Type of the Paper (Article)

The three horses of sustainability – population, affluence and technology

David O. Obura

CORDIO East Africa, Mombasa, Kenya. Email: dobura@cordioea.net.
* Correspondence: CORDIO East Africa, P.O.BOX 10135 Mombasa 80101, Kenya; Tel: +254-715-067417, dobura@cordioea.net

Abstract: The IPAT equation provides a simple but powerful model for understanding sustainability, particularly from the challenge posed by the Anthropocene – how to reduce personal or societal impact. Impact is calculated by multiplying population, affluence and technology, and a 'reduction coefficient' e is used to explore targeted reductions in impact of different entities to cap total (summed) impact. The model offers two solutions. First, that all three factors are essential in determining total impact; a focus on just one or two is not justifiable without credibly addressing the other(s). Second, by presenting reduction of impact as a proportion of current activity, the solution becomes accessible to an individual actor (e.g. an individual, family, organization, or country). Application of the model is illustrated based on household weekly food consumption from cultures around the world. The model helps unify a) disparate perspectives on population, affluence and technology, which currently oppose one another from a basis of belief or dogma, and b) different sectors (e.g. food production, energy, climate impacts and others), as well as actors, so they can jointly identify strategies to resolve their contributions to approaching larger scale sustainability.

Keywords: affluence, business as usual, climate change, planetary boundaries, population, societal impact, sustainability.

---

1. Introduction

The Anthropocene is an era in which human population has grown to have an impact on multiple bio-physical systems on a planetary scale, among which anthropogenically-driven climate change is a dramatic symptom [1-3]. The middle of the 20th century marked a turning point when human population size, per capita affluence and per capita footprint (technology) all entered a phase of rapid and mutually reinforcing growth. The compounding interactions of these factors [4] has led to societal impact that has exceeded the provisioning capacity of planet Earth [2,5]. Across many domains, including scientific, government, business and civil society, realization of the need for profound change in economic and social practices has grown rapidly (Supplementary Material, Text S4).

However, our ability to know what to do to change course – i.e. what actions, and therefore cost, each person, household, business or country has to shoulder to do this – has not caught up with this awareness. This is partly because we have been unable to project exactly what potential futures will be, though global assessments are becoming increasingly precise [6]. A traditional economic focus on costs of change (how much will it cost?) has dominated professional and public discourse, though there is growing realization of the need to think in terms of investment in change (how much will we benefit?) and linked social-ecological systems (how do we avoid tipping points?). We are far from understanding how individual people or social entities gain motivation to change their behaviors on the scale of collective action that is needed [7,8].

The IPAT model initially developed with a balance between ecological and economic perspectives [9-11]. Economic applications of the model have been numerous, with debates around quantities and units, variability and elasticity in its factors, and statistical and empirical improvements [12-17]. Other discussions explored the limitations of the model, particularly around how to incorporate human behaviour and choice theoretically [18-20] and empirically at household levels [21]. It has been applied with a climate perspective [13], in relation to carbon emissions in the IPCC framework [22,23], and at national environmental impact levels particularly in Asia [22,24]. These have led to greater complexity of the model and as a result, lower generality and accessibility to non-specialists. Ecological applications of the IPAT model focused on carrying capacity, or the limits to how many individuals or how much biomass an ecosystem can support [25,26]. This has been explored through many different levels of biological organization from species interactions to ecosystem dynamics [27] and in limits to growth models, most notably the global footprint [5] and planetary boundary [3,28] models. However, though the formulations of the footprint and planetary boundary models are crafted to aid interpretation and buy-in among non-specialists, there has remained a gap between messages clearly expressing global consequences and individuals making personal choices on the basis of these findings [8]. At the same time, with growing assertion of localized and indigenous or traditional perspectives, the generalizations inherent in models has led to a backlash against models such as IPAT for not accounting for the cultural and locational differences that differentiate population, affluence and technology, and their inter-relations, in different societies [29].

