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Perspective

Energy transitions or additions? Why a transition from fossil fuels requires more than the growth of renewable energy

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ABSTRACT

Is an energy transition currently in progress, where renewable energy sources are replacing fossil fuels? Previous changes in the proportion of energy produced by various sources – such as in the nineteenth century when coal surpassed biomass in providing the largest share of the global energy supply and in the twentieth century when petroleum overtook coal – could more accurately be characterized as energy *additions* rather than transitions. In both cases, the use of the older energy source continued to grow, despite rapid growth in the new source. Evidence from contemporary trends in energy production likewise suggest that as renewable energy sources compose a larger share of overall energy production, they are not replacing fossil fuels but are rather expanding the overall amount of energy that is produced. We argue that although it is reasonable to expect that renewables will come to provide a growing share of the global energy supply, it is misleading to characterize this growth in renewable energy as a "transition" and that doing so could inhibit the implementation of meaningful policies aimed at reducing fossil fuel use.

Given the severity of the threat posed by anthropogenic climate change, which is in large part driven by fossil fuel combustion, it is becoming widely recognized that societies need a transition in how they produce and consume energy. Expressing a view common among energy analysts, Michelle Grayson [1: S133] asserts in the introduction to a special supplement to *Nature* focused on energy transitions, "The transition from fossil fuels is well underway. Each year sees an increase in the amount of electricity generated from renewable sources…." Some recent data on global energy consumption and carbon emissions appear to support the claim that we may be in the midst of an energy transition. Over the past decade, non-hydro renewable energy has been growing rapidly, averaging an annual rate of 16.2% [2]. Additionally, global carbon emissions, most of which come from fossil fuels, were approximately flat from 2014 to 2016 [2]. The primary reason for the leveling-off of carbon emissions is that the global consumption of coal (the most carbon intensive fossil fuel) declined by about 1% each year over this period [2].

However, belying the 2014–2016 decline in coal consumption, the historical pattern of changes in energy systems suggests that asserting a "*transition from* fossil fuels" [1: S133, our emphasis] at the global level is underway may be premature and potentially misleading. In fact, optimism based on the recent decline in coal consumption and stabilization of carbon emissions may be an example of "recency bias" [3], where overly focusing on the most recent data and failing to take into account longer-term patterns biases the assessment of the likelihood of various potential future trajectories.

A key point we highlight here is that there is a fundamental difference between (1) developing the infrastructure for and expanding the production of a new energy source (what we call an energy *addition*) and (2) a *transition away from* (i.e., a genuine decline in the use of) more established energy sources. The phrase "energy transition" typically implies that both of these processes are taking place, such that established energy sources are being replaced by new ones, not just supplemented by them. So as to avoid confusion and sharpen analytic acuity, we argue that "energy transition" should be used only when there is an actual move away from one source to another, not just when

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a new source expands (which is simply an "energy addition").[1] The addition of new energy sources (e.g., wind farms, solar installations) to the global system is clearly underway. However, it is not yet clear that societies are decisively moving away from fossil fuels; therefore, it may not be the case that we are in the midst of a transition, at least in the full sense of the word.

History shows us that although new energy sources have been successfully added to the global energy system and have grown to provide a large share of the overall energy supply, it is entirely *unprecedented* for these additions to cause a sustained decline in the use of established energy sources. Thus, calling the addition of renewables to the energy supply an "energy *transition*" may not only be misleading, but also potentially counter-productive, as such claims may provide the false impression of imminent reductions in carbon emissions and thereby suppress efforts to bring about a genuine transition *away from* fossil fuels. In fact, despite widespread optimism about the decline in coal consumption and the leveling of carbon emissions between 2014 and 2016, the pattern reverted to its historical norm in 2017, when carbon emissions grew by 1.6% and coal consumption by 1% [2].

Why, then, is the claim of an "energy transition" so prevalent? Indeed, there is a growing body of research focused on studying energy transitions both historical and contemporary, which accepts that a number of transitions have occurred in the past [e.g., 4–9]. However, a common mistake made in analyses documenting so-called energy transitions is centering the argument on the *proportion* of the energy supply that is generated from various sources. In Fig. 1, we present the percentage of global energy consumption from various sources from 1800 to 2017 based on data provided by Smil [6: 155], which we supplemented with data from BP [2] to calculate the 2017 values[2] . An important note is that in these data, biofuel is a broader category than is used in many data sources in that it includes estimated use of wood, agricultural waste, and other biomass that is not used for electricity generation and that does not enter the market. In addition, we do not show energy from solar or wind, since these are so low they would hardly register on the graph – e.g., despite rapid growth in recent years, wind and solar combined provided only about 2% of the global energy supply in 2017 [2].

