Why the energy transition is not enough

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Article

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Abstract

Efforts to accommodate the growth in global energy consumption within a fragile biosphere are primarily focused on managing the transition towards a low-carbon energy mix. We show evidence that a more fundamental problem exists through a scaling relation, akin to Kleiber's Law, between society's energy consumption and material stocks. Humanity's energy consumption scales at 0.78 of its material stocks, which implies predictable environmental pressure regardless of the energy mix. If true, future global energy scenarios imply vast amounts of materials and corresponding environmental degradation, which have not been previously acknowledged. Given this reality, we also show evidence that a worldwide lifestyle limit at 2.0 kW/capita enables a dignified life for all while stabilizing human intervention in the biosphere to current levels, yet the political viability of establishing such limit is very low.

Introduction

Humanity's energy consumption over time (i.e., power) of 16.1 TW in 2010 is projected to increase by 70–180% by 2050 (1). On track with these expectations, humanity reached 18.9 TW in 2018 - a yearly 2% growth since 2010. Such growth is confronted by the well-documented realities of climate change (2), persistent 80% share of fossil fuels in the global energy mix (3), and declining quantity and quality of fossil fuel reserves (4, 5). These issues have drawn considerable attention towards the energy transition (6–8), energy sources such as renewables and nuclear (9, 10), and the obstacles for their massification such as slow deployment (11) and low energy return over investment (12, 13).

An additional yet scarcely debated issue with future energy scenarios is the fundamental relation between power and material rearrangements. The use of power requires the rearrangement of materials into prime movers such as people, engines, computers, etc., and such use inevitably rearranges materials in the environment. Thus, greater power implies more materials being rearranged from otherwise healthy ecosystems into social structures such as firms, cities, and governments and into goods such as furniture, electronics, and food. In fact, the 20th century saw a 9-fold increase in humanity's power alongside a 16-fold increase in its material stocks (14). We contend that current ecosystem degradation (15), biodiversity loss (16), and dangerous human intervention in the Earth system (17) could have only partially been avoided by replacing fossils with low-carbon alternatives.

We show that the relation between power and material stocks of social systems resembles Kleiber's Law and present what we believe is the first documentation of this relationship. Previous social allometric scaling relationships like the ones studied in (18) relate power to birthrate and child mortality, not to society´s mass. We use a newly compiled dataset from published estimates of power and material stocks which covers Human civilization between 1900–2010 and the USA and Japan between 1980 and 2005. Ordinary least squares are used on the logarithms of these variables to estimate the scaling parameter between them and study the resemblance to relationships found in biological organisms.

If true, this relation implies a novel and strict limit to power growth. Thus, we also study the existence of decreasing social returns to power and use this concept to identify reasonable power levels that maintain a dignified life yet contain human intervention in the Biosphere. We use another newly compiled dataset from published estimates of power per capita, the Human Development Index, years of schooling, life expectancy, GDP per capita, women fertility, exposure to PM 2.5, murder rates, and self-reported satisfaction for 151 countries between 1970 and 2014. A kernel-weighted local polynomial smoothing regression is used to find the best fit curves and confidence intervals relating power per capita and these social outcomes.

Results

Extended Kleiber's Law

Biological organisms use foodstuff through mitochondria, cells, and muscles to rearrange carbon, hydrogen, and other elements into the components of a functional body. Macroecological theory and Kleiber's Law in particular show that a biological organisms' power (P) is allometrically proportional to its mass (M) such that with and for intraspecific and interspecific species, respectively (19–21). Similarly, social systems act as super-organisms that also use energy to rearrange mass into living support structures (Fig. 1) (22, 23). The main difference is that social systems use a wider array of energy goods (e.g., foodstuff, biomass, fossil fuels, electricity) through diverse prime movers types (e.g., people, gas turbines, computers) to arrange a broad set of materials (e.g., biomass, gravel, iron) into the components of a functional society (e.g., products, infrastructure, firms, governments).

Our data shows that power and material stocks are related in a manner consistent with Kleiber's Law in the USA [0.67 (95% CI 0.58-0.75, 95)], Japan [0.61 (95% CI 0.54-0.69, 94.3)], and globally [0.78 (95% CI 0.76-0.80, 98.6)] (Fig. 2.A). Combining these three super-organisms with a sample of biological ones relates power and material stocks over 14 and 17 orders of magnitude respectively with 0.86 (95% CI 0.85-0.86, 99.9) (Fig. 2.B). This higher-than-expected exponent is a numerical artifact due to the different y-intercepts of the individual series' best-fit curves. Independently centering each series eliminates the regression constants yielding 0.74 (95% CI 0.71-0.77, R^2 = 96.7) (Fig. 2.C). Whereas the results for the USA and Japan corresponds to biological intraspecific scaling (0.67 and 0.61 versus 0.67), Humanity's scaling corresponds to biological interspecific scaling (0.78 versus 0.75), and the combined super and biological organism scaling is identical to Kleiber's original result in 1961 (i.e., 0.74).

