Briefing Paper 01-19

For the Scientific Advisory Committee (SAC) of the Footprint Data Foundation (FODAFO)

Published Critiques of the Ecological Footprint and Biocapacity

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Summary: This briefing paper identifies the main themes resulting from a literature review of the critiques posed towards the Ecological Footprint and biocapacity accounting. It conveys the Zotero bibliographic database that has been initiated to store the literature and also contain notes of the shortcomings as well as strengths and recommendations of items included in the bibliographic database. These notes appear in an Appendix as a summary table. Biocapacity has been **emboldened** as a way to separate criticisms geared towards it apart from the Ecological Footprint. Ten themes emerging from the preliminary literature review concern aggregation, scale (spatial and temporal), "false concreteness," utility, quality, land-use, energy-centrism, equivalence and yield factors, and data quality. These will unfold with added literature and potentially expand as the bibliographic database grows.

Background:

There is much that can be gleaned from the Global Footprint Network's website, including data and methodology, various tools and resources, etc. (https://www.footprintnetwork.org/). The recent encyclopedia entry by Wackernagel et al. (2019) provides fundamental background.

Bibliography:

A Zotero collection entitled "Critiques" can be accessed online at zotero.org housed in My Library. Instructions on how to use Zotero can be found in the user guide that is available online (https://www.zotero.org/static/download/zotero_user_guide.pdf). There are currently some 60 items listed chronologically since 1998. They were found and accessed via Google Scholar using the search <<Critiques "ecological footprint" methodologies data>> for articles, excluding patents and citations from any time, which resulted in 16,100 results.

As part of the preliminary examination of the bibliographic database, selected items have been chosen based on their contribution to the debate and include responses to critiques as well as critiques of the methodologies and data. These critiques have been summarized as notes of weaknesses as well as strengths and suggestions that annotate each entry in the bibliographic database and can be output as a Zotero report, although a summary table appears here instead – found in the Appendix. In the summary table, "Weaknesses" refer to criticisms (shortcomings) identified in each paper, whereas "Strengths & Suggestions" refer to the positive aspects (benefits) and/ or recommendations apparent in each paper. Notes specific to biocapacity have been **emboldened** to separate commentary on the Ecological Footprint and biocapacity.

Common Acronyms:

cF = carbon Footprint
CO2 or CO2 = Carbon Dioxide
EF = Ecological Footprint
EFA = Ecological Footprint Analysis
EFc = Ecological Footprint of Consumption
EQF = Equivalence Factor(s)
FAO = Food and Agriculture Organization of the United Nations
FAOSTAT = Food and Agriculture Organization Corporate Statistical Database
GAEZ = Global Agro-Ecological Zones
GFN = Global Footprint Network
GMO = Genetically Modified Organism
GHG or GHGs = Greenhouse Gas(es)
Ha = Hectare
IEA = International Energy Agency
IPCC = Intergovernmental Panel on Climate Change
NFA or NFAs = National Footprint Accounts
NPP = Net Primary Production
t C = Tons Carbon
UN COMTRADE = United Nations International Trade Statistics Database

This briefing paper conveys some preliminary findings of major themes stemming from the published criticisms as well as strengths and recommendations. These are listed below chronologically by author(s), with a reference list appearing at the end of this briefing paper.

Criticisms:

The main criticisms are both conceptual and methodological and address both the Ecological Footprint and biocapacity. They concern the following 10 main thematic issues, ranked in order of priority from lowest to highest:

- *Aggregation* – "…accounting methods need to avoid the risk of simplifications typical of reductionism" (Giampietro & Saltelli, 2014, p. 10). Echoes earlier criticisms of using a single (one-dimensional) indicator (van den Bergh & Verbruggen, 1999; van Vuuren & Smeets, 2000; Wackernagel & Yount, 2000; more recently van den Bergh & Grazi, 2014). But, has six components (crop land, grazing land, forest land, fishing grounds, built-up land, and carbon Footprint) that helps to differentiate it.

- a) *Spatial Scale* – arbitrary spatial scale used to calculate the Ecological Footprint, e.g. regionally – national boundaries affected by geo-political and culture with no environmental meaning. Boundaries are already set and arbitrary, so are meaningless (Fiala, 2008). "Rather than measuring sustainability of a given area, the footprint of a region or nation in fact measures inequality of resources." (p. 520), as consumption is income-dependent. Others, e.g. van den Bergh and Verbruggen (1999), suggest that regions need to be defined from an environmental perspective, e.g. using hydrological, ecological boundaries, or bioregions. But some regions are already included in the data, e.g. Asia.

- b) *Temporal Scale* – a static measurement that is incapable of making future predictions, e.g. Ecological Footprint includes only the area demand of primary and secondary products and not any potential effects on future loss of bioproductivity (**biocapacity**), e.g. water is addressed only indirectly even though overuse of freshwater affects present and future plant growth (McManus & Haughton, 2006). There is a need to consider the long-term in sustainability (Lenzen, Borgstrom Hansson, & Bond, 2007).

- *"False concreteness"* – creating false concreteness because of hypothetical rather than actual land use (since van den Bergh & Verbruggen, 1999; and more recently van den Bergh & Grazi, 2014). But, "…all flows tracked in Ecological Footprint accounts are real flows from real areas of land. Expressing these flows as a globally comparable unit, the global hectare, does not make them virtual" (Lin et al., 2015, p. 465).

- *Utility* – draws heavily from utility theory and an anthropocentric version of environmentalism – therefore, counts **biocapacity** only in terms of portions of the Earth which can be of direct use by people; **biocapacity** calculations exclude 36 billion hectares of land considered too unproductive to support agriculture or aquaculture as well as the outer reaches of the oceans (Venetoulis & Talberth, 2008). According to Venetoulis and Talberth (2008), by excluding significant natural areas from estimates of **biocapacity**, the accounts do not recognize the interdependence of all ecosystems.

