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Assessing global renewable energy forecasts

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Abstract

In 2013, renewable energy accounted for only 8.9% of global commercial primary energy use, with fossil fuels supplying nearly all the rest. A number of official forecasts project such global energy growing by 50% or more by mid-century, and continuing to rise thereafter, in parallel with continued global economic growth. All energy sources of the future must meet three criteria: reserves or annual technical capacity must be adequate to meet projected demand; their climate change effects must be minimal; finally, they must be able to be widely deployed in the limited time available for climate mitigation. It is argued here that existing future energy scenarios generally fail to meet all three criteria. Most scenarios assume that adequate fossil/nuclear reserves are available, and that technical fixes can overcome greenhouse gas emissions from fossil fuels. The few scenarios projecting that renewables will supply most of the world's energy by mid-century assume unrealistic technical potentials and implementation times. To meet all three criteria, global energy use will need to be reduced, through a combination of energy efficiency improvements and energy conservation efforts.

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Keywords: Climate change; energy forecasting; fossil fuels; future energy availability; renewable energy.

1. Introduction

According to BP [1], global primary energy consumption (excluding fuel wood) in 2013 was 12.730 billion tonnes of oil equivalent, or about 535 EJ. Fossil fuels accounted for 86.7%, nuclear energy for 4.4%, and renewable energy (RE) for the remaining 8.9%. The share of non-fossil fuels in the global commercial energy mix is growing only slowly, and their share in 2013 was still lower than in 1995. However, RE is now increasing its share of both total energy and electricity. Although hydro is still the largest source of electrical RE, wind and solar electricity are the fastest growing sources [Table 1].

Future RE (and future total primary energy) use has been the subject of many studies, including those by official groups such as the Intergovernmental Panel on Climate Change (IPCC) [2], the International

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Energy Agency (IEA) [3], the US Energy Information Administration (EIA) [4], the European Commission (EC) [5], and the World Energy Council (WEC) [6]. In addition, RE industry groups such as the Global Wind Energy Council (GWEC) [7] give regular projections for the various RE sources. Many factors will be important in determining actual RE use in the long-term, including the monetary costs and technical potential for each RE source, and any remaining technical problems hindering their widespread use. Other important determinants of future RE growth will be actions for climate change mitigation and obstacles hindering future use of fossil fuel or nuclear energy. Climate change mitigation could potentially take very different forms, from RE being the main approach for reducing CO_2 emissions, to a much lesser role for RE—at least for the next few decades—if either solar radiation management (geoengineering) or carbon sequestration (either biological or mechanical) allow continued use of remaining fossil fuels.

Both geoengineering and carbon capture and sequestration as climate change solutions assume that fossil fuel reserves are adequate for the task of supplying ever-increasing amounts of fossil fuels annually. Much controversy surrounds this issue, with one group from Germany, the Energy Watch Group, even arguing that combined fossil fuel and nuclear energy use will peak in the next few years, and will fall steeply after 2020, largely owing to supply constraints [8]. Höök and Tang [9] argue similarly that peak global fossil fuel use will occur soon. Although it is now generally acknowledged that *conventional* oil production has peaked, most official sources believe that rising fossil fuel (and nuclear energy) production can continue for many decades to come. The latest IPCC report, for example, gives total fossil reserves at over 100,000 EJ, with nearly two-thirds of this total from unconventional gas [2]. An increased role is also seen for nuclear energy, even though its annual electrical output has been falling for nearly a decade [1]. Further, given the ageing reactor fleet, a large share of new reactor construction will be needed just to maintain existing output.

But if geoengineering, carbon capture and sequestration, and nuclear power all continue to encounter difficulties, then either RE will need to replace fossil fuels as the dominant energy source, or energy use will need to be curtailed. This short paper argues that RE will not be able to deliver enough energy in the limited time frame available, so that large energy cuts will be needed.

Nomenclature

EC	European Commission
EIA	Energy Information Administration (US)
EJ	exajoule (10^{18} joule)
GW	gigawatt (10^{9} watt)
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
RE	renewable energy
TWh	terawatt-hour (10^{12} watt-hour)
WEC	World Energy Council

Table 1. RE output (in TWh) for years 2000 and 2013 [8].

