Renewables are not Sustainable

Incessant greenwashing cannot hide that wind and solar are poor sources of energy that are bad for the environment

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MAR 19

Summary

Both Government and Opposition want us to decarbonise our electricity system and spend even more billions on renewable wind and solar technologies. They justify this on the grounds of low CO_2 emissions, even though the supposed low costs have been shown to be a fantasy.

However, CO_2 is not the only yardstick by which we should measure the sustainability or desirability of energy technologies. We should also look at energy return on investment, land usage, mineral requirements and overall mortality.

Metric/Source	Coal (No CCS)	Biomass[1]	Gas (No CCS)	Nuclear	Hydro (Med-Large)	Wind[2]	Solar Silicon PV[3]
GHG Emissions (g CO_2e/kWh)[4]	903	900	449	12	24	12	48
EROEI (buffered)	30.00	3.50	28.00	75.00	35.00	3.90	1.60
Land Use (CCUS) (m^2/MWh)	21.0	760.0	1.3	0.3	14.0	99.0	19.0
Critical Mineral Usage (kg/TWh)	7	7	8	12	6	165	124
Bulk Material Usage (CCUS) (t/TWh)	606	606	713	1,192	15,658	5,931	2,441
Mortality (Deaths/TWh)	64.4	14.3	3.4	0.04	0.71	0.10	0.23
Dispatchable/Intermittent (R/I)	D	D	D	D	D	I	I

1. Biomass gross CO2 emissions per Drax annual report; EROEI for corn biomass; Land Use from Freeing Energy; Mineral usage assumed same as coal
2. Wind land usage taken as median of Our World in Data analysis
3. Solar PV land use assumed ground-based silicon
4. GHG Emissions (except biomass) taken as median from UNECE report p83 https://unece.org/sites/default/files/2021-10/LCA-2.pdf

Wind and Solar Energy Score Badly on EROI, Land Usage and Mineral Requirements

This analysis shows that the energy return on energy invested in wind, solar and biomass falls below that required to run a modern economy. Indeed, bioenergy with carbon capture (BECCS) is probably a net energy sink. If we cannot even maintain, let alone increase living standards using these technologies, then we are consigning our children to a future of deprivation. This alone is sufficient grounds to end further subsidy and investment in these technologies. Wind and solar are also very profligate in their use of land (up to 300 times that of nuclear), land that could be used to grow crops or graze animals for food. Biomass requires thousands of acres of trees to be felled to feed inefficiently feed power stations, only to pretend they emit no CO_2.

Wind and solar also gobble up 10-20 times more critical minerals than other technologies, with knock on effects on the number of mines required across the world. In addition, wind and solar are intermittent sources that require back-up either from fossil fuels or batteries. They only score well on the mortality metric.

It is time to conclude that wind, solar and biomass renewables are not green, they are not sustainable and are unable to support a modern economy. Hydropower scores well, but its usefulness is limited by geography. The only low-carbon, scalable, sustainable, dispatchable source of electricity generation is nuclear.

Introduction

Both the Government and Opposition continue to burnish their environmental credentials by making ever more incredulous claims about decarbonising the electricity system. The Government has set a target of 2035 to achieve that ambition through massive investment in renewables. The Government wants the UK to become the Saudi Arabia of wind. The opposition Labour Party has entered into the renewable energy arms race by giving a commitment to end the use of fossil fuels in the power system by 2030 and make us into a clean energy superpower. However, their spokesman Jon Ashworth could not answer the question about where the power is going to come from if the wind isn't blowing or the sun isn't shining (from 28:20).

It is time to look at the key renewable technologies to see just how environmentally friendly they really are. These technologies are lauded because they supposedly emit little CO_2 to produce electricity. However, CO_2 is not the only yardstick by which we should measure the environmental friendliness or sustainability of energy sources. According to Wikipedia, "energy is sustainable if it meets the needs of the present without compromising the ability of future generations to meet their own needs." We should therefore consider other factors such as energy return on investment, land usage, the minerals required and mortality for these technologies.

Greenhouse Gas Emissions by Energy Source

We begin with the metric most often used to determine how green a particular energy source is. Metrics vary, some look at just CO_2, others look at other greenhouse gases (GHG) and of course methodologies vary. However, all methodologies show a broadly similar picture. For the purposes of this article, I have chosen the UNECE as a source (p73) and taken their median figures for representative technologies (see Figure1).

Energy Source	GHG Emissions (gCO_2e/kWh)
Coal (No CCS)	903
Gas (No CCS)	449
Solar PV	48
Hydro (Med-Large)	24
Nuclear	12
Wind	12

Figure 1 - GHG Emissions by Energy Source (gCO2e per kWh)

As might be expected, coal comes out badly at 903gCO_2e/kWh with natural gas at 449. Solar, Hydro, Nuclear and Wind have emissions 10, 20 or nearly 40 times lower than natural gas. UNECE do not cover biomass in their analysis. Biomass, particularly in the guise of burning trees at Drax power station deserves special attention.

Biomass – Burning Trees at Drax is Not Green

In the UK, the biggest biomass generator is the Drax power plant near Selby. Biomass is the euphemistic term used to describe burning trees to produce electricity. Millions of tonnes of trees are felled in North America, pulped, dried (requiring energy) and shipped on fossil-fuel burning ships to the UK where they are burned at the Drax power station. In 2022, Drax produced 3.9m tonnes of wood pellets. According to the Drax Annual report, in 2021 they received a total of £893m in subsidies comprising £658m of Renewable Obligation Certificates from generation (note 3.3) as well as £235m in CfD payments (note 2.2) to burn wood pellets. They would have made massive losses without these subsidies.

The trouble is that wood pellets have a lower energy density than coal. Wood has an energy density of around 16MJ/kg and coal used for power generation 17-24MJ/kg. This means wood pellets produce more CO_2 per MWh of electricity produced than burning coal. Drax has also been criticised for the amount of noxious particulate emissions emitted by its plant.

Despite Drax being the biggest single CO_2 emitter in the country, they manage to get away with calling this "green" energy by pretending that the CO_2 emitted from burning trees doesn't exist. Figure 2 below shows an excerpt from their annual report on carbon emissions.