- *Quality* – does not differentiate between extensive and intensive production (van den Bergh & Verbruggen, 1999; Lenzen, Borgstrom Hansson, & Bond, 2007; Fiala, 2008) – latter known to increase waste, land depletion, and land degradation. Therefore, does not differentiate between un/sustainable land use, e.g. monoculture (higher yields) versus organic agriculture (lower yields, in the short-term). A measure of extensive production but does not consider intensive production and its environmental impacts (Fiala, 2008). Does not consider environmental issues, e.g. land degradation – can be assessed through soil erosion rates (Fiala, 2008).

- *Land-use* – single land-use functions are considered, when that may not be the reality – e.g. Costa Rica: shade coffee that is an agricultural crop (crop land) but grows in forest (forest land); to avoid double-counting – however, neglect of multiple use can bias the Ecological Footprint upwards (McManus & Haughton, 2006). Furthermore, it is an incomplete environmental measure because it does not consider water use, persistent pollutants, and biodiversity (Kitzes et al., 2009).

- *Energy-centrism* – the Ecological Footprint is dominated by energy, e.g. carbon Footprint represents upwards of 60% of the world's total Ecological Footprint (for 2014, according to Lin et al., 2018). It is too much dominated by energy use due to the hypothetical conversion of energy to land use, using one strategy (reforestation) to assimilate wastes (McManus & Haughton, 2006). Ecological overshoot is mostly attributable to the carbon Footprint (Blomqvist et al., 2013).

- *Equivalence factors (EQF)* – use of equivalence factors (affecting **biocapacity**) is problematic – as for example according to Monfreda, Wackernagel, & Deumling (2004), if the EQF goes down 1 year, so does the Footprint because less **biocapacity** is assumed to be utilized. Moreover, equivalence factors do not address large productivity differences within land-use types (van Vuuren & Smeets, 2000). Various assumptions exist, e.g. that built-up land occupies productive land – what about in permafrost regions? (Kitzes et al., 2009).

- *Yield factors* – Yield factors (affecting the Ecological Footprint) have also been criticized, e.g. Monfreda, Wackernagel, & Deumling (2004), for vast countries (such as Canada), can stretch over climatic zones. Use of local yields? (van Vuuren & Smeets, 2000).

- *Data quality* – data (from official statistics) do not have an error margin, and it cannot be quantified (Monfreda, Wackernagel, & Deumling, 2004). Land use, production, and consumption data are primarily from the FAO Statistical Database, International Energy Agency, and IPCC form the primary inputs into the template (Venetoulis & Talberth, 2008). The accounts err on the side of overreporting **biocapacity** and underreporting the Ecological Footprint – errors leading to an under-reporting of the global ecological overshoot almost certainly overshadow other errors (Monfreda, Wackernagel, & Deumling, 2004).

As a wholly environmental indicator, the Ecological Footprint has limitations concerning the lack of a cultural and socioeconomic context, even though it has been compared to the Human Development Index and this approach could remedy its application within an integrated sustainability framework. There are such specific criticisms that could not be merged into the main themes identified.

Going Forward:

There appears to be a lack of understanding and misinterpretations regarding how the accounts work that cause there to be many questions and criticisms, often due to misinformation or lack of understanding. These need to be tackled through methodological articles and responses (e.g., Borucke et al., 2013; Goldfinger et al., 2014; Lin et al., 2018; Rees & Wackernagel, 2013) and methodological updates and guides (Lin et al., 2018, 2019) that help to clarify the methodology and dispel issues. Answering specific questions, e.g. Lin et al. (2015) and having debates found in one place (e.g., Galli et al., 2016) are effective for outreach while handling the debate. Having information that is accessible to the non-expert (e.g. the general public, policymakers, etc.), such as the recent encyclopedia entry by Wackernagel et al. (2019), can aid outreach. Specific recommendation ideas so far include performing sensitivity analysis, as suggested in some publications (e.g., Kitzes & Wackernagel, 2009; Giampietro & Saltelli, 2014; van den Bergh & Grazi, 2014).

Continue to add to the collection and read items to develop the bibliographic database for criticisms as well as the science underlying the conceptualization and methodology. The main themes will continue to be defined – and even expanded – as more literature is added to the Zotero bibliographic database (notes) and summary table.

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APPENDIX – Summary Table

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
Van den Bergh & Verbruggen (1999) **Reference:** van den Bergh, J. C. J. M., & Verbruggen, H. (1999). Spatial sustainability, trade and indicators: An evaluation of the 'ecological footprint.' *Ecological Economics, 29*(1), 61–72. https://doi.org/10.1016/S0921-8009(99)00032-4	- Aggregation needed as a one-dimensional indicator/ as a single aggregate indicator - Physical weights used – do not consider social weights - Fixed weighting scheme used, e.g. land used by infrastructure versus agriculture – the former seen as more environmentally destructive - Case of "false concreteness" – hypothetical land area can be interpreted as actual or realistic land use - Does not provide a distinction between sustainable and unsustainable land use (assumes sustainable land use?) - Does not allow for a trade-off between environmental sustainability and intensive (high environmental pressure)/ extensive land use, e.g. in agriculture - Associated with single land functions only – this neglect of multiple use can bias the EF upwards - Sustainability is assumed when carbon sinks are not exceeded, but not all land is suited to forests (climate, soil) and depends on availability and cost of land as well as productivity of reforestation - EF calls for CO_2 reductions that are unrealistic environmentally, technically, and economically – it is unlikely that the cheapest option to realise sustainable energy is carbon sink land - Neglects economically rational options, e.g. carbon capture and storage - Too much dominated by energy use due to the hypothetical conversion of	- Decomposition approach needed that distinguishes between population density, consumption, and production of goods and services (per capita) and unsustainable land use for each type of good or service – needs a system of multiple, complementary indicators that consider economic efficiency, spatial equity, and environmental sustainability - Use multiple sustainable energy use scenarios (instead of one), e.g. alternative scenarios that are technical, environmental, and economic feasible, e.g. Senbel, McDaniels, & Dowlatabadi (2003) - Use a model (rather than an accounts system) to calculate indirect effects – considers changes in income, production and consumption due to increasing costs of energy use stemming from specific sustainability policies – such a model needs to recognise the carrying capacity is finite and limits the economy; and extended to consider open regions and trade - Regions need to be defined from an environmental perspective, e.g. using hydrological, ecological boundaries - Calculate actual (rather than hypothetical) footprints of un/sustainable actual land use per capita - Follow a scenario approach rather than use a single, absolute value - Aforementioned: model rather than accounting approach capable of

