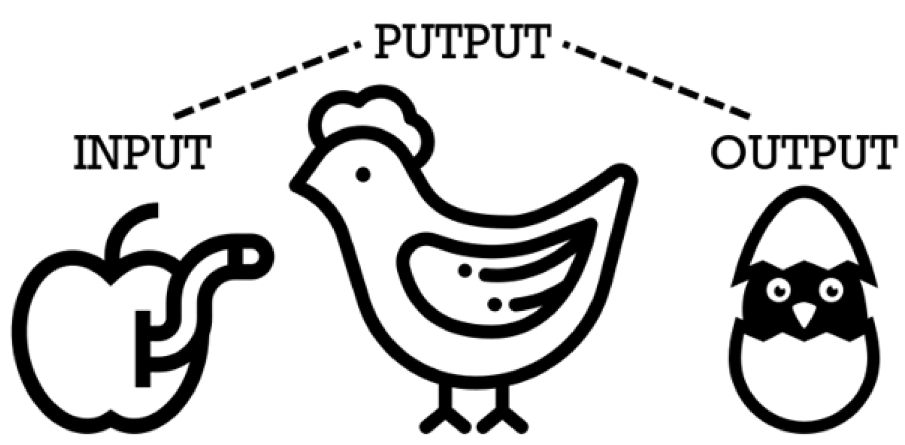
Is Green Electricity Sustainable?
Evolution of EROIs until 2050

Adrien Fabre

Paris School of Economics, Universit Paris 1 Panthon-Sorbonne

adrien.fabre@psemail.eu — bit.ly/future_eroi_code



Abstract

Abstract The EROI for Energy Returned On Invested of an energy technology measures its ability to provide energy efficiently. Previous studies draw a link between the affluence of a society and the EROI of its energy system, and show that EROIs of renewables are lower than those of conventional fossil fuels. Logically, concerns have been expressed that system-wide EROI may decrease during a renewable energy transition. First, I explain theoretically that the EROIs of renewables themselves could then decrease as energy-efficient fossil fuels would be replaced by less energy-efficient renewables in the chain of production. Then, using the multiregional input-output model THEMIS, I estimate the evolution of EROIs and prices of electric technologies from 2010 to 2050 for the baseline and the Blue Map scenarios of the International Energy Agency, and for the 100% renewable Greenpeace's electricity [r]evolution scenario. Global EROI of electricity is predicted to remain quite stable, going from 8 in 2010 to 6 or 7 in 2050, depending on the scenario. Finally, I study the economic implication of a declining EROI through its relation with price. I show that in theory both quantities can decrease at the same time. This suggests that the inverse relation found empirically represents an average tendency which should not overshadow the high unexplained variability and the theoretical finding that anything can happen.

Introduction

- Renewable electricity is much more material-intensive than electricity from fossils:
- Mineral extraction and processing is energy-intensive, it uses about 10% of global primary energy (Nuss & Eckelman, 2014)
- How to measure the efficiency of an energy technology, i.e. the ability to deliver more energy that it requires to be built, operated and dismantled?
- Using the Energy Returned On Invested (EROI):

$$\text{EROI} = \frac{\text{delivered energy}}{\text{net embodied energy}}$$

- For an energy system to be energetically sustainable, it needs to deliver more energy than it requires, i.e. EROI> 1
- EROI of electricity from renewables is lower than that from fossils

