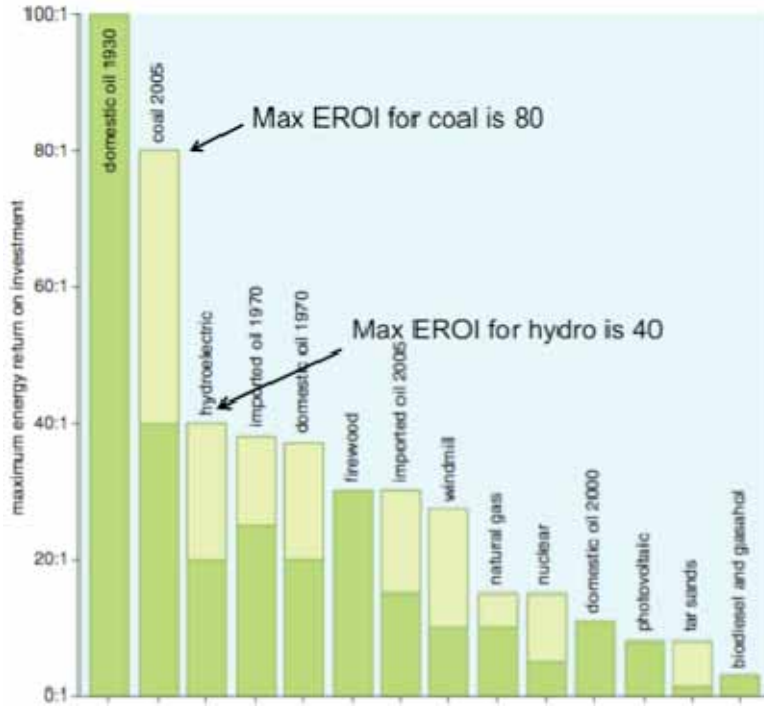


The Energy Return on Investment Threshold

David Murphy, <http://www.theoildrum.com/node/8625> , novembre 2011

Hall and Day (2009) report that the EROI for coal might be as high as 80 and that for hydropower, EROI is 40. Does this mean that coal is twice as 'good' as hydro? The answer is no, and in this post I will discuss how this relates to the idea of an EROI Threshold.



The Net Energy Cliff

This post is based on a presentation that I gave at the recent ASPO conference on November 4th, 2011.

We must first realize that EROI is a somewhat theoretical concept; it is a unitless ratio that does not describe actual flows of energy. What society really cares about, and what is really used to grow economies around the world, are actual flows of energy. More precisely, the economy utilizes flows of *net* energy. What, if anything, can EROI tell us about the flow of net energy?

To understand how EROI influences the flow of net energy, we must first look at the equation for both net energy and EROI, which are:

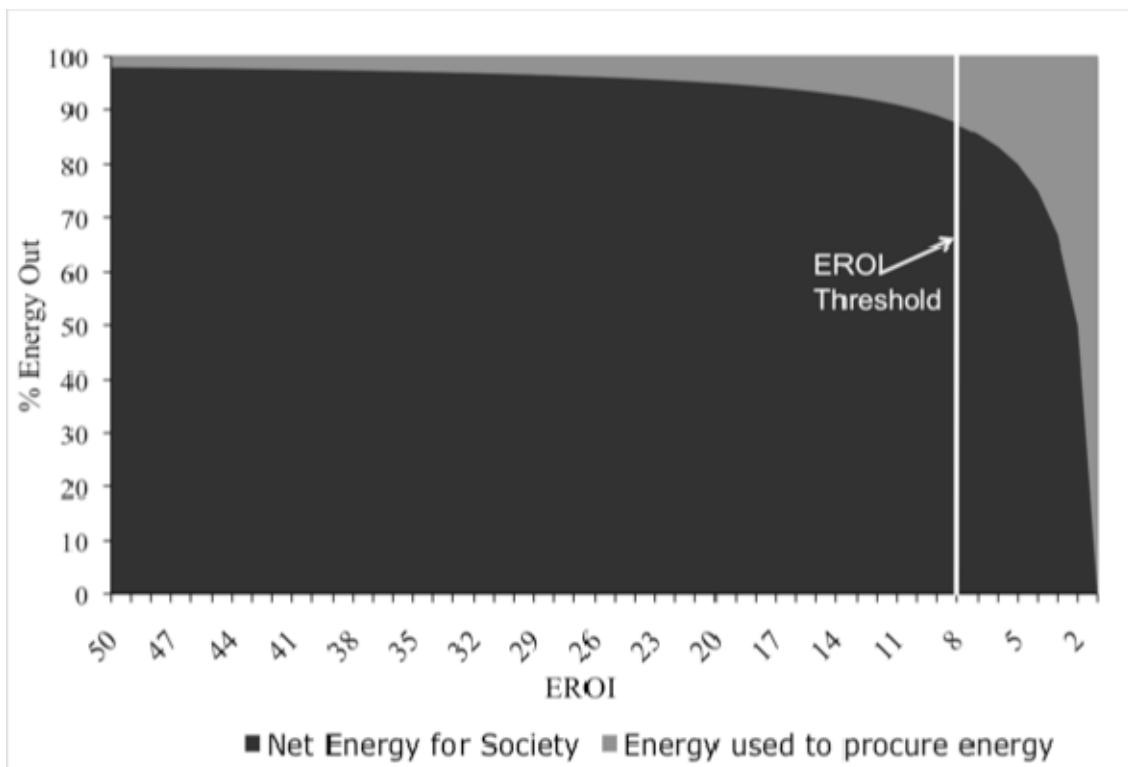
$$\text{Net Energy} = E_{\text{out}} - E_{\text{in}}$$