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	energy to land use, using one strategy (reforestation) to assimilate wastes - Arbitrary spatial scale used to calculate the EF, e.g. regionally – national boundaries effected by geo-political and culture with no environmental meaning - Has an anti-trade bias and, therefore, cannot be considered to be objective - Neglects resource endowments, e.g. space, population density - Does not present/ distinguish between imports based on un/sustainable land use - Global application provides no new insights and regional application can be misinterpreted - Summary of main issues: "…the EF is too aggregate, uses a fixed sustainable energy scenario, represents hypothetical rather than actual land use, makes no distinction between sustainable and unsustainable land use, does not recognize advantages of spatial concentration and specialization, and is in certain applications biased against trade." - Conclude that: "the EF is unsuitable as a tool for informing policy-making: it can support unsustainable, inefficient and even immoral policy options."	determining economically feasible outcomes - Different conceptions of sustainability leading to different footprints, cf. Fang, Heijungs, & de Snoo (2015); Galli et al., 2012; Hoekstra & Wiedmann (2014); – critiques the EF as a single score with problematic weighting (cf. Kitzes & Wackernagel, 2009; Lenzen & Murray, 2001) due to misinterpretation of consumption crossing land boundaries and lack of differentiation between aggregated (land use) and systemic (carbon emissions) issues; these issues may be partially resolved by presenting results at both aggregate and disaggregate levels, also through the use of bioregions (rather than national boundaries that are politically constrained)
Van Vuuren & Smeets (2000) **Reference:** van Vuuren, D. P., & Smeets, E. M. W. (2000). Ecological footprints of Benin, Bhutan, Costa Rica and the Netherlands. *Ecological Economics, 34*(1), 115–130.	- Weak points in the calculation method, e.g. aggregation – (subjective) assumptions used in weights, so they use components instead because of the effects of different resources and multi-functional land use - Focus on the aggregated EF	- Provides basis for discussion of the environmental effects of consumption patterns (both inside and outside national borders) and concerning equitable resource use - Focus on components - Use local yields for agricultural products

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
https://doi.org/10.1016/S0921-8009(00)00155-5	- Use of global average yields - Use of equivalence factors for different types of land use – these factors do not address large productivity differences within land use types - 23 product categories for land use - Include the use of fish	- Do not use equivalence factors to assess the real (actual?) amount of land used by each country - 35 product categories for land use - Do not include the use of fish resources to not mix up sea and land, which would require weighting factors, e.g. countries where fish is an important source of food consumption, the EF will be lower
Wackernagel & Yount (2000) **Reference:** Wackernagel, M., & Yount, J. D. (2000). Footprints for Sustainability: The Next Steps. *Environment, Development and Sustainability*, *2*, 21–42. https://doi.org/10.1023/A:1010050700699	- Could be construed as being overly "simplistic" in summarizing human impacts in one figure - A utilitarian approach, where nature is seen as provider of resources, waste sinks, etc.; also, may appear to be fragmentary, with separate ecological functions - Ignores some ecological services, e.g. water cycles - Use of "hypothetical land" especially for waste assimilation, e.g. CO_2 absorption, which is not any less real than for resource production – points to the problem that: "humans are consuming resources at a rate that would require more land than actually exists." (p. 26); a "robust underestimate"; planting trees seen only as a temporary solution to carbon sequestration – better sequestration technology needed to reduce the footprint - Some human activities that have major impacts are still missing in current footprint accounts, e.g. waste assimilation, such as area required to process degradable substances – e.g. domestic solid waste or most	- Provides a common ground and basic consensus about how the world operates from where to springboard discussions - Does not claim to be a precise measure of human impact, but provides an estimate that errs on the low side of human use of ecological space – as such, it is a minimum requirement for ecological sustainability - As such, "…footprint accounts can document that humanity's aggregate resource demand and waste production are overshooting the biosphere's capacity thereby foreclosing options for the future." (p. 25) - Components of the EF represent a meaningful whole and not just the compilation of index points - The EF documents the competition for ecological space, e.g., various pressures on nature, such as biodiversity loss, erosion, CO_2 accumulation, etc. - Use official data from national or international para-governmental or governmental organizations

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	of the industrial wastes – and mineral and metallic resource use are underestimated "mining and processing footprint"? - The availability of internationally comparative and ecologically meaningful water data is limited, especially water in arid areas - Better data also needed on sustainable yields for crops, but also forests, aquifers, and the waste absorbing functions of nature – it is assumed that industrial yields are sustainable, contributing to the underestimation of overshoot - Biodiversity represented as 12% of bio-productive area (a conservative number, after Brundtland Report) – not all of Earth's bio-productive capacity is available for human use	- All major human consumption categories covered in accounts - Both footprint and **biocapacity** included in the accounts - Standardized measurements using yield and equivalence factors – yield factors compare productivity of a nation to world-average productivity in the same ecosystem category; and the equivalence factor shows how productive a particular ecosystem category is compared to average bio-productive space - Present assessments are made more realistic as they include the use of oceans and fishing - CO_2 absorption estimates and forest yield data using IPCC statistics
Monfreda, Wackernagel, & Deumling (2004) **Reference:** Monfreda, C., Wackernagel, M., & Deumling, D. (2004). Establishing national natural capital accounts based on detailed Ecological Footprint and biological capacity assessments. *Land Use Policy, 21*(3), 231–246. https://doi.org/10.1016/j.landusepol.2003.10.009	- Uses economic and biophysical data from international statistical and scientific agencies, with data gaps filled using research from sources in government, non-profit, academic, and the private sector - Such data (from official statistics) do not have an error margin, and it cannot be quantified - Equivalence factors derived from a spatial model of agricultural yields, namely the suitability index of Global Agro-Ecological Zones (GAEZ) 2000 – does not consider current management practices or rates of biomass production - Focuses on potentially (not actual) "usable" productivity at specific level of technical inputs makes equivalence	- Governments have the opportunity to develop and submit better (more accurate) data - Accounts built on independent data is a future endeavour to increase transparency and enable the analysis of data accuracy - Food Balance Sheets from FAOSTAT provided a standardized database documentation production, import, and export data in a common accounting framework that replaced manual data entry from disparate printed materials in previous accounts, increasing input reliability and the number of datapoints for calculations; also enabled reliable trade and production analysis (in addition to consumption) – some of the