2. Methods

The IPAT model is used here to bring the scale of the sustainability problem, and accessibility of solutions, to the sphere of action of an individual entity – be this an individual, a household, a company or a country. Most simply, IPAT treats impact (I) as a function of population (P), affluence (A), and technology (T):

$$I = f(P, A, T) \qquad \text{Equation (1)}$$

This article focuses on a coefficient e that varies between zero and 1 and simple multiplication of P, A and T (fig. S1):

$$I = (1-e) \times (P \times A \times T) \qquad \text{Equation (2)}$$

The identity between the left and right hand sides of the equation mean that within a particular application of the model, the units used to measure population, affluence and technology are not critical. The focus is on the proportionate reduction expressed by e and the specific question "how can entity X reduce their impact?". Further details on the assumptions made in the model are included in the Supplementary Material (Text S1).

Application of the model is illustrated by analyzing images of weekly food intake for households around the world [30]. Population, affluence and technology were parametrized from the images as follows: population by the number of people, and affluence by the per capita cost of weekly food intake. Technology was parametrized using an additive index that combined food type (four types), packaging (3 types) and energy source (3 types), ranked by their footprint or material use and waste (see Supplementary Material, Text S3). The product of P, A and T was standardized from 0 to 100 (highest impact household) to ease comparisons, and summary statistics calculated by HDI country category [31]. Projected impact levels in 2030 and 2100 were calculated using the values of e selected to achieve the sustainability scenario, and differential economic growth by HDI country category was estimated to allow for improvements in income in countries with lower HDI.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 December 2018 doi:10.20944/preprints201812.0176.v1

3. Results

The IPAT model is illustrated here at the country level. In a business as usual scenario (e = 0), total impact of the global population will continue to rise throughout the 21st century, reaching 3 times current levels with no discernible flattening (fig. 1a). That is, humanity's ecological footprint will grow from 1.5 planet Earths today [5] to 4.5 by 2100. Population in Very High and High Human Development Index (HDI) countries peaks mid-century and is declining by 2100, in Medium HDI countries population has stabilized, but in Low HDI countries, population is still growing in 2100 (fig. S1a). Thus, even as Very High HDI countries reduce their total impact, which in this example is exclusively due to declining population, the increased population, affluence and technology use in High, Medium and Low HDI countries lead to a continuing increase in total impact. Also, by 2100 the primary source of impact will have shifted from the Very High HDI countries, to today's Medium and Low HDI countries.

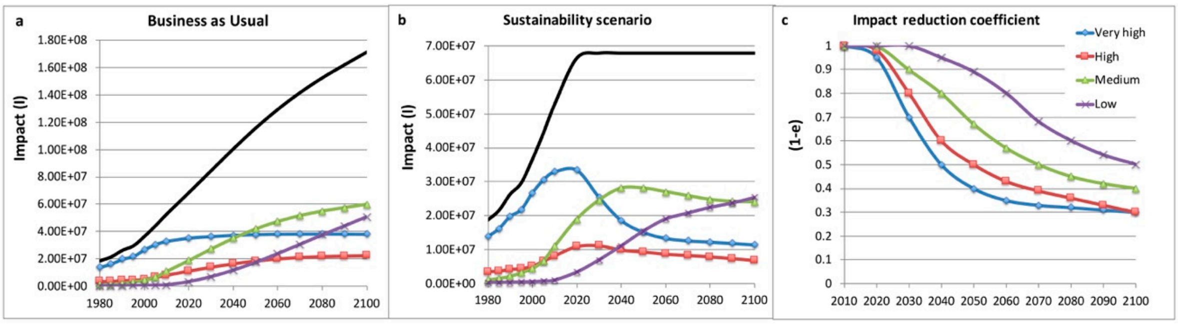

Figure 1. Business as usual and sustainability scenarios illustrated by the IPAT equation. The IPAT function illustrated by multiplying population, affluence and technology and used to illustrate two scenarios: a) business as usual versus b) a sustainability scenario where total impact is capped at 2020 levels. Curves are shown for four HDI country groups: Low, Medium, High and Very High; and their sum (heavy black line). c) values of coefficient 'e', plotted as (1 - e) to illustrate the proportionate effort require to cap total impact among HDI country groups.