Decreasing social returns to power

Early hunter-gatherers used just enough energy to satisfy their metabolic needs of ~0.1 kW/capita. Power per capita increased throughout the agricultural and successive industrial revolutions such that the current global average is ~2.3 kW/capita and surpasses 10kW/capita in some high-income countries. Such an increase has brought ample social benefits, yet at a diminishing rate as documented with the

Human Development Index (HDI) (24-27) and other indicators such as political freedom and improved water access (26, 28, 29).

Moreover, most social gains are generally obtained from increasing power up to 1.0 kW/capita (approximately the per capita power level of Western Europe in the mid-1970s), milder gains accrue between 1.0 and 5.0 kW/capita, and almost none after 5.0 kW/capita. For example, we find that the HDI (driven by schooling and life expectancy) increases rapidly up to 1.0 kW/capita, slower up to 5.1 kW/capita, and then ceases to improve (Fig. 3A). Similar thresholds also exist for female fertility (1.0 and 4.5 kW/capita), yet for murder rates and exposure to PM 2.5 only the upper threshold exists at 4.9 and 5.4 kW/capita respectively. (Fig. 3B). GDP per capita also shows the upper threshold only at 5.1 kW/capita. Variation from these stylized thresholds exist, with self-reported satisfaction showing improvements up to 8.4 kW/capita.

Discussion

The extended Kleiber's Law implies that, regardless of the energy mix, future energy growth scenarios are associated with the rearrangement of prodigious amounts of materials. For a projected power growth of 70–180% between 2010 and 2050, results point to a 56–191% (95% CI 45–218%) increase in Humanity´s material stocks equivalent to 440–1516 Gt (95% CI 355–1725 Gt). The actual amount of raw materials taken from nature would be higher because more than one ton of materials must be extracted from nature per ton of material included in civilization (14). Given that Humanity's current material stocks is roughly 800 Gt, how can material stocks be increased by such magnitude while maintaining the biosphere's integrity?

These estimates account for technological progress and thus cannot be avoided through it. For example, Humanity's power scaled at $\alpha =$ 0.78 and not proportionally to mass at $\alpha =$ 1 during the 20th century because the energy cost of ammonia dropped from over 100 to 33 MJ/kg (30), of iron from over 50 to 10 MJ/kg (29), of aluminum from 50 to 13 MJ/kg (31), light bulbs' efficiency improved from less than 25 to more than 175 lumen/W (32), and engines reduced their mass-to-power ratios from 90 to less than 1 g/W (31). Without these and other technological achievements power would have scaled proportionally to mass, and with $\alpha =$ 1 humanity's 2010 material stock level would have been associated with power 8,000 times higher. If social systems obey Kleiber's Law, such relation is a constraint for social metabolism as fundamental as in animal metabolism (33), and technological innovation plays a role in the former as important as the role evolution has played in the latter.

The extended Kleiber's Law and decreasing social returns to power provide compelling limits to per capita power. While social benefits accrued from power consumption up to 1.0 kW/capita make power growth easily justified, further growth into the 1.0–5.0 kW/capita range becomes contentious, and beyond 5.0 kW/capita difficult to defend given the limited material harvesting that the biosphere can sustain (34, 35).

As an illustration, mean population and power growth projections by 2050 point to a world with 9.7 billion people (36) with a power of 4.5 kW/capita (1). Under this scenario, global power reaches 43.7 TW and material stocks 2211 Gt (95% CI 2030–2409), which is 2.79 (95% CI 2.56–3.04) times 2010 levels. Alternatively, if by 2050 population reaches 9.7 billion but per capita power is decreased to 2.0 kW/capita by 2050 (instead of increased to 4.5 kW/capita), power reaches 19.4 TW and material stocks remain at today´s levels with 797 Gt (95% CI 750–847). The continuum of per capita power, population, and their mean material stocks estimate using 0.78 scaling are shown in Fig. 4.A. The tradeoff between population and per capita power to maintain current material stocks is shown in Fig. 4.B.

A 2.0 kW/capita limit seems like a reasonable goal to contain human intervention in the biosphere without sacrificing considerable social gains according to our results and those in (28, 37, 38). Yet, it is unlikely for countries to willingly reduce their average per capita power (29). Historically this has only happened under extreme circumstances such as the fall of the Roman Empire and the breakdown of the Soviet Union. A peaceful and ordered lowering of per capita power to 2.0 kW would be unprecedented in medium-high-powered countries with 3.0 kW/capita (e.g., China, Chile), let alone in very-high-powered countries with more than 10.0 kW/capita (e.g., USA, Australia). In all, 53% of the 151 countries with data in 2014 had more than 2.0 kW/capita (Fig. 5).

A worldwide limit of 2.0 kW/capita could be achieved through a radical increase in resource productivity reducing both energy and material throughput as outlined in (39), yet such an approach ignores the rebound effect (e.g., Jevons paradox) that has prevented previous efficiency gains to translate into lower aggregate energy and material use. Another option to lower per capita power is through widespread reduction of working time and per capita consumption, which could be welfare-enhancing (40) but would require a profound paradigm shift (41–43).