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	factors more robust in the time series - Additionally, yield factors are used to and calculated anew each year – they convey the extent to which a bioproductive area in a given country is more/ less productive than the global average of the same bioproductive area; they reflect prevailing technology and management practices as well as renewable resource productivity – for vast countries (such as Canada), it can stretch over climatic zones - EF of primary products calculated from global yield, but that of secondary products derived from parent primary product – it is affected by a country's conversion efficiency – and it is only added to EFc when traded, so that secondary goods that are produced but not traded are included in the EF of the parent product - EF includes only the area demand of primary and secondary products and not any potential effects on future loss of bioproductivity (**biocapacity**) - EF does not include the area demand of agricultural side-effects, e.g. water pollution, due to lack of data – also contributes to underestimation of real demand - Accounts err on the side of overreporting **biocapacity** and underreporting the EF – errors leading to an under-reporting of the global ecological overshoot almost certainly overshadow other errors	new sources differentiate changes in stocks, production, waste, and secondary uses - Improvements using more comprehensive datasets and independent data sources make for more consistent and reliable data as well as more robust calculations

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
McManus & Haughton (2006) **Reference:** McManus, P., & Haughton, G. (2006). Planning with Ecological Footprints: A sympathetic critique of theory and practice. *Environment and Urbanization, 18*(1), 113–127. https://doi.org/10.1177/0956247806063963	- Problematic when used to compare jurisdictions – works best at national level - Do not support aggregation at city-level at a particular point in time and the use of numerical outputs for comparison of disparate cities – can result in inaccurate portrayal of environmental impacts at city-scale - Concerns that carrying capacity should not be applied to humans because they are able to change limits - Footprint accounts are incomplete, especially where water and waste streams are concerned - Reducing the size of the EF does not necessarily equate to reducing environmental impacts - What we consume may be as important as how much we consume – quantity versus quality issue – we need to differentiate between how different types of consumption behaviour create different types of environmental impacts, which may not be possible with a single land measure - EF analysis only differentiates between non/productive land at global scale; and deploys abstract types of land use without acknowledging differences in local environmental and socioeconomic conditions - EF is not the same as environmental impact because its land categories are limited and underplays ecosystem value, e.g. biodiversity, species scarcity, habitat, landscape uniqueness, etc. – a smaller EF does not equate to less	- Concept of the EF as a metaphor for ecological impact – of consumption (food, housing, transportation, consumer goods and services) and waste discharge – regardless of where it occurs, converting it into a single unit of land; popularly used at the national, urban, and personal scales - Enables consideration of material flows (of resources and wastes), in and out of cities, as part of "linear metabolism" - Considered to be an effective way to promote policy debate as well as an educational tool - Use of the lifecycle principle and focus on consumption - Aggregation and synthesis considered to be strengths, e.g. by Holden (2004), versus van den Bergh & Verbruggen (1999) – who opposed aggregation and favoured decomposition approaches to measuring sustainability - Like the environmental space concept, there is an underlying premise that equity needs to be addressed through the way that environmental impacts are measured and assessed, although the EF is not sensitive to social equity issues - Concept useful for identifying sustainability issues and for use by policymakers and urban planners to promote sustainable cities (and sustainability) - Need to recognize the multifunctionality of land, e.g. carbon Footprint inflated because of the assumption that forest land is needed to absorb carbon dioxide and that this forest cannot service

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	qualitative impact, e.g. in the case of high-value ecological area - Water is addressed only indirectly, even though overuse of freshwater affects present and future plant growth (**biocapacity**) - Environmental issues are geographically uneven due to variable local conditions, e.g. poor-quality environmental conditions where socially excluded appear in wealthy or poor cities (environmental justice issues) - EF analysis does not provide insight into where and on which types of people and habitats burdens fall outside cities - Should consider the cultural element (e.g. of cities as cultural landscapes) and the benefits that they offer (e.g., services, reduced travel time, etc.) – focuses on quantifying transference of carrying capacity from one location to another - Need to consider the productive capacity of different cities and their hinterlands, e.g. differences in soil fertility, rainfall reliability, etc. - Translation problem of the EF used for policy development (one of the most contentious debates) because of jurisdictional responsibility and international flows of natural resources; can only be used for limited policy development by local governments due to inadequate policy implementation - Areas with a high population and without agricultural land	other functions, e.g. construction material, recreational or water catchment value – to avoid double-counting - Patent or copyright protection to control consultancy organizations – for quality assurance and control - Can be used as a catalyst to promote actions to reduce the footprint as part of a move towards sustainability - Has visual and “common-sense” appeal, making it useful for raising awareness

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	within its borders will generate a higher EF - Ignore multiple land-uses biases the EF upwards - Anti-trade bias – needs to address that international trade is necessary and valuable; sociocultural deficiency in the methodology; need to recognize the complex balance sheet of gains and losses; a balancing act needs to be considered, e.g. Fair Trade over no trade relations - A technical tool that becomes a political instrument for local agendas - Problems finding appropriate disaggregated data, necessitating compromises and assumptions to progress - Easier to calculate the EF at national and personal levels than individual towns and cities – differences at town-scale too small to justify estimates at this level - "We are concerned too about the ways in which, without due care, the approach in effect decontextualizes place and the diversity and wonderment of nature, by suggesting that the problems, even if not solutions, are essentially reducible to a common metric." (p. 126)	
Lenzen, Borgstrom Hansson, & Bond (2007) **Reference:** Lenzen, M., Borgstrom Hansson, C., & Bond, S. (2007). On the bioproductivity and land-disturbance metrics of the Ecological Footprint. *Ecological Economics, 61*(1), 6–10.	- Following up on discussions held at the EF Forum in Italy, 2006, bioproductivity metric (**biocapacity**) needs to be accompanied with additional information, e.g. land disturbance and biodiversity – specifically, monoculture forests have higher yields that increases national **biocapacity** (= favourable comparison of Footprint with **biocapacity**) –	- To make the tool robust, it is necessary to consider the long-term: "In the long term, human demand may well be limited by biodiversity and ecosystem health, rather than by bioproductivity. This is not only because biodiversity controls long-term bioproductivity, but also because biodiversity controls other ecosystem services such