To achieve sustainability, the reduction coefficient e can be varied between 0 and 1. A scenario is presented where total impact is arbitrarily capped at 2020 levels (fig. 1b, and Supplementary Material S1). This article assumes that population in each country grows consistently with current UN projections, and affluence and technology use are allowed to grow to approach current levels in Very High HDI countries. To accommodate equity among countries, values of e are different for each HDI country category, though e increases in all categories over time, approaching a similar value (fig. 1c). For Very High HDI countries e is set at 30 per cent in 2030 and increases to 70 per cent by 2100. The corresponding levels for High, Medium and Low HDI countries in 2030 and 2100 are 20/70, 10/60 and 0/50 per cent, respectively. Different combinations of curves across HDI categories are possible that achieve the same overall result of capped total impact.

4. Discussion

Reducing impact can be achieved through changes in any of the three factors, or a combination of them. For example, an overall reduction of 50% (e = 0.5) could be achieved by a 50% reduction in any one factor, or by approximately 30% reduction in two (0.702 = 0.49), or 20% reduction in all three (0.803 = 0.51). This formulation of IPAT helps open up the debate about which factor is most important – all have a role in 'pulling the chariot of sustainability'. Not accounting for the level (or increases) in any one factor consumes benefits obtained from reducing others. Some challenges and

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 December 2018 doi:10.20944/preprints201812.0176.v1

advantages of reduction in each of the three factors are explored by HDI country category (Table 1) and in more general terms in the Supplementary Material (Text S2). Thus, *e* represents multiple combinations of policy options that may be applied across population, affluence and technology, with the example presented here being only one of many ways to achieve the same result.

Table 1. Pathways to sustainability among Human Development Index (HDI) country groups.

HDI group	**Challenges**	**Advantages**
Very High and High	People, businesses and countries accepting limits to growth, both in affluence and technology, and recognizing the need to internalize externalities (i.e. eliminate waste). The reductions of 30/60 and 20/60 per cent of 2020 output by 2030 and 2100 are precisely opposite to the dominant market pressures for continuous growth evidenced by stock exchanges and financial institutions, and the recurrent economic bubbles that create the global financial economic crises of the last decades.	High wealth and standard of living can be invested in innovation and transformation to sustainable pathways. Greater leisure time and wealth enable more personal choices to be made on how to achieve sustainability. Technical innovations (e.g. large solar batteries, declining cost of wind and solar energy below that of fossil fuels) already in reach before 2020.
Medium	The largest problem this century due to compounding of their large and growing populations with high-growth phases of HDI and GNI (fig. S1). Emerging economies – China and India primarily, but many others too – may not be ready to adopt more sustainable aspirations in the next 1-2 decades and set in place the low-in-the-near-future but high-in-the-medium-future efficiencies that are needed (i.e. 5 and 60 per cent).	Driven by science, technology and entrepreneurial innovation, are making strides at local, sub-national and national levels in the face of very local social, environmental and economic manifestations of the global problem. Tangible benefits accruing in real time from greater efficiency in energy and materials use and reduced waste. Leapfrogging of technologies provides scope for the large reductions needed, but good governance and investment policies are needed to liberate innovations.
Low	The key countries are in Africa, which is projected to account for more than half of the global population growth expected by 2100 [32] and is the last major world region set to enter its period of fastest economic growth (i.e. increasing affluence and technology) from a low baseline [33].	The smallest part of the problem through to 2050-2080 due to low GNI and lower populations than Medium HDI countries, providing ample time for change. Leapfrogging technologies with greatest potential impact, particularly

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 December 2018 doi:10.20944/preprints201812.0176.v1

	Least capacity among all groups to invest in change, such as in education and governance systems, necessary to change behaviours. High dependence on ecosystem services, which are already severely stressed - immediate challenges in food, water and other essential service security undermine a focus on the need for long term change.	in energy and material uses, recycling and information technologies.