$$\text{EROI} = E_{\text{out}}/E_{\text{in}}$$

If we solve the EROI equation for E_{in} and substitute it into the Net Energy equation, we get:

$$\text{Net Energy} = E_{\text{out}} * ((\text{EROI} - 1) / \text{EROI})$$

From this equation Means (2008) created the "Net Energy Cliff" graph. The net energy cliff figure relates the percent of energy delivered as net energy (y-axis, dark grey) and the percent of energy used to procure energy (y-axis, light grey) as a function of EROI (x-axis).



The Net Energy Cliff

The exponential relation between net energy and EROI creates what I am calling an *EROI Threshold* at roughly 8. Due to the asymptotic nature of the curve at high EROIs, there is little difference in the actual flow of net energy delivered from technologies that have EROIs above 8. The corollary is that extraction/conversion processes with EROIs below 8 result in vastly different flows of net energy.

For example, a drop in the EROI of oil extraction from 50 to 10 would result in a change in net energy flow from 98% (of the gross energy flow) to 90%. Yet, a drop in EROI from 10 to 2 would result in a net energy change from 90% to 50% of the gross energy flow.

This means that the relevance of EROI as a meaningful comparison of extraction/conversion technologies decreases as EROI increases. This is also the reason why I stated in the beginning of the article that coal, with an EROI of 80, is not twice as good as hydro, with an EROI of 40, because the actual difference in the flow of net energy between these two is very small. The truth is that they both deliver well over 90% net energy. What this threshold effect means is that, when substituting renewables for fossil fuels, it is less important to match EROIs (i.e. substituting coal for a renewable that also has an EROI of 80), and more important to focus simply on avoiding very low EROI technologies (EROI < 8).

Major Caveat to the EROI Threshold

There is one major caveat to this discussion. The logic behind the EROI Threshold only applies if the EROIs being compared are actually commensurable: i.e. that the EROI analyses utilize the same set of assumptions. This is often, however, not the case.

One significant difference between the EROIs calculated for fossil fuels and that for renewable technologies results from the intermittent nature of renewable energy. It is commonly thought that scaling renewable energy will require the adoption of some sort of storage system to account for times of over- and under-production. The EROI of wind or solar PV will surely decrease if we allocate the energy costs of those storage systems to the solar PV or wind conversion process. The question is whether this added energy cost will decrease the EROI of these systems below the EROI threshold, but to my knowledge, there are no peer-reviewed papers reporting EROI numbers that included these costs.

Bottom-Line

EROI is a useful metric for comparing across energy extraction/conversion technologies, or for comparing the extraction/conversion process of one resource over time. But as EROI increases, and especially as it increases much beyond 8, its relevance, as it pertains to net energy flows, fades. Furthermore, due to the aggregated nature of the EROI statistic, every analysis involves assumptions. It is important that those who use these EROI statistics understand what those assumptions are and what they indicate about the utility of the EROI statistic produced.