Carbon and energy performance

	Unit	2021	2020	2019
Carbon emissions				
Generation CO_2 emissions[1]	$ktCO_2$	**525**	2,682	1,958
Group total scope 1[2]	$ktCO_2e$	**932***	2,762	2,049
Group total scope 2 (location-based)[3]	$ktCO_2e$	**323***	318	322
Group total scope 1 and 2	$ktCO_2e$	**1,255***	3,080	2,371
Proportion of Group emissions within the UK	%	**78***	95.3	93.2
Group total scope 3[4]	$ktCO_2e$	**3,121***	3,135	–
Biologically sequestered carbon[5]	$ktCO_2e$	**13,415**	13,273	12,795
Carbon intensity				
Generation emissions per GWh of electricity generation	tCO_2/GWh	**33***	143	113
Group emissions per GWh of electricity generation[6]	tCO_2e/GWh	**78***	164	137
Total energy consumption				
Group total energy consumption	kWh	**44,112,891,484***	48,253,807,865	46,025,306,198
Group total energy consumption within the UK	kWh	**40,112,110,277**	47,090,524,296	43,852,816,521

Figure 2 - Drax Biomass Carbon Dioxide Emissions

As can be seen, in 2021 they claim that their generation emissions were "only" 525ktCO_2 in 2021. However, the 13,415ktCO_2e of "biologically sequestered carbon" are not included in their group emissions per GWh of electricity generated calculation. If they were, the emissions would rise more than 10-fold from 78tCO_2e/GWh to over 900tCO_2e/GWh, similar to that of coal-fired plants.

They get to make the claim of being green, because they assume the trees they burned will grow back, sequestering the CO_2 emitted. However, this will take ~50 years, just the length of time we are supposed to be most worried about CO_2 emissions.

It is difficult to see how clear-cutting thousands of acres of forest, burning it to produce more CO_2 and particulates than burning coal can be classified as green or is in any way sustainable or environmentally friendly.

Energy Return on Energy Invested (EROEI) by Energy Source

Now let us compare the energy return on energy invested (EROEI, sometimes just EROI) for a range of different technologies. This measure compares the amount of energy required to mine the minerals, make the power plants, produce the fuel and so on to the amount of useful energy returned. In short energy output/energy input. Several attempts have been made to compare EROEI of various technologies. The definitive work appears to be this paper by Weissbach from 2013, to which most other studies, including Wikipedia refer. The World Nuclear Association quotes Weissbach and a range of other sources in its work on the subject. Figure 3 shows the results in graphical form (credit Energy Transition).

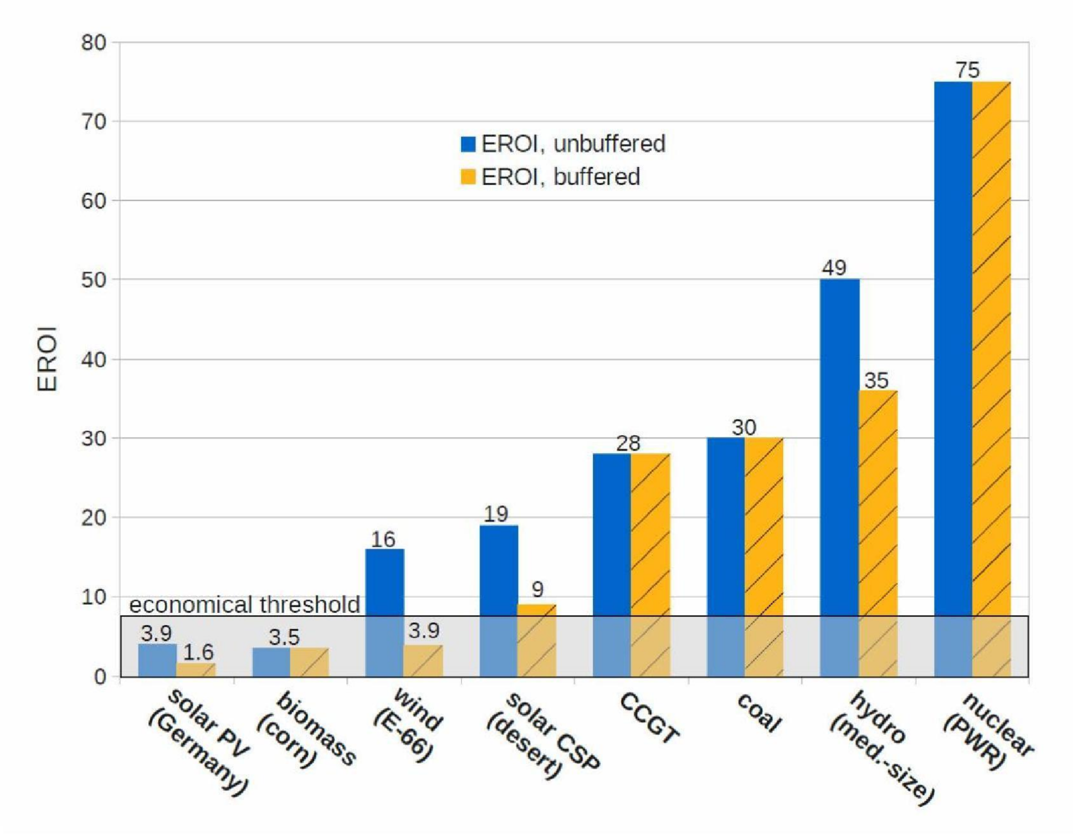


Figure 3 - EROEI EROI comparison by Energy Source

The blue bars show the "raw" EROI calculation. The yellow bars take account of the intermittency of renewables such as wind and solar, recognising that some form of storage or buffering will be required to maintain a stable grid which in turn requires more energy.

As can be seen nuclear and hydro come out top with EROI of 75 and 35 (buffered) respectively. Gas and coal fare well on this metric with similar ratings of 28 to 30. Concentrated solar power in the desert with a buffered EROI of 9 just about makes it above the economic threshold. However, corn biomass and buffered wind and solar fall well below the requirement with EROIs of 3.5, 3.9 and 1.6 respectively.

The economic threshold recognises that modern society can only afford to spend a certain amount of effort and money on generating energy. Weissbach concludes that in order to maintain our lifestyles, we need energy sources that return at least 7 times more than the energy invested in creating the source. Even this is a substantial reduction from the situation we now enjoy.

This is also neatly summarised by Euan Mears as a Net Energy Cliff (See Figure 4).