The illustrated scenario shows a degree of differentiation in action among countries in 2030 (30, 20, 10 and 0 per cent for Very High, High, Medium and Low HDI countries, respectively), that reduces as they converge towards welfare parity in 2100 (70, 70, 60 and 50 per cent) (fig. 2b). This implements the principle of 'common but differentiated responsibilities' among countries [34,35]. This is an essential foundation for addressing unequal wealth among countries [36] as well as among groups of people with different levels of wealth. Differentiated responsibilities in reducing total impact are essential for countries at all levels of development to agree on what actions are expected from each now. Equally important, projecting the reduction in differentiation that comes with greater wealth in lower-income countries, and equity among countries over time (fig. 1c), helps to maintain transparency and trust among all countries as capabilities change.

4.1 A picture, or model, worth a thousand words

The application of IPAT used here frames it as a causal relationship [37], but instead of focusing on the technical challenge of deriving a more complete model, as others have done (see Introduction), this article takes on the challenge of a simpler heuristic approach, for people to answer the personal question: "given what we do now (however measured or estimated), how to reduce our footprint by a certain proportion?" The iconic images of weekly food intake for households around the world [30] provide a vivid illustration of the model. These show population (family size), affluence (amount and diversity of food) and technology (processing of food, packaging, appliances, etc.) across a spectrum of affluence and cultures in a way that can be quantified (see Supplementary Material, Text S3). Summarized by HDI country group gives values of 0.5, 8.6, 15.1 and 55.8, for Low, Medium, High and Very High HDI countries respectively (fig. 2a). Compared to Low HDI countries, impact levels for Medium, High and Very High HDI countries are higher by factors of 25.8 , 41.6 and 170.3 times, respectively. This disparity of 2 orders of magnitude captures the dramatic difference in material wealth visible in the images - the constructed home, food quantity, variety and packaging, and energy-dependent appliances in the wealthier households. A simple projection of impact levels to 2030 and 2100, applying the assumptions of the model, show that disparity among households can decrease significantly (fig. 2b), even as the material wealth of Low and Medium HDI households is allowed to increase and approach parity with High and Very High HDI households (fig. 2c).

Two interesting corollaries are suggested: first, that at the lowest levels of affluence and technology the influence of population shrinks to near-insignificance compared to the impact of technology/material wealth and affluence. This supports arguments that even at current high populations in least developed countries, total impact on global systems is disproportionately from higher material wealth countries [38]. But second, as affluence increases (as it should in Low and Medium HDI countries), the importance of population gains in significance, and in the long term, avoiding over-population by reducing family sizes is wise (e.g. in relation to climate change [39]), to reduce ‘overshoot’ as countries transition from low to middle and high-income standards of living [40] (Supplementary Material, Text S1).