Limiting per capita power allows for a worldwide acceptable standard of living but requires unprecedented degrowth in more than half of all countries. Although technically feasible, achieving this poses a seemingly impossible political challenge given the prevailing growth paradigm (44, 45). Yet the extended Kleiber´s Law shows that keeping global power growth unchecked is technically unfeasible regardless of the energy mix given the intimate relation between energy use and material rearrangements. Avoiding such disruption without limiting power could only be achieved by embarking on the costly, technically complex and risky enterprise of becoming an interplanetary species. Setting limits seems like a more pragmatic, safe, and reasonable path forward.

Materials And Methods

All codes and data are available as supplementary information.

Humanity’s material stocks come from (14) and those of the USA and Japan from (46). Both sources contain roughly the same non-human types of mass. A human type of mass was included by multiplying yearly population by yearly average weight. This type of mass accounts for virtually 0% of total material t.

Humanity’s power comes from (47) and (48). Data between 1900 and 1910 was linearly extrapolated. Power for the USA and Japan comes from (49). Mass and power for biological organisms comes from (50).

The Extended Kleiber’s Law model was estimated with Ordinary Least Squares using Eicker–Huber–White standard errors. Figure 2A was obtained by independently regressing the series for Humanity, the USA and Japan; Fig. 2B by regressing those three series together alongside the series with biological organisms; and Fig. 2C by regressing these four series together after demeaning them independently.

The mass associated with future power levels was estimated with the inverse of the Extended Kleiber´s Law, i.e. $M = BP^{\beta}$ with $\beta \approx 1 / \alpha$. The range of additional material stocks was estimated with the lower bound of the conservative future power prediction and the upper bound of the generous future power prediction.

Per capita power is country-level primary energy consumption per capita. The series on primary energy consumption comes from (49), and another series on energy consumption is available from Our World in Data which yields very similar results. This latter series is only presented as supporting material, it is not used in this article, and thus it is not referenced. Data on population comes from (51), on life expectancy from (52), on mean years in school for women of age 15–44 from (53), on the murder rate from (54), on children per woman from (55), on GDP per capita from (56), on the HDI from (57), on PM2.5 from (58), and on self-reported satisfaction from (59).

The best fit lines were obtained through kernel-weighted local polynomial smoothing. The Epanechnikov kernel function was used by default. All countries with a population of less than 1 million in a given year were dropped in that year only. Observations were also excluded if they had more than 10 kW/capita, 60,000 USD/capita, 50 murders for every 100,000 people, and 100 μ/m3 of PM2.5.

The mass associated with different population levels at 2.0 and 4.5 kW/capita were estimated with the inverse of the Extended Kleiber´s Law. This equation is also used to obtain the three-dimensional graphs depicting the relation for a continuum of population and per capita power levels.

Declarations

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1. B. J. van Ruijven, E. De Cian, I. Sue Wing, Amplification of future energy demand growth due to climate change. *Nat. Commun.* **10**, 2762 (2019).
2. D. Tong, *et al.*, Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target. *Nature*, 1 (2019).
3. IEA, "Global Energy & CO2 Status Report 2018: The latest trends in energy and emissions in 2018" (2019).
4. S. H. Mohr, J. Wang, G. Ellem, J. Ward, D. Giurco, Projection of world fossil fuels by country. *Fuel* **141**, 120–135 (2015).
5. I. Chapman, The end of Peak Oil? Why this topic is still relevant despite recent denials. *Energy Policy* **64**, 93–101 (2014).
6. B. K. Sovacool, How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Res. Soc. Sci.* **13**, 202–215 (2016).
7. V. Smil, Examining energy transitions: A dozen insights based on performance. *Energy Res. Soc. Sci.* **22**, 194–197 (2016).
8. A. Grubler, Energy transitions research: Insights and cautionary tales. *Energy Policy* **50**, 8–16 (2012).
9. World Nuclear Association, "Harmony: What would power our electric future?" (2019).
10. P. Moriarty, D. Honnery, Can renewable energy power the future? *Energy Policy* **93**, 3–7 (2016).
11. P. Moriarty, D. Honnery, What energy levels can the Earth sustain? *Energy Policy* **37**, 2469–2474 (2009).
12. D. J. Murphy, The implications of the declining energy return on investment of oil production. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **372** (2014).
13. C. D. Rye, T. Jackson, A review of EROEI-dynamics energy-transition models. *Energy Policy* **122**, 260 (2018).
14. F. Krausmann, *et al.*, Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proc. Natl. Acad. Sci.* **114**, 1880–1885 (2017).
15. Millennium Ecosystem Assessment, " Ecosystems and Human Well-being: Synthesis" (2005).
16. IPBES, *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.*, S. Díaz, *et al.*, Eds. (IPBES secretariat, 2019).
17. W. Steffen, *et al.*, Planetary boundaries: Guiding human development on a changing planet. *Science (80-.).* **347** (2015).
18. O. Burger, J. P. DeLong, M. J. Hamilton, Industrial energy use and the human life history. *Sci. Rep.* **1**, 1–7 (2011).
19. A. A. Heusner, Energy metabolism and body size. I. Is the 0.75 mass exponent of Kleiber's equation a statistical artifact? *Respir. Physiol.* **48**, 1–12 (1982).
20. H. A. Feldman, T. A. McMahon, The 3/4 mass exponent for energy metabolism is not a statistical

983).

