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EROEI Calculations for Solar PV Are Misleading

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The Energy Returned on Energy Invested (EROEI) concept is very frequently used in energy studies. In fact, many readers seem to think, "Of course, EROEI is what we should be looking at when comparing different types of energy. What else is important?" Unfortunately, the closer to the discussions of researchers a person gets, the more problems a person discovers. People who work with EROEI regularly say, "EROEI is a tool, but it is a blunt tool. An EROEI of 100 is good compared to an EROEI of 10. For small differences, it is not so clear."

Because of the idiosyncrasies of how EROEI works, different researchers using EROEI analyses come to very different conclusions. This issue has recently come up in two different solar PV analyses. One author used EROEI analysis to justify scaling up of solar PV. Another author published an article in Nature Communications that claims, "A break-even between the cumulative disadvantages and benefits of photovoltaics, for both energy use and greenhouse gas emissions, occurs between 1997 and 2018, depending on photovoltaic performance and model uncertainties."

Other EROEI researchers with whom I correspond don't agree with these conclusions. They recognize that in complex situations, EROEI analyses cannot cover everything. Somehow, the user needs to be informed enough to realize that these omissions result in biases. Researchers need to work around these biases when coming to conclusions. They themselves do it (or try to); why can't everyone else?

The underlying problem with EROEI calculations is that EROEI is based on a very simple model. The model works passably well in simple situations, but it was not designed to handle the complexities of intermittent renewables, such as wind and solar PV. Indirect costs, and costs that are hard to measure, tend to get left out. The result is a serious bias that tends to make the EROEIs of solar PV (as well as other intermittent energy sources, such as wind) appear far more favorable than they would be, if a level playing field were used. In fact, published EROEIs for solar PV (and wind) might be called misleading. This issue also exists for other similar calculations, such as *Life Cycle Analyses* and *Energy Payback Periods*.

Some Background on EROEI

Proposed types of energy alternatives are often analyzed using Energy Returned on Energy Invested (EROEI) calculations. For each type of energy product that is produced, a ratio of the *energy output* to *energy input* is calculated. A high ratio gives an indication that the particular approach is very efficient, and thus is likely to produce an inexpensive energy product. Coal is a typical of example of a fuel with high EROEI. Wood cut using a hand saw would also have a very high EROEI. On the other hand, a low ratio of *energy output* to *energy input*, such as occurs in the production of biofuels, is expected to be high cost, and thus is not suitable for expanding.

A derivative concept is "net energy." This is defined as the amount of energy added, when "Energy Input" is subtracted from "Energy Output," or variations on this amount.[1] There are many other related concepts, including "Energy Payback Period" and "Life Cycle Analysis." The latter can consider materials of all sorts, not just energy materials, and can consider pollution issues as well as energy issues. My discussion here indirectly also relates to these derivative concepts, as well as to the direct calculation of EROEI.

The actual calculation of EROEI amounts varies a moderate amount from researcher to researcher. On the input side, the researcher must make decisions regarding exactly what energy inputs should be included (manufacturing the solar panel, transporting the solar panel to the construction site, building the factory that makes the solar panel, disposing of toxic waste, etc.). These energy inputs are then all converted to a common base, such as British Thermal Units (Btus). On the output side, amounts are fairly clear when the production of fossil fuels is involved, and the calculation is "at the wellhead." When output from a device such as a solar panel is involved, there are many issues to be considered, including how long the solar panel is expected to last and how many hours of solar output will actually become available given the solar panel's siting (which may not be known to the researcher). In theory, the energy costs of ongoing maintenance should come into the calculation as well, but will not be available early in the life of the panel when the calculations are made.

Two Kinds of EROEI: Return on *Fossil Fuel Energy* or Return on Labor

The type of EROEI we generally hear about today is what I would call "**energy return on fossil fuel energy invested**." This is a concept developed by Charles Hall in the early 1970s, shortly after the book The Limits to Growth was published in 1972. In fact, it sometimes includes other kinds of energy in the denominator as well, such as hydroelectric. Most people who follow today's academic literature would probably assume that this is the only kind of EROEI of interest when discussing today's energy problems.

In fact, there is a different kind of EROEI analysis that preceded fossil fuel EROEI. This is return on the labor of an animal, a theory that now goes under the name Optimal Foraging Theory. Falling return on labor for animals represents the situation in which an animal has to walk (or fly or swim) increasingly far, or is required to swim increasingly upstream, to find the food it needs. Animal populations tend to collapse when their EROEIs fall too low. Prof. Hall taught ecology, so is well versed in the issues of energy return on animal labor.

