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Further considerations to: Energy Return on Energy Invested (ERoEI) for photovoltaic solar systems in regions of moderate insolation

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ABSTRACT

A paper by Ferroni and Hopkirk (2016) provided evidence that presently available PV systems in regions of moderate insolation like Switzerland and countries north of the Swiss Alps act as net energy sink. These findings were disputed in a paper (Raugei et al., 2017). Additional clarifications in support of our conclusions are explained, including mention of weak points in the argumentation by Raugei et al.

Our study is based on the concept of the extended ERoEI ($ERoEI_{EXT}$) for PV systems, knowing that this is not the mainstream concept in the Life Cycle Assessment (LCA), applying the Process-Based Life Cycle Assessment. The concept of the $ERoEI_{EXT}$ considers many possible energy contributions needed for assessing the envisioned transition from fossil fuel to other types of energy sources and here in particular to photovoltaics in regions of moderate insolation.

The conclusions of our original study remain unchanged. Any attempt to adopt an Energy Transition strategy by substitution of intermittent for base load power generation in countries like Switzerland or further north will result in unavoidable net energy loss. This applies both to the technologies considered, to the available data from the original study and to newer data from recent studies.

1. Introduction

The paper published by the authors (Ferroni and Hopkirk, 2016) has provided evidence that presently available PV systems in regions of moderate insolation like Switzerland and countries north of the Swiss Alps, provide little more than material-intensive, labour-intensive and capital-intensive energy, resulting in high consumption of resources. These findings have been disputed in a recent paper (Raugei et al., 2017). In the following we shall offer additional clarification in support of our conclusions and expose basic errors in the argumentation by Raugei et al. (2017).

Regions of higher insolation (e.g. in southern Europe) as well as geographical diversity or combination with wind turbines were explicitly excluded from our published study. Our proof was accompanied by a short comparison between electricity production from solar generators with other energy sources to demonstrate that PV energy is particularly material, labour and capital intensive. Since nuclear power generation is also more labour and capital intensive than the combustion of fossil fuels, we had included estimations valid for nuclear energy. However, our conclusions stand for themselves: the extended ERoEI ($ERoEI_{EXT}$) for PV systems is below 1 and thus has a negative impact. Society receives few or no benefits from their use. For this reason, it will not be necessary to comment further on statements made by Raugei et al. regarding nuclear energy.

The concept of $ERoEI_{EXT}$ has been applied, knowing that this is not the mainstream concept in the Life Cycle Assessment (LCA) community. However, this concept has gained and is gaining more attention, especially since the current LCA does not take into consideration many possible energy contributions needed for assessing the envisioned transition of our civilisation from fossil fuel to other types of energy sources and here in particular to the photovoltaic energy source in regions of moderate insolation.

Important in this respect is the recent publication of a book by Charles A. S. Hall "Energy Return on Investment – A Unifying Principle for Biology, Economics, and Sustainability" (Hall, 2017) outlining the basic generally valid methodology for the calculation of the ERoEI for different energy sources.

In addition, the experience gained from the "Energiewende" (Energy Transition) in Germany has shown that 464 billion Euro have been spent up to the end of 2015 (Limburg and Müller, 2015) for the

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renewable energy program without any notable reduction of CO_2 emissions. In 2015 these amounted to 535 g CO_2-eq/kWh (Emissionen des deutschen Strommix, 2016). Servicing such huge amounts of capital also implies a considerable consumption of energy.

We recommend that the $ERoEI_{EXT}$ approach be applied to all energy system sources, including nuclear energy. Therefore, the standards and protocols such as those recommended by the International Standards Organisation (ISO) and the International Energy Agency (IEA) can only be partially applied for the better calculation of the $ERoEI_{EXT}$. We are aware of the fact that the results of the various ERoEI-analyses published up to now in the scientific literature cannot be compared with each other, without a rigorous and deontological investigation. In our previous paper, we specified the scope of the $ERoEI_{EXT}$, bearing in mind the full specification of this extended scope. In our case this amounts to: energy demand for the materials, for the labour, for the installation, operation, decommissioning, integration of the intermittent PV generated electricity into the grid with storage capability and for obtaining and servicing the required capital.

The purpose of the study is to assess the energetic feasibility of the envisaged electricity policy in Switzerland – one aspect of the Swiss Energy Transition – where the actual base load assured by nuclear power plants generating yearly 25 TWh is to be substituted until the end of the year 2050 by intermittent electricity produced by PV-systems or wind power plus geothermal electricity. Note that a recent study (Heard et al., 2017) concludes that this is not feasible. In Germany the energy policy is also to substitute the baseload assured by coal power plants with so-called renewable energy. For our scenario, we have selected a hypothetical division of the PV-system in 2/3 as roof mounted and 1/3 as free field PV-plants.