21. M. Kleiber, *The Fire of Life: an Introduction to Animal Energetics*, Revised ed (Wiley, 1961).
22. H. Haberl, *et al.*, Contributions of sociometabolic research to sustainability science. *Nat. Sustain.* **2**, 173–184 (2019).
23. 10.1007/978-1-4614-3188-6_12
W. E. Rees, “Cities as Dissipative Structures: Global Change and the Vulnerability of Urban Civilization” in *Sustainability Science*, M. Weinstein, R. Turner, Eds. (Springer, 2012) https:/doi.org/https://doi.org/10.1007/978-1-4614-3188-6_12.
24. J. G. Lambert, C. A. S. Hall, S. Balogh, A. Gupta, M. Arnold, Energy, EROI and quality of life. *Energy Policy* **64**, 153–167 (2014).
25. A. Annila, E. Kuismanen, Natural hierarchy emerges from energy dispersal. *BioSystems* **95**, 227–233 (2009).
26. I. Arto, I. Capellán-Pérez, R. Lago, G. Bueno, R. Bermejo, The energy requirements of a developed world. *Energy Sustain. Dev.* **33**, 1–13 (2016).
27. D. M. Martínez, B. W. Ebenhack, Understanding the role of energy consumption in human development through the use of saturation phenomena. *Energy Policy* **36**, 1430–1435 (2008).
28. C. Pasten, J. C. Santamarina, Energy and quality of life. *Energy Policy* **49**, 468–476 (2012).
29. V. Smil, *Energy in Nature and Society: General Energetics of complex systems* (The MIT Press, 2008).
30. V. Smil, *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production* (MIT Press, 2001).
31. V. Smil, *Creating the Twentieth Century: Technical Innovations of 1867–1914 and their lasting impacts* (Oxford University Press, 2005).
32. V. Smil, *Energy at the crossroads: Global Perspectives and Uncertainties* (MIT Press, 2003).
33. G. B. West, J. H. Brown, The origin of allometric scaling laws in biology from genomes to ecosystems: Towards a quantitative unifying theory of biological structure and organization. *J. Exp. Biol.* **208**, 1575–1592 (2005).
34. A. D. Barnosky, *et al.*, Approaching a state shift in Earth’s biosphere. *Nature*, 52–58 (2012).
35. W. Steffen, W. Broadgate, L. Deutsch, O. Gaffney, C. Ludwig, The trajectory of the Anthropocene: The Great Acceleration. *Anthr. Rev.* **2**, 81–98 (2015).
36. United Nations, “World Population Prospects 2019: Highlights” (2019).
37. J. Goldemberg, T. Johansson, A. Reddy, R. Williams, Basic needs and much more with one kilowatt per capita. *Ambio* **14**, 190–200 (1985).
38. T. F. Schulz, S. Kypreos, L. Barreto, A. Wokaun, Intermediate steps towards the 2000 W society in Switzerland: An energy – economic scenario analysis. *Energy Policy* **36**, 1303–1305 (2008).
39. A. Grubler, *et al.*, A low energy demand scenario for meeting the 1.5 °c target and sustainable development goals without negative emission technologies. *Nat. Energy* **3**, 515–527 (2018).
40. M. Pullinger, Working time reduction policy in a sustainable economy: Criteria and options for its

41. L. I. Brand-Correa, J. K. Steinberger, A Framework for Decoupling Human Need Satisfaction From Energy Use. *Ecol. Econ.* **141**, 43–52 (2017).

42. T. Kuhn, *The Structure of Scientific Revolutions* (University of Chicago Press, 1962).

43. J. Vanhulst, A. E. Beling, Buen vivir: Emergent discourse within or beyond sustainable development? *Ecol. Econ.* (2014) https:/doi.org/10.1016/j.ecolecon.2014.02.017.

44. H. Daly, In Defense of a Steady-State Economy. *Am. J. Agric. Econ.* **54**, 945–954 (1972).

45. M. Schmelzer, The growth paradigm: History, hegemony, and the contested making of economic growthmanship. *Ecol. Econ.* **118**, 262–271 (2015).

46. T. Fishman, H. Schandl, H. Tanikawa, P. Walker, F. Krausmann, Accounting for the Material Stock of Nations. *J. Ind. Ecol.* **18**, 407–420 (2014).

47. V. Smil, Energy Transitions: Global and National Perspectives. *Publ. online OurWorldInData.org. Retrieved from 'https*//ourworldindata.org/energy-production-and-changing-energy-sources'*[Online Resour. accessed Novemb. 14th, 2019]* (2017).

48. BP, BP Statistical Review of World Energy. *Publ. online OurWorldInData.org. Retrieved from 'https*//ourworldindata.org/energy-production-and-changing-energy-sources *[Online Resour. accessed Novemb. 14th, 2019]* (2019).

49. U.S. Energy Information Administration, International Energy Statistics. *Publ. online TheShiftProject.org. Retrieved from 'http*//www.tsp-data-portal.org/Energy-Consumption-Statistics#tspQvChart*'[Online Resour. accessed Novemb. 14th, 2019]* (2019).

