Ecological Footprint Accounting: Limitations and Criticism

A Comprehensive Collection of Criticisms and Responses

Global Footprint Network research team[1]

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[1] For correspondence, contact Dr. David Lin, Global Footprint Network's Chief Science Officer at david.lin@footprintnetwork.org

Imprint

Ecological Footprint Accounting: Limitations and Criticism
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Lead Authors of Version 1.4
Mathis Wackernagel, Ph.D.
David Lin, Ph.D.

Original Authors (alphabetical):
Alessandro Galli, Ph.D.
Laurel Hanscom
David Lin, Ph.D.
Mathis Wackernagel, Ph.D.

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For further information, please contact:
Global Footprint Network
1528 Webster Street, Suite 11
Oakland, CA 94612 USA

E-mail: data@footprintnetwork.org

Main website: https://www.footprintnetwork.org
Section on Limitations and Criticisms: https://www.footprintnetwork.org/our-work/ecological-footprint/limitations-and-criticisms
Open data website: https://data.footprintnetwork.org

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Introduction

Complementary Criticism is vital

The Ecological Footprint was introduced in 1991 in response to a simple question: *How much humanity takes from nature compared to what the Earth's ecosystems can renew?* Although the question remains the same, the concept's accounting methodologies have steadily evolved, producing more robust results.

Over the past decades, the Ecological Footprint has gained increasing prominence. For example, the annual Earth Overshoot Day campaign, which draws on Footprint data, receives substantial global media attention—typically several billion media impressions each year.[2] In addition, Google Scholar indicates that roughly 50,000 academic papers on the Ecological Footprint have been published over the past decade. [3] The concept is also widely used in sustainability textbooks and university courses.

Greater visibility and striking findings naturally invite scrutiny and debate. The Ecological Footprint is no exception. There is always room to improve these accounts, and constructive criticism plays an important role in that process. Indeed, critical engagement is a key driver of scientific progress.

Based on simple principles

Ecological Footprint and biocapacity accounting are grounded in a simple scientific principle: when you sum all human demands that compete for biologically productive space, you arrive at the total area required to sustain those demands. Crucially, there is no double counting: the same area is only allocated once. [4] As a result, these accounts describe observable reality rather than speculation.

At their core, the Ecological Footprint and biocapacity concepts rely on fundamental principles. They do not require advanced or abstract physics. There is no quantum mechanics, gravitational waves, or relativity. Instead, they are based on basic thermodynamics and the conservation of mass. In essence, this is an accounting framework that allows consistent

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[2] Media search via the meltwater.com service showed for instance in 2019, 6,500 trackable web-based stories generated over 4 billion media impressions in 120 countries. 11,800 web-based stories were generated over the entire year. In 2023, it was about 9 billion media impression based on 5,264 articles during the 7 days around Earth Overshoot Day.

[3] Also consult Anjum et al. (2026) for their bibliometric analysis.

[4] An introduction to basic principles behind Ecological Footprint accounting is provided in section 1 and 2 of the open access paper "Defying the Footprint Oracle: Implications of Country Resource Trends" available here or in the supplementary information of the paper "The importance of resource security for poverty eradication".

tracking of material and energy flows in a coherent, transparent way, based on a common unit of measurement: ecosystem regeneration.

Despite this simplicity in principle, applying the approach to households, companies, cities, or countries can be complex. Comprehensive accounting must include all competing demands on productive ecosystems, which requires extensive and diverse data inputs. This level of detail can make assessments intricate and sometimes difficult to navigate. For this reason, standardized Footprint accounting methods were developed (available at www.footprintstandards.org).

Potential for improvement

Because Ecological Footprint accounting covers all human demands across a wide range of activities, data availability is one of the main constraints. Analysts constantly face trade-offs: use weak data, exclude certain components, or introduce assumptions. Each option reduces the robustness of the results.

The most widely used Ecological Footprint datasets are the National Footprint and Biocapacity Accounts.[5] These accounts draw exclusively on relevant UN and para-UN statistical sources. This choice ensures neutrality, cross-country comparability, and alignment with international standards. By prioritizing official data and focusing on proof of concept, the accounts emphasize the consistency and transparency of the accounting framework, while remaining compatible with continuously improving global statistics.

At the same time, more detailed or context-specific assessments may exist in individual cases. The framework is designed to accommodate such improvements: new or better data can be incorporated directly into the accounting workbook. Researchers can also extend the core accounts with additional non-UN datasets, as described in the Ecological Footprint standards (www.footprintstandards.org).

Recent editions of the National Footprint and Biocapacity Accounts use up to 15,000 data points per country per year. As with any large dataset, “the devil is in the details.” Some countries, particularly those with well-developed statistical systems, provide consistent input data. Others have gaps, inconsistencies in category definitions, or missing documentation. These limitations mean that, in practice, the implementation cannot always fully match the simplicity and clarity of the underlying principles. There are also other challenges: trade data is inherently noisier, which adds analytical challenges when assessing smaller countries with large trade flows.