RE source	2000 (TWh)	2013 (TWh)
All RE	2895.2	5016.3

Hydro	*2666.2*	*3782.0*
Wind	*29.5*	*628.2*
Solar	*1.0*	*124.8*
Other RE	*198.5*	*481.3*

2. Future RE output

Assessments of both the global potential and forecast future consumption of RE show huge variations. For individual RE sources, the estimated annual technical potential can span several orders of magnitude, with the total for all RE estimated at 7500 EJ or even much higher [2,10,11]. Even 7500 EJ is nearly an order of magnitude higher than typical projected global energy needs for 2050. Hence many believe that availability of RE will not be a limiting factor; the only problem is the unit cost and how fast RE supply can be introduced. The main RE sources are bioenergy, hydroelectricity, and geothermal, wind and solar energy. The emphasis will be mainly on RE electricity, although bioenergy and geothermal and solar energy can also be used in non-electrical forms. Indeed, most RE used today is in the form of fuel wood, burnt at low efficiency in industrialising countries [3]. In Section 2.2, we argue that declining energy ratio is the main obstacle facing high RE output.

2.1. Projections for global RE output

Table 2 presents the scenario ranges for both global RE and total energy use given by various official sources for the period 2030 to 2100. It is clear that RE is expected to be a minor energy source (accounting for less than 25% of total energy) even in 2050. Nevertheless, researchers such as Fronk et al [12] envision a transition to 100% RE by the end of the 21st century, with about two-thirds of projected total primary energy of about 900 EJ from RE sources by 2050. These latter numbers seem reasonable, *assuming* both business-as-usual energy projections and decisive action on climate change.

Table 2. Range of forcasts for global total primary energy and RE (in EJ), for years 2030, 2050, 2100

Organization/Source	2030	2050	2100
IEA [3]	662-690	NA	NA
IEA (RE only)	*111-139*	*NA*	*NA*
EC [5]	648-706	821-937	NA
EC (RE only)	*84-93*	*141-168*	*NA*
WEC [6]	630-743	696-879	NA
WEC (RE only)	*90-109*	*169-204*	*NA*
IPCC [2,13][1]	575-805	680-1185	845-1730
IPCC (RE only)[1]	*130-220*	*201-274*	*285-410*

[1] indicative only

2.2. Declining energy return on energy invested for RE

As reported by Hall [14], the energy return on energy invested, here simply called the *energy ratio*, is declining for fossil fuels because of, for instance, the shift to unconventional oil (eg tar sands) and deep sea oil, or for US coal, declining calorific value [15]. The energy ratios reported for the various RE sources are already much lower than those for fossil fuels [16], and will progressively decline as their annual output rises. This decline can occur for a number of reasons:

- The quality of the RE resource decreases as annual usage rises. Wind power will face declining average wind speeds, geothermal power lower steam temperatures, hydropower less suitable sites for development. (See [17] for the example of global wind energy ratio vs cumulative annual power output). Also, distance from load centres could rise, necessitating expensive transmission infrastructure and energy losses, as in the proposal to link large-scale solar electricity farms in North Africa to European electricity grids.
- Particularly for bioenergy, competition for input resources (fertile land, fresh water) will intensify. In future not only is rising use of bioenergy anticipated, but other uses for biomass (food, fibre, timber and forage) are also expected to rise in step with rising global population [17].
- Large future demand for RE would have to rely heavily on wind and solar energy, both *intermittent* energy sources. As their share of the electricity mix rises, it will become progressively more difficult to absorb their output into the grid, necessitating conversion of a growing share into an energy carrier such as hydrogen, which can be stored for later use. Such conversion and storage is itself energy intensive and will further lower the energy ratio [17].
- Several research studies [eg 18,19] have stressed that RE production is dependent on a number of metals which are in short supply (for example rare earth elements used in wind turbines), or have limited global reserves compared with annual production, such as copper. As ore grades decline, input energy costs for metal production will rise, and so add to the input energy costs for RE at the same time as the quality of RE resource falls.