50. F. L. Ramsey, D. W. Schafer, *The Statistical Sleuth: A Course in Methods of Data Analysis*, 3rd editio (Cengage Learning, 2013).

51. Gapminder, Total Population. *Publ. online gapminder.org. Retrieved from 'https*//www.gapminder.org/data/documentation/gd003/ *[Online Resour. accessed Novemb. 14th, 2019]* (2008).

52. Gapminder, Life Expectancy at birth. *Publ. online gapminder.org. Retrieved from 'https*//www.gapminder.org/data/documentation/gd004/ *[Online Resour. accessed Novemb. 14th, 2019]* (2014).

53. Gapminder, Mean years in school (women of reproductive age 15 to 44). *Publ. online gapminder.org. Retrieved from* 'https//www.gapminder.org/data/ *[Online Resour. accessed Novemb. 14th, 2019]* (2010).

54. Gapminder, Murders (per 100 000 people). *Publ. online gapminder.org. Retrieved from* 'https//www.gapminder.org/data/ *[Online Resour. accessed Novemb. 14th, 2019]* (2017).

55. Gapminder, Children per woman. *Publ. online gapminder.org. Retrieved from 'https*//www.gapminder.org/data/documentation/gd008/ *[Online Resour. accessed Novemb. 14th, 2019]* (2010).

56. Gapminder, GDP per capita, constant PPP dollars. *Publ. online gapminder.org. Retrieved from 'https*//www.gapminder.org/data/documentation/gd001/ *[Online Resour. accessed Novemb. 14th,*

2019] (2011).

57. UNDP, Human Development Index. *Publ. online OurWorldInData.org. Retrieved from 'https*//ourworldindata.org/human-development-index' *[Online Resour. accessed Novemb. 14th, 2019]* (2018).
58. The World Bank, Particulate matter air pollution. *Publ. online OurWorldInData.org. Retrieved from 'https*//ourworldindata.org/air-pollution' *[Online Resour. accessed Novemb. 14th, 2019]* (2016).
59. Gallup World Poll surveys, World Happiness Report 2019. *Publ. online OurWorldInData.org. Retrieved from 'https*//ourworldindata.org/happiness-and-life-satisfaction' *[Online Resour. accessed Novemb. 14th, 2019]* (2019).

Supplementary Information

Supplementary Information was not provided with this version of the manuscript.