 doi:10.20944/preprints201812.0176.v1

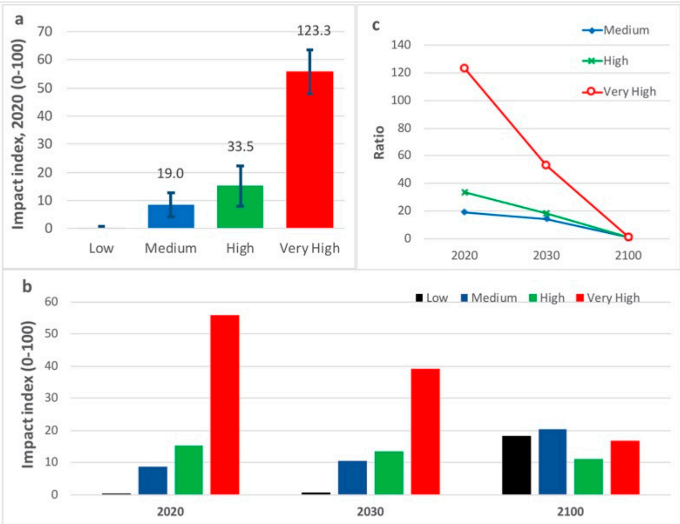

Figure 2. Application if the IPAT model to images of weekly household food in cultures around the world [30]. a) Impact on a scale from 0 to 100 (highest scoring household) grouped by Human Development Impact (HDI) categories (mean and standard error). b) Applying the assumptions of the IPAT model developed here and projecting forward to 2030 and 2100 enables calculation of Impact at household levels across the HDI country groups. c) the ratio of mean Impact values (in b) for Medium, High and Very High compared to Low HDI countries in 2020, 2030 and 2100 (see Supplementary Material, Text S3).

This formulation of the IPAT equation provides a simple calculator for guiding individual choice – with a given parametrization and measurement of population, affluence or technology how does a person, family, business or country achieve a specific reduction in impact? Even if only one of the factors can be quantified, it gives a strong formulation of the benefit derived from reducing that factor, and a warning to ensure that other, perhaps unquantified, factors are not allowed to increase. Even more, if none of the factors can be accurately quantified, reducing current activities (e.g. energy use, waste) can be done through considering proxies and focusing on these to reduce impact. Even down to the level of a single individual and trivial population size of one, the model helps to identify how affluence or material use can be altered to reduce impact.

Many public and political discourses on population, economic growth and sustainability start from a priori statements of which one is most important for a particular interest group, culture or country, and which are deemed 'not relevant' or off-limits. Sensitivities around birth control, family size and cross-cultural mores enabled the 'missing population agenda' [41] during the critical decades of the Great Acceleration [4]. The IPAT model puts them explicitly on equal ground: for example, if a cultural position is "we value economic growth", the compensatory actions in the other factors (population and energy/material use) that are necessary to balance the equation must be made explicit.

Thus IPAT transforms the problem of reducing impact to a practical personal problem, and provides a direct mechanism for any entity to understand their contribution to sustainability. While this simplification may frustrate experts, it may provide the 'behavioural wedge' [18,21] and a sketch map [42] or calculator that helps plan individual choices and behaviour changes [18,39], and inform discourse in political and major media platforms. Even in December 2018 mainstream media fail to question the mantra of economic growth [43], and far from getting its message across into mainstream discourse, IPAT still has a role to play, simplified to its essentials, in communicating limits to growth [14,17,19]. This level of simplification and personalization may be necessary to motivate the collective action [8] by the diversity of actors, acceleration and scale that is required [44]. While there are many pitfalls in applying a simple relation such as this, this is the purpose of a model – to be, as is commonly attributed to Albert Einstein 'as simple as possible, but not too simple' (and see Supplementary Material, Table S1).

4.2 Transforming value

Can the reductions in population, affluence and/or technology required for sustainability be realistically achieved? Achieving sustainability does mean fewer televisions, cars and consumer goods per family (at least in Very High and High HDI countries [21,39]) unless, as the IPAT equation allows, new technologies with fractions of today's energy and material cost are developed. Surely the 10-30 per cent efficiencies in Medium to Very High HDI countries by 2030 are conceivable within the next decade of technological progress, and the reductions of 50-70 per cent by 2100 in all countries are also well within the innovative capacity of human society, science and technology over these time periods? In individual sectors, many argue this is possible, such as in food systems [40] and energy generation [45], and in limiting climate change to minimum levels [6].

Crucially, this does not necessarily mean a worse quality of life than today. Given the higher environmental and social quality in the sustainability scenario, and that delivery of the outcome may only be possible with a preceding shift in values away from monetary and material growth, individuals, companies and countries may well feel better off (perceive greater value and wealth) than they do now (see Table S1). This transforms all costs of achieving this end state from what are now regarded as costs deducted from the profit line into investments in varied forms of capital, and quality of life. People will not be giving up wealth, they will be building greater wealth, measured differently.