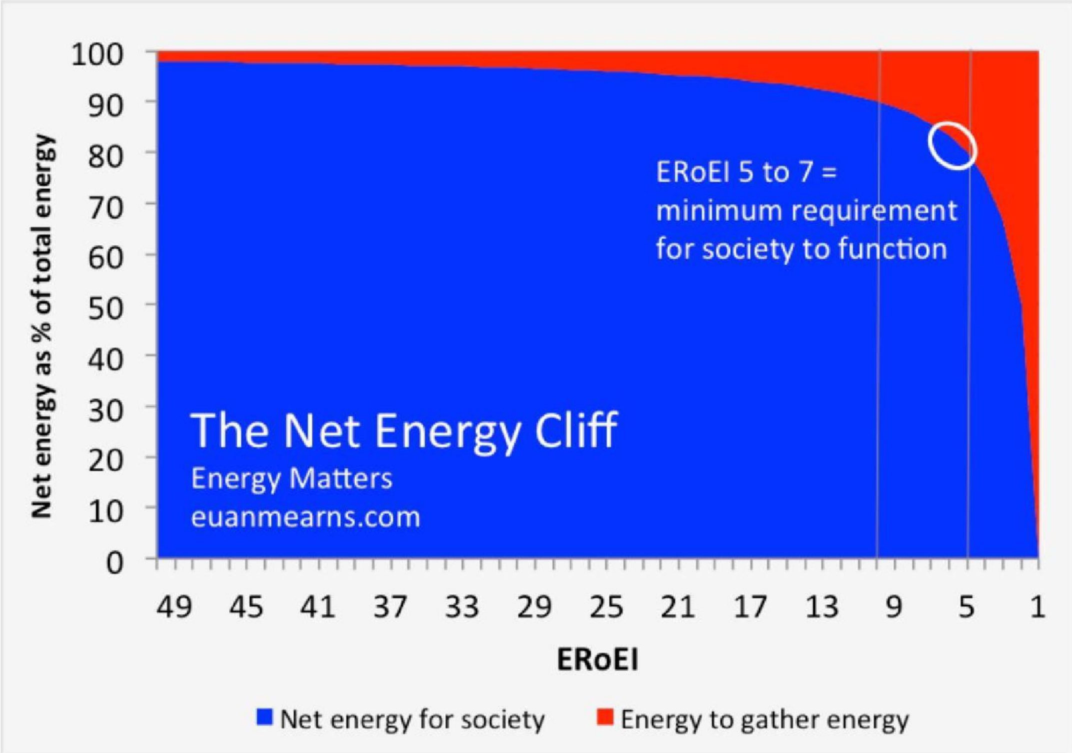


Figure 4 - Net Energy Cliff when EROI falls too low

In summary, society requires high density, reliable energy and EROI needs to be above 7 for society to function. We cannot run a modern society of the vicissitudes of the weather. That rules out solar PV at Germany latitudes and above, corn-based biomass and wind. Even concentrated solar power (CSP) is close to the boundary when buffering is considered.

The Royal Society of Chemistry has conducted an analysis of biomass EROI and in particular the EROI of bioenergy with carbon capture and storage (BECCS). They come up with a range of <2 for North American biomass pellets used to produce electricity. This corresponds is lower than the Weissbach analysis. However, they assess that BECCS could have an EROI of less than 1 and be a threat to energy security (see Figure 5, from their Figure 5).

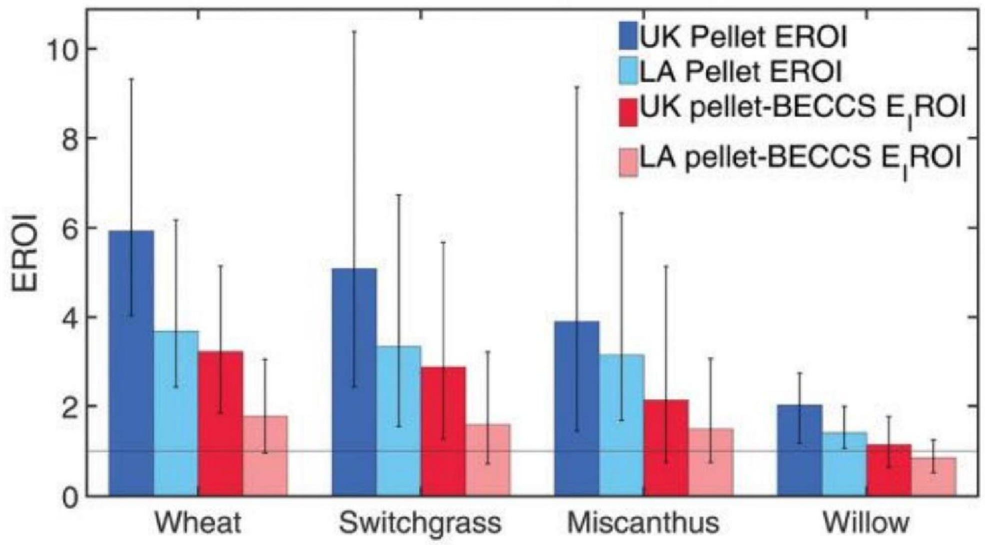


Fig. 5 Lifetime EROI of biomass pellets (blue) and lifetime E_lROI of abated bioelectricity (red) for the two case studies. The lifetime cumulative EROI vary from 1.1 to 10.4, whereas the lifetime cumulative E_lROI values drop to between 0.5 to 5.7.

Figure 5 - Royal Society of Chemistry Louisiana Wood Pellets and BECCS is a net energy sink

In other words, BECCS could be a net energy sink, particularly when it relies upon importing pellets from Louisiana, USA. Needless to say, Drax with its forests in Mississippi, Louisiana and Canada is touting this technology as a means of achieving negative CO_2 emissions. The UK Government has consulted on how best to subsidise BECCS. This is a proposal to subsidise cutting down even more trees and consume more energy than useful energy produced in the process. Absolute insanity.

Land Requirements by Energy Source

Land use, or the amount of energy produced per square metre of land required is an important measure to look at. As a species, we need land to produce food to sustain the population. We also need land for recreation and enjoyment of nature. More widely, other species need land to live and hunt for food. The more land we take for our energy production, the more likely we are to have a negative effect on the overall ecosystem.

Our World in Data have produced a helpful chart using data from UNECE (2021) to compare the land use of the main energy sources (see Figure 6), excluding biomass.