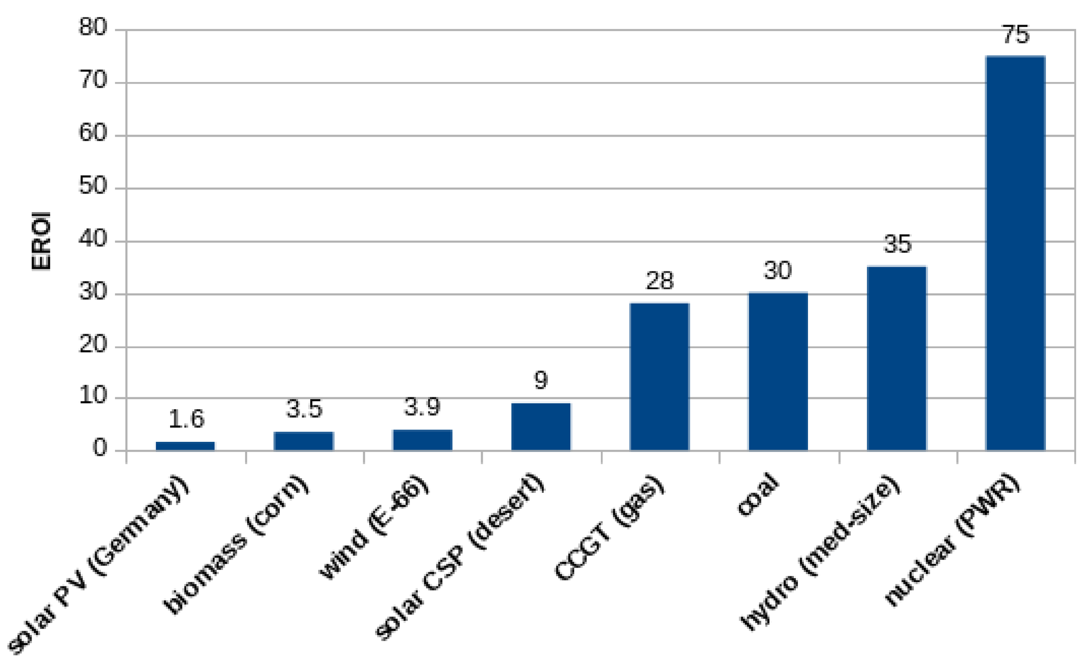


Figure 1: EROI estimates of electricity technos, from [6]

- Size of EROI matters, e.g. Lambert & Lambert (2011) or Hall (2011):

  Think of a society dependent upon one resource: its domestic oil. If the EROI for this oil was 1.1:1 then one could pump the oil out of the ground and look at it. (...) Hall et al. (2009) [3] examined the EROI required to actually run a truck and found that if the energy included was enough to build and maintain the truck and the roads and bridges required to use it (i.e., depreciation), one would need at least a 3:1 EROI at the wellhead. Now if you wanted to put something in the truck, say some grain, and deliver it that would require an EROI of, say, 5:1 to grow the grain. (...) 7 or 8:1 to support the families. If the children were to be educated you would need perhaps 9 or 10:1, have health care 12:1, have arts in their life maybe 14:1 and so on. Hall (2011)

- Even though this reasoning relies on strong underlying assumptions (factors of production used at their full capacity, and no future progress), it holds in the short run.
- Given that EROIs of electricity from renewables are lower than that from fossil, system-wide EROI should decrease in a renewable energy transition.
- More worryingly, the EROI of renewables themselves may decrease. Indeed, if plants where solar panels (PV) are currently built employed renewable electricity instead of electricity from coal as their sources of energy, the EROI of PV would decrease.
- This is the first study to estimate the evolution of EROIs in a 100% renewable scenario.

Data

I use THEMIS: prospective input-output tables which represents the whole economy from 2010 to 2050, with a focus on energy. THEMIS models two scenarios of the International Energy Agency (IEA): Baseline (with almost constant shares in the mix) and Blue Map (compatible with a 50% probability of +2C warming in 2100). As 30% of electricity still comes from fossils in Blue Map 2050 (including 17% with Carbon Capture and Storage (CCS)), I modify THEMIS to embed a 100% renewable scenario, from Greenpeace's energy [r]evolution report [2].

