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Interactive comment on "Resource acquisition, distribution and end-use efficiencies and the growth of industrial society" *by* A. Jarvis et al.

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I found this paper interesting and thought-provoking. The general perspective of treating civilization as a physical network is highly compelling. Still, a non-anthropocentric perspective will always be inclined to meet resistance, particularly where climate policy is involved. My suggestion would be for the paper to limit speculation as much as possible and tighten the physical definitions to the greatest degree possible. Hopefully my comments below provide suggestions for how the manuscript might be clarified and improved.

1. p. 135 Points 1 to 4 aren't particularly user-friendly because the terminology is novel, especially for an introduction. E.g. "resource distribution networks must

inhabit the space occupied by industrial society". Can more enticing language be used?

2. I find that acronyms can obfuscate more than they clarify, particularly for unfamiliar concepts. Can RADE system be replaced with perhaps "distribution network" or some other language that is descriptive?

3. Why use the symbol x for an energetic quantity and y for carbon emissions? The symbol V is used for volume, which is natural, so can some basic thermodynamic quantity be used instead for energy (e.g. G or H)?

4. p. 138, The distinction between $x$and $x^{\star}$, or between primary energy and the points of end use, lies at the core of the paper, but seems somewhat arbitrary. It seems one could view the entirety of civilization as a network, in which case there are primary energy reserves for which the end user is outer-space which basks in civilization's dissipative warmth. Civilization is only the network that dissipates the energy so that it can be radiated to this end-user. Or, if a coal-fired power plant is the primary energy source, should we suppose that the end user is the electric company that builds the transmission lines, or the toaster that consumes the power, or the toast that consumes the toaster heat, or the person who eats the toast, or some component of human body networks in the form of gastro-intestinal tubes, veins and nerves, all of which benefit from toast consumption. Absent a truly precise definition, it is hard to see where it all starts and ends in a manner that could precisely be laid out in terms of equations yielding power laws.

5. Put another way, what element of society is not associated with distribution losses? Through the Second Law, it seems that nodes and networks are indistinguishable since they must all be dissipative.

6. p. 140. My understanding is that food is not a primary energy source in modern society because it's manufacture depends almost entirely on fossil fuels for

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fertilizer production, crop management, and distribution.

7. p. 140 and p. 141 “a small fraction”; “relatively small”. Please define.

8. p. 140 and p. 141. A variety of assumptions are made here for how to define x and $x^\star$. These lead to the very interesting result shown in Figure 1a of a 3/4 power scaling law, potentially the most compelling of the paper. To some degree this result must have been anticipated so it begs the question of the extent to which the value of the scaling law is sensitive to how x and $x^\star$ are defined. Can this be explored so that the fit for the value c expresses more than just a statistical uncertainty?

9. p. 142. As justification for civilization occupying three dimensions, it might be worth drawing a comparison to the atmosphere, which is also very thin due to gravitational forces, yet is nearly always modeled as a 3D entity.

10. p. 143 Points 1 to 3. Please also see Garrett (2014), which makes similar points.

11. p. 144 It is not obvious to me that $x^\star = \sum x_i^\star$. It seems that this would be true only if there were no interactions between nodes. Countries are purely political boundaries having little to do with exchanges of mass along networks associated with international trade. Where are the interaction terms in the summation?

12. Sections 6 to 8 rest upon there being a constant growth rate in primary energy consumption, a result that is based on statistics taken from Grubler (2003). The Grubler statistics indicate that no wind, solar, or water power was used in the 1800s where each were clearly major drivers of the distribution networks that existed at the time. Towns and cities were built to the greatest extent possible along rivers and canals because these offered hydro power for distributing goods and for milling grains. Wind power formed the thrust for the sailing industry which for centuries formed the backbone of international trade. Animal and human power

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was used to till farms, which in turn relied upon solar energy and photosynthesis for food. How do these omissions affect the result?

13. Consider further that 2.4% per year constitutes a doubling time of 28 years for global energy consumption. Is it really reasonable to presume that 300 years of industrial revolution corresponds to a global jump of a factor of 2000 in energy consumption? What about 2000 years of civilization, covering only the era since Roman times? Was civilization energy consumption really 2.3$\times$10^{21} times smaller in 1 AD? That would imply just 10 nano-Watts available for the world. It seems some further discussion is required on this point. If growth rates changed in the interim, how and why did such changes stop?

14. As a point of comparison, an alternative reconstruction of energy consumption over the past 2000 years is provide in the supplementary material of Garrett (2014), pointing to varying rates of growth over time, culminating in an all-time high of about 2.2% per year over the past decade.

15. p. 147. I don't understand the precise definition of dematerialization. Can an equation be provided?

16. Please check the spelling of Ausubel, which is correct in the references but not the text.

17. p. 149. Gas may be lower energy density per unit volume, but it is shipped in compressed form and it is has the highest energy density per unit mass due to the saturation of hydrogens. If international transport takes the form of shipping, isn't it energy per mass that matters most?

18. Section 7 Eq. 1 might benefit from further discussion. There are physical reasons to suppose that $x \propto V^{1/3}$ (Garrett, 2014).

19. Eq. 7 See also Garrett (2011) where it is expressed as $w = \epsilon a$.

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20. p. 154 The EROEI concept needs to be defined, with references.

21. The argument that the growth rate of civilization is constrained by human lifetimes is thought-provoking. It does beg the question of whether it exists for plants and animals since these are also network driven (just look at a tree). Is the growth rate of plants and animals proportional to their lifetimes in a similar fashion? What about cities (e.g. Bettencourt et al. (2007))?

22. p. 159 Measures of GDP may be disputed for on the point of whether they are linked to societal measures of success, but the metric is nonetheless well-defined and well-measured. It is reported quarterly at the national level as the total sum of all financial exchanges. Energy statistics on the other hand are only reported three years after the fact.

References

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