The value transformation that this will require is of course profound. The current value system has not only failed to facilitate earlier adoption of a sustainable and globally efficient path, it has delivered the Great Acceleration and the Anthropocene as direct consequences of its values. The Sustainable Development Goals can be considered a 'strong sustainability' concept [47], within which positive and negative interactions among goals [47,48] can focus policy and decision-making on key opportunities and challenges for reducing impact at scale. This is where IPAT can help people, organizations and even countries to formulate their individual strategies for sustainability within their particular environmental, economic and social context. In the household food example: where affluence should rightfully increase, where material/energy footprint should decrease, and where reducing population growth will have a major influence. How these manifest will be very context-dependent, facilitating contributions 'for all' [49] and 'by all' [8]. IPAT can provide a simple calculator for entities - whether a country, an organization, a family or an individual - to calculate on their own terms what reductions need to be made to make their contribution to sustainability not only within their own frame of reference, but as part of a diverse collective whole.

Supplementary Materials: The following are available online, Text S1 to S4, Figures S1 and S2, Tables S1 and S2.

Author Contributions: DOO conceived of and wrote the entire article.

Funding: This research received no external funding.

Acknowledgments: I would like to thank Peter Sale, Ida Grum, Anna Obura and several reviewers for improvements on earlier drafts, and Aliya Shah for assistance with figure 2.

Conflicts of Interest: The author declares no conflict of interest.

5. References

1. Crutzen P.J. Geology of mankind, Nature 2002 415, 23
2. Steffen W, Crutzen PJ and McNeill JR . The Anthropocene: Are humans now overwhelming the great forces of Nature? Ambio 2007 36: 614–621.
3. Rockström J., Steffen W.L., Noone K., Persson A., Chapin F.S. III, Lambin E., Lenton T.M., Scheffer M., Folke C., & Schellnhuber H.J. Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society, 2009 14, 1–32.
4. Steffen W., Broadgate W., Deutsch L., Gaffney O., & Ludwig C. The trajectory of the Anthropocene: The Great Acceleration. The Anthropocene Review 2015 2, 81–98.
5. WWF . Living Planet report. WWF, Gland, Switzerland. 2016. ISBN 978-2-940529-41-4.
6. IPCC . Global Warming of 1.5 °C - an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. 2018; http://www.ipcc.ch/report/sr15/ [Accessed 9 October 2018].
7. Adger, N.W. Social capital, collective action, and adaptation to climate change. Economic geography, 2003 79 (4), 387–404.
8. Amel E., Manning C., Scott B., & Koger S. Beyond the roots of human inaction: Fostering collective effort toward ecosystem conservation. Science, 2017 356, 275–279.
9. Ehrlich P.R. & Holdren J.P. Impact of Population Growth. Science, 1971 171, 1212–1217.
10. Ehrlich P.R. & Holdren J.P. A bulletin dialogue on the 'Closing Circle'. Critique: One dimensional ecology, Bulletin of the Atomic Scientists 1972 28(5), 16–27
11. Commoner B. Resources and the Environment. Washington, DC: Government Printing Office, 1972 339-363
12. Dietz T. & Rosa E.A. Rethinking the environmental impacts of population, affluence and technology. Human Ecology Review, 1994 1, 277–300.
13. Dietz T. & Rosa E.A. Effects of population and affluence on CO2 emissions. Proceedings of the National Academy of Sciences, 1997 94, 175–179.
14. Waggoner P.E. & Ausubel J.H. A framework for sustainability science: a renovated IPAT identity. Proceedings of the National Academy of Sciences of the United States of America, 2002 99, 7860–7865.
15. York R., Rosa E.A., & Dietz T. STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecological Economics, 2003 46, 351–365.
16. Wei T. What STIRPAT tells about effects of population and affluence on the environment? Ecological Economics, 2013 72, 70–74.
17. Chertow M.R. The IPAT equation and its variants. Journal of industrial ecology 2000 4: 13-29
18. Schulze P.C. I= PBAT. Ecological Economics, 2002 40, 149–150.
19. Roca J. The IPAT formula and its limitations. Ecological Economics, 2002 42, 1–2.
20. Diesendorf M. I= PAT or I= PBAT? Ecological Economics, 2002 42, 3
21. Dietz T., Gardner G.T., Gilligan J., Stern P.C., & Vandenbergh M.P. Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. Proceedings of the National Academy of Sciences 2009 106, 18452–18456.
22. Chen L., Yang Z., & Chen B. Scenario Analysis and Path Selection of Low-Carbon Transformation in China Based on a Modified IPAT Model. PLoS ONE, 2013, 8, e77699.
23. Fan Y., Liu L.-C., Wu G., & Wei Y.-M. Analyzing impact factors of CO2 emissions using the STIRPAT model. Environmental Impact Assessment Review 2006 26 , 377–395.
24. Lin S., Zhao D., & Marinova D. Environmental Impact Assessment Review. Environmental Impact Assessment Review, 2009 29, 341–347.
25. Fretwell, S. Food Chain Dynamics: The Central Theory of Ecology? Oikos, 1987 50(3), 291-301. doi:10.2307/3565489
26. Pianka, E.R. "r and K Selection or b and d Selection?," The American Naturalist 1972 106, 581-588.
27. Chapman E.J. & Byron C.J. Global Ecology and Conservation. Global Ecology and Conservation, 2018, e00365.
28. Scheffer M., Barrett S., Carpenter S.R., Folke C., Green A.J., Holmgren M., Hughes T.P., Kosten S., van de Leemput I.A., Nepstad D.C., van Nes E.H., Peeters E.T.H.M., & Walker B. Creating a safe operating space for iconic ecosystems. Science, 2015 347, 1317–1319.