Figures

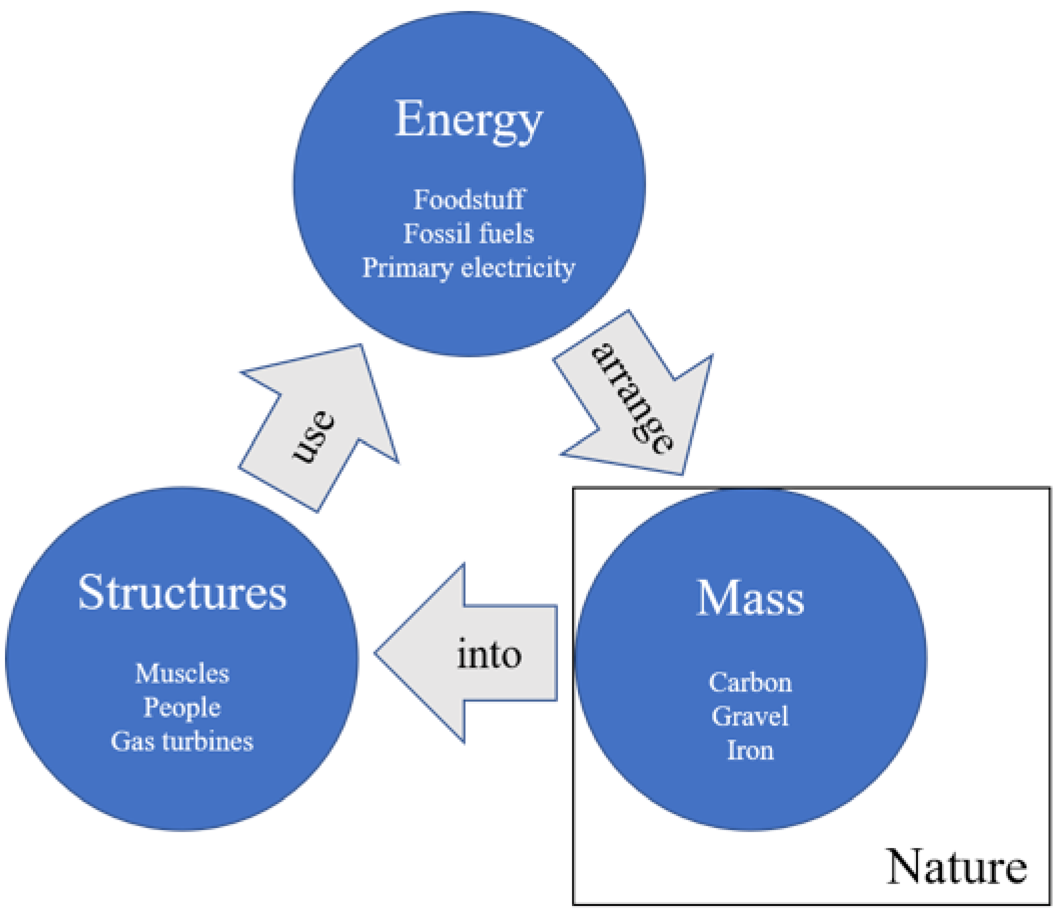

Figure 1

The relation between structures, energy, and mass

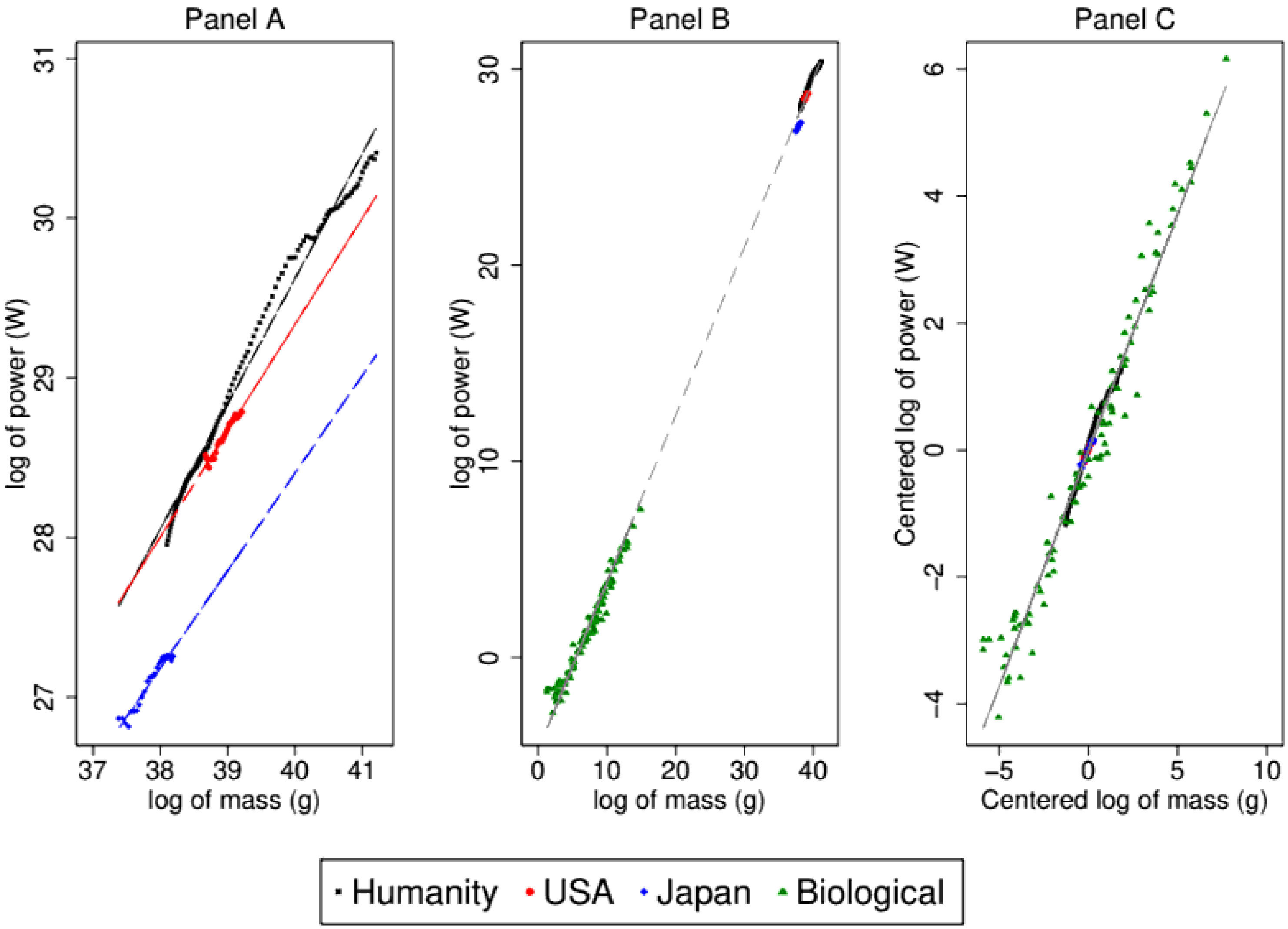

Figure 2

The relation between material stocks and energy. Panel A shows the scatter plot for Japan in blue, the USA in red, and globally in black. Lines are the individual Ordinary Least Squares (OLS) best fit curve. Panel B depicts the information from Panel A in the top right with a sample of biological ones in the bottom left. The line is the OLS best fit curve for all data. Panel C shows the same scatter plot but demeaning the series independently. The line is the OLS best fit curve for all the demeaned data. Data available in S.I.