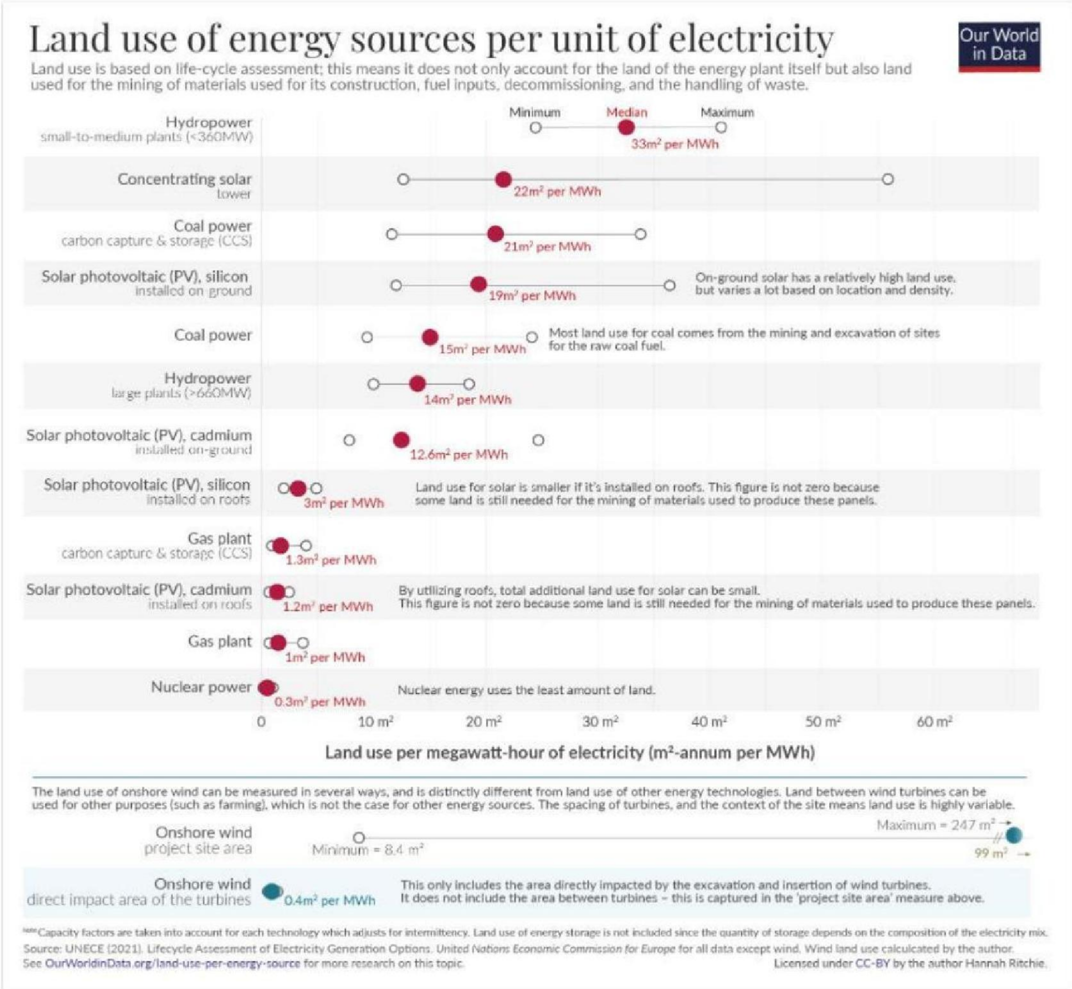


Figure 6 - Our World in Data Land Use by Energy Source m2 per MWh

In their analysis, small hydropower fares worst because of the huge amount of land taken up by the reservoirs required to run the turbines. CSP fares next worst, followed by coal with carbon capture. Coal rates badly because of the land damage caused by strip mines and the extra space required to capture the CO_2 emitted. Solar PV has a wide variation in land use dependent upon whether it is installed at grid scale on the ground, or smaller scale on rooftops. Grid-scale solar PV is very land intensive at $19m^2$/MWh, but small-scale rooftop installations are very competitive. Wind too is variable depending upon how the space between turbines is treated and whether it is onshore or offshore. If you assume the space between turbines is usable, then it is quite competitive, otherwise not. Offshore wind is more complex, depending on how the space between turbines is treated. Some countries such as Belgium and Germany treat offshore windfarms as exclusion zones, whereas other countries such as UK and Denmark are more lenient. For the purposes of further analysis, I have used the median $99m^2$/MWh in the chart above, because land or sea use around windfarms is certainly curtailed. Nuclear power and gas-fired plants are consistently good performers with ratings of 0.3-1.0m^2/MWh, some 19-300 times less land use than solar or wind.

The Our World in Data analysis does not include biomass. However, Freeing Energy have done an analysis (see Figure 7) that includes biomass.

Land required for generating electricity FREEING ENERGY

Land use	Electricity generated *per acre* over 75 years	over 25 years	Acres per GWh per year[1]	Reclamation options
Solar	**25.00 GWh**	8.33 GWh	3 (*perpetual*)	Remove panels or dual-use[2]
Nuclear (mining)	16.66 GWh	16.66 GWh	0.06 (*only once*)	Very high cost (radioactive)
Coal (mining)	11.11 GWh	11.11 GWh	0.09 (*only once*)	Costly (<15% reclaimed)
Wind	2.90 GWh	0.96 GWh	26 (*perpetual*)	Remove turbines or dual-use[2]
Hydro	2.50 GWh	0.83 GWh	30 (*perpetual*)	Drain dam + restoration
Biomass	0.40 GWh	0.13 GWh	188 (*perpetual*)	Replant trees

Figure 7 - Biomass Land Use Comparison Freeing Energy Acres per GWh per year

They use a different methodology and different units. They come up with 3 acres/GWh for solar and 0.06 acres/GWh for nuclear. This translates to 12m^2/MWh for solar and 0.24m^2/MWh for nuclear. Both are slightly lower than the Our World in Data figures for nuclear and silicon PV ground installations, but in a similar ballpark. Converting their 188 acres/GWh for biomass gives a result of 760m^2/MWh which is close to an order of magnitude larger than the median value for wind. So, despite the differences in methodology, we can safely say, biomass fares very poorly on land use calculations, because of the thousands of acres of trees that need to be cut down.

Mineral Intensity by Energy Source

Mineral Intensity is another key metric by which to measure the different sources of energy. The more minerals required, then the larger the environmental impact because more earth needs to be torn up to mine the required minerals. There are a couple of different ways of looking at this. The first is Critical Materials such as copper, cobalt, nickel and rare earths. The second is Bulk Materials like concrete, steel and aluminium.

Critical Minerals by Energy Source

The International Energy Association (IEA) has done important work looking at Critical Materials as seen in Figure 8, updated in October 2022.