There is also a parallel analysis of the return on *human labor*. Return on *human labor* has been studied for many years, and is documented in books such as The Upside of Down, by Thomas Homer-Dixon. In fact, Homer-Dixon talks about falling EROEI with respect to human labor being the cause of the fall of the Roman Empire.

The return on human labor can drop too low in several ways:

1. If resources deplete or erode. For example, if topsoil becomes too thin, or energy supplies become depleted.

2. If population rises too much, relative to resources. We are really interested in things like arable land per capita, and barrels of oil per capita.
3. If a disproportionate share of the return the economy receives goes to some elite group, so the workers themselves don't receive enough.

Falling return on human labor is very similar to *falling wages*. This falling return affects those at the bottom of the employment hierarchy most, such as young people just out of school and workers without too much education. These wages may or may not fall in monetary terms; what is important is that *the goods and services that these wages buy fall on a per capita basis*. Once falling return on human labor starts happening, the whole system starts unraveling:

1. Governments cannot collect enough taxes.
2. Businesses lose the economies of scale that they previously had.
3. A large share of debt cannot be repaid with interest.
4. Individual citizens find that they cannot afford to get married and start new families because their wages are too low, and they have too much debt.
5. In earlier times, epidemics became more common because workers could not afford adequate diets.

I would argue that falling return on human labor is the primary type of falling EROEI that we should be concerned about, because it represents the summation of all of the types of returns that the economy is getting. It might be considered the Societal Return on Energy Invested.

I would also argue that Societal EROEI, defined in this way, is already too low. One way this can be seen is through the higher unemployment rate of young people in many countries. Another is a delayed rate of starting new families. Another is wages of many of the less educated workers rising less rapidly than inflation.

The key things that make the calculation of EROEI of human labor and EROEI of animal labor "work" as intended are

1. Clear boundaries on what is to be included. The boundary is per animal, or per human being.
2. Very close timing between when the energy is consumed (food or other) and when the output is available (animal energy used or goods and services consumed by humans).
3. There is an easy way of adding up diverse inputs and outputs, namely using the financial system to count the worth of human labor, or an animal's energy system to determine whether the food input is sufficient.

The one thing that doesn't entirely "work" in this model is the fact that the actions of humans can have an adverse impact on other species, but this is not directly reflected in the EROEI of human labor. This is not handled by the wage system, but it can be somewhat handled in the tax system. Of course, if taxes are used to compensate for the adverse impact that humans are having on the ecosystems, the higher taxes will tend to reduce the return on human labor further, and thus bring about collapse more quickly.

Fossil Fuel EROEI as a Cost Estimate

When Prof. Hall developed the concept of EROEI, the concept was intended to be a rough cost estimate. If a particular type of alternative energy required a lot of energy to be created, it would likely be a very expensive type of energy; if very little energy was required, it likely would be inexpensive. When making one energy product using other energy products, energy is usually a major item of input. Thus, it seems reasonable to expect that EROEI calculations will work at least as a "blunt tool" for pricing.

The problem in making EROEI more than a blunt tool is the fact that **none of the three characteristics that make EROEI on human labor work as expected is present for fossil fuel EROEI**. (1) Fossil fuel EROEI boundaries can be made wider by making the list of energy inputs counted longer, but they always remain short of the entire system. (2) Timing is a huge issue, leading to a need for capital and a return on that capital, but there is no adjustment for this in the calculation. (3) The fact that energy quantities rather than prices are being used to add up inputs means that we can never determine something that is comparable to the overall cost of the complete supply chain. Furthermore, similar to the problem with humans adversely affecting other species, intermittent electricity adversely affects both the electric grid and the pricing of other types of electricity. EROEI calculations leave out these impacts.

The fossil fuel EROEI system ends up being similar to a system that compares tops of icebergs, when these icebergs are floating at somewhat different levels, and we can't measure the relative levels well. Furthermore, our measuring tool is restricted to only one type of input: energy that can be counted somewhere in the cycle. Adverse impacts, such as damage to the grid or to the electricity pricing system, are not counted at all.

The danger with EROEI comparisons is that a person ends up with "apples to oranges" comparisons. Generally, the more similar energy types are, the more likely EROEI comparisons are likely to be truly comparable. For example, EROEIs for the same oil field, made with data a year or two apart, are more likely to be more meaningful than a comparison of EROEIs for fossil fuels with those for intermittent electricity.

