A Comment on EROI

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The energy available to make things is decreasing as fossil carbon energy becomes more difficult to extract. So, naturally, it is interesting to ask just how much energy it takes to make something and whether or not a renewable energy source can return energy to society that is greater than the energy used to make it. An example might be a wind turbine–how much energy does it take to make and install one compared to the energy it generates over its lifetime?

The currently popular way to judge this is the energy return over the energy input, called EROI or EROEI. It is the ratio of energy returned over the energy input. If greater than one, this is good–how good is maybe a subject of dispute. If the ratio is less than one, the thing made is an energy sink, not an energy producer. So the ratio is ER = Energy Out (over the lifetime of the device)/ Energy In (to make it).

This ratio is not easy to calculate if you want to do it right–that is, to add up all the individual energy inputs. (The energy out is usually easier to get.) But you do have to do that if your aim is to identify the energy inputs and make them as small as possible. This will be vital to the future of energy that replaces declining fossil carbon energy.

This comment is on an easy way to get a "ballpark" estimate of ER (I find it hard to write EROEI everywhere for this ratio.)

There are some problems with my estimate. The big one is that for replacement energy sources we are building now (wind turbines, solar energy, geothermal energy) the input energy is in the form of "primary energy" from fossil carbon. But this source suffers from thermodynamic losses. A ballpark estimate is that only about a third of the primary energy ends up as Newtonian work used to make things (sometimes called "useful energy"). But the output energy from our replacement energy source is much higher value electrical energy. The useful work from electric power can be 90 percent of the input electrical energy. This is a huge difference, it amounts now to loosing two thirds of the input energy in the calculation of ER. In the future, the input energy, if electrical in nature, will be much more efficient and the ER ratio correspondingly larger. Of course, this problem affects all calculations of ER in the modern economy that are based on fossil carbon energy. A second problem with my estimate will become clear: it is based on counting energy in terms of its end cost of the replacement energy device in question (a wind turbine, for example). Moreover, I will do this in average terms. But energy efficiency surely varies across the manufacturing sector, so there is an error in using the average. I also ignore maintenance costs in energy terms.

Here are some resulting very rough calculations. First: how much energy is embodied in a manufactured object per dollar of its end cost? Here is my estimate. A reasonable estimate of the end cost of all manufactured objects in the U.S. is about \$2 trillion ($\$2 \times 10^{12}$) per year and the energy input to the manufacturing sector is about 30 EJ (exajoules or 30×10^{18}Joules) So I get an estimate of the embodied energy in an object per dollar of its cost,

$$\frac{30 \times 10^{18} J}{\$2 \times 10^{12}} = 15 MJ/\$$$

(the unit here is the megajoule, MJ $10^6 J$)

Here is how to use this for a ballpark estimate of ER. Suppose the end cost of some device, divided by the average energy it produces in Watts (average meaning the energy produced over a year in Joules divided by the number of seconds in a year) is one dollar per Watt of average power produced or $\$1/W$. The device can be a big as you like, just divide the total cost of the project in dollars by the total average power produced in Watts. This is often available on the website for energy projects. (But here is another source of error: the manufacturing part of a project is less than the total project cost.) To keep things simple, suppose that the device lasts for 30 years. So 15 MJ of energy input ends up as one dollar of input cost and over 30 years the energy produced–the total we want–in the same Joule units, is

$$1\frac{\text{J}}{\text{sec}} \times 3.15 \times 10^7 \frac{\text{sec}}{\text{yr}} \times 30\text{yr} = 945MJ$$

Now we divide this total energy by the energy input that the one dollar brought us and the ER for \$1/W is

$$ER_1 = \frac{945MJ}{15MJ} = 63$$

(I used ER_1because this is the ER per \$1/W–if the cost is higher the ER is lower.)

To use this number, simply divide it by the corresponding number of dollars per Watt of the device or project. The result is the ER for that.