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
https://doi.org/10.1016/j.ecolecon.2006.11.010	therefore, biodiversity indicators needed; organic agriculture will lower yields, at least in the short-term (on the other hand, soil-saving techniques and ecological service conservation may also have impacts); forest-to-cropland conversion is another yield-increasing practice – standing forests have an equivalent factor of 1.4, but as primary crop land this increases to 2.2 – also affects local yield factor for primary crop land = misleading effects because compromises the resilience and long-term regenerative capacity of ecosystems, when biodiversity-rich tropical forests are converted to monocultures, e.g. palm oil - Intensive systems, e.g. Welsh Black beef, will generally have higher yields and negative consequences if EF used to inform policy where external inputs are used to increase beef yields at the expense of land somewhere else, e.g. primary forest converted to soy plantation – therefore, increases **biocapacity** of country of feed origin, e.g. Brazil, and also affects **biocapacity** through feed inputs to Welsh pastures - Issues such as landcover disturbance, soil degradation, and biodiversity – e.g. that are decline in Australia – are not getting attention: "If Australian decision-makers acted only according to the bioproductivity metric, clearing and degradation of grazing lands would be paid minor attention." (p. 8)	as resilience against disruptions … If the analysis of policy decisions were restricted to the bioproductivity metric, it would not provide sufficient information and feedback to decision-makers and communities who are concerned about and affected by ecosystem degradation and biodiversity decline." (p. 8)

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
Fiala (2008) **Reference:** Fiala, N. (2008). Measuring sustainability: Why the ecological footprint is bad economics and bad environmental science. *Ecological Economics, 67*(4), 519–525. https://doi.org/10.1016/j.ecolecon.2008.07.023	- Supports criticisms made by van den Bergh & Verbruggen (1999), e.g. EF dominated by energy - Footprint cannot take on intensive production, so that comparisons to **biocapacity** are erroneous; larger production can be supported – based on historical records of sustainable production - Footprint not well-correlated with land degradation, which has larger repercussions for sustainability; looking at land-usage alone can misrepresent the sustainability of a system: "A large land footprint then could be more sustainable than a small one, depending on how the land is used." (p. 523) Cannot be addressed by the Footprint as a static concept - Suggests abandoning composite indicators and, instead, focus on two major issues: land degradation and CO_2 aggregations - Use of boundaries already set and arbitrary – so are meaningless: "Rather than measuring sustainability of a given area, the footprint of a region or nation in fact measures inequality of resources." (p. 520); consumption is income-dependent - It is important to measure production at the source; does not consider technological change affecting future consumption growth – can only describe production growth without technological progress – therefore, useless for future predictions - Intensive versus extensive production – affecting	– More research needs to target land degradation and investigate its relationship with development as well as the Footprint; examine soil erosion rates for estimating land degradation - Footprint capturing effect from carbon, when using CO_2 equivalents (for greenhouse gases) would be more informative and policy-relevant

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	biocapacity by increasing yield or using more land for production – Footprint cannot address intensive production growth, but can be used to understand extensive growth, but which type has more of an impact on production growth? E.g. intensive production increases waste, land depletion, and land degradation	
Venetoulis & Talberth (2008) **Reference:** Venetoulis, J., & Talberth, J. (2008). Refining the ecological footprint. *Environment, Development and Sustainability, 10*(4), 441–469. https://doi.org/10.1007/s10668-006-9074-z	- Excludes open oceans and less productive lands from **biocapacity**; does not allocate space for other species (biodiversity); use of agricultural productivity potential for equivalence factors; allocation of global carbon budget; and does not capture unsustainable use of aquatic and terrestrial ecosystems - Standard approach largely based on FAO and GAEZ suitability indices - Draws heavily from utility theory and an anthropocentric version of environmentalism – therefore, counts **biocapacity** only in terms of portions of the Earth which can be of direct use by people; **biocapacity** calculations exclude 36 billion hectares of land considered too unproductive to support agriculture or aquaculture as well as the outer reaches of the oceans - Does not matter that such (unproductive land) areas, including mountains, deserts, tundra, ice sheets, and most of the ocean, are degraded or destroyed because they are counted as areas from which humanity derives sustenance - None of this capacity is needed to sustain other	- Land use, production, and consumption data primarily from the FAOSTAT, IEA, and IPCC form the primary inputs into the template - Propose refinements, e.g. including entire Earth in **biocapacity**, allocating space for other species, NPP used for EQF, reallocates carbon budget, and report carbon sequestration **biocapacity** - These improvements “the new approach” (EF-NPP) increase the global Footprint and ecological overshoot, but makes EFA (compares the EF with available **biocapacity** – measures sustainability) more accurate and a meaningful sustainability assessment tool

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	species that may indirectly contribute to **biocapacity** and quality of renewable resources available to future generations - Carbon sequestration rates expressed as fossil energy Footprint in terms of forest hectares needed to sequester carbon emissions after deducting 35% of emissions sequestered by the oceans. Sequestration rate based on averages from samples of 26 forest biomes in 1980 and 1990 - Assumption that land can only serve one purpose, so if a forest provides wood it does not also serve other functions, e.g. carbon sequestration, soil stabilization, or wildlife habitat; carbon dioxide absorption internalized in calculations, but not made explicit - By excluding significant natural areas from estimates of **biocapacity**, the accounts do not recognize the interdependence of all ecosystems	
Kitzes & Wackernagel (2009) **Reference:** Kitzes, J., Galli, A., Bagliani, M., Barrett, J., Dige, G., Ede, S., … Wiedmann, T. (2009). A research agenda for improving national Ecological Footprint accounts. *Ecological Economics, 68*(7), 1991–2007. https://doi.org/10.1016/j.ecolecon.2008.06.022	- **Biocapacity** includes bioproductive land (cropland, forest, fishing grounds), but excludes deserts, glaciers, and the open ocean - To avoid double-counting, wastes are considered to be inherent in the Footprint calculation and not counted separately or in addition to it; however, waste the ends up in landfill occupies formerly bioproductive areas and is calculated as the infrastructure or built-up area used for its long-term storage - Because the EF measures the productive area required to produce a material or absorb a	- Estimates of the amount of **biocapacity** that is dependent on freshwater supply, or of the lost capacity associated with water use for non-bioproductive purposes, could be calculated at the local to regional scale or on a case-by-case basis - The EF can be used as an indicator of the drivers or pressures that cause biodiversity loss - Pollutants and toxics cause ecosystem damage when released and this reduced **biocapacity** can be measured and allocated to the activity that caused its release – it will