[5] A description of the accounts, and recent improvements, is “Ecological Footprint Accounting for Countries: Updates and Results of the National Footprint Accounts, 2012–2018” available here.

To strengthen confidence in the metric, Global Footprint Network and its academic partner, York University in Toronto, established the non-profit **Footprint Data Foundation (FoDaFo)** in 2019. The foundation's role is to ensure that the National Footprint and Biocapacity Accounts remain accurate, neutral, transparent, and accessible, while supporting their use in decision-making. By maintaining strong governance and a clear separation between data and advocacy, FoDaFo helps build trust in the dataset and supports more effective sustainability transitions. Further details are provided in Section 5.

Ecological Footprint accounting is an evolving field that benefits from both criticism and new perspectives. All sincere criticism is valuable, whether it stems from misunderstanding or from well-founded analytical arguments. [6] The former helps improve how the principles and results are communicated. The latter helps refine the methodology and identify better ways to apply the tool.

What we have learned from criticism

Criticism has been essential to the development of the Ecological Footprint concept, especially its most widely used application, the National Footprint and Biocapacity Accounts. Since the first national calculation for Canada in the early 1990s, [7] much has evolved, largely in response to feedback and critique.

A key example concerns the use of hectares as a measure of biological productivity. Critics rightly noted that not all hectares are equivalent: some landscapes, such as tropical rainforests and wetlands, are highly productive, while others, such as tundra or steppe, are far less so. In response, we introduced **global hectares**, a standardized unit that reflects average biological productivity. Because productivity varies across space and time, global hectares account for differences across ecosystems as well as shifts driven by climate change and agricultural practices.

This revision also opened up further lines of inquiry. For example, we examined how global hectares compare with Net Primary Productivity, clarifying the strengths and limitations of each approach. [8]

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[6] See for example a brief discussion on Trellis (formerly called Greenbiz) entitled "Ecological footprint accounting and its critics" available here.

[7] Published in the Ph.D. thesis of Matis Wackernagel, "Ecological Footprint and Appropriated Carrying Capacity: A Tool for Planning Toward Sustainability." 1994. School of Community and Regional Planning. The University of British Columbia. https://dx.doi.org/10.14288/1.0088048

[8] Helmut Haberl initiated this inquiry through a special issue in Land Policy. Some of the relevant papers from this issue are:

- Haberl, H., Wackernagel, M., and Wrbka, T. 2004. "Editorial: Land use and sustainability indicators. An introduction" Land Use Policy 21 (2004) 193–198.

Another instance of constructive critique concerns our early treatment of nuclear electricity. In the initial National Footprint and Biocapacity Accounts, we made an arbitrary decision to treat nuclear energy as if it were produced by coal. This choice was motivated by a desire to remain neutral and avoid the Footprint being used in debates for or against nuclear power. However, this approach was scientifically flawed, as it did not accurately reflect the underlying research question.

Beginning with the 2008 edition, we revised the methodology. National Footprints now account for nuclear energy only through its direct biocapacity demands—primarily the carbon emissions associated with plant construction, fuel extraction, processing, and waste management. Due to data limitations, we do not yet include the biocapacity losses caused by exclusion zones following accidents, such as those at Chernobyl and Fukushima. These losses can be substantial over time.

At the same time, we emphasized that the Ecological Footprint is not the most appropriate framework for evaluating the risks and benefits of nuclear energy. More relevant considerations include financial costs, operational safety, long-term waste storage, and proliferation risks.[9]

For many more examples of how criticism has helped improve Ecological Footprint accounting see Section 5.

- Haberl, H., Wackernagel, M., Krausmann, F., Erb, K.-H., Monfreda, C., 2004. "Ecological Footprints and Human Appropriation of Net Primary Production: A Comparison." Land Use Policy, 21 (2004) 279–288.
- Krausmann, F., Haberl, H., Erb, K.-H., Wackernagel, M, 2004. "Resource flows and land use in Austria 1950-2000: Using the MEFA framework to monitor society-nature interaction for sustainability." Land Use Policy, 21 (2004) 215–230.
- Monfreda, C., Wackernagel, M., Deumling, D., 2004. "Establishing national natural capital accounts based on detailed ecological footprint and biological capacity accounts." Land Use Policy, 21 (2004) 231–246.
- Wackernagel, M., Monfreda, C, Erb, K.-H., Haberl, H., Schulz, N.B. 2004. "Ecological Footprint time series of Austria, the Philippines, and South Korea for 1961-1999: Comparing the conventional approach to an actual area demand approach." Land Use Policy, 21 (2004) 261–269.
- Wackernagel, M., Monfreda, C., Schulz, N.B., Erb, K.-H., Haberl, H., Krausmann, F. 2004. "Calculating national and global ecological footprint time series: Resolving conceptual challenges." Land Use Policy, 21 (2004) 271–278.