References

1. Hall, C.A.S.; Day, J.W., Revisiting the limits to growth after peak oil. *American Scientist* 2009, 97, 230-237.
 2. Mearns, E. In *The global energy crises and its role in the pending collapse of the global economy*, Royal Society of Chemists, Aberdeen, Scotland, October 29th, 2008; Aberdeen, Scotland, 2008.
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--- Commentaires les plus intéressants

David – A very interesting and logical approach. It parallels the economic aspects of oil/NG drilling. As discussed before the oil patch doesn't consider EROI when making investment decisions...at least not directly. The actual fuel used to drill a well is not only a small fraction of the total costs but also represents a very small percentage of energy even from a marginally successful well. At the upper end it's totally irrelevant. The difficult aspect of estimating EROI for a well is estimating the embedded energy in the equipment. And the additional problem of amortizing that energy across the number of wells eventually drilled.

In a similar way to your analysis our economic evaluation makes little difference at the upper end. Two exploratory wells may both cost \$6 million but one has a target of \$30 million net reserves and the other \$60 million. Both are quite economic projects but one is not twice as good as the other. First, the \$60 million may find \$20 million worth of reserves...or none at all. Dry holes happen. This is why I tease exploration geologists about doing detailed economic analysis of the projects: all exploratory wells are great investments because the geologist is free to pump the reserves up since there is a lack of data...that's why it's called exploration.

I'm a career development/reservoir geologist. Economic analysis of these types of projects is more similar to your EROI threshold. The reserve targets tend to be much smaller than exploration goals. Thus energy input is more closely approaching energy output. This is why development projects must have a high probability of success: little room for error. And that has always been the balance: exploration is high risk/high potential yield and development is low risk/low potential.

But now we have major plays that fall between these two extremes: the fractured shale plays. Almost every fractured shale exploratory well is completed because it's nearly impossible to tell what it will produce from indications while drilling. When was the last time anyone reported a dry hole in the Eagle Ford or Marcellus? I've seen wells with excellent fracture indicators lose money. And wells with little or no indication of commercial quality produce huge profits. Every shale well completed will produce some hydrocarbons...the question is how much and how fast.

The shale plays are a statistical game. Success isn't based upon what any one well discovered...despite the fact most of the public oils like to report their big wells (and tend to not put out press releases on the less impressive results). My very rough estimate is that some shale plays will, in general, fall not too far above your threshold. Which isn't that bad for the public oils. Their primary goal is not high profits (and thus not high EROI). It's the maintain/grow shareholder equity. As discussed many times Wall Street rewards reserve base growth while typically ignoring ROR. I drill only conventional reservoirs and generate 2 to 3 times the return than even the better Eagle Ford wells. But if my company were public Wall Street would have very little interest in us...we don't care how much of our reserve base we replace. It's all about \$'s in/\$'s out. Of course, we would like to increase our reserve base as much as possible...but not at the cost of ROR.

But in the end there is a factor that has a significant effect on the EROI threshold: oil path economics will kill a project long before the projected EROI gets too low. The total non-energy costs of drilling a well are much greater than the energy consumed. And it's the total costs that determine what gets drilled. Perhaps not coincidentally I recently estimated the minimum limit for a project to pass economic muster would fall close to an EROI of 10. Though it's difficult to equate ROR and EROI directly to each other, there is obviously a relationship. But that relationship is made even foggy when the shale plays are analyzed. In theory a public oil could break even (make no profit) on every shale well they drilled but as long as they increased their reserve base y-o-y Wall Street would bid their stock price up. I suspect such an effort would produce a threshold below your EROI of 8.

In primitive agriculture, the only energy inputs and outputs were food energy. So, in primitive subsistence agriculture, the inputs and outputs are equal, and the EROEI was not much more than 1. Being a subsistence farmer in ancient times was not a lot of fun, his main objective was to live until he died, which was not a long time.

Civilization stepped up this rate, until in the late Middle Ages, with the introduction of metal plows and horses the EROEI may have reached 4. They still burned up 25% of their food to feed the horses, but it was a lot better than burning up 100% of their food to grow enough food to work hard enough to feed themselves.

And then the industrial revolution hit, and with the burning of coal for fuel and the use of machines for farming and manufacturing, the EROEI skyrocketed. The introduction of oil for fuel pushed it even higher.

But I don't think an EROEI of 10 for ancient agriculture can be justified. I think it was a lot lower than that.

The way you come to ten is to calculate how much calorie you get from each calorie spent. It must be higher than one because, you need energy for the elderly and children, who can't feed themselves. You need spare calorie to build your house and make your clothes. Overall, you don't save much however. EROI is not used to calculate the net energy of the economy, just the energy flow in the energy production.

Roman empire has collapsed when its EROI dropped following the conquest of all valuable land. Their EROI ended to about 10 following the collapse.