Now we can check this using the starting number. What is the resulting embodied energy in a \$20,000 automobile? At 15 MJ per dollar this comes out to be 300 GJ (300 gigajoules). If you look on Wikipedia, an Australian study is quoted that does a proper job of this and gets 240 GJ. The close agreement is surely accidental, but the method is not obviously crazy.

Let us apply this to the calculation of ER for a wind turbine. Nowadays they cost about \$2 Million installed per megawatt of "nameplate power". If I use a rough number of the efficiency of 0.3 (from the book America 2100), this is \$2 Million per 300 kilowatts average delivered power or

$$\frac{\$2 \times 10^6}{300 \times 10^3 W} = 6.7 \frac{\$}{W}$$

So the ER, or EROEI, is

$$ER = \frac{63}{6.7} \simeq 9$$

and I used the symbol $\simeq$ to show it is only good to one significant figure–I can hardly expect more from a ballpark estimate. How realistic is this number? I checked it quickly against tables in a paper by D. Weissbach et al on "Energy Intensities" (an Elsevier publication), who got ER=16. So my number is almost a factor two smaller; this is not unreasonable.

What about solar photovoltaic energy? In "America 2100" I mentioned that a few large PV installations in Germany and Spain cost about \$50/W - \$60/W, so their ER number are, for the lower cost number

$$ER = \frac{63}{50} \simeq 1$$

which does not look too good. Again for comparison, D. Weissbach et al got ER=4 for PV power, perhaps as a result of the decreasing costs of PV installations (my numbers in the book are four years old). Updating the number using the now complete Topaz solar farm in California, it it delivers the promised 1.0 GWhr per year at the claimed \$2.4 billion in cost, or roughly \$20 per average watt, the corresponding $ER = 63/20 \simeq 3$ without energy storage.

In both cases, these ER numbers do not include the need to store power for times when the wind does not blow or the sun does not shine. I think that for the U.S. this would reduce the wind ER number by about a factor 2, accounting for energy averaging over the country and for energy storage.

What about solar thermal electric power from a "power tower" installation, which can store energy in the form of molten salt and generate power at night? There is such an installation, in Spain, called "PS10", again mentioned in the book. The number for this facility is \$15/W so the ER is

$$ER = \frac{63}{15} \simeq 4$$

but, of course, this includes the buffering of power for when the sun does not shine.

I do not claim much for these estimates–they are all likely low–but it is interesting just how easy it is to get ballpark nuimbers for the energy return on energy invested. The more important job is to break down the real input energy numbers to see where improvements can be made. And even current more detailed numbers are likely too small compared to a future economy where efficient electric power from replacement energy sources forms the input to the energy return on energy invested, the future industrial economy willing.

A tricky problem is whether or not the ER numbers for replacement energy make it economically viable or not. Sometimes large ER numbers are quoted as necessary for a modern economy. My own view is that it is far too early to claim anything here, because as fossil energy declines and replacement energy rises, society and the economy will change in ways we cannot anticipate. The future manufacturing sector will not look much like what we have now. If the comment above on the efficiency of future electric power in manufacturing is correct, ER does not give us much reason to worry about the viability of future energy. More important, the role of ER in the future depends on what an informed society wants, not what economists say it should want.

It might be useful here to mention that the ratio for Great Britain of GDP to the cost of coal energy in about 1870 seems to have been around 100. Energy costs for the early industrial revolution were very small. For the U.S. now this ratio is closer to 20, so the ratio of GDP to energy cost has dropped by a factor 5 or so. Energy has been getting more expensive for a long time. It seems reasonable that it can get yet more expensive, in the form of replacement energy, by another factor 2 or so; our society should be able to withstand this. After all, the cost of energy per unit of GDP rising by a factor 5 has produced a new significant sector of our economy when compared to 1870.

I do not see any convincing reason why the sources of replacement energy mentioned here cannot be widely used in a future economy with much less fossil carbon energy available.