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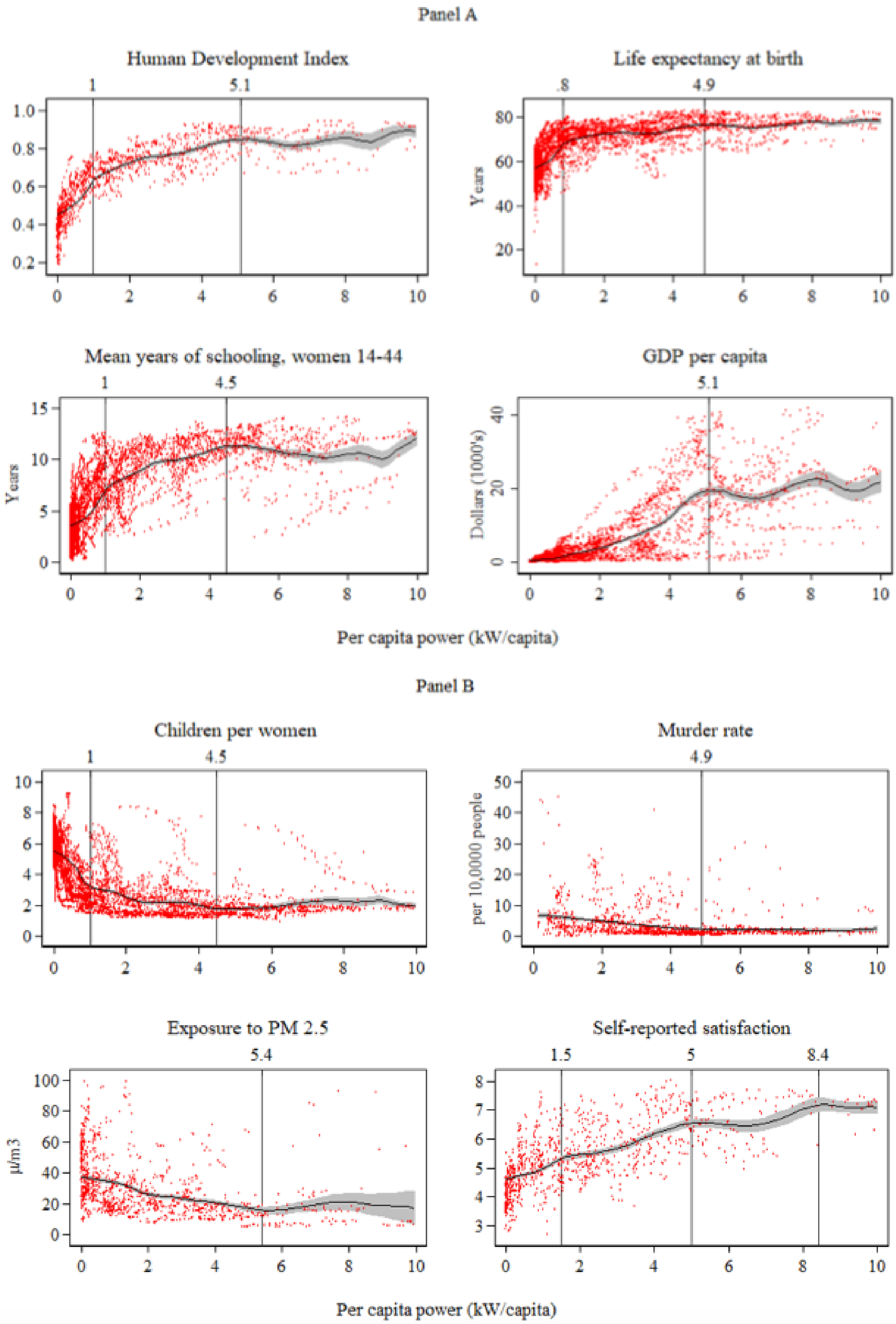

Figure 3

Decreasing social returns to per capita power (n varies from 1,061 for self-reported satisfaction to 10,349 for life expectancy). Red dots are data points, black lines are a kernel-weighted local polynomial regression, and shaded areas are the best-fit-line's 95% confidence interval. Panel A contains the Human Development Index and its components. Panel B contains additional socially relevant variables. Data