[9] For more discussion on the nuclear dimension, consult: - Wackernagel, M., A. Galli, L. Hanscom, D. Lin, L. Mailhes, T. Drummond (2018), CHAPTER 33: Ecological Footprint Accounts: Criticisms and Applications" p521-539 in Simon Bell and Stephen Morse (Editors) 2018. Routledge Handbook of Sustainability Indictors, Routledge International Handbooks. Routledge, https://www.routledgehandbooks.com; a pre-publication draft is here.

What this briefing document covers

If you have further questions or comments, please do not hesitate to send them to Global Footprint Network at info@footprintnetwork.org and include CRITICISM in the subject heading.

SECTION 1: Should Footprint Accounts be trusted?

Don't trust. Test and verify.

The important question is not whether Ecological Footprint accounts should be trusted by default. The question is whether they help answer a critical sustainability challenge better than available alternatives, and whether they improve our ability to make sound decisions about investing in a successful future.

Any quantitative assessment, including Ecological Footprint accounting, should be evaluated through four sequential questions:

1. **Does the assessment address a clearly defined and testable research question?**
2. **Is that research question relevant to its intended audience?**
3. **Are there more accurate methods available to answer the same question?**
4. **If not, would society be better off without the information this method provides, for example because the results are too misleading?**

Following these steps helps determine whether a method's results are useful and actionable.

Understanding Different Types of Criticism

These questions also help distinguish between three fundamentally different forms of criticism:

- **Criticism of the underlying concept**
  For example, whether biocapacity is a useful lens for understanding humanity's dependence on ecosystems.
- **Criticism of the measurement methodology**
  For example, whether the National Footprint and Biocapacity Accounts appropriately translate the concept into a measurable framework.
- **Criticism of implementation and data quality**
  For example, whether the methodology is executed accurately given existing data limitations.

Keeping these distinctions clear is essential when evaluating any sustainability metric.

The Core Research Question

Ecological Footprint accounting is built around a simple question:

How much of the biosphere's regenerative capacity is required to support a particular human activity? More specifically: **How much of the planet's (or a region's) biocapacity is needed to provide the resources and ecological services demanded by a defined activity?**

This question lies at the heart of Ecological Footprint accounting (Wackernagel et al. 2018a, 2018b; Wackernagel et al. 2019). Given that human demand is currently exceeding our planet's ability to regenerate, this issue is highly relevant to humanity's long-term prospects.

Measuring Regenerative Capacity (or Biocapacity)

In principle, regenerative capacity could be assessed using **potential net primary productivity**. Under such an approach, one would estimate:

- How much area is required to satisfy a particular demand; and
- How productive that area is relative to the global average, based on its potential biological productivity.

This would be an ideal approach. However, no reliable global dataset currently exists for potential net primary productivity. As a result, country-level Footprint assessments continue to rely on the FAO's **Global Agro-Ecological Zones** **(GAEZ)** dataset.

The National Footprint and Biocapacity Accounts

The most comprehensive country-level implementation of Ecological Footprint accounting is the **National Footprint and Biocapacity Accounts (NFBA)**. These accounts are based primarily on United Nations statistical datasets.

The methodology has been extensively documented in the scientific literature, including:

- Lin et al. (2018)
- Borucke et al. (2013)
- Wackernagel et al. (1999)
- Wackernagel et al. (2002)

Additional papers, handbooks, and methodological resources are available in the reference section and through Global Footprint Network's data resources as well as, increasingly through FoDaFo and its affiliates.

Independent Reviews and Reproducibility

Ecological Footprint accounts have been reviewed by more than ten national governments. Several government agencies have independently reproduced the accounts, including rebuilding historical time series from the underlying data.

These independent reproductions successfully replicated the published results. Information about these reviews is available at Global Footprint Network Reviews.

The National Footprint and Biocapacity Accounts are publicly available through the Footprint Data Platform.

The latest edition was released in 2026. It includes data points through 2025, while complete results are currently available through 2023, the most recent year for which a complete UN dataset exists.

What About the Criticisms?

Like any scientific framework, Ecological Footprint accounting has attracted criticism. Global Footprint Network actively studies these critiques, and some have led to improvements in both methodology and communication.

For readers seeking an introduction to the debate, Global Footprint Network was invited to contribute a discussion of common critiques and responses in:

- *Ecological Footprint Accounting and Its Critics* (GreenBiz article)

A more detailed treatment is provided in Wackernagel et al. (2018b).

Methodological uncertainty has also been examined in academic research. For example, Jóhannesson's 2021 Ph.D. dissertation focuses specifically on uncertainties associated with Ecological Footprint standards and accounting methods (Jóhannesson 2021).