Specific Problems with the EROEI of Solar PV

(1) **Prospective EROEI calculations tend to have a bias toward what is "hoped for," rather than serving as a direct calculation of what has been achieved.** If the EROEI of an oil field, or of a hydroelectric plant that has been in operation for many years, is desired, it is not terribly hard to find reasonable numbers for inputs and outputs. All a researcher needs to do is figure out pounds of concrete, steel, and other materials that went into the initial structure, as well as inputs needed on a regular basis, and actual outputs; with these, a calculation can be made. When estimates are made for new devices, the bias is always toward what is hoped to be achieved. How much electricity will a solar panel produce, if it is properly sited, properly maintained, maintenance costs are very low, the electric grid can actually use all of the electricity that the panel produces, and all parts of the system last for the expected life of the solar panel?

(2) **All energy is given the same "weight,"** whether it is high quality or low quality energy. Intermittent

energy, such as is produced by solar PV, is in fact extremely low quality output, but there is no adjustment for this fact in the calculation. It counts the same as much better quality electrical output, such as that provided by hydroelectric.

(3) **There is no charge for the use of capital**. When capital goods such as solar panels are used to produce energy products, this has several negative impacts on the economy: (a) Part of the energy produced must go to pay for the interest and/or dividends related to long-term capital use, but there is energy cost assigned to this; (b) A country's debt to GDP ratio tends to rise, as the economy is required to use ever-more debt to finance all of the new capital goods; and (c) The wealth of the economy tends to become ever-more concentrated in the owners of capital goods, leaving workers less well off. EROEI calculations don't charge for any of these deficiencies. These deficiencies are part of what makes it virtually impossible to scale up the use of wind and solar PV as a substitute for fossil fuels.

(4) **EROEI indications tend to be misleadingly favorable, because they leave out hard-to-estimate costs**. EROEI analyses tend to focus on amounts that are "easy to count." For solar PV, the amount that is easiest to count is the cost of making and transporting the solar PV. Installation costs vary greatly from site to site, especially for home installations, so these costs are likely to be left out. Indirect benefits provided by governments, such as newly built roads to accommodate a new solar PV installation, are also likely to be omitted. The electric utility that has to deal with all of the intermittent electricity has to deal with a whole host of problems being dumped on it, including offsetting the impact of intermittency and upgrading the newly added electricity so that it truly meets grid standards. There are individual studies (such as here and here) that look directly at some of these issues, but they tend to be omitted from the narrow-boundary analyses included in the meta-studies, which researchers tend to rely on.

(5) **Precisely how solar PV at scale can be integrated into the grid is unclear, so costs required for grid integration are not considered in EROEI calculations**. There are a number of approaches that might be used to integrate solar PV into the electric grid. One approach would be to use complete battery backup of all solar PV and wind. The catch is that there is seasonal variation as well as daily variation in output; huge overbuilding and a very large amount of batteries would be required if the grid system were to provide electricity from intermittent renewables throughout the winter months, without supplementation from other sources. Even if storage is only used to smooth out daily fluctuations, the energy cost would be very high.

Another approach would be to continue to maintain the entire fossil fuel and nuclear generation systems, even though they would run only for a small part of the time. This would require paying staff for year-around work, even though they are needed for only part of the year. Other costs, such as maintaining pipelines, would continue year around as well.

A partial approach, which might somewhat reduce the energy needs for other approaches, would be to greatly increase the amount of electricity transmission, to try to smooth out fluctuations in electricity availability. None of these costs are included in EROEI calculations, even though they are very material.

(6) **Solar PV (as well as other intermittent electricity, such as wind) causes direct harm to other types of energy producers by artificially lowering wholesale electricity prices.** Wholesale prices tend to fall to artificially low levels, because intermittent electricity, including solar PV, is added to the electric grid, whether or not it is really needed. In fact, solar PV adds very little, if any, true "capacity" to a system, so there is no logical reason why prices for other producers should be reduced when solar PV is added. These other producers need the full wholesale cost of electricity, without the downward adjustment caused by the addition of intermittent energy sources, if they are to obtain a sufficient return on their investment to make it possible to continue to provide their services.

These issues tend to drive needed back-up electricity generation out of business. This is a problem, especially for nuclear electricity providers. Nuclear providers find themselves being pressured to close before the ends of their lifetimes, because of the low prices. This is true both in France and the United States.

In some cases, extra "capacity payments" are being made to try to work around these issues. These capacity payments usually result in the building of more natural gas fired electricity generating units. Unfortunately, these payments do nothing to guarantee that the natural gas required to operate these plants will actually be available when it is needed. But gas-fired generating units are cheap to build. Problem (sort of) solved!

(7) **Electricity generation using solar PV cannot be scaled up very well.** There are multiple issues involved, including cost, debt, difficulty in handling the variable output, and the adverse impact of the intermittent electricity on the profitability of other carriers.