The use of the $ERoEI_{EXT}$ methodology and not of the LCA methodology should be mandatory in the future to avoid annihilation of resources and to provide a clear answer to consumers, faced with the huge increase in electricity prices. It is worth noting that in Germany and Denmark, the two countries with the highest installed wind and solar capacity per capita in Europe, the electricity prices for residents are also high, at about 0.30 Euro/kWh (2016), as discussed by Gail Tverberg in her article "Intermittent Renewables Can't Favorably Transform Grid Electricity" published online in Tverberg (2016). A similar observation can be made for the domestic consumer prices of energy. The data collected by Eurostat (2017), the statistical office of the European Union, as "Energy and Supply" over the last ten years shows that the electricity prices for households in countries with very high installed solar capacity per capita are also quite high, as evidenced for example by the numbers for Spain, the United Kingdom and Italy.

The emphasis of valid scientific research should be placed on calculations of the energy return based on the actual experience in a specific country and on the energy invested, including all energetic factors contributing to this investment. In our review, we discuss the points considered as “*supposed errors*” or “*double counting*” in the so-called "*comprehensive response*" by Raugei et al., which are:

- Methodology used for the extended ERoEI ($ERoEI_{EXT}$)
- Energy return of photovoltaic systems in regions of moderate insolation
- Energy demand/ invested for materials
- Energy demand for the integration of the intermittent PV-electricity into the existing grid
- Energy demand for labour
- Energy demand for servicing the capital
- Other arguments of the “comprehensive response”

All our data are supported by references. This is not the case for some key data from the Raugei et al. paper as for example for their purported cumulative energy demand (CED), degradation rate, downtime (or lack thereof) and module prices, as shown hereafter.

What is important for societal needs is to know whether PV systems in regions of moderate insolation are producing energy at a net energy gain or loss. In the latter case the depletion of fossil resources is accelerated by state subsidies for solar electricity generation.

2. Methodology used for the ERoEI extended ($ERoEI_{EXT}$)

Raugei et al. claim that our methodology of the extended ERoEI ($ERoEI_{EXT}$) "…. *shifts the goal of the analysis from the (comparative) assessment ….to the assessment of the ability of the analysed system to support the entire societal demand for the type of energy carrier it produces*.. and *makes inappropriate comparisons"*. This claim is incorrect.

The goal of our analysis is the determination of $ERoEI_{EXT}$ for calculating the quotient: Energy Return on Energy Invested, considering thereby all energy contributions to both numerator and denominator. Therefore, there is no shift in the goal of the analysis. No energy input should *a priori* be excluded. We have considered additional energy contributions that are excluded from the "mainstream" analysis, which follows the recommendations of the IEA. The IEA guidelines reflect rather the position of the PV industry and offer false and misleading results through erroneous calculation of the energy invested and do not provide a comprehensive examination of the value of PV to our society. As a consequence, the societal benefits of PV turn out to be wrongfully amplified.

The concept of $ERoEI_{EXT}$ applied specifically to photovoltaic systems has been treated in two books. The first one is entitled “Spain's Photovoltaic Revolution – The Energy Return on Investment “ (Prieto and Hall, 2013) and the second one “Energy in Australia - Peak Oil, Solar Power, and Asia's Economic Growth“ (Palmer, 2014). In addition, the investigations performed by Weissbach in Germany (Weissbach et al., 2013) include some energy contributions in the $ERoEI_{EXT}$.

Therefore, the concept of $ERoEI_{EXT}$ is not new and is quite independent of the standardized method used in the LCA. The main question should be to know whether the photovoltaic energy for regions of moderate insolation like Switzerland and Germany is a net energy source or a net energy sink and how much it contributes to human welfare. Where is our energy going to come from as we rely less on fossil fuel? What operating energy systems are replaced by the new energy sources? This is a task for ERoEI researchers and not for Life Cycle analysts, who often confine themselves within unrealistic boundaries.

Furthermore, we should like to add that energy contributions due to labour and servicing the capital (not the capital itself) are already considered in standard analyses of the cumulative energy demand in the building industry. The financial interest that society demands for servicing the principal sum of a loan represents additional capital, which flows from the activity for which its principal is used and which is paid to the lender. This additional capital has its equivalent in an amount of energy. The engineers involved in such analyses in the civil construction sector are probably unaware of any IEA guidelines, but apply common sense in considering labour and servicing the capital. The fact that Raugei et al. entirely disregard such contributions indicates the narrowness of their boundary conditions and their reluctance to seriously deal with subjects outside the strict IEA fence.

Our study has demonstrated that important contributions were previously not accounted for in most of the published literature on PV systems. The breakdown and the details of our methodology ($ERoEI_{EXT}$) are given in our original paper (Ferroni and Hopkirk, 2016) under chapter 4.

Because of the different methodologies, it is necessary before comparing our results with those of other analyses to first consider the details of the system boundaries and the climatic conditions. As we shall see, the "mainstream" methodology considers only about 30–50% of the total invested energy and this is an important source of