Estimation of Current and Future EROIs

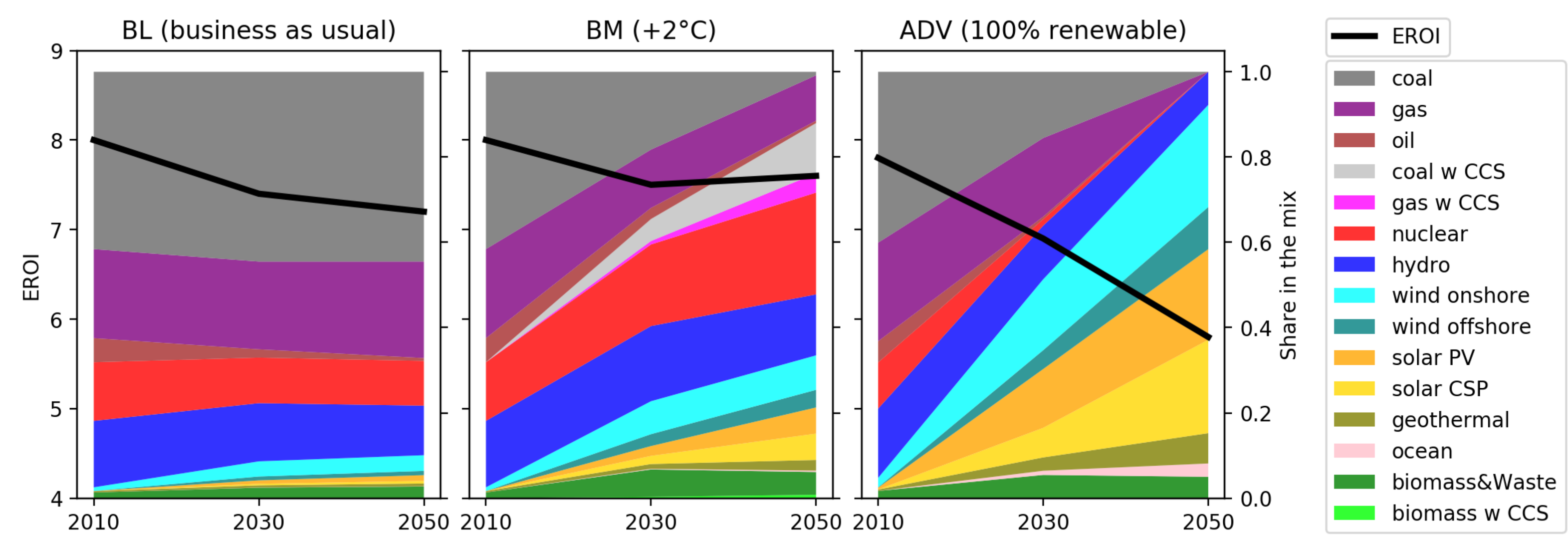


Figure 2: Evolution of global EROIs and mixes of electricity for different scenarios.

- The EROIs of renewables should decrease, as anticipated.
- However they will remain largely above 1, suggesting that renewables are truly sustainable.
- The system-wide EROI is currently 8.0; it decreases slightly until 7.4 ± 0.2 in 2030 and 2050 in both THEMIS scenarios.
- The decrease is more pronounced in the Greenpeace scenario: at 6.9 in 2030 and 5.8 in 2050.
- First and crude attempt: room for improvement, e.g. including the transportation system. However, technical progress is notoriously difficult to predict, so we will never know future EROIs for sure.

Economic Implications of a Declining EROI

- Several authors express concerns that advanced standards of living cannot be sustained with a lower EROI. They also link EROI to the inverse of the price of energy.
- King & Hall (2011) [5] show empirically and theoretically that EROI is inversely related to price:

$$p = \frac{\$_{\text{out}}}{\$_{\text{investment}}} \frac{\$_{\text{investment}}}{E_{\text{in}}} \frac{E_{\text{in}}}{E_{\text{out}}} = \frac{\text{MROI}}{\text{EROI}} \frac{\$_{\text{investment}}}{E_{\text{in}}}$$

- Heun & de Wit (2012) find an equivalent formula. But there is a problem with such formulas: all variables move together, the parameters are not constant.
- Using EROIs and prices estimated from THEMIS, I study the relation emprically. The inverse relation is as good a fit as the log-log ($R^2 = 0.6$, see Figure 4), but a high share of the variability remains unexplained.
- I generalize a result that Herendeen (2015) [4] showed in a two sectors model.