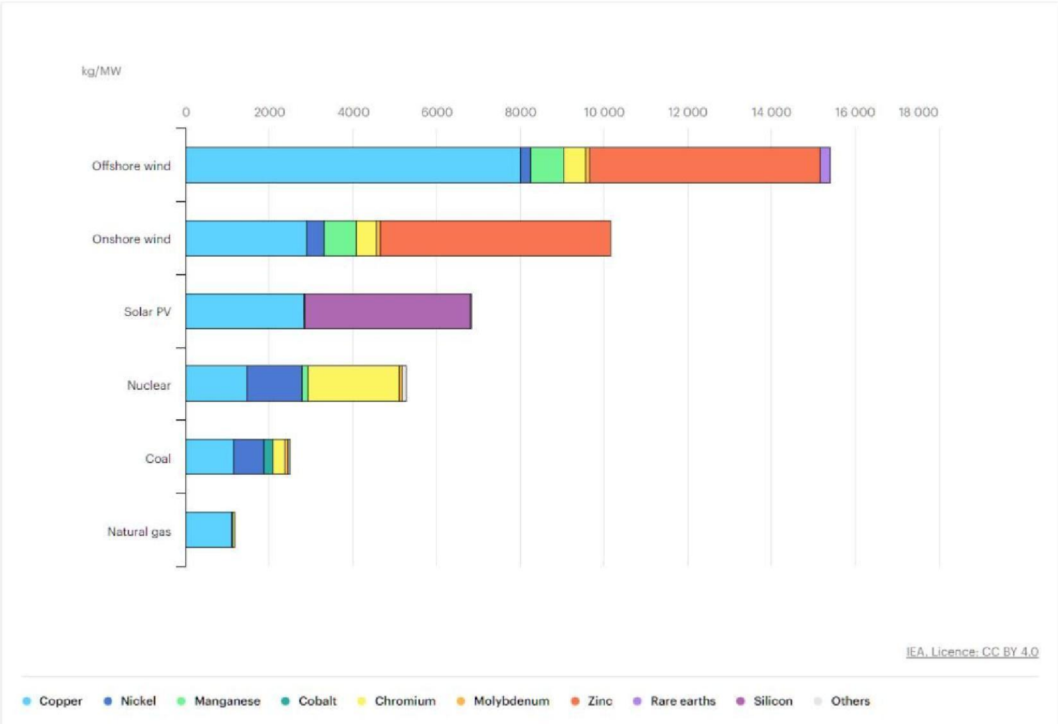


Figure 8 - IEA Critical Material Requirements kg per MW nominal capacity

This shows wind and solar having much higher critical mineral requirements than nuclear, coal or natural gas. However, the flaw in this analysis is that it just looks at material requirement per MW of nominal capacity. It does not consider the load factor or the life of the plant. The World Nuclear Association has reanalysed the IEA data to present it as tonnes of critical minerals per TWh electricity generated as seen in Figure 9.

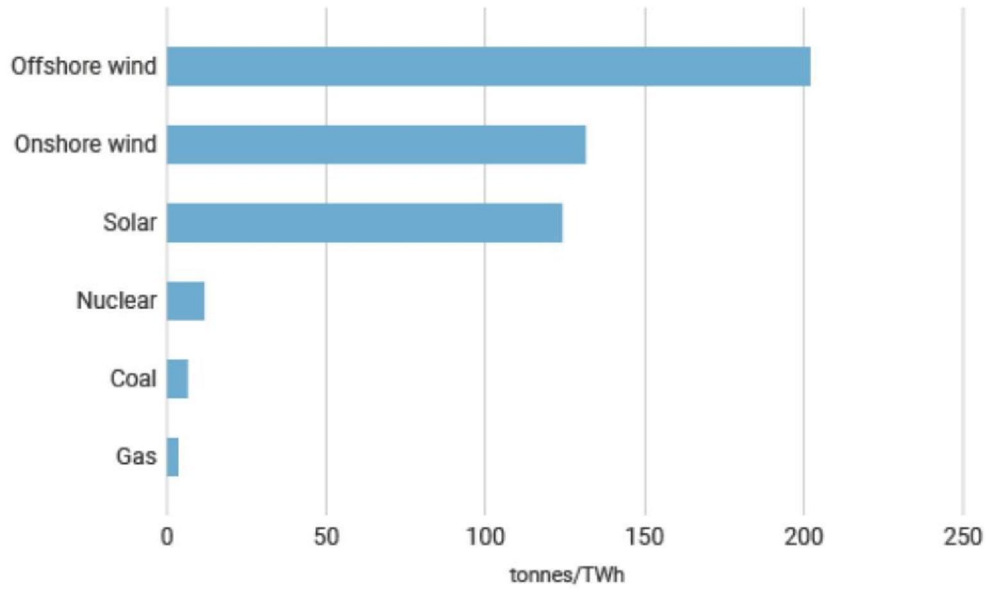
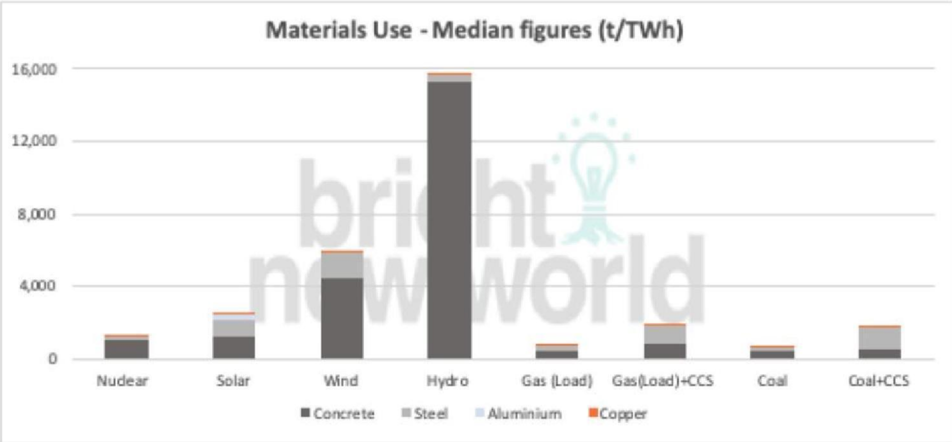


Figure 9 - Critical mineral requirements by Generation Technology tonnes per TWh

This gives a similar result, but the gap between wind and solar and the rest is much larger because the plant life and load factor for wind and solar tends to be much lower than for nuclear, coal or gas. On a tonnes per TWh basis, wind (200t/TWh) and solar (124t/TWh) require at least an order of magnitude more critical minerals than nuclear (12t/TWh). Coal (7t/TWh) and gas (8t/TWh) perform even better than nuclear by this measure. Hydropower is not included in the IEA nor the WNA analysis, however, Glex have estimated that hydropower consumes 6.4 t/kWh.