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	waste, plastics and such materials that are not created by biological systems do not themselves have a Footprint - Water treated as a production factor in creating biological resources for human use - Is not a biodiversity indicator, e.g. given the same yields, the EF of ‘‘sustainably harvested’’ timber and uncertified timber is identical, which will affect future **biocapacity** assessments but not current EF accounts - Aggregate results applied to complex systems can oversimplify them; however, it is possible to disaggregate the results into components (six major land types) or several hundred different product categories	be captured in future assessments of the affected area - Need to capture toxic materials with complementary indicators and accounts, including impacts on human health, long-term storage, or remediation - As an aggregate indicator, the EF can condense information into summarized statistics and gha used to show trade-offs and substitutions made between ecosystems - In any given year, the EF reflects prevailing technology in calculating total demand for biological capacity, but document historic states only as they occur – the EF makes no assumption about technological possibilities and reflects their actual influences on current demand; it does not attempt to capture aspects of socioeconomic sustainability, other than conveying human demand for biological goods and services, as it attempts to answer the research question concerning how much of the planet’s productive capacity is demanded “Sustainability means living well, within the means of nature, and the Ecological Footprint highlights a minimum condition for achieving this goal” (p. 816).
Kitzes et al. (2009) **Reference:** Kitzes, J., & Wackernagel, M. (2009). Answers to common questions in Ecological Footprint accounting. *Ecological Indicators, 9*(4), 812–817.	- Data source: NFAs depend on the accuracy of international and national data sources, e.g. FAOSTAT, UN Comtrade, IEA – affects data quality – e.g. UAE data influenced by frequency of data reporting, lack of reporting for some commodities, methods for measuring population, etc. as	- Suggest that independent scientific reviews of the underlying datasets used to calculate NFAs be executed, e.g. already performed by agencies in Finland, Ireland, Japan, and Switzerland - Potential to perform “sensitivity analysis” using high-resolution national data

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
https://doi.org/10.1016/j.ecolind.2008.09.014	biasing national data; another example: China's systematic distortions in marine fish catch throwing off national fishing grounds and possibly affecting estimates for the entire world, e.g. "off-the-books" transactions, household-level production and consumption, e.g. subsistence farming at the small-scale; also need to address errors from systematic distortions produced in the translation of national data into standardized international classification systems - Caution against calculations based on different data sources, e.g. product lists, classification systems; cross-temporal record for carbon Footprint - Key constants used to translate material extraction and waste emission into units of productive area (**biocapacity**) that are influential on overall calculations, e.g. carbon sequestered per hectare of world-average forest, total sustainable marine fish harvest, invertebrate, and plant species, feed conversion ratios and feed baskets of various livestock, etc., need additional scientific analysis - Use of global hectares normalized to world-average bioproductivity in a given year continues to be debated, e.g. the use of a constant for global hectares adjustment similar to an inflation adjustment may be necessary to convey cross-temporal change, e.g. rates, future impacts - Is a productivity weighting necessary – are equivalence factors needed?	that is consistently regionally formatted - Encouraged to publish (affecting transparency) and review the compilers manuals and correspondence tables used to convert national statistical classifications to international systems – to correct for errors or distortions - Could use ranges for constants deployed in calculations to generate a range or set of standard error estimates – the standard error has been criticized to be high, but no major systematic analyses have been made to scrutinize and test confidence levels of source data; furthermore: "Accounting methods and assumptions should be subject to additional formal analysis and "reality checks" using a range of published data sources." (p. 1993) - Comparison of alternate methods to existing methods, e.g. basis for calculating the carbon Footprint – with documentation of the differences and their significance - Use of calculated area for a specific land use without deploying equivalence factors; also, measured area data could be input from land use and land cover surveys (including disturbance and intensity multipliers, which show significant geographic variation), with Footprints measured in actual hectares – based on the notion that there are smaller uncertainties in land cover surveys than production and yield datasets;

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	- Is there a discrepancy between the treatment of primary and secondary products in the current (gha) methodology? - From the major land types, major changes have bene suggested for fishing grounds, crop land, and built-up land, e.g. adding more land types; fishing grounds based on a single estimate of sustainable yield ignores availability and quality of fishing stocks (and regenerative capacity) in a given year, causing a small estimate of overshoot in global marine fisheries - The assumption that built-up land (land under human infrastructure) occupies formerly productive crop land does not apply everywhere, e.g. Arctic, tropical environments – assumption developed for temperate countries; should have no associated **biocapacity** - Tourism is incompletely implemented in the accounts; traded goods – avoid double-counting using a shared responsibility framework that allocates Footprint to importing countries where consumption occurs; however, tourism allocated to the country of travel rather than to the home country (where the demand is based) = methodological inconsistency - For the carbon Footprint, include greenhouse gas emissions other than carbon dioxide, such as methane, (e.g., through the use of global warming potentials or carbon dioxide equivalents or through atmospheric lifetime) as well as from land-use change either	could use local or national Footprint to answer the research question: "How much bioproductive area is used by a given human activity or population?" – rather than the one that global hectares answers, namely: "How much of the planet's regenerative capacity is used by a specific human activity or population?" (p. 1994) – based on calculated or measured area approaches: "Local hectare Footprints can be determined either through a measured area approach, where calculations are based on measured land use as reported in national statistics or derived from remote sensing applications, or through a calculated area approach, in which product flows are simply divided by local yields." - Calculate yields for fisheries based on stock quality – at least for the most significant fish species if not all - Should determine exactly which land type was replaced by infrastructure (for built-up land), e.g. modelled using CORINE or GLC – use global NPP datasets? Otherwise, should remove built-up land completely from Footprint and **biocapacity** estimates because it is no longer bioproductive land that should be excluded from the accounts, e.g. tundra and deserts are excluded; should either expand categories, e.g. add wetlands, or include all land types; should include all land types for carbon sequestration in addition to forest land – also consider age, as mature forests have little remaining

