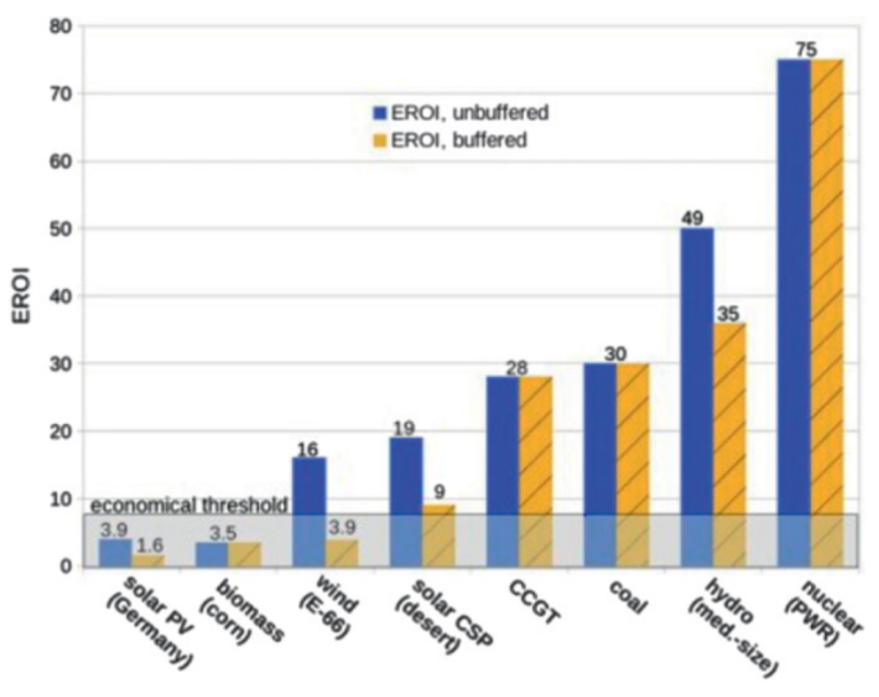
Energy Return on Energy Investment

Prof. M.J. Kelly from Cambridge University (Electrical Engineering Division, Department of Engineering) just published a very interesting paper "**Lessons from technology development for energy and sustainability**" where he is very critical of the current fashionable decarbonization politics. He strongly warns that trying to massively deploy yet unfit technologies can be counter-productive.

Here in this comment I just want to stress two problems related to energy production, which he mentions in his paper. The first is the EROI (Energy Return on Investment) which we will read as Energy Return on Energy Investment (EROEI), the second the energy density and surface needs of various power technologies.

1. **The EROI**

   This is a very easy to understand parameter which gives a number to the following question: *how much energy will a given technology produce during its life-time, compared to the energy needed to build it and keep it working during this period*. This problem is practically always fudged by green energy advocates, who say for instance that a wind turbine will pay back its energy budget during the first year (**link**), ignoring all the associated problems of backup power, grid investments etc. Prof. Kelly does not agree, and gives the following graph:



The left scale represents the fraction of (energy produced)/(energy invested); the blue histogram considers this without any regards to energy storage, the yellow columns show the result if one considers all the energy needed to implement large-scale storage technologies (as pumped hydro, batteries …) needed by intermittent producers like wind and solar. He says that the economical threshold is about 8; of the 4 renewable producers only thermal solar plants in desert regions barely exceed this minimum,whereas nuclear power reigns supreme with a factor of 75.

A serious problem with such analyses are the life cycle assessments (LCA), often difficult to grasp in a scientific non-partisan manner. Kelly cites a **book** by Pietro and Hall (Springer, 2013) which studied the EROI of the Spanish solar "revolution", where clear and unambiguous data are available: these authors give an EROEI of 2.45 for the Spanish solar politics.