Bulk Material Usage by Energy Source

Bright New World have looked at bulk material use by energy source and the results are shown in Figure 10 below. For the purposes of this analysis, I have excluded copper because copper is included in the critical minerals analysis above.



t/TWh	Nuclear	Solar	Wind	Hydro	Gas (Load)	Gas(Load)+CCS	Coal	Coal+CCS
Concrete	1057.61	1216.30	4466.03	15318.07	390.03	824.45	447.67	522.65
Steel	134.30	937.70	1447.38	326.80	317.10	974.17	156.68	1174.08
Aluminium	0.34	287.48	17.40	8.73	5.71	21.39	1.57	37.38
Copper	2.46	67.95	39.14	4.81	5.39	8.76	3.02	11.80
cf.	85%	28%	35%	50%	30%	30%	85%	85%
Lifespan	60	30	30	100	60	60	60	60

Figure 10 - Bulk Material Usage by Energy Source tonnes per TWh

By this measure hydropower is an outlier because of all the concrete required to build the dams. However, wind and solar do not fare well compared to nuclear, coal or gas. Wind consumes 5,931 tonnes of bulk material per TWh and solar 2,441, many times higher than coal, gas or nuclear. The lifespan of 30 years assumed for wind and solar also probably flatters the actual real world performance, but the 60 year lifespan assumed for gas and coal are probably too high too.

Mortality by Energy Source

It would be remiss not to look at the human mortality from various energy sources. Thankfully, Glex have looked at this and a summary of their findings is shown in Figure 11.

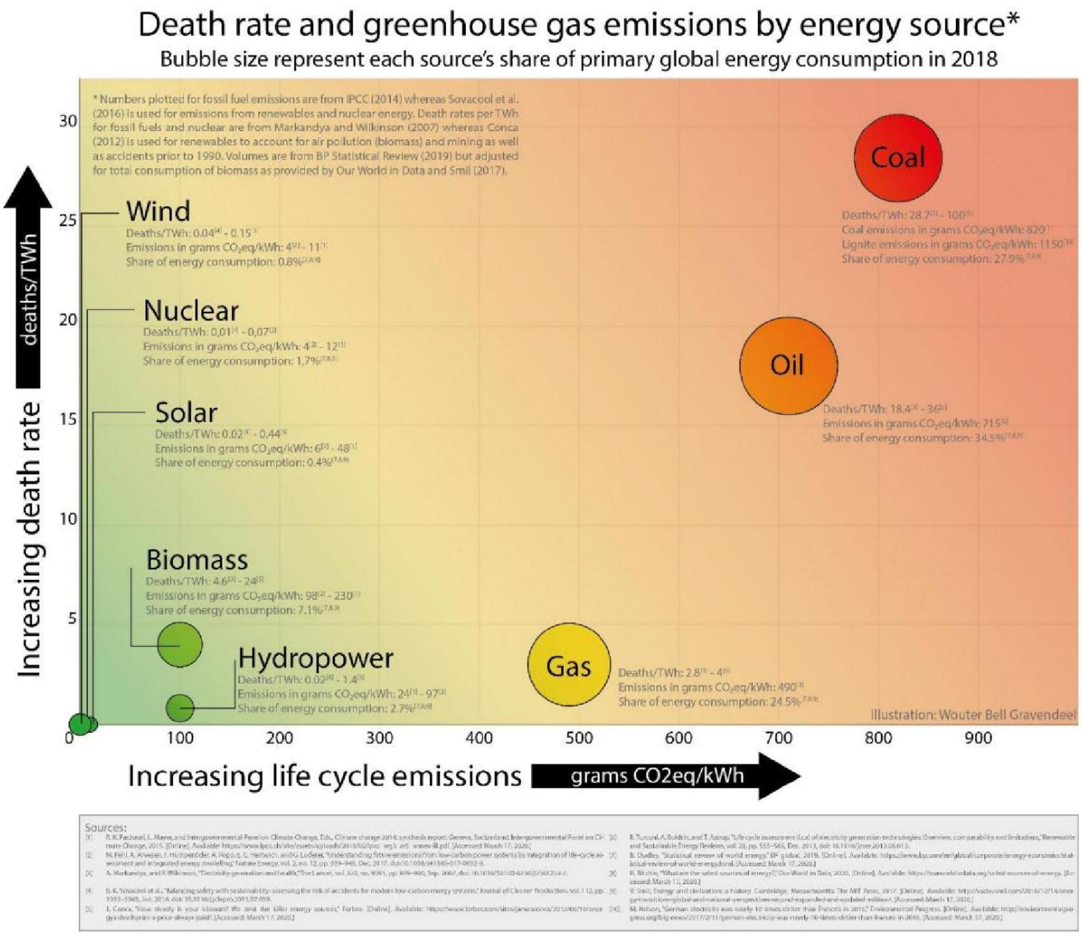


Figure 11 - Deaths vs Emissions by Energy Source (Glex)

Nuclear, wind and solar are by far the safest energy sources with mean deaths per TWh of 0.04, 0.1 and 0.23 respectively. Hydropower is somewhat worse at 0.71 deaths per TWh. Natural gas comes in a 3.4 and biomass at 14.3 deaths per TWh. Coal is by far the deadliest fuel with 64.4 deaths per TWh of electricity generated.

Impact of Renewable Energy Efficiency Improvements

Proponents of renewables are always quick to point out that the efficiency of renewables is improving all the time, so all of the analysis above is out of date. They do this in an attempt to portray renewables in a better light. Let us analyse that in a bit more detail.

First, take biomass. Growing and burning trees for energy uses mature processes that have been developed over many decades. There are no doubt incremental improvements to be made in the efficiency of boilers and turbines, but they are not going to make a significant difference to land use or CO_2 emissions.

Second, let us look at wind power. There's been a lot of talk about improving load factors by using larger turbines and the Government have assumed significant increases in load factors in their estimates of future costs of wind power. However, the Government figures (Table ET6.1) on actual achieved load factors show only a small increase in offshore wind, which is still below their forecast levels and an actual decrease in onshore wind load factors, see Figure 12. These improvements are not going to make a material difference to EROEI, land use or mineral usage.