29. Roy S. A Critique on Current Paradigms of Economic 'Growth' and 'Development' in the Context of Environment and Sustainability Issues. Consilience: The Journal of Sustainable Development, 2016 16, 74-90
30. Menzel P. Hungy Planet family food portraits. 2013. Available at: https://menzelphoto.photoshelter.com/gallery/Hungry-Planet-Family-Food-Portraits/G0000zmgWvU6SiKM/C0000k7JgEHhEq0w [Accessed 1 May 2018]
31. UNDP Human Development Index (HDI), United Nations Development Programme (UNDP) - (2015) http://hdr.undp.org/en/content/human-development-index-hdi; Accessed 1 August 2015.
32. Gerland P., Raftery A.E., ev ikova H., Li N., Gu D., Spoorenberg T., Alkema L., Fosdick B.K., Chunn J., Lalic N., Bay G., Buettner T., Heilig G.K., & Wilmoth J. World population stabilization unlikely this century. Science (2014), 346, 234–237.
33. AEO
34. United Nations Framework Convention on Climate Change (UNFCCC) . The Paris Agreement, United Nations Framework Convention on Climate Change. http://unfccc.int/paris_agreement/items/9485.php. 2015 [Accessed 1 March 2017]
35. Pauw P., Bauer S., Richerzhagen C., Brandi C., & Schmole H. Different Perspectives on Differentiated Responsibilities 2014, 1–76.
36. Srinivasan U.T., Carey S.P., Hallstein E., Higgins P.A.T., Kerr A.C., Koteen L.E., Smith A.B., Watson R., Harte J., & Norgaard R.B. The debt of nations and the distribution of ecological impacts from human activities. Proceedings of the National Academy of Sciences, 2008 105: 1768–1773.
37. McNicoll G. IPAT (Impact, Population, Affluence, and Technology). International Encyclopedia of Social & Behavioral Sciences, 2001 12: 716–718.
38. Bradshaw CJA, Giam X, Sodhi NS Evaluating the Relative Environmental Impact of Countries. PLoS ONE 2010 5(5): e10440. https://doi.org/10.1371/journal.pone.0010440
39. Wynes S. & Nicholas K.A. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environmental Research Letters 2017 12: 074024. doi.org/10.1088/1748-9326/aa7541.
40. Springmann M., Clark M., Mason-D'Croz D., Wiebe K., Bodirsky B.L., Lassaletta L., de Vries W., Vermeulen S.J., Herrero M., Carlson K.M., Jonell M., Troell M., DeClerck F., Gordon L.J., Zurayk R., Scarborough P., Rayner M., Loken B., Fanzo J., Godfray H.C.J., Tilman D., Rockström J., & Willett W. Options for keeping the food system within environmental limits. Nature, 2018 https://doi.org/10.1038/s41586-018-0594-0
41. Meffe G.K., Ehrlich A.H., & Ehrenfeld D. Human population control: the missing agenda. Conservation Biology 1993 7, 1-3
42. Raworth K. A Doughnut for the Anthropocene: humanity's compass in the 21st century. Lancet Planetary Health 2017 1 e48-e49.
43. Hernández, J.C. Bui Q The American Dream Is Alive. In China. New York Times, November 18, 2018. Special section: China Rules. How China became a superpower. https://www.nytimes.com/interactive/2018/11/18/world/asia/china-social-mobility.html
44. Obama B. The irreversible momentum of clean energy. Science, 2017 355, 126–129.
45. Chan G, Goldstein A.P., Bin-Nun A., Anadon L.D. & Narayanamurti V. Six principles for energy innovation. Nature 2017 552, 25-27. doi: 10.1038/d41586-017-07761-0
46. ICSU . A guide to SDG interactions: from science to implementation. International Council for Science. 2017 https://www.icsu.org/publications/a-guide-to-sdg-interactions-from-science-to-implementation [Accessed 10 November 2017]
47. Neumann B., Ott K., & Kenchington R. Strong sustainability in coastal areas: a conceptual interpretation of SDG 14, 2017 [access: http://rdcu.be/vEU6]. Sustainability Science, 1–18.
48. Le Blanc D, Freire C and Vierros M . Mapping the linkages between oceans and other Sustainable Development Goals: A preliminary exploration. United Nations Department of Economic & Social Affairs. DESA Working Paper No. 149, 2017 ST/ESA/2017/DWP/149. February 2017
49. Bojer M . What if we really meant it? Transformative approaches for the Sustainable Development Goals. December 8, 2017. Available at: https://reospartners.com/really-meant-transformative-approaches-sustainable-development-goals/ [Accessed 1 July 2018]
50. Giambona F., Jacono V.L., & Scuderi R. The IPAT Model: an Empirical Evidence. (undated) sis-statistica.org