In conclusion, the credibility of Ecological Footprint accounting should not be judged on trust alone. Instead, it should be evaluated by the same standards applied to any scientific assessment, and more particularly through the four sequential test questions introduced above. These questions will also guide the discussion in the following sessions for readers to determine whether Ecological Footprint accounting offers a sufficiently transparent and widely scrutinized approach for quantifying humanity's demand on the regenerative capacity of the biosphere.

SECTION 2: Why Ecological Footprint accounts are needed

Our argument is simple: there is no viable future for any country, or for humanity as a whole, other than eventually living on nature's regeneration rather than its liquidation. The only real choice we have is **how quickly people make that transition**.

The sooner people adapt, the more natural capital will remain available, and the easier it will be to operate within the planet's ecological budget. Early action also brings significant practical advantages. Countries, cities, and businesses that prepare sooner can adapt their infrastructure, energy systems, and investments before ecological constraints become more severe. They will face fewer stranded assets and be better positioned to thrive in a resource-constrained world.

In this sense, sustainability is not only an environmental challenge. It is increasingly a question of **competitiveness**.

The Importance of Resource Security

A clearer focus on **resource security**, particularly the security of biological resources, can make the need for this transition more tangible (Wackernagel et al. 2021).

Ecological Footprint accounting is currently the only comprehensive accounting framework that compares humanity's total demand on the biosphere, including carbon emissions, with what the biosphere can regenerate. It provides a fundamental resource balance: a comparison between the scale of human demand and the planet's capacity to renew the resources and ecological services on which that demand depends.

This perspective helps reveal the degree to which economies, countries, and communities depend on ecological assets that may be under increasing pressure.

Why Metrics Matter

Metrics alone do not drive transformation. Nor are they the only ingredient needed for change.

However, it is difficult to imagine an effective transition without clear and credible ways of measuring progress. Metrics help us understand:

- Where we are today;
- How rapidly conditions are changing;
- Whether we are moving in the right direction; and
- How far we still have to go.

Without measurement, managing a transition becomes largely a matter of guesswork.

Building Ecological Literacy

To support this need, Global Footprint Network has developed and continuously improved one of the world's most comprehensive accounting systems for comparing human demand with Earth's regenerative capacity.

These accounts are intended to strengthen ecological literacy by making humanity's dependence on nature visible, measurable, and understandable.

The Need for a Metric that Can Link Human Activity to Planetary Constraints

Without a metric that evaluates performance against the ecological limits of a single planet, there can be no meaningful assessment of whether humanity is moving toward sustainability.

Such a metric enables:

- Accountability;
- Progress tracking;
- Goal setting;
- Policy evaluation; and
- Comparison across countries, cities, organizations, and populations.

In this sense, living within the means of one planet represents the ultimate science-based target. Understanding whether demand exceeds nature's capacity to regenerate is essential for assessing current conditions, identifying trends, and evaluating long-term success.

Supporting Better Decisions

The Footprint and biocapacity accounts, which are publicly available to governments, cities, businesses, researchers, and citizens, help identify ecological dependencies and potential resource risks.

By providing a consistent picture of demand and regenerative capacity, these accounts support more informed decisions and help organizations manage their transition toward a future that can be sustained by the planet's available resources.

SECTION 3: Ecological Footprint Accounts – A Short Introduction to the Underlying Accounting Principles

Ecological Footprint accounting compares two sides of the same balance sheet:

1. **Biocapacity**: the regenerative capacity of ecosystems.
2. **Ecological Footprint**: humanity's demand on that regenerative capacity.

The Ecological Footprint measures the biologically productive areas required to provide the resources people use and absorb the waste they generate. These demands include:

- Food production
- Fiber production[10]
- Timber and forest products
- Built infrastructure
- Waste absorption.

The largest portion of humanity's current Ecological Footprint is the regenerative capacity needed to neutralize the excessive greenhouse gases from burning fossil fuels.[11] Note that the current National Footprint and Biocapacity Accounts only include the carbon dioxide (CO_2) portion that is released through the combustion of fossil fuels, while other waste streams are excluded for lack of complete data sets.

A key accounting principle is that only **mutually exclusive uses of productive space**[12] are counted. A hectare of land used to grow crops cannot simultaneously function as a productive forest. By focusing on competing claims on biologically productive areas, the different demands can be added together without double counting.

This makes it possible to compare:

- **Human demand on nature** (Ecological Footprint), and

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[10] For instance, for clothes, paper, or building materials.