Graphics very similar to Fig. 1 (although only ranging from the years 1800 to 2000) are presented by others to illustrate previous changes in global energy production [e.g., [8]: 206; [10]: 396]. These authors characterize some of these historical changes as *transitions*. At a first glance, our Fig. 1 also seems to suggest, as Smil [10: 395–396] explains, that a "transition" from biofuels (mostly wood) to coal occurred during the nineteenth century, a "transition" from coal to oil occurred in the mid-twentieth century, and, now, a "transition" to natural gas is currently in progress.[3] But are these shifts actually transitions in the sense of *moving away from* one energy source to another?

If we examine the absolute quantity, instead of the proportion, of total energy from various sources, we get a different impression from that given by Fig. 1. Fig. 2 presents total global energy consumption in exajoules from various sources from 1800 to 2017 (based on the same data sources used to make Fig. 1). Note that Sovacool [8] and Smil [6,10], while presenting the proportional composition of the global energy supply (like in Fig. 1), do not focus their discussions on or graphically present the absolute quantity of energy (like Fig. 2) in their assessments of purported energy transitions. As can be seen clearly in Fig. 2, historically, no established energy source has undergone a sustained decline with the addition of a new energy source. Rather, consumption of all energy sources has typically grown, a trend that has been maintained for over two centuries. Of course, there have been some periods of slight decline in the consumption of some sources, such as with coal between 1990 and 2000 (due largely to the collapse of the economies of former Soviet Republics and other Eastern Bloc nations) and with biofuels toward the end of the nineteenth century. However, in all cases, growth has returned, dominating the historical trajectory of each energy source. Although Fig. 1 appears to demonstrate there was a decline in biofuels and coal once new energy sources were introduced, Fig. 2 corrects this inaccurate impression. As Fig. 2 makes clear, biofuel consumption is currently more than double what it was in 1800, and coal use is likewise more than double what it was when oil became the dominant energy source in the 1950s.

The historical pattern presented in Fig. 2 suggests that past energy "transitions" could be more accurately described as energy *additions*. There were not transitions *away from* established energy sources, but rather additions of new energy sources on top of established ones. In each of the major historical shifts in energy-source proportions illustrated in Fig. 1 (biofuels to coal, coal to oil, and oil to natural gas), even as consumption of the newly introduced energy source grew explosively, consumption of the older energy source continued to grow as well (as Fig. 2 shows). In effect, the addition of newer energy sources has simply allowed for further growth in overall energy consumption, rather than serving as a replacement for older sources.[4]

A growing body of cross-national research examining how the addition of new energy sources affects established sources further supports our argument. For example, in an analysis of data for most nations of the world from 1960 to 2009, York [11] found that, controlling for a variety of economic and demographic factors, growth in non-fossil fuel energy only had a very modest effect on curbing fossil fuel use, where it took between four and thirteen units of non-fossil energy to displace one unit of fossil energy. Similarly, Greiner et al. [12] focused on assessing whether natural gas consumption suppressed coal consumption, analyzing data for most nations in the world from 1960 to 2013, and found that increases in gas consumption did not suppress coal

[1] Our interest here, of course, is not primarily a sematic one, but rather an analytic one. Our point is not to quibble about the various definitions of the word *transition* – some of which may only imply an addition. The distinction we make between a transition and an addition allows for a more accurate and clear characterization on the nature of these processes.

[2] The last year of data provided by Smil [6] is 2008. For all sources except biofuels, we calculated the growth rate from 2008 to 2017 using BP [2] data, and extended Smil's 2008 estimate by this growth rate so as to keep the values calibrated to Smil's method. The biofuels category in BP [2] is more limited than the one used by Smil in that it does not include non-commercial biomass use, so we could not use it to extend Smil's estimates to 2017. Since traditional biomass for energy does not necessarily enter the market, it is harder to evaluate than other energy sources. Therefore, we set 2017 value for biofuels at 9.20% of total energy consumption, the same percentage as in 2008, and this should be taken only as a rough approximation.

[3] The timing of how long these previous proportional shifts took (50-75 years) is informative with regard to how long it takes to provide an infrastructure to widely utilize a new energy source, and is therefore appropriately a topic of interest to researchers [8,6,10]. Additionally, researchers have explored some of the reasons for changes in the composition of the global energy supply, such

(*footnote continued*)
as prices and patterns across different sectors of the economy [4,5]. However, all of the researchers cited above characterize past changes in the global energy supply as *transitions*, which is the issue we are critiquing here.

