

## ***Interactive comment on “Revolutions in energy input and material cycling in Earth history and human history” by T. M. Lenton et al.***

### **Anonymous Referee #2**

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This is a well-argued and fascinating paper which I enjoyed reading very much. It presents a new approach to measuring the size of human society, its resource use and environmental impact against a natural background. The paper provides a long term perspective on energy transitions from the 3-4 Ga to present, brilliantly depicting six energetic revolutions, three in earth history and three in human history. The authors present a calculation of the resulting increase in energy input to the biosphere and human societies, respectively. This allows comparing the orders of magnitude of energy use by human society with energy inputs to the entire biosphere. Based on this, the paper establishes a link between energy flows and global material cycles and the associated environmental changes (e.g. by shifts in and scaling up of metabolic waste production) and the resulting feedbacks on energy capturing.

The paper is unique as it tries to link a long term earth history perspective with a short

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term socioeconomic perspective on energy revolutions. In doing so, the paper provides a comprehensive overview of the current knowledge on energy revolutions in earth and human history, integrating knowledge from typically separate disciplinary approaches. What makes the paper innovative and outstanding is not so much new empirical evidence, but the attempt to link the different approaches and time scales of analysis from earth history and human environmental history. The paper impressively shows remarkable similarities between the six energy revolutions, each involving a new mechanism to capture free energy and accessing of previously underutilized sources. It shows how material constraints became limiting to the expansion of the scale of energy flows, either because of negative feedbacks of increasing waste outflows or because resources become scarce. From such a perspective, the ability to recycle the involved materials was crucial even in earth history revolutions. The analysis also underlines that the capacity of humans to push energy inputs towards planetary scales only emerged with industrial revolution. From the analysis of the past energy revolutions the authors draw lessons for a next energy revolution, the need for a closure of disrupted material cycles and the implications for socio-economic development.

Overall this is a well-structured and written, highly innovative and truly interdisciplinary paper - as far as I know, it is the first attempt to link earth and human history perspectives on energy transitions and their impact on the biosphere. The paper yields crucial insights for current debates about the Anthropocene, Planetary Boundaries and socio-economic metabolism research. I recommend to accept the paper for publication and only have a few very minor remarks.

4/103 provide reference!

6/173 . . .lower weathering fluxes of phosphorus. . . (lower compared to what reference level? Why lower?

6/189 what is meant by “sinking export production” here?

10/330 looking at the information provided in Figure 2 I would say that energy use in

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industrial is two orders of magnitude higher than the biological metabolic requirements of humans (300 GJ/cap/yr compared to ca. 3 GJ/ca/yr).

11/343 . . .accounted for as socioeconomic input. . .

11/363 – vulnerable to the scale and quantity of metabolic changes. . . Unclear what this refers to.

12/405f –some references would be useful here

13/414 – something wrong with the sentence

Figure 2: Provide source information in Figure captions

16/525 – I think Krausmann et al. 2013 is the wrong reference here. This paper is about human appropriation of NPP!

16/529 – provide reference for CO2 emissions

16/540 – in a recent paper in the Journal of Industrial Ecology, Haas et al. (2015) have estimated that only 6% of all globally extracted materials are currently recycled within the socioeconomic system.

18/590 – Specify year of reference: Do the 25%-75% refer to current or projected (2050) energy demand.

18/580ff – The authors discuss the transition to a solar powered industrial energy system (biomass, PV, wind etc.). Even though I agree that solar powered technologies (PV, wind, biomass) are the way to go, I would appreciate a statement here on the possible significance and limitations of nuclear energy sources (fusion/fission) in future energy provision (based on the framework applied in the article) – These technologies are considered of high relevance in some sustainable energy strategies (see e.g. the recently published ecomodernist manifesto <http://www.ecomodernism.org/> ) and should be addressed in one way or another!

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