[11] See data.footprintnetwork.org or Lin, David; Hanscom, Laurel; Murthy, Adeline; Galli, Alessandro; Evans, Mikel; Neill, Evan; Mancini, Maria S.; Martindill, Jon; Medouar, Fatime-Zahra; Huang, Shiyu; Wackernagel, Mathis. 2018. "Ecological Footprint Accounting for Countries: Updates and Results of the National Footprint Accounts, 2012–2018." *Resources* 7, no. 3: 58. https://www.mdpi.com/2079-9276/7/3/58

[12] Mutually exclusive means that only those uses that exclude other uses are counted. Otherwise, there is double counting. For example, if potatoes are grown on a field, the same space cannot be occupied by a forest at the same time. The two uses mutually exclude each other.

- **Nature's regenerative capacity** (biocapacity)

using a common unit.

The Global Hectare

Both Ecological Footprint and biocapacity are expressed in **global hectares (gha)**.

A global hectare represents one hectare of biologically productive area with world-average productivity in a given year. Using productivity-adjusted hectares makes it possible to compare:

- Different regions of the world,
- Different land-use types, and
- Different years.

In essence, Ecological Footprint accounting asks a straightforward question: *How much biologically productive area is required to meet human demand, and how does that compare with the biologically productive area available?* Because of seasonal variations, it typically makes the most sense to assess this on a yearly basis.

The accounting framework itself is deliberately simple: it adds together competing demands on biocapacity and compares those demands to the capacity of ecosystems to regenerate.

For country-level assessments, the National Footprint and Biocapacity Accounts are calculated almost entirely from official UN data sources, providing a consistent and transparent basis for comparison.

Overview of Strengths and Limitations

Like any accounting framework, Ecological Footprint accounts have both strengths and limitations. Section 4 provides more detail.

Their ***strength*** lies in providing an integrated picture of humanity's demand on nature. They make it possible to compare diverse forms of resource use within a single framework and reveal whether overall demand exceeds ecological regeneration.

Their ***limitation*** is that they are not designed to answer highly specific environmental questions. For example, they are not intended to evaluate:

- Household water consumption,
- Plastic pollution pathways,
- Soil microbial health,
- Species-specific biodiversity impacts, or

- Other highly specialized environmental issues.

Such questions require more targeted tools and indicators.

Rather than replacing specialized metrics, Ecological Footprint accounting provides context for them. It helps place climate change, land use, forestry, food systems, and other environmental pressures within a common framework of ecological demand and regeneration.

If humanity is serious about addressing climate change, the challenge is not only to reduce greenhouse gas emissions but also to operate within the regenerative capacity of the planet. In a post-fossil-fuel future, long-term prosperity must ultimately be supported by ecological regeneration and renewable energy flows rather than by the depletion of natural capital. [13]

This section provides some key results for context, and then addresses three conceptual issues:

3a) Ecological Footprint accounts – key numbers

Earth's surface stretches over 51 billion hectares.[14] According to FAO, of these hectares, 12.2 billion harbour the majority of the biological productivity area, including continental shelves of oceans, forests, and cropland. Given that global hectares represent world average productive hectares, these 12.2 billion hectares are also worth 12.2 billion **global hectares**. In other words, each global hectare represents about a 12.2 billionth of the planet's regeneration.

Footprint accounting is possible at any scale, from humanity's total demand on nature down to the demand of a country, city, individual or a single activity. Details on Ecological Footprint and biocapacity accounting can be found in the reference section of this document under "More on the Ecological Footprint".

[13] Yes, there are also some other minor energy budgets, including lunar energy by harnessing tidal flows, fusion and fission.

[14] In the aftermath of the French Revolution, the French defined the kilometer as a 10 000th of the distance from the Equator to the North pole, or a 40 000th part of the length of the circumference of the planet. The initial measure in 1799, was about 0.02% off. Still assuming a circumference of 40 000 km implies a spherical surface of $4 * \pi * r^2$ = 50.9 billion hectares.

Global Footprint Network has maintained national calculations since the organization's inception in 2003 by building on earlier ones starting in 1997, the first one being produced for the Rio+5 report in 1997 (Wackernagel et al. 1997). The annually updated calculations are called National Footprint and Biocapacity Accounts and are entirely based on UN data sets. All results are available on an open data platform (data.footprintnetwork.org). The latest edition of these accounts, published in 2026, and extended to 2026 when estimating Earth Overshoot Day, [15] show that today, humanity's demand exceeded the planet's biocapacity by 73%.[16]

Why the Estimate Is Likely Conservative

Importantly, the results National Footprint and Biocapacity Accounts produce are likely to understate rather than overstate the extent of ecological overshoot. This directional bias arises because both sides of the calculation tend to make overshoot appear smaller than it actually is.

Since the UN datasets do not include all aspects of consumption, the Footprint results are most likely underestimates. The data also does not document all depletion of nature's assets. As a result, the biocapacity numbers most likely overestimate the real situation. In consequence, humanity's actual overshoot is in all likelihood larger than what the National Footprint and Biocapacity Accounts document.

