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?

Perhaps the problem word in this particular example is "inhabit"? We suggest replacing with 'fill'. On the four points in general, we accept that there will be a significant degree of novelty for the reader, but this is the point behind using these to introduce the reader to this novelty so that they are given a heads up on what they are about to encounter. Many have commented this is very useful because of the novelty of the concepts being introduced. As for rewording them differently, we have attempted to make them as transparent as possible given the reader hasn't yet been introduced to the detailed concepts they pertain to.

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?

Where we mean 'distribution network' explicitly we say this. However, it is important to also name the entire system from resource acquisition through to end use i.e. including the non-distributional components too. Given we need to do this often we find this particular acronym very useful rather than writing it out in full each time and because this gives the system a clear identity. This is the only acronym we introduce. The others (e.g. IEA and ERoEI) are standard in the energy literature. That said, we are happy to review our use of RADE and see if it can simply be replaced with 'distribution networks' or similar.

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)?

Although our work shares many close parallels with e.g. Garrett (2011) where thermodynamics is used to describe the growth of industrial society, our work does not explicitly use this framing and hence we do not feel obliged to adopt the standard from that discipline. Our works owes as much to systems biology or statistics as it does thermodynamics. We believe our symbols are clear and used consistently.

4. p. 138, The distinction between x and x^*, 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 gastrointestinal 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.

We need to draw system boundaries somewhere in order to do the analysis. Our choice is largely dictated for us by how energy use data are presented. Fortunately the choices exercised when compiling primary and final energy use data appear to relate to boundaries in the system that are not completely arbitrary. Primary energy is the energy harvested by industrial society from the environment and so mark this boundary clearly. Industrial society cannot substantially exercise any control over

flows upstream of this boundary. Final energy is more problematic as Prof. Garrett indicates. Here we define it as primary energy less the acquisition and distribution costs, less all transport. Although precisely defined, which boundary this relates to is much harder to accurately tie down. We offer an extensive account of our definition of final energy in the text. To further clarify, it is energy arriving in some space where further decisions on relocating energy and materials are irrelevant. So yes, the energy keeps flowing and changing state within these spaces, but these flows are not 'directed' by human agents and hence industrial society. We will expand the text to attempt to clarify this.

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.

As discussed above, we are specifically interested in 'directed' distributional losses i.e. ones where human agents exercise control (either explicitly or implicitly). Therefore, the distribution networks we are focusing on are ones constructed and exploited by humans.

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 fertilizer production, crop management, and distribution.

All forms of primary energy depend on other forms of primary energy for their acquisition and distribution.

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

Where possible we will replace with quantitative estimates.

8. p. 140 and p. 141. A variety of assumptions are made here for how to define x and $x_?$. These lead to the very interesting result shown in Figure 1a of a ¾ 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_* are defined. Can this be explored so that the fit for the value c expresses more than just a statistical uncertainty?

The uncertainties we cite attempt to include the uncertainties in the data sources themselves. With respect to the structural uncertainties arising from the assumptions on the definitions of primary and final energy, there are not many degrees of freedom to explore here. Primary energy is largely a given. As for final energy, the key difference in our definition is the inclusion of transport. We present the IEA final estimates in Figure 1a which do not include transport and can include the regression stats for these data for comparison.

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.

Clever. We will include offering acknowledgement and thank you for pointing that out.

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

We accept that Garrett (2014) is covering similar material but couldn't see that it addresses the specific topics of innovation on distribution mechanisms,

dematerialisation and urbanisation and so would prefer to claim uniqueness here, but cite Garrett (2014) elsewhere as it is clearly very relevant to our work.

11. p. 144 It is not obvious to me that $x^* = \Sigma x^*_i$. 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?

Clearly nodes interact with each other through trade. But the IEA data we are describing accounts for this and hence the global energy totals are simply the sum of the country values. That is all we are saying here.

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

This is an interesting point. The Grubler data is a little ambiguous here stating the pre-coal primary energy is comprised of "wood, dung, crop residue, other biomass, etc". We suggest we expand the description of the data at this point to highlight this ambiguity.

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_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?

We restrict our discussion of growth rates to the 160 years covered by the data. When a ~2.4%/yr growth rate first emerged we do not know. Clearly the Industrial Revolution marked the emergence of novel systemic behaviour and it is erroneous to extrapolate growth rates back prior to this. Any such discussion would be highly speculative.

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.

We will expand the discussion of variable verses constant growth contrasting your work with ours. However, given there is no data on global primary energy use pre 1800 we will lean toward inferring a somewhat constant relative growth rate given this is what the data indicate (item 12 above considered)

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

Not really. It is simply falling unit mass of a resource flow. We can expand the sentence to state this explicitly.

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

OK

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?

Not necessarily. LNG is bulky (as in unit energy per unit volume), and this appears to add to the transport costs along with the need to keep it cold/compressed.

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

We agree the discussion could be expanded here, especially in response to Garrett (2014). This does not however invalidate our assumed position of $x \propto V$ because the geometry of the interface is by definition complex.

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

Will also cite Garrett (2011).

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

OK, although it is a widely used and understood concept.

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))?

An interesting point that we will touch on in the text. Cities however do not have characteristic lifetimes in the same way.

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.

Here we will have to disagree. Not only can the accuracy of GDP be disputed, because data are collected at the national level their precision is also disputable because values can change depending on judgment alone. This is not the case with primary energy data. Here the key uncertainty is the energy value of the material traded and how much of the physical resource was traded. Beyond that the uncertainties are comparatively low, requiring no exchange rate or inflation adjustment. On the issue of reporting interval, the IEA report three years after the fact after extremely careful and rigorous quality assurance. BP report 1 year after the fact. This has no bearing on the quality of the data other than the amount of time taken for verification.

Thank you Prof. Garrett for a really good, thorough review and apologies for the slow response.