DISPELLING THE MISCONCEPTION OF LOW-EROI PHOTOVOLTAICS:

PEAK OIL IS HERE, LET US NOT SQUANDER WHAT IS LEFT

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ABSTRACT

Fossil fuel reserves have played a crucial role for over a century, by providing high net energy gains to fuel our societies. The Energy Return on Investment (EROI) of conventional oil and gas has been in constant decline since the 1930's, though, and the common belief has been that no viable alternatives exist to offset this trend. In particular, photovoltaic (PV) technologies have long been shunned because of supposedly low EROI. We show that the latter is an artifact of inconsistent calculations, and that switching from burning fossil fuels as feedstock in thermal power plants to using them for building large-scale PV systems would increase the associated EROI by at least one order of magnitude. Deploying large PV capacities worldwide, long before the EROI of fossil fuels eventually approaches unity, may actually be amongst the most effective strategies to reach the ultimate long-term goal of putting an end to our dependence on non-renewable energy.

Keywords: Photovoltaics, PV, EROI

1. INTRODUCTION

Energy Return on Energy Investment (EROI) has long been held as an indicator of the ultimate viability of an energy option [Cleveland et al., 1984]. The EROI of a fossil fuel has been defined as the ratio of the energy in the fuel itself (E_F) to the primary energy which was required to extract and deliver it (E_{ED}):

$$EROI_F = E_F/E_{ED} \tag{1}$$

Following decades of continuous extraction and subsequent impoverishment of the Earth's fossil fuel stocks, the EROI of oil and gas reserves have shrunk from over 100 at the beginning of last century to between 10 to 30 today, depending on the specific field and its proximity to exhaustion [Hall et al., 2008; Hall and Day, 2009]. Since the late 1970's, net energy analysts have been voicing their concern about this worrying trend, arguing that the global peak in oil production would happen shortly after the turn of the century [Campbell and Laherrère, 1998], and that we should start being more thrifty in our management of the oil and gas reserves that are left. The EROI of coal has remained relatively stable at 40 to 80, but coal is a less flexible fuel than oil or gas, cannot be directly used to power vehicles, and its combustion invariably entails higher environmental impact, in terms of greenhouse gas as well as acidic and particle emissions.

In parallel to the dwindling of fossil fuels reserves and the corresponding decrease in their average EROI, modern societies have turned more and more to electricity as the preferred vector to satisfy their end-use energy needs, because of its unsurpassed flexibility, transferability and cleanness at the point of use. This has only exacerbated the problem, since to date over 80% of the world's electricity is generated in thermal plants, which use essentially 100-year old technology to burn fossil fuels and use roughly 30% of the resulting thermal energy (the rest being irreversibly lost as waste heat) to turn water into high-pressure steam and run a turbine. Most of the remaining 20% of the world's electricity is produced in hydroelectric dams, which themselves are not free from environmental side-effects, and in any case cannot be easily scaled up because of geographical constraints. Geothermal electricity is even smaller in global potential, and most available reserves have already been tapped. Which leaves us with nuclear, and the so-called "renewable" alternatives, such as wind, biomass and photovoltaics (PV). In the existing EROI literature, though, renewables have almost invariably been downplayed as being hampered by intrinsically and inescapably low EROIs, and thus little attention has been paid to them as potential substitutes for thermal power plants. We show here that, in the case of PV, this is a misconception based on outdated energy performance data and, more importantly, inconsistent calculations, and that PV should really be looked at as a more efficient way to make use of the remaining fossil fuel reserves.

2. A MATTER OF CONSISTENCY

In order to evaluate if and to which extent PV represents today a viable alternative to thermal electricity produced through the combustion of fossil fuels, it is first and foremost of paramount importance to perform the comparison in a consistent fashion, i.e. adopting the same system boundaries and equations. Unfortunately, this does not appear to have been the case in the hitherto published scientific literature.