[4] Perhaps one could argue that this continued growth across all energy sources should not be surprising, since over the past two centuries there have been dramatic increases in population and growth in economies around the world (and in per capita terms, biofuel consumption has declined). However, population and economic growth is expected to continue over the coming decades, so, at least in this regard, the expected future context is not entirely different from the context prevalent since 1800. Of course, the global pattern masks regional differences and country specific trends, where there are examples of declines in consumption of some energy sources [22,10]. Nonetheless, energy production and consumption patterns are globally interconnected, so that national processes are not independent, and, therefore, reductions in the consumption of an energy source in one nation may be connected with growth in consumption of that source in another nation [10,23].

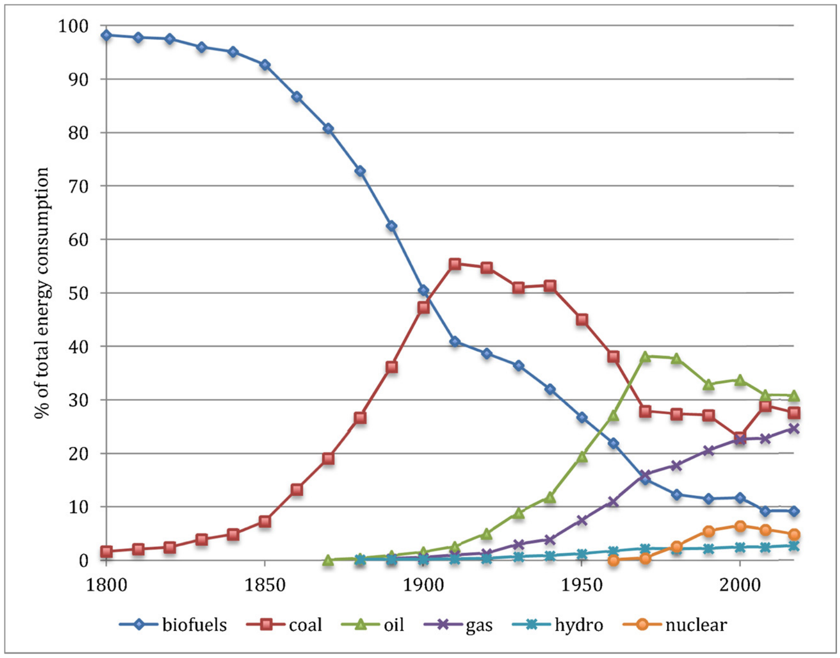

Fig. 1. Percentage of global energy consumption from various sources.1800–2017.

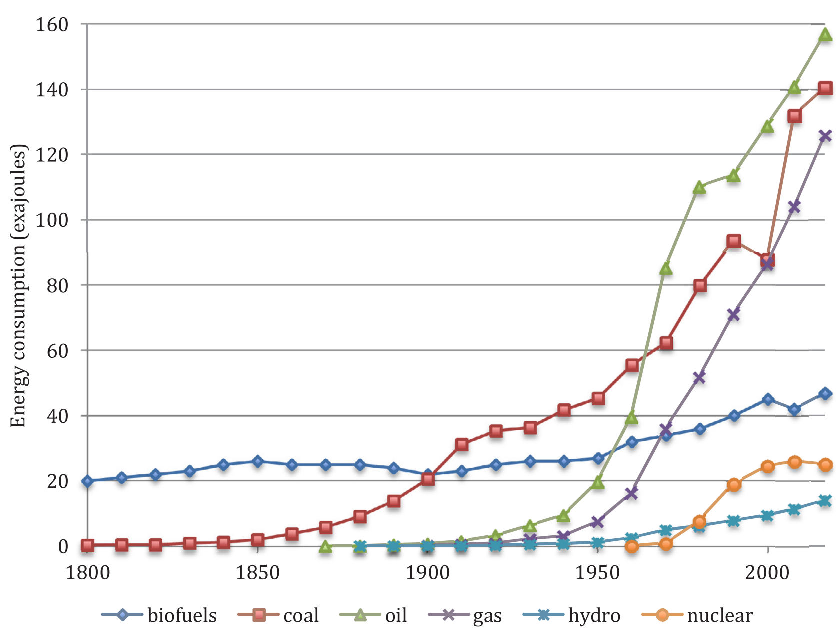

Fig. 2. Global energy consumption (exajoules) by source.1800–2017.

consumption. These authors note that there are likely multiple reasons why energy sources tend not to strongly compete with each other, but one major reason is related to the structure of market economies, which are driven by a growth dynamic in pursuit of profits, not a concern for conservation. These studies suggest that newer sources of energy are, for the most part, added to – rather than in place of – older ones.