This directional bias deserves emphasis, because it is systematic and explainable, not a shrug of uncertainty. The National Footprint and Biocapacity Accounts are deliberately built almost entirely on official UN and para-UN statistics. That is a design choice, not a limitation stumbled into: relying on a single, neutral, third-party data source is what allows the accounts to avoid any accusation of cherry-picking data to dramatize the result. But that same discipline has a predictable consequence. Official statistics register what has been measured and reported, not the full extent of what is actually occurring. Building on them pulls the results toward understating overshoot, never toward overstating it.

Both sides of the ledger move towards underestimating overshoot. On the demand side, the Ecological Footprint still leaves out real, competing pressures on nature that current data sets do not yet capture, particularly at the county level since some data is not included in UN and UN-affiliated data sets. For other aspects, data may not be complete or is hard to allocate to

[15] Earth Overshoot Day is calculated as the day in the year when human demand exceeds, for the year, what Earth can renew in the entire year. This means that the amount humanity demands from nature from January 1 to that day is as much as Earth's ecosystems renew in the full year.

[16] For details, consult David Lin and Mathis Wackernagel's "Estimating the Date of Earth Overshoot Day 2026" Global Footprint Network's National Footprint and Biocapacity Accounts 2026 edition www.footprintnetwork.org – key results at data.footprintnetwork.org ; for explanations, consult papers in the reference section. You can also download the free public data set, a rich, searchable workbook, from Global Footprint Network's webpage at https://www.footprintnetwork.org/licenses/public-data-package-free

final demand as in the case of methane. Livestock, landfills, rice paddies, and fossil fuel operations release large volumes of methane, but methane is not yet built into the Footprint accounts. It could be translated into the same global hectares used for CO_2, by translating methane amounts into a CO_2 equivalent. If done, then methane alone would likely add on the order of 15 percent to humanity's Ecological Footprint, equivalent to roughly a quarter of an additional Earth of demand (for an established approach to incorporating methane into Footprint accounting, see Walsh, O'Regan and Moles 2009). Toxic pollution and other undocumented demands such as informal hunting or firewood collection, work the same way: real, but not yet counted.

On the supply side, biocapacity is if anything more overstated. The accounts currently assume forests regenerate at historical average rates, an assumption that is increasingly out of date. Wildfires, such as Canada's recent record fire seasons, and pest outbreaks are pushing large forest areas from net carbon sinks toward net carbon sources, meaning they now absorb less than the accounts assume, not more. Freshwater-dependent biocapacity such as irrigated cropland carries a related risk: in drier regions, water stress can undercut the very productivity the accounts assume will continue uninterrupted. The Aral Sea remains the starkest illustration of how fast this can unfold, though robust global figures for this specific effect do not yet exist; this is an area we flag for further research rather than a claim we are prepared to quantify today.

None of this weakens the finding. It rather sharpens it. When the demand-side and supply-side biases both point the same direction, true overshoot is larger than the headline number, not smaller. This is why Global Footprint Network treats the published results as a conservative floor rather than a worst case, and why we would rather understate our case than be accused of overstating it.

3b) Indices versus accounts

Accounts such as these are distinct from multi-dimensional indices (such as Environmental Performance Index, SDG-Index or Sustainable Society Index etc.), since the latter are, by nature, arbitrary scoring systems based on their architects' constructed aggregation approach (giving subjective weights to diverse aspects), rather than being driven by a clear, testable research question. Other accounts in the sustainability domain are (as distinct from multi-dimensional indices) GDP, greenhouse gas inventories, virtual water in trade, or the Living Planet Index, all of which emerge from a clear research question.

Several metrics exist for assessing the material dependence or environmental performance of human economies. The primary ones are based on overall mass flows, greenhouse gases (in CO_2 equivalent, or sometimes only CO_2, typically expressed in tonnes per year), dollars, energy, biomass, land areas, bioproductivity, and planetary boundaries. Only accounting systems are discussed herein, i.e., metrics that are based on clear research questions and, hence, are built on clearly defined, testable aggregation principles. Therefore, this paper excludes indices with arbitrary aggregations, such as the Environmental Performance Index,[17] SDG-Index,[18] Human Influence Index,[19] Biodiversity Intactness Index,[20] and others. Such indices, while potentially useful in different contexts outside the domain of scientific inquiry, are not viable for comparing human demand against ecosystem regeneration, since they are not based on a clear research question and reflect their author's scoring preferences rather than scientific principles.

3c) Comparison to other measurement units to quantify human demand on nature

Other metrics also exist to measure human demand on nature. This section, building on Wackernagel et al. (2019), briefly explains the benefit of using biocapacity as the lens when comparing human demand against nature's capacity to renew.