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	from IPCC or IEA (e.g., from tundra or wetlands; land conversions) – carbon Footprint calculated using the amount of forest land necessary to absorb carbon dioxide from fossil fuel combustion through sequestration for world-average forest, after adjusting for uptake by the oceans - The Footprint cannot be considered a complete environmental sustainability measure because it does not consider water use, persistent pollutants, and biodiversity (lost **biocapacity**; or **biocapacity** left for other species, e.g. in protected areas) - A single indictor can only answer one research question, whereas an integrated approach using multiple criteria can have broader coverage	potential for absorption; should account for climate change and its impact bioproductive land – therefore, use actual sequestration values for biosphere as a whole rather than the regenerative capacity for absorbing carbon - Use of predictive future models to shift the accounts away from a focus on the past/ historical and present - EF accounts seen as relevant to assess biodiversity loss because they measure the consumption of biological resources and generation of wastes – indirect drivers of biodiversity loss; they are useful for setting policies to halt or reverse biodiversity declines; a disturbance-based EF would be helpful to determine biodiversity loss - Should be compared with other indicators, e.g. HDI, to become more policy-relevant
Blomqvist et al. (2013) **Reference:** Blomqvist, L., Brook, B. W., Ellis, E. C., Kareiva, P. M., Nordhaus, T., & Shellenberger, M. (2013). Does the Shoe Fit? Real versus Imagined Ecological Footprints. *PLoS Biology, 11*(11), e1001700. https://doi.org/10.1371/journal.pbio.1001700	- Much of the EF depends on atmospheric carbon, e.g. if a carbon sequestration rate of 2.6 t C per ha per year or higher is deployed the entire global ecological overshoot disappears; conversely, changes to the management or distribution of croplands, grazing lands, or built-up land would have virtually no effect on global ecological overshoot or surplus - Carbon sequestration by forests is the only mechanism considered for carbon sequestration - EF is not a robust measure of ecological sustainability and offers poor guidance for policymakers in identifying and evaluating options	- Forest need not be the only mechanism used to offset atmospheric carbon accumulation – solar panels or wind farms be used; use eucalyptus plantations to sequester carbon at rates up to 12 t C per ha per year; less than half the area of the United States planted with eucalypts could essentially give us an EF equal to one Earth - Should include estimates of uncertainty to avoid giving an impression of precision, which can be misleading - "By understanding the strengths and weaknesses of the EF, it will be possible to better develop and select

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	- The EF is unable to reflect the sustainability of croplands, built-up land, and grazing land, since these are by definition always in near balance in the EF accounts - The EF is inconsistent across scales – its meaning at the global scale differs from sub-global scales	ecological indicators as ecologists and environmental scientists go back to the drawing board" (p. 5).
Borucke et al. (2013) **Reference:** Borucke, M., Moore, D., Cranston, G., Gracey, K., Iha, K., Larson, J., … Galli, A. (2013). Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. *Ecological Indicators, 24*, 518–533. https://doi.org/10.1016/j.ecolind.2012.08.005	- The National Footprint Accounts measure one main aspect of sustainability only – how much **biocapacity** humans demand in comparison to how much is available – not all aspects of sustainability, nor all environmental concerns - Areas identified by the literature that need improvement on p. 523, e.g. it is problematic to equate marine and terrestrial resources in the calculation of EQF – do calories of salmon and beef equate? EQF for inland water equal to marine area, etc. - Is it double-counting when forest for timber and fuelwood is not separated from forest for carbon uptake? - Soil depletion is not tracking, e.g. in grazing land - Static based on constants from 1961 in some cases, e.g. 82% of anthropogenic emissions taken up by the ocean in 1961, which has caused an underestimation of the carbon Footprint in the early decades tracked by the NFAs – but now use ocean update of carbon dioxide divided by total anthropogenic carbon emissions data, totaling 28-35%	- Table 1 (p. 520) delineates details of data sources used by the NFAs - Aggregating results into a single value has the advantage of monitoring the combined demand of anthropogenic activities against nature's overall regenerative capacity - Figure 4 (p. 524) compares land use types in hectares versus global hectares to clarify differences, e.g. virtual hectares - Human "infrastructure" (built-up land) actually includes transportation, housing, industrial structures, and reservoirs for hydroelectric power generation

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	- Datasets have incomplete coverage and do not include confidence limits - NFAs are constructed to yield conservative estimates of global overshoot, e.g. supply side – **biocapacity** – overestimated because land degradation and long-term sustainability of resource extraction are not considered; also, does not track freshwater consumption, soil erosion, GHGs emissions other than CO_2, as well as impacts for which no regenerative capacity exists (e.g., pollution in terms of waste generation, toxicity, eutrophication, etc.)	
Rees & Wackernagel (2013) **Reference:** Rees, W. E., & Wackernagel, M. (2013). The Shoe Fits, but the Footprint is Larger than Earth. *PLoS Biology, 11*(11), e1001701. https://doi.org/10.1371/journal.pbio.1001701	- Recognize that local ecosystem abuse is a problem and the Footprint accounts should reflect **biocapacity** losses due to soil/ land degradation and overfishing – fixing this would increase ecological deficit estimates; however, globally consistent datasets do not exist - Carbon dioxide emissions data based on fossil fuel burning and cement production – whose emissions far exceed the sequestration capacity of the ecosphere	- National Footprint estimates are the most comprehensive assessments of the ecological status of nations available – based on consistent United Nations datasets - There are presently no better estimates than those delivered by the Global Footprint Network's current Footprint accounts - Estimated sequestration rates by average forest ecosystem based on FAO and IPCC reports of approximately 1 metric ton per ha per year
Giampietro & Saltelli (2014) **Reference:** Giampietro, M., & Saltelli, A. (2014). Footprints to nowhere. *Ecological Indicators, 46*, 610–621. https://doi.org/10.1016/j.ecolind.2014.01.030	- The carbon Footprint has been increasing linearly in time, even though it only considers the **biocapacity** needed to absorb CO_2 emissions for energy consumed and does not include the **biocapacity** needed for energy supply, which would cause a 10-fold increase; moreover, a hectare of forest cannot grow and fix CO_2 forever, e.g. need growing trees/ young forests for that	- Quality assessment needed using sensitivity analysis