Theorem. *The element $a_{i,j}$ of the technology matrix A represents the quantity of input i required to produce one unit of output j. Assuming that all coefficients of A are constant except one, noted $x = a_{i_0,j_0}$, and that EROI varies with x; the price of t can be expressed as a linear function of its energy intensity $\varepsilon_t = 1 + \frac{1}{EROI_t}$, so that:*

$$\exists! \, (\alpha, \beta) \in \mathbb{R}^2, \; p_t = \frac{\alpha}{EROI_t} + \beta$$

- The assumptions of this theorem are the weakest possible: as long as two coefficients of the technology matrix A vary, the inverse relation (with constant parameters) does not hold.
- Indeed, I give an example where EROI and price both increase at the same time.
- This theoretical finding weakens the view of Fizaine & Court (2016) [1] that a declining EROI would necessarily lead to a recession, channeled by increased energy expenditures. Indeed, their argument relies on an inverse relation between price and EROI.

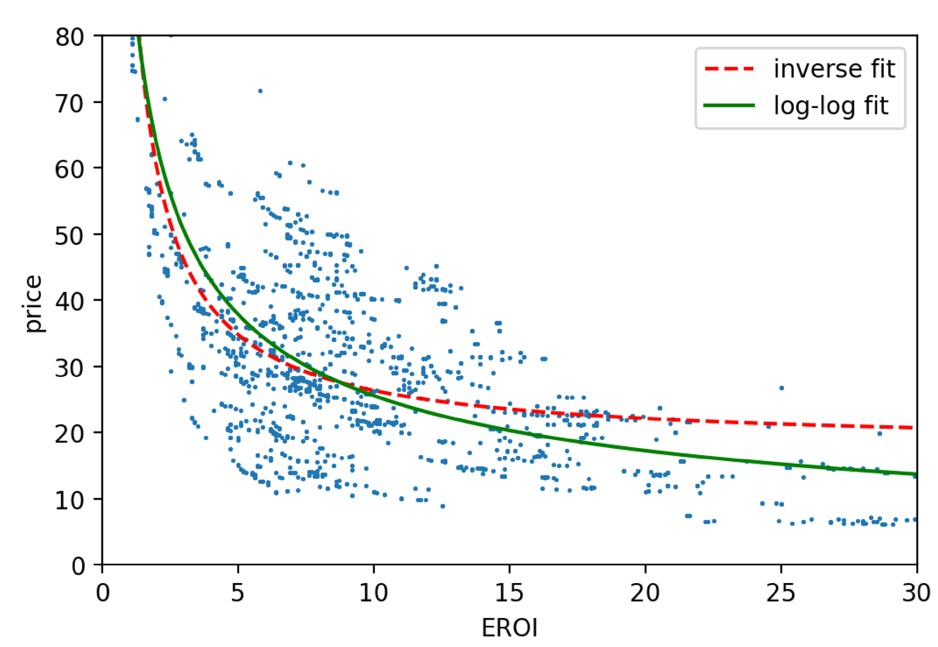


Figure 3: Regressions p $\sim$ EROI using all scenario estimates

References

[1] Florian Fizaine and Victor Court. Energy expenditure, economic growth, and the minimum EROI of society. *Energy Policy*, 2016.

[2] Greenpeace. energy [r]evolution - a sustainable world energy outlook 2015, 2015. 00000.

[3] Charles A. S. Hall, Stephen Balogh, and David J. R. Murphy. What is the Minimum EROI that a Sustainable Society Must Have? *Energies*, 2009.

[4] Robert A. Herendeen. Connecting net energy with the price of energy and other goods and services. *Ecological Economics*, 2015.

[5] Carey W. King and Charles A. S. Hall. Relating Financial and Energy Return on Investment. *Sustainability*, 2011.

[6] D. Weißbach, G. Ruprecht, A. Huke, K. Czerski, S. Gottlieb, and A. Hussein. Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants. *Energy*, 2013.