It is also worth noting that adding new energy sources may, in some circumstances, actually accelerate consumption of other resources, even in areas outside the energy sector. For example, wood is not only used for fuel but is also used for other materials, such as lumber and paper. The rise of fossil fuels greatly accelerated logging and deforestation by powering chain saws, bulldozers, log trucks, and lumber mills, while also driving the development of larger homes and other structures constructed from wood [13]. Thus, not only has the use of biomass as an energy source continued to grow since the advent of fossil fuel energy production, but also the use of biomass as a material expanded even more dramatically as a result of fossil fuel-powered machinery. Likewise, counter to common misperceptions, the discovery of petroleum did not suppress whale oil consumption, helping to save the whales; rather, it actually spurred a dramatic *increase* in whaling [14]. This increase occurred because fossil fuel-powered ships could catch more and larger whales more rapidly than could sail ships and rowboats, and new uses were developed for whale oil (e.g., for margarine after the development of hydrogenation) [14]. Thus, in previous energy "transitions," it was not only the case that new fuel sources were added to old, but also that new sources sometimes contributed to the growth and development of non-fuel uses of old resources. Such patterns are important to identify, since these non-fuel uses may have serious environmental consequences; for example, petroleum has a variety of environmentally problematic non-fuel uses, such as feedstock for plastics.

The key point we make here, then, is that we should not assume that growth in the production of renewable energy sources is indicative of a move away from fossil fuels. Indeed, if the current moment of change in energy composition is like previous ones, we may expect simply an expansion of the overall amount of energy that is produced. This point is a crucial one since, due to the threat of global climate change, it is not simply the case that we need renewable energy sources to provide more power, but that we need them to *replace* fossil fuels if we are to avert a climate crisis.

Of course, it is entirely possible that a transition away from fossil fuels to renewable energy may be in its early stages, breaking from the historical pattern discussed here. After all, in the past, nations, industries, and publics were not trying to reduce the use of any particular source of energy, but they were rather simply seeking ways to provide more energy. In contrast, in recent years a large share of the world has clearly acknowledged that global climate change is a serious threat to societies and that a sharp reduction in the use of fossil fuels is necessary to minimize the severity of climate change [15]. In this distinct context, perhaps there are reasons for optimism that we will see an energy transition in the full sense of the word, where renewable energy sources actually come to *replace* fossil fuels [15].

However, there are also clear reasons to worry that the standard historical pattern may simply be repeating itself such that renewable energy sources are allowing for more growth in energy consumption and are not replacing other energy sources. Despite the promise suggested by the leveling off of carbon emissions and the modest decline of coal consumption between 2014 and 2016 (noted at the start of this essay), longer-term historical patterns are usually better predictors of future trends than are a few recent data points. Thus, it may not be wise to count on a continuing decline in coal consumption (and other fossil fuels) even as the production of renewable energy grows, unless concerted efforts are made to ensure that we bring about an energy transition that is entirely unlike previous ones, where new energy sources actually replace – rather than add to – established ones.

What measures will be necessary to bring about a full transition away from fossil fuels to renewables? Clearly, one pressure that has contributed to the tandem expansion of consumption of all energy sources is the fundamental growth dynamic of modern, particularly capitalist, economies. The rapid and continuing growth of total energy consumption – which is connected with continuing economic growth – makes it so that removing an energy source like fossil fuels is very difficult, even when the production of other energy sources is growing. Therefore, challenging the forces that push for relentless economic growth may be necessary to change the historic pattern of energy additions without transition. Since the fossil fuel industry has a vested interest in maintaining growth in fossil fuel consumption and has been active in resisting a fundamental energy transition (including promoting the climate change denial movement), serious progress to a sustainable future cannot be achieved without confronting the power of this industry in particular.

The historical pattern of energy additions without energy transitions suggests that simply promoting renewables will not lead to a full transition. What is necessary is an active suppression of fossil fuels. Simply expanding renewables is unlikely to be effective, since, all else equal, adding more energy to the energy supply suppresses prices and, therefore, helps to spur consumption [16]. Increasing the price of extracting and importing fossil fuels through a carbon fee and dividend system, as suggested by James Hansen and the Citizens' Climate Lobby [17,18], is one promising route, but it may need to be implemented alongside other supply-focused approaches [19] to increase its impact. One such approach is limiting the growth of overall electricity production, also known as "capping the grid" [20]. Through implementing what is essentially a moratorium on the growth of the energy sector, prices would increase due to scarcity, "ushering in the largest conservation and efficiency movement ever seen" [20, p. 232]. Another potential approach is restricting the extraction of fossil fuels through strong government regulations. To this end, nationalizing fossil fuel assets, as Gowan [21] has suggested, may be necessary. This suggestion may seem extreme, but we are in extreme times, where the consequences of continued fossil fuel use have dire implications for humanity and the ecological integrity of the planet.

Conflicts of interest

The authors declare no conflicts of interest.

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