What Should Be Done Next?

It seems to me that a statement needs to be made that EROEI was a preliminary pricing method for various fuel types developed back in the early 1970s. Unfortunately, it is a blunt tool, and is not really suitable for pricing intermittent electricity, including solar PV, wind energy, and wave energy. It presents a far more favorable view of adding these energy types to the electric grid than is really the case. Hydroelectric energy is sometimes considered intermittent, but is really "dispatchable" most of the time, so it does not present the same problems.

EROEI calculations are in a sense the output of a very simple model. What we are finding now is that this model is not sufficiently complex to deal with the way intermittent electricity affects the system as a whole. What needs to be substituted for all of these EROEI model results (including "net energy," Life Cycle Analysis, and other derivative results) is real world cost levels using very much wider boundaries than are included in EROEI calculations.

Euan Mearns has shown that in Europe, countries that use large amounts of wind and solar tend to have very high residential electricity prices. This comparison strongly suggests that when costs are charged back to consumers, they are very high. (In the US, subsidies tend to be hidden in the tax system instead of raising prices, so the same pattern is not observed.)

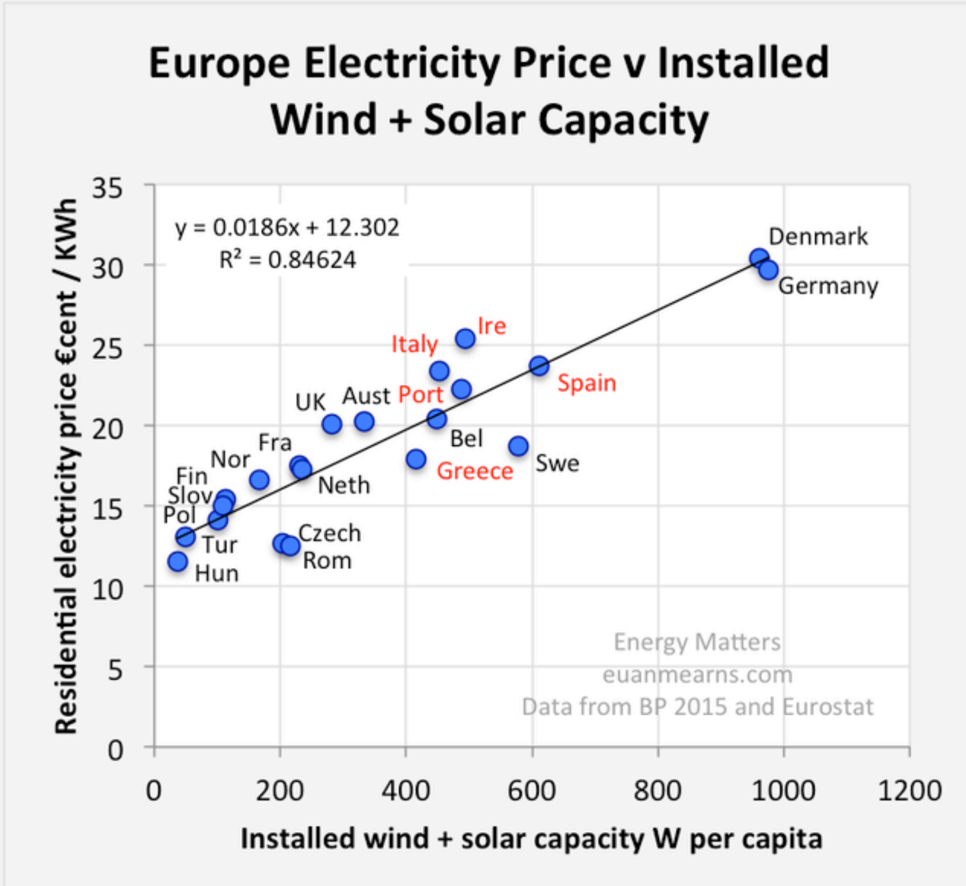

Figure 1. Figure by Euan Mearns showing relationship between installed wind + solar capacity and European electricity rates. Source Energy Matters.

Even this comparison omits some potential costs involved, because intermittent electricity concentration levels are not yet at the point where it has been necessary to add huge banks of backup batteries. Also, the adverse impact on the profitability of other types of electricity generation is a major issue, but it is not something that can easily be reflected in a chart such as that shown in Figure 1.