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	- Non-energy categories remain relatively unchanged in the last 45 years – counter to the MEA (2005) - **Biocapacity** does not inform regarding quantity, level of preservation, or damage to available local natural capital - GFN protocol perceives intensification (of pesticides, synthetic fertilizers, and GMO crops) as an improvement, since these increase **biocapacity** – therefore, ignores un/sustainable land-use - Monoculture forests (that destroy natural habitat) positively affect **biocapacity** and, therefore, create a favourable comparison between the Ecological Footprint and **biocapacity** (or ecological overshoot analysis) - Question logic behind using area of **biocapacity** crop-equivalent used for building and infrastructure - Because it is based on world averages, the peculiarity of local situations (heterogeneity) is alluded - There is no direct relation between the carbon Footprint and the energy used by society, as it is calculated using forests as carbon sinks, but what about other options, e.g. underground/ sea storage? - Use of a single unit problematic; can be used to misdirect policy, e.g. it comfortably underestimates ecological overshoot	
Van den Bergh & Grazi (2014) **Reference:** Van den Bergh, J. C. J. M., & Grazi, F. (2014). Ecological Footprint Policy? Land Use as	- "False concreteness" – that actual land is represented, stemming mostly from carbon sink land; transformations needed to arrive at the global hectare rather than real	- Focus on real land use and omit all hypothetical elements present in the EF approach – this would mean removing EQF based on suitability index (GAEZ)

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
an Environmental Indicator: Footprint Policy? *Journal of Industrial Ecology, 18*(1), 10–19. https://doi.org/10.1111/jiec.12045	(actual land use, which could never exceed available land area) land in hectares - Do EQF change over time to reflect changes in productivity, e.g. due to land degradation? - Assumption that production and consumption are limited only by land availability suggests that land policy is the main public response to unsustainability - Can all human environmental impacts be captured or approximated by land use? E.g. agriculture – pesticide use, concentrated fertilizers difficult to transform to land-area units as a proxy of environmental pressures - EF as an aggregate environmental indicator not effectively estimating appropriated **biocapacity** – it excludes important environmental pressures created by human activities and, therefore, underestimates human impact on the biosphere, e.g. water pollution, emissions of toxic substances (including heavy metals), noise pollution, depletion of the ozone layer, acid rain, fragmentation of ecosystems resulting from land use and road infrastructure, biodiversity, as well as GHG emissions other than CO_2 – that are not accounted for by the EF approach; also, carbon Footprint accounting for half of national Footprints, leading to an unclear net effect - Aggregation through weights that are arbitrary and fixed - Use of hypothetical land for CO_2 emissions through the use of assumption on sustainable energy scenario – there is	- Need to be explicit on what motivated use of weights - Should not assume that trade is unsustainable by definition - Use of a two-region world model - The EF is regarded to be a strong communication tool, although it is viewed as having a very limited impact in terms of policy lessons - To be useful for policy, the EF needs to have sub-indicators that reflect environmental stress factors or environmental/ human-social impacts capturing effects on production, consumption, and human health and well-being; it also needs to use the "best" aggregation approach based on logical weights and aggregation schemes or perform sensitivity analysis

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
	insufficient land available on Earth to support a quantity of forest area that can capture all anthropogenic CO_2 emissions - Performance ranking of countries; country borders are not environmentally relevant - Anti-trade sentiment that does not encapsulate or appreciate the need for spatial disparities; cities are also not seen as plausible contributors to sustainable development - EF does not make a distinction between sustainable and unsustainable land use - Methodological extensions (e.g. suggested in 2009) do not resolve the main methodological shortcomings identified by early criticisms - It is a biophysical evaluation of sustainability, so cannot be used to inform economics, policy, etc. in the human domain - Its apparent simplicity is misleading, although it is a good communication tool well-suited to raise public awareness	
Lin et al. (2015) **Reference:** Lin, D., Wackernagel, M., Galli, A., & Kelly, R. (2015). Ecological Footprint: Informative and evolving – A response to van den Bergh and Grazi (2014). *Ecological Indicators, 58*, 464–468. https://doi.org/10.1016/j.ecolind.2015.05.001	- Only those resources, pollutants, or services that can be measured in terms of biologically productive surfaces are included in the EF	Response to van den Bergh & Grazi (2014): - Use of real flows and real areas of land – not virtual - Track overshoot through the differences in real flows, not by assessing the change in stocks - A global hectare is a hectare-equivalent unit representing the capacity of a hectare of land with world-average productivity (across all croplands, grazing lands, forests, and fishing grounds on the planet) to provide ecosystem services that people demand

Zotero Source (Chronological)	Weaknesses	Strengths & Suggestions
		- The current methodology is suited to a first approximation of human demand on **biocapacity**, but can be improved by incorporating new data and benefiting from advances in scientific knowledge - Set weights are not arbitrary, but in accordance with an activity's relative demand on **biocapacity** or an area's relative productivity - Not set on pre-set scenarios; the accounts are sensitive to both reduced emissions and changed sequestration capacity - Nation-level data are particularly useful for policymakers - Reserve and deficit are descriptive and not judgemental; Footprint accounts make no judgments about optimal allocation – the accounts merely track demand on **biocapacity** - Research question: How much do people demand from ecosystems compared to what those ecosystems (or the biosphere as a whole) can regenerate? - Is relevant to policy concerning the research question - User needs to determine whether other instruments are better-suited (more accurate methods) to their needs - Useful as a tool for decisionmakers to gain sustainability information - Footprint results are inline with many other studies addressing humanity's dependence on the Earth's resources and services, so can make a viable contribution