Indirect evidence for the decline in the energy ratios for some RE sources is available from historical global energy statistics. According to the WEC [20], in 1993 the ratio of annual global hydropower output to the installed capacity of 609 gigawatt (GW = 10^9 watt) was 3.75 terawatt-hour (TWh = 10^{12} watt-hour) per GW. Over the period to 2011, an additional capacity of 337 GW was installed worldwide, but the ratio for this additional capacity was only 1.43 TWh per GW. (Global hydro output can vary from year to year, but time series data [1] shows that 1993 and 2011 were average years for output.) This drop most likely signals a fall in the energy ratio for hydropower, despite the present installed capacity worldwide being only about one-third of assessed technical potential. Similarly, time series data for geothermal electricity show that New Zealand and the US, both early adopters of geothermal power, are experiencing declines in electric output per unit of installed capacity [1].

3. Discussion and conclusions

As has been argued earlier, it is unlikely that even the combined output of fossil fuels and nuclear energy can supply the greater part of the total energy demand for 2050 and beyond, as required in the official scenarios of Table 2. Increasing use of fossil fuels up to 2050 and beyond would require two conditions to be met. First, reserves of fossil and nuclear fuels would need to be adequate, yet in Section 1 it was argued that their combined production peak could occur soon. Second, assuming annual production can be increased out to 2050 and even beyond, the urgent need for climate change mitigation would require large-scale successful implementation of carbon sequestration, either mechanical or biological, as in the IPCC's Representative Concentration Pathway 2.6. This scenario is the only IPCC scenario which would keep global temperatures within the limit of 2 °C above the pre-industrial global average temperature [21]. Mechanical carbon sequestration is open to doubts about technical feasibility, and in any case is energy intensive, and so would hasten fossil fuel depletion [22]. Biological sequestration may sequester carbon, but could lead to increased absorption of insolation, tending to raise global temperatures [23].

If fossil (and nuclear) fuel use declines before 2050 for either of these two reasons, RE would need to supply the greater part of the world's primary energy needs in the second half of this century in a business-as-usual world. As discussed earlier, Fronk et al [12] have outlined a possible transition. But can RE supply some 600 EJ of primary energy as early as 2050, and over 1000 EJ by 2100? As with fossil/nuclear energy, RE would need adequate global potential, and would have be to be far superior to fossil fuels on climate change mitigation overall—not just CO_2 reductions. As discussed in Section 2.2, RE technical potential cannot be readily separated from its energy ratio [10]. In general, as the energy ratio falls, not only do money costs for RE rise, but so do the climate change and other environmental costs of any net energy produced. For example, some researchers have argued that the climate change effects of ethanol fuels from biomass will not be much lower than those from petroleum, because of emissions of nitrous oxide (an effective and long-lived greenhouse gas) from fertilisers, lower than expected biomass yields [24], and indirect effects on land clearance for agriculture.

RE will face a further constraint: time needed for implementation. Time would not be a problem for fossil fuels, assuming no other constraints, since it already accounts for some 80% of global fuel production. With global energy growth only about 2% [1], it would not have to grow much faster to meet 100% of fuel use. But with modern RE presently less than 50 EJ, growth would have to be very rapid to supply 600 EJ by 2050. After the initial growth spurt (such as is presently occurring for solar energy, and to a lesser extent, wind energy), further rapid growth is difficult to sustain because of dynamic energy considerations [25]. Unlike fossil fuels, RE sources are characterised by high up-front energy costs and low operating and maintenance energy costs. Wind turbines, for instance, have to be manufactured and erected, their access roads built, and connections made to the grid before any electricity is generated.

Too rapid growth in RE could thus entail the need for increased energy output from existing energy sources (mainly fossil fuels), rather than the decrease needed for carbon mitigation. This problem would become even more acute if energy-intensive energy conversion and storage systems are needed. Additionally, manufacturing capacity for each RE source would have to expand rapidly, then later decline rapidly when only RE equipment replacement are needed [25]. If all this means that rapid RE growth is not possible, then global primary energy demand will have to be greatly reduced.

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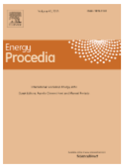
Biography



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