It seems to me that going forward, a completely different approach is needed, if we want to evaluate which energy products should be included in our electricity mix. The low energy prices (for oil, natural gas, coal, and electricity) that we have been experiencing during the last 30 months are a sign that consumers cannot really afford very high electricity prices. Analysts need to be looking at various scenarios to see what changes can be made to try to keep costs within the amounts consumers can actually afford to pay. In fact, it probably would be helpful if building of new generation could be reduced to a minimum and existing generation could be kept operating as long as possible, to keep costs down.

The issue of low wholesale prices for electricity generated by nuclear, gas, and coal needs to be analyzed carefully, since, for example, France cannot easily get along without nuclear electricity. Nuclear energy is generally a much larger provider of electricity than wind and solar. Somehow, the financial returns of non-intermittent providers need to be made high enough that they can continue in operation, if they are not at the ends of their normal lifetimes. I am not sure how this can be done, short of banning intermittent electricity providers, including those currently in operation, from the grid.

A Long-Term Role for Solar PV

It appears that our civilization is reaching limits. In fact, it seems likely that our current electric grid will not last many years–probably not as long as people expect solar panels will last. We also know that in past collapses, the only thing that seemed to partially mitigate the situation was radical simplification. For example, China transported goods in animal-powered carts prior to collapse, but changed to transporting goods in wheelbarrows, after it collapsed about the third century A. D.

Building on this idea, the place for intermittent renewables would seem to be off the electric grid. They would likely need to operate in very small networks, probably serving individual homes or businesses. For example, some homeowners might want to set up 12 volt direct current systems, operating a few LED lights and a few specially designed 12 volt direct current appliances. Businesses might want to do more. The problem, of course, comes in maintaining these systems, as batteries degrade and other parts need to be replaced. It would seem that this type of transition could be handled without huge subsidies from governments.

The belief that we can maintain our current electric grid system practically indefinitely, using only wind + solar + hydroelectric + biomass, is almost certainly a pipe dream. We need to be looking at the situation more realistically, and making plans based on what might actually be feasible.

Note:

[1] In defining net energy, some would say that Energy Input should be multiplied by a factor of three before the subtraction is done, because input energy is only partially counted in most calculations. Another variation is that the calculation varies by energy product, and whether EROEI has been calculated using a "wellhead" or "point of use" approach. These variations further add to confusion regarding exactly which amounts are comparable to which other amounts.

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About Gail Tverberg

My name is Gail Tverberg. I am an actuary interested in finite world issues - oil depletion, natural gas depletion, water shortages, and climate change. Oil limits look very different from what most expect, with high prices leading to recession, and low prices leading to inadequate supply.

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says:

January 10, 2017 at 9:16 am

In my EROEI presentation I point out that the number you estimate depends heavily on where you draw your "fence" – the closed curve through which flow the energy inputs and outputs that you're identifying and tabulating. For example, one can analyze EROEI for underground coal mining with the fence drawn at the "mine mouth." That's a very cut-and-dried way to do it; energy goes in the hole in the form of human labor and fuel or electricity for machines and comes out in the form of coal. But to then compare the number you get from a mine-mouth analysis to some other energy production activity, you've got to draw that activity's analysis' fence in an analogous way and that's not easy when you're talking about e.g. wind or solar.

There's also a wrinkle in that the fence has to be drawn not only in space but also in time. A lot of energy goes into the production of a dam and hydro plant, but the moment it begins running, the EROEI for the entire installation starts at effectively zero, then rises past one once it makes up for its creation energy plus its operating energy consumption to date, and then continues to climb for as long as it's in operation. The point is that you can't talk about the total EROEI of a hydro dam unless you circumscribe the time period over which the dam operates past its first kilowatthour.

The frustrating/fascinating thing about EROEI is that the true numbers actually exist for any given specific definition – but finding them or even their upper or lower bounds can be exasperating. And as I also say in my presentation, *societal* EROEI is a number that rose from a barely-over-one-to-one time when all our forebears had was their own strength to work with up to the point where labor could specialize…and eventually the day came when we could build schools, hospitals, lunar modules, and Angry Birds. If societal EROEI begins falling because the energy inputs required just to "fly level" keep increasing, so does the available surplus from which we create what we think of as "modern civilization." And if that number continues to fall, society will be forced to descend through the stages through which it rose, and you won't be able to have things like hospitals. In truth, such a descent would fall unevenly among the world's population and we, as a civilization, face a decision as to either how the fall will be allocated among it or how to reengineer the energy system to keep the number from falling through those stages – if that's even possible.

Niels Colding?iframe=true&theme_preview=true *says:*

January 10, 2017 at 10:00 am

Money is the tokenization of energy. So just follow the money. So easy is it. However, Vestas doesn't like it!

JT Roberts?iframe=true&theme_preview=true *says:*

January 10, 2017 at 10:14 am