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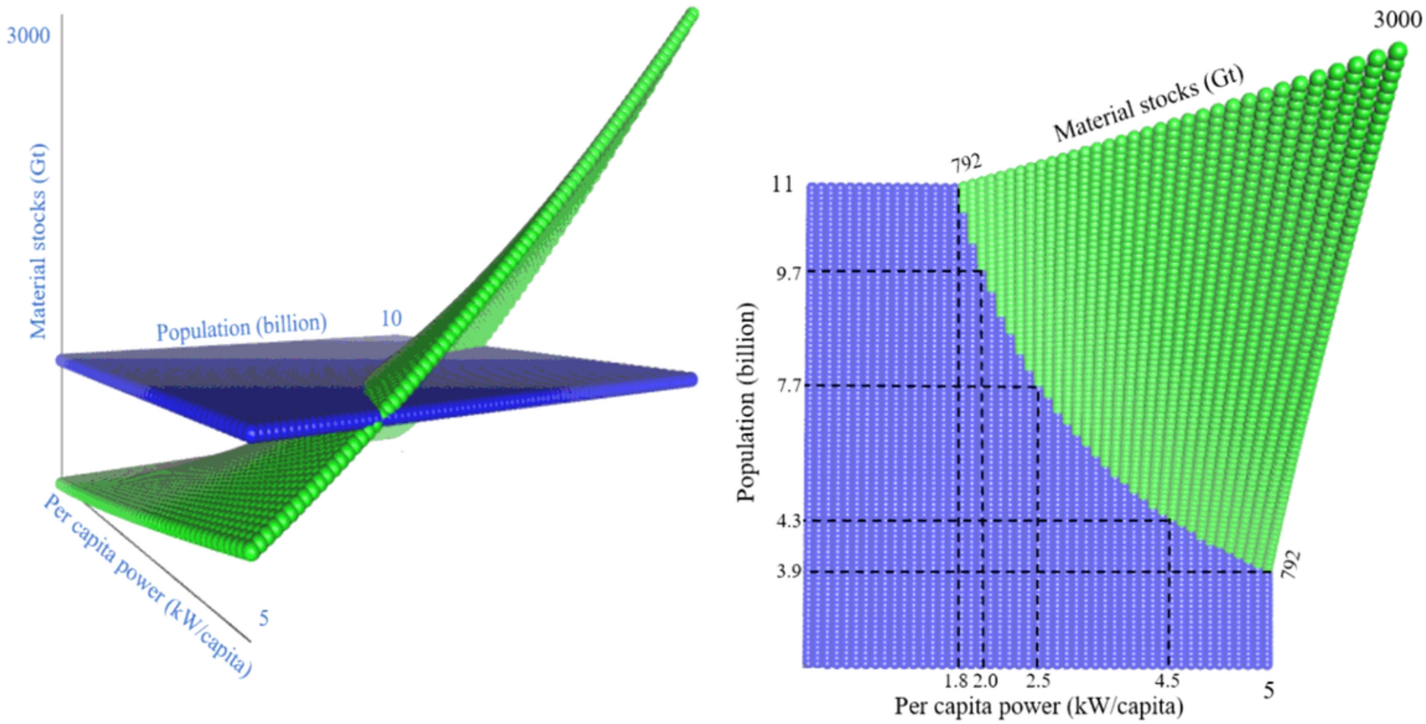
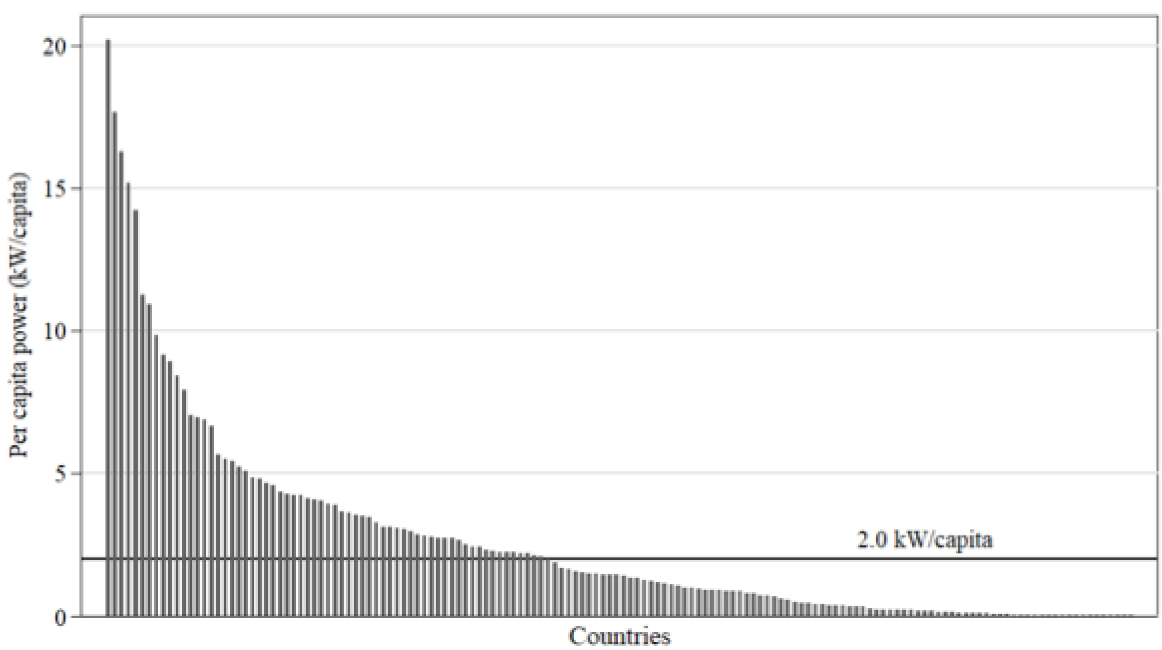


Figure 4

The relation between per capita power, population, and material stocks. The green plane shows per capita power, population, and their associated material stocks given 0.78 scaling. The blue plane represents 2010 material stocks. Panel A shows the three-dimensional figure. Panel B shows the same figure in two dimensions as seen from above, which reveals the 2010 iso-material stocks curve at 792 Gt.



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Per capita power for 150 countries in 2014, of which 53% have more than 2.0 kW/capita