- **Kilograms** can be used as a unit to measure mass flows. Describing mass flows of resources in kilograms (or more precisely in kilograms per year) seems precise. But there are several problems. **A)** Demand on nature per kilogram is vastly different between materials, and sometimes even for the same material. Consider the difference in the demand on nature of removing 1 tonne of water in a relatively wet country like Finland to 1 tonne of water in a relatively dry country like Jordan. Certainly, removing 1 kg of birds is of bigger significance than moving 1 kg of rocks. Further, when comparing biomass, there can be confusion between wet or dry weight. **B)** There is arbitrary exclusion. For instance, Material Footprint accounts exclude air and water flows. Furthermore, among other material flows it is not so clear what should be excluded or not. Ploughing? Earth compacted by a tractor? Moving

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[17] Esty, D.C.; Emerson, J.W. Chapter 5: From crises and gurus to science and metrics: Yale's Environmental Performance Index and the rise of data-driven policymaking. In Routledge Handbook of Sustainability Indicators; Bell, S., Morse, S., Eds.; Routledge: New York, NY, USA, 2018; pp. 93–102, ISBN 978-1-138-67476-9.

[18] Sachs, J.; Schmidt-Traub, G.; Kroll, C.; Lafortune, G.; Fuller, G. SDG Index and Dashboards Report 2018; Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN): New York, NY, USA, 2018; p. 476 or www.sdgindex.org . A paper on what the SDG Index obscures is here: Wackernagel, Mathis, Laurel Hanscom and David Lin (2017) Making the Sustainable Development Goals Consistent with Sustainability. Front. Energy Res. 5:18. doi: 10.3389/fenrg.2017.00018 http://journal.frontiersin.org/article/10.3389/fenrg.2017.00018/full

[19] Sanderson, E.W.; Jaiteh, M.; Levy, M.A.; Redford, K.H.; Wannebo, A.V.; Woolmer, G. The Human Footprint and the Last of the Wild. The human footprint is a global map of human influence on the land surface, which suggests that human beings are stewards of nature, whether we like it or not. BioScience 2002, 52, 891–904.

[20] Purvis, A.; Newbold, T.; De Palma, A.; Contu, S.; Hill, S.L.L.; Sanchez-Ortiz, K.; Phillips, H.R.P.; Hudson, L.N.; Lysenko, I.; Börger, L.; et al. Chapter Five-Modelling and Projecting the Response of Local Terrestrial Biodiversity Worldwide to Land Use and Related Pressures: The PREDICTS Project. In Advances in Ecological Research; Bohan, D.A., Dumbrell, A.J., Woodward, G., Jackson, M., Eds.; Next Generation Biomonitoring: Part 1; Academic Press: Cambridge, MA, USA, 2018; Volume 58, pp. 201–241.

rocks on a field? Terracing a mountain slope? Moving trains? What about the roots of the cut trees left in the forest; the leaves? **C)** There are no clear upper limits for mass flows, reducing this approach's utility for measuring environmental limits. Some publications claim that eight tonnes of material Footprint per person and per year is a sustainable level,[21] but this number is based on a declaration not scientific deduction.[22] For these reasons, assessments based on mass flow are not well suited to compare human demand against regeneration.

- **CO_2 emissions** include carbon dioxide released from burning fossil fuel, producing cement, or changing land-use patterns. **CO_2 equivalents** are broader as it aggregates all gases, including CO_2, on the basis of their global warming potential. Human induced emissions of carbon and other greenhouse gases are increasingly tracked given their growing climate impact and that their concentrations in the atmosphere are rising. Emissions can be compared to the upper emission limit, which in turn is a function of what temperature increase humanity is able to tolerate. Even with a temperature limit set by the Paris Agreement of "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels",[23] there is great discrepancy in the literature about how much carbon is left to emit. Some, like NOAA, conclude that humanity is facing a *negative* budget if humanity wants to achieve the Paris goal.[24] Others, like Figueres et al.,[25] estimate a remaining CO_2 budget of between 150 and 1050 Gigatons. Given this uncertainty, and the fact that greenhouse gas emissions are not the complete set of competing demands on the

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[21] Lettenmeier, M.; Liedtke, C.; Rohn, H. Eight Tons of Material Footprint—Suggestion for a Resource Cap for Household Consumption in Finland. *Resources* 2014, 3, 488–515. Or Stefan Bringezu. Visions of a sustainable resource use. pp. 155–215 in Bringezu, S., Bleischwitz, R., Eds, 2017. *Sustainable Resource Management: Global Trends, Visions and Policies*. Routledge: New York, NY, USA, 2017, ISBN 978-1-906093-26-6.