2.2 EROI of thermal electricity

The EROI of thermal electricity has traditionally been calculated by taking the ratio of the *electric energy* in output from the power plant to the *primary energy* that was required to extract and deliver the feedstock fuel used by the plant itself. This is illustrated in Eq. 2, where E_{ED} stands for the energy used for fuel extraction and delivery, E_F stands for the energy in the feedstock fuel, and E_{el} is the output electricity.

$$EROI_{el} = E_{el}/E_{ED} \qquad (2)$$

Given the definition of the EROI of the feedstock fuel above (Eq. 1), the EROI of thermal electricity can be rewritten as:

$$EROI_{el} = EROI_F * E_{el}/E_F \qquad (3)$$

where $E_{el}/E_F = R$ is the heat rate of the power plant.

Assuming an average heat rate = 0.3, one can thus calculate a range for the $EROI_{el}$ of thermal electricity of 3 to 24.

2.3 EROI of PV electricity

In the published literature, it has been suggested that the EROI of PV electricity should be calculated as the ratio of its lifetime (T) to its energy pay-back time (EPBT) [Hall, 2008; Heinberg, 2009; Reich-Weiser et al., 2008]. The latter is defined as the time it takes for PV to produce the same amount of electricity that could be produced by the existing electric grid, using the same cumulative primary energy demand (CED). This can be expressed by Eq. 4:

$$EPBT = CED/SE \tag{4}$$

where SE (spared energy) is the amount of primary energy required by the grid to produce the same amount of electricity as a PV power plant produces in one year.

The advocated ratio EROI = T/EPBT thus equals to EROI = (T*SE) / CED, where T*SE is the total spared primary energy over the PV plant's lifetime.

One first observation is readily apparent: this ratio is *not consistent* with the $EROI_{el}$ as defined and calculated for thermal electricity. In fact, EROI = T/EPBT is a ratio of the *primary energy* that is spared from consumption by the grid to the *primary energy* that is required for the construction and maintenance of the PV plant. It therefore implies a comparison across different technologies (PV vs. the grid), and represents the ratio of two primary energy quantities. Conversely, the $EROI_{el}$ of thermal electricity is, as we have seen in section 2.2, the ratio of the *electric energy* in output from the power plant to the *primary energy* required for the extraction and delivery of the fossil fuel used as feedstock in that same plant.

Moreover, it should be noted that the most recent updates on the EPBT of modern PV point to EPBTs for the complete systems ranging from 2 to 0.8 years [Fthenakis et al., 2009; Fthenakis and Alsema, 2006], and that all commercial systems are guaranteed to work for a minimum of 30 years. Thus, even applying this inconsistent formula, the EROI of modern PV would still lie between 15 to 37.5.

Such results cannot and should not be directly compared to those for thermal electricity, though, because of the inherent methodological inconsistency explained above. Instead, the same system boundaries and methodological approach should be applied in the calculation of the EROI of both thermal and PV electricity, as illustrated in Figure 1.