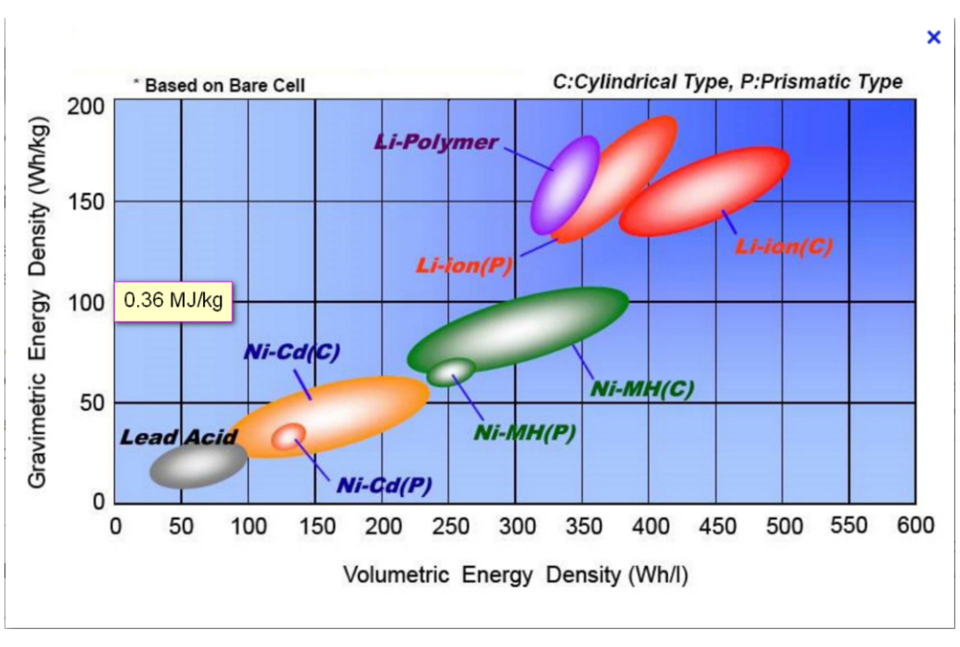
2. Energy density and land usage

A second problem with wind and solar is these are extremely low-density power sources. The following table shows the numbers in MJ/kg:

Table 1. Energy densities of different fuels.

Fuel type	Energy density MJ/kg
Wind	0.00006
Battery	0.001
Hydro	0.72
TNT	4.6
Wood	5.0
Petrol	50
Hydrogen	143
Nuclear fission	88250000
Nuclear fusion	645000000

I do not quite agree concerning modern, non-lead batteries: the energy densities are much higher, but still minuscule compared to nuclear:



This graph (from http://www.epectec.com) shows that the most recent batteries may go close to 0.76 MJ/kg, similar to hydro dams . Energy density is an important factor when the question of land usage is important, as it is for most populated regions of the world and especially for the mega-cities of the future which are assumed to hold 50% of the world population in 2050.

This Breakthrough paper gives the following numbers for land use in m2 per GWh delivered in one year:

Energy Source	Land Use m^2/GWh/yr	Comments
Geothermal	900	Flash plant including wells and pipes
Wind – onshore	1100	Turbine footprint plus access only
Nuclear	1200	Plant site including cooling water
Solar Thermal	3200	Desert based – 6 hours storage
Coal (strip mining)	5700	Including mining site
Solar PV	7500	Solar farm with dedicated land
Hydro (reservoir)	200,000	100m head, 20m depth
Biomass	460,000	Tree area with 20 year fuel supply

and these are the numbers for material use:

Material tonnes/GWh/yr	Capacity Factor	Concrete	Steel
Nuclear	85%	43	8
Solar PV farm 10%	20%	43 86	10 20
Wind – onshore 20%	30%	159 239	43 65
Solar Thermal – 7.5 hrs storage	44%	338	105

I have added the capacity factors that are close to those in Germany/Luxembourg (on-shore wind practically never reaches 30%) and for Solar PV (here 10% is still optimstic); with these more realistic capacity factors, onshore wind would have a land use closer to 2200. What comes a bit of a surprise (even if we accept the very optimistic original numbers) is that solar PV has about the same material footprint as nuclear (which instinctively we associate with enormous volumes of concrete and steel).

Let us take tiny Luxembourg's electricity consumption as a rough indicator of what part of the ~2500 km2 area of the country would be needed if a certain energy source would produce all the energy needed. According to **this report** the total energy consumption was about 50000 GWh in 2013. Here the area in km2 and in % of total country area if all these energy had to be produced by the given source:

Nuclear: 60 km2 = 2.4 % (assumes cooling water comes from new lakes)

Solar PV: 320 km2 = 12.8% (land use taken as 6400)

Wind on-shore: 83 km2 = 3.3% (land use taken as 1650)

Biomass: 23000 km2 = more than 9 times the total area of Luxembourg !

The wind and solar numbers are more or less meaningless except that full storage solutions would exist (which will not be the case in the foreseeable future).

I do not accept the numbers for nuclear. The nearby Cattenom nuclear plant produces about 35000 GWh per year and occupies an area of maximum 4 km2 (checked with Google Earth). Using this as a more realistic example, we would have a total land use for the nuclear choice of about 6 km2 or **0.24** %, i.e. 10 times less.

3. Conclusion

Both EROI and land use show that the nuclear choice for energy is unbeatable as a "carbon-free" energy producer. This is also the conclusion of Prof. Kelly's paper and that of the late Prof. McKay in his last interview.

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