

Resource acquisition, distribution and end-use efficiencies and the growth of industrial society: Response to reviewer comments and changes to the manuscript.

Response to Prof. Garrett's residual comments.

1. Point 6. The response to the concern that food is not a form of primary energy is that "All forms of primary energy depend on other forms of primary energy for their acquisition and distribution." I see the point, but if that is the stance taken in this paper, then I think a more clear definition of primary energy needs to be provided. How then is my body fat not a source of primary energy given it depends on food as a primary source of energy for its acquisition? My understanding is that food is not normally considered to be a source of primary energy since it, like my body fat, but unlike coal or sunlight, has its origins within civilization not the natural environment.

Food is no different to e.g. biomass in this regard, which is traditionally included in primary energy estimates. Both require socially constructed systems to acquire solar energy fixed through photosynthesis. Indeed, all forms of primary energy require some form of socially constructed system to acquire them leading to ambiguities in the definition of 'primary'. For example, in extracting coal or oil one is often ignoring the gas that is also present which is instead flared or vented off. This residual is not included in the measure of the primary energy yield despite being part of the environmental take in just the same way as crop residues and food waste are also often ignored in food primary energy estimates. We believe the definitions as given are as full and clear as they can be under the circumstances and are definitely more clearly stated than the norms in this discipline.

2. Points 12 and 13. I remain concerned by the response. A crux of much of the paper is that there is a fixed 2.4% growth rate that applies to the period encompassed by the industrial revolution. My concern is that the 2.4% growth rate for energy consumption would appear to discount the importance of traditional energy sources such as animals, wind and water power, and wood that remained prevalent for much of that earlier period. If early energy consumption was higher than accounted for in the Gruber data set, then this would imply an overall acceleration of growth rates over the total time series, not the fixed value mentioned. It is hard (for me) to believe that the (very high) 2.4% growth is a real feature of civilization for the past 200 years or so if extrapolating back (or even ahead) another 200 years yields unrealistically low or high energy consumption rates for the world as a whole. 2.4% per year translates to a doubling time of about 30 years. I just can't believe that energy consumption was 130,000 times smaller in year 1500 than today, or 1000 times smaller than in year 1800. A lot was going on in the Renaissance, even where primary energy sources were not that different for the most of the world than they were for the early 1800s. To believe that such a rapid rate is fixed, I would hope to see speculation for why a 2.4% growth rate should apply for the past 200 years, but not for the period prior. Perhaps a clue is that in the O'Connor and Cleveland 2014 paper mentioned in the response there is an interesting distinction between energy inputs and work done. For example, Figure 16 suggests that for the first 100 years of the industrial revolution, at least in the United States, the primary source of per capita work and growth of work was draught animals. Fossil fuels may have propelled the world in the late 19th and 20th century, but other sources appear to have dominated previously. Perhaps the author can comment on this distinction between inputs and work for calculation of primary energy supplies.

Biomass (including wood) and hydro are included in the Grubler data set. It is impossible for us to know the relative importance of the additional sources Prof. Garrett raises. We have modified the revision to read:

"Using global Gross Domestic Product (GDP) data as a proxy for global energy use, Garrett (2014) suggests that the relative growth rate of global primary energy has

increased significantly over the past 40 years. The data and analysis in Figure 3 would indicate otherwise, although clearly there are significant uncertainties over actual global primary energy measures both now and, more significantly, pre-1900. For example, it is unclear what contribution wind makes through merchant shipping over this period.”

We also note the original response included the following paragraph:

“We note that compiling long-term historic series for virtually any relevant measure of economic activity is challenging due to the paucity of available data and increasing uncertainties the further back one goes. Data on energy use is not exempt from these limitations. For example, the Grubler data we use do not appear to capture the full portfolio of renewables in use in the 1800s (e.g. wind and water power). However, we also note that the energy data used here still represents one of the best observed metrics of global economic activity. Also on the specific issue of renewables post-1850, evidence suggests that they constituted a negligible part of the global energy portfolio during this period (O’Connor and Cleveland, 2014, and Fouquet, 2014).”

We agree a lot of relevance was going on in the pre-industrial era, but unlike Prof. Garrett we do not wish to speculate on the growth dynamics of the pre-industrial era in this paper, choosing instead to restrict our comments to the period for which we have observations.

3. Point 14. The statement now included in the paper in reference to my work is “he assumes the apparent proportionality observed between primary energy and GDP observed for the last 40 years holds throughout the Industrial Revolution and before.” This is incorrect. Please correct this as it is a common misconception, not to mention the data don’t show this. The constant relationship that is found and extrapolated is for global primary energy and the time integral of global GDP. This is an entirely different thing.

Sincere apologies for not including the words “the time integral of” in our original response. As can be seen from the revision suggested above we have now deleted this sentence.