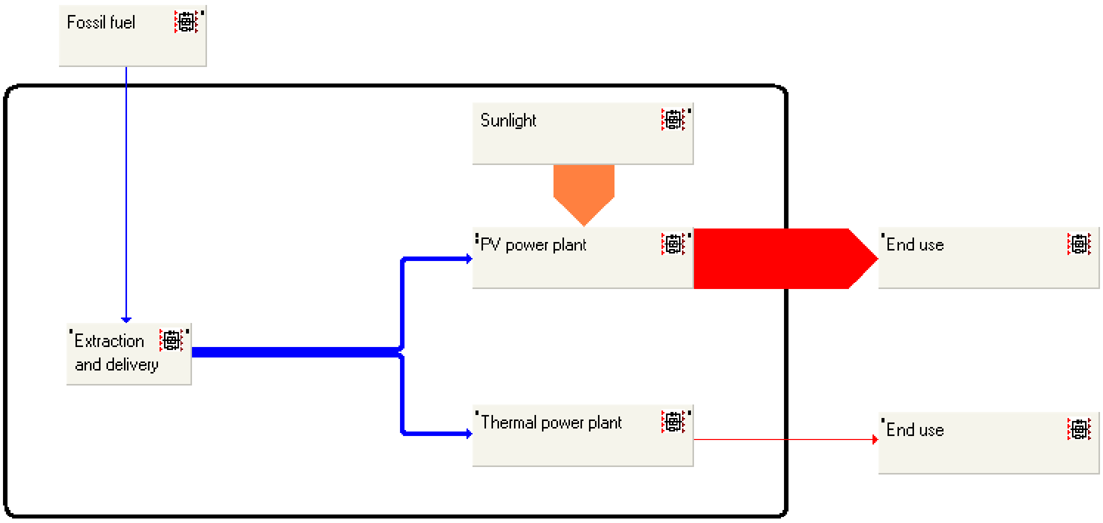

Figure 1. Flow diagram for thermal vs. PV electricity generation. Arrow thicknesses are proportional to energy flows.

Let us recall Eq. 3 from section 2.2 above: $EROI_{el} = EROI_F * E_{el}/E_F$

We may take an average $EROI_F = 40$ for the mix of fossil fuels used for the construction and maintenance of the PV plant, and then calculate E_{el} (total electricity produced during the PV plant's lifetime) and E_F according to Eqs. 5 and 6 below.

$$E_{el} = E_s * \eta * PR * T \tag{5}$$

where:

E_s = solar energy input per year;

η = module efficiency;

PR = performance ratio (which takes into account all system efficiency losses);

T = PV plant lifetime.

$$E_F = CED - E_{ED} = CED - E_F/40 = 40/41 * CED \tag{6}$$

where CED = cumulative energy demand of PV power plant.

Using the world average solar irradiation [NASA, 2008] and up-to-date values for η, PR, T and CED [Fthenakis et al., 2009; Fthenakis and Alsema, 2006] leads to an $EROI_{el}$ for PV electricity ranging from roughly 100 to 700, depending on the specific PV technology.

We argue that these are the only EROI numbers for PV that can be meaningfully compared to those for conventional electricity, since both are ratios of *electric energy output* to *primary energy input* for fuel extraction and delivery, and both are based on the same equations and are calculated with consistent system boundaries.

In fact, this comparison sheds light on what should have been clear all along, i.e. that photovoltaics should not (yet) be looked at as an alternative energy source vs. fossil fuels, but rather as an alternative energy transformation process vs. thermal electricity production. If looked at this way, it becomes quite apparent that deploying fossil fuels in PV is far more efficient than burning them directly at roughly 30% efficiency to produce electricity in conventional power plants (which of course is due to the ability of PV to harness a second energy source, i.e. sunlight).

3. A LOOK AHEAD

Current PV technologies are improving fast, and new, more efficient, technologies may become available in the future. However, none of these PV technologies can serve as base-load electricity sources on their own, because of the intrinsic intermittency of solar power generation. Recent prospective studies have shown that deploying PV on a large scale beyond 20% grid penetration will require establishing an extensive energy storage infrastructure [Denholm and Margolis, 2006]. Even if potentially feasible, the latter will likely be costly, both in economic and energy terms, and will inevitably drag down the medium-term EROI of such PV-storage ensemble.

One further strategic issue is that of short-term power return per unit of energy invested. Put it simply, PV takes years to give back all the electricity it can produce, while the energy investments to deploy it will largely have to be made up front.

However, in spite of all these lingering issues and looming problems, the fact remains that using fossil fuels for the production of PV power plants is, today, at least one order of magnitude more energy-efficient than burning the same fuels in conventional thermal power plants, and this advantage will remain even as the EROI of oil and gas go down. If large enough investments in PV are made early enough, the additional energy return from PV electricity vs. today's mostly thermal grid may afford us valuable time in our race against time after peak oil. In fact, being pro-active and deploying large PV capacities worldwide, long before the EROI of fossil fuels eventually approaches unity, may even end up being amongst the most effective strategies to reach the ultimate long-term goal of putting an end to our dependence on non-renewable energy.

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