, grid, or storage investment, making the result artificially high), the energy output comes to 2125 GWH. That's a price-estimated-EROEI of 3.2:1.

Again, these are just representative samples, and I recognize the weaknesses and uncertainties with this model. However, I must ask two questions. First, if there are market or price inaccuracies internal to these calculations that make them inaccurate, how can they be explained? For example, if it's inaccurate to use the price of a unit of energy outputted as the cost of energy input, why hasn't the market addressed this? Second, recognizing these inaccuracies, how do we know whether this measure is more or less inaccurate than "conventional" EROEI measures? We cannot definitively characterize the uncertainties inherent in price-estimated EROEI, nor can we definitively characterize the significance of the unaccounted for energy in "long-tail" of conventional EROEI measurements, so we have little basis to say that one measure is more accurate than the other. We can only say with high confidence that "conventional" EROEI is some degree higher than an inclusive "systemic" EROEI—how much higher we do not know. But if the very high (40:1, 70:1, etc.) figures sometimes floated for the EROEI of renewables is accurate, how can we explain the inability to monetize this value?

This fundamental uncertainty does not render the discussion pointless. I think that we can say with confidence that existing EROEI measures do not answer one question that is critical to the continuation of civilization as we know it: do renewable energy systems like wind, solar, tidal, or geothermal power have sufficiently high EROEI to facilitate a transition away from fossil fuels? This leads us to the precautionary principle which, crudely summarized, states that where the potential impact is significant and we have insufficient confidence to choose between two future scenarios, prudence demands that we plan for the more pessimistic. This certainly seems to be the case here: the prospects for "transition" look starkly different at "systemic" EROEI values of 40:1 vs. 4:1. In this vein, and in the final post in this series, I will explore the significance of EROEI uncertainty and our path forward in light of this uncertainty.