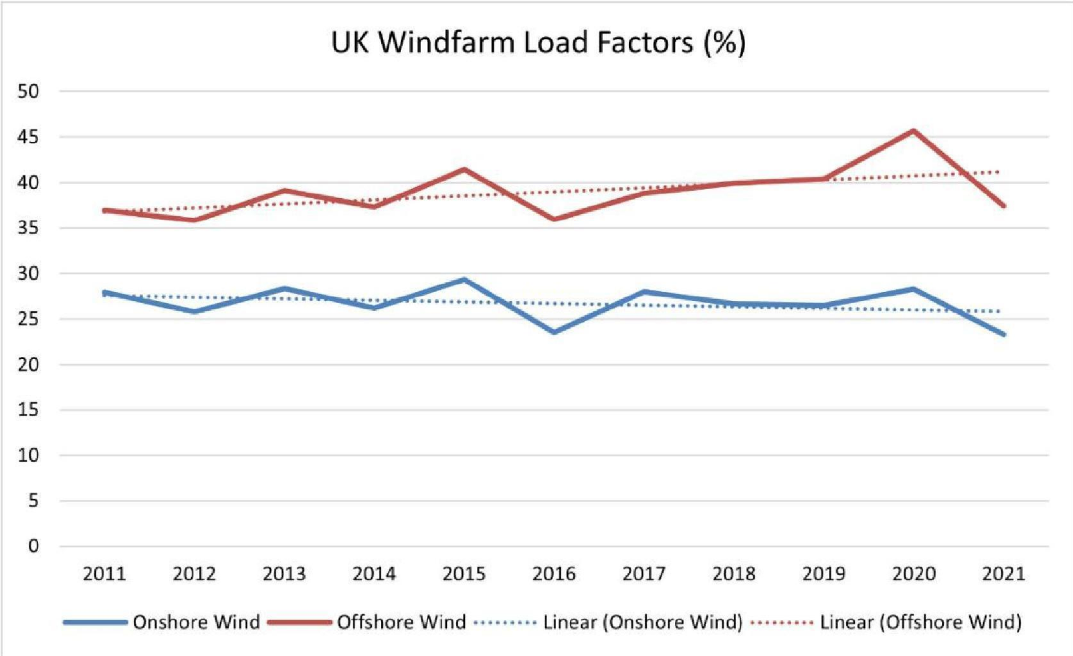


Figure 12 - UK Offshore and Onshore Windfarm Load Factors 2011-2021

Now on to solar power. It is true that the efficiency of solar panels has increased over time and Weissbach's EROI calculations were made about a decade ago. The EROEI metric might be expected to have improved since 2013. However, Lafayette have compiled a chart (see Figure 13) from NREL data that shows the improvements in module efficiency for crystalline silicon PV panels have not been particularly great since 2010, and appear to be close to topping out.

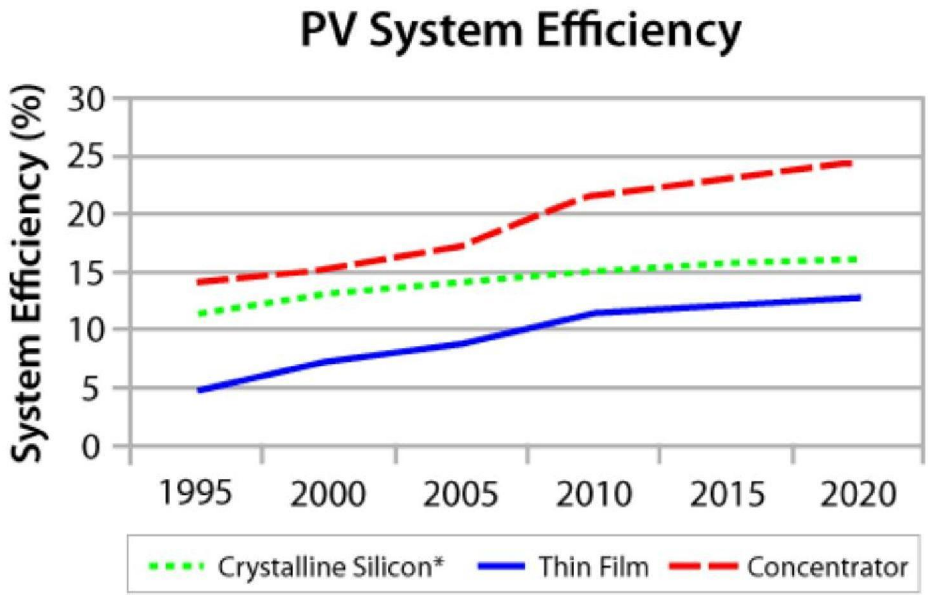


Figure 13 - Photovoltaic PV System Efficiency Over Time (Lafayette)

An order of magnitude or 10x improvement would be required to bring critical material usage into line with other technologies. Efficiencies for buffered Solar PV power would have to increase by a factor of 5 to exceed the EROEI economic threshold.

Moreover, as Figure 14 shows, taken from Mining Intelligence, the grade of new discoveries of critical materials like copper is declining.

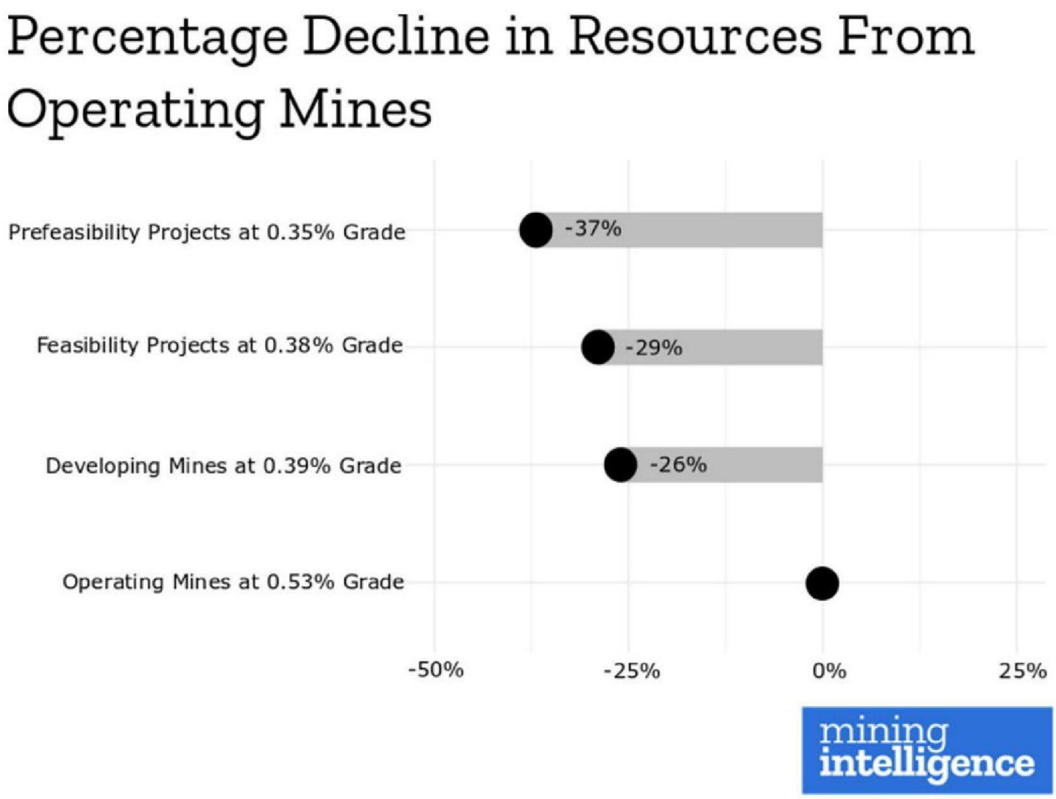


Figure 14 - Declining Grade of Copper Projects (Mining Intelligence)

As ore grades decline, the energy required to extract the required material rises exponentially (see Figure 15) as this paper by Calvo and Mudd explains.