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 December 2018 doi:10.20944/preprints201812.0176.v1

51. Thompson W. The demographic transition model Encyclopedia of Population 2. Macmillan Reference, 939–940. (2003)
52. United Nations Framework Convention on Climate Change (UNFCCC) (1972). Convention Text.
53. Gleeson-White J. Six Capitals, Or Can Accountants Save the Planet? Rethinking Capitalism for the Twenty-First Century. WW Norton & Company Inc., (2014)
54. International Integrated Reporting (IRI) Framework (2016). http://integratedreporting.org/resource/international-ir-framework/, Accessed 7 February 2016
55. IPCC Fourth Assessment Report. Climate Change 2007: Working Group I: The Physical Science Basis. Section 2.3.1 Atmospheric Carbon Dioxide. (2007)
56. Steffen W. & Smith M.S. Planetary boundaries, equity and global sustainability: why wealthy countries could benefit from more equity. Current Opinion in Environmental Sustainability (2013), 1–6.
57. Africa Progress Report, Power People Planet – Seizing Africa's Energy and Climate Opportunities. Africa Progress Panel. www.africaprogresspanel.org/publications/policy- papers/2015-africa-progress-report, (2015)
58. de Sherbinin A., Carr D., Cassels S., & Jiang L. Population and Environment. Annual Review of Environment and Resources (2007), 32: 345–373