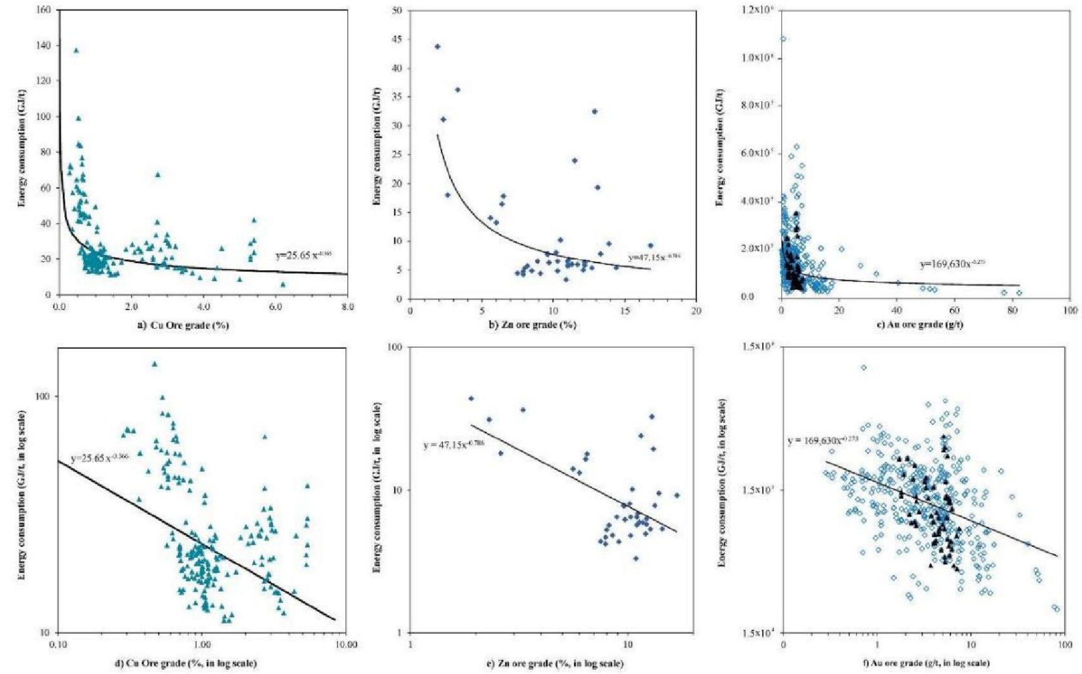


Figure 15 - Energy Consumption Rises Exponentially with Grade Decline (Calvo and Mudd)

The impact of this will dramatically worsen the EROEI and land use (more mines required) calculations for material intensive technologies such as wind and solar.

What About Waste?

As Figure 16 shows (credit for images used here, here and here), every source of energy has some sort of waste problem.

Figure 16 - Waste from Different Energy Sources

The energy source most frequently criticised for its waste problem is nuclear. However, this problem needs to be put into perspective. For instance, all of the spent nuclear fuel assemblies ever produced in the US packed into concrete dry casks could be stacked 135m high and stored in an area the size of a US football field. So, yes nuclear waste is a problem, but not an insurmountable one. Deep geological storage is also an option, with Finland leading the way with its Onkalo deep geologic repository.

In addition, spent nuclear fuel still contains around 90% usable material. It can be reprocessed and reused in nuclear reactors as MOX fuel, effectively closing the fuel cycle. France currently does this and the much smaller amount of residual waste is vitrified in borosilicate glass. Another option to close the fuel cycle is breeder reactors and the remaining waste is much less dangerous.

By contrast, coal produces toxic ash which is often put into landfill. It is not economic to recycle most current solar panels and they end up in landfill too despite containing toxic materials such as lead and cadmium. Wind turbines contain Chromium and most turbine blades are made from composite material that is not recyclable and they end up in landfill too. However, both Siemens Gamesa and Vestas are working on recyclable blades that may alleviate that problem.

Conclusion: Renewable Energy is not Green or Sustainable

If you limit your assessment solely to CO_2 or broader GHG emissions, then renewables in the form of hydro, wind and solar perform well compared to all other energy sources. However, biomass only performs well if the actual emissions from burning wood are ignored which seems a perverse thing to do, especially as noxious particulates accompany the CO_2.

However, we need to look at broader measures when assessing the sustainability and the green credentials of generation technologies. The results of the above analysis are summarised in Figure 17 below. Biomass, wind and solar perform very badly compared to the alternatives.

Metric/Source	Coal (No CCS)	Biomass[1]	Gas (No CCS)	Nuclear	Hydro (Med-Large)	Wind[2]	Solar Silicon PV[3]
GHG Emissions (g CO_2e/kWh)[4]	903	900	449	12	24	12	48
EROEI (buffered)	30.00	3.50	28.00	75.00	35.00	3.90	1.60
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Figure 17 - Summary Environmental Footprint by Electricity Generation Source

On the energy return on energy invested, wind and solar perform below the economic threshold when the requirement for buffering to cope with their inherent intermittency is taken into account. Biomass also performs below the economic threshold and if the BECCS proposals are carried out actually becomes a net energy sink. On this measure alone wind, solar and biomass should be ruled out for further subsidy or development.

Wind and solar require 10-300 times more space than nuclear or gas and more than hydro. They also require 10-20 times more critical minerals per unit of electricity than all other sources of electricity generation and several times more bulk materials than all other sources except hydropower.

Hydro, wind and solar perform very well on mortality, although not quite as well and nuclear power. Biomass performs worse than gas, but coal is the big killer.

Improvements in the efficiency of wind turbines and solar panels are not going to be enough to close these massive gaps in performance, and they will never overcome the fundamental issue of intermittency. The sun will always rise in the morning and set in the evening. The wind will continue wax and wane unpredictably.

Hydro performs well on every metric except bulk materials. However, hydropower is limited by geography, so it seems unlikely that it will play a key role in delivering our future energy needs. The only technology that can deliver reliable, scalable, sustainable power with a small carbon footprint is nuclear.

The drawback with nuclear is waste. However, most sources of power have a problem with waste. The waste issue with nuclear is significant, but manageable through cask storage, deep geological storage and fuel recycling.