[22] In his paper "Possible Target Corridor for Sustainable Use of Global Material Resources" (*Resources* 2015, 4, 25-54; doi:10.3390/resources4010025) Stefan Bringezu explains that Factor 10 scientists postulated that "very large flows of resources occur naturally, either from volcanoes or land erosion or other biosphere processes. Together these flows amount to some 50 billion tons per year, although more research is required to establish a precise number". They argued that "human induced flows of resources into the economy" should not exceed natural flows by a factor of 2 and therefore should be reduced by a factor of 2. "Assuming seven billion people on planet Earth (...) that would result in an allowance of about 6 to 8 tons per capita per year"" This may be the right magnitude, but one could also argue that the composition of these flows matters a lot.

[23] UNFCCC Paris Agreement 2015. https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[24] Butler, J.H.; Montzka, S.A. The NOAA Annual Greenhouse Gas Index (AGGI); NOAA Earth System Research Laboratory: Boulder, CO, USA, 2020. https://www.esrl.noaa.gov/gmd/aggi/aggi.html

[25] Figueres, C.; Schellnhuber, H.J.; Whiteman, G.; Rockström, J.; Hobley, A.; Rahmstorf, S. Three years to safeguard our climate. *Nature* 2017, 546, 593–595. https://www.nature.com/news/three-years-to-safeguard-our-climate-1.22201

biosphere, emissions of CO_2 or CO_2 equivalents are also not fit to fully answer the question of how much people use compared to how much Earth's ecosystems can regenerate.

- **Monetary currencies**, such as US dollars or Euros, are useful as an accounting unit for comparing human activities but cannot link human demand to biological regeneration. As the value of dollars can change from year to year due to inflation, accounts can also be expressed in constant dollars. Further, the same financial amount represents dissimilar values to different people. This is recognized by UNDP / United Nation Development Programme's Human Development Index (HDI). There, the income dimension, one of the index's three pillars, is measured as the logarithm of people's financial income. (The other two pillars are longevity and access to basic education[26]). Additionally, the same monetary unit can purchase different amounts of goods in different markets. Monetary amounts can be made comparable by adjusting them according to their purchasing power. This translation is called purchasing power parity [ppp]. Any currency can be converted into other countries' local currency, with conversion rates changing daily. Still, with all this variance, monetary units, in local currencies or expressed in US Dollars, can be a useful measure of comparison at the micro scale. For instance, it can reveal social preferences such as pursued by The Economics of Ecosystems and Biodiversity (TEEB) when comparing project options in their effort to "mainstream the values of biodiversity and ecosystem services into decision-making". However, financial assessments do not compare resource use against regeneration. Moreover, at the macro level, financial metrics become problematic, as dollars reflect market preferences, not ecological necessities or regeneration. The two leading studies that financially value natural capital at a macro scale vastly underestimate the significance of natural capital vis-à-vis other capital assets. They are *Changing Wealth of Nations* by the World Bank (2011/2018), and *Inclusive Wealth Report* by UNU (2012/2018). The former study concludes that the value of the planet, as a percentage of humanity's total assets, only accounts for 9% of humanity's total wealth. We believe this likely understates the importance of natural capital given that all wealth depends on natural capital, and that there is wide recognition that the planet's natural capital is overused. These financial valuations do not recognize the importance of ecosystem regeneration in meeting humanity's material demands. Essentially, they do not help us detect the massive overshoot and may give the impression of natural capital's substitutability.

- **Energy units** can be defined precisely and measured in a lab but are highly ambiguous for describing flows through ecosystems or societies because of entropy cascades. For instance, the sun's 175,000 TW (or Terawatt) of solar radiation onto Earth generates approximately 70 TW of Net Primary Productivity (NPP) on the land and more if including the NPP of the

[26] United Nations Development Programme 2016 Human Development Report: Human Development for Everyone; 2016. Or United Nations Development Programme. Human Development Indices and Indicators: 2018 Statistical Update; United Nations Development Programme: New York, NY, USA, 2018; p. 123.

oceans (half of that NPP is currently used to produce about 1 TW of food)[27]. Of the land-based NPP, 1/3 or more is used for generating about one TW of food calories for people.[28] This energy cascade illustrates the stark difference of one TW solar radiation and one TW of food. Thus, energy, as common denominator, can lead to confusion. The closest to a consistent energy accounting approach that includes the quality of energy is Odum's eMergy calculation.[29] However, the commonly published conversion factors ('transformaties') that translate final use back into solar input are not robust.[30]

- **Biomass balances** (whether expressed in tonnes of carbon, dry matter, or energy content) as used in Net Primary Production (NPP) assessments and the complementary Human Appropriation of NPP (HANPP) are very closely related to the question of human demand and regeneration.[31] The challenge is that demand as measured by HANPP cannot be compared with clarity to available regeneration, nor can a sustainable level of NPP extraction be clearly defined, let alone measured. Studies that compare the two come up with wide ranges of answers, for definitional reasons, as well as measurement challenges.[32] While NPP assessments are undoubtedly an important tool, particularly to evaluate intensity of biological uses,[33] they have limited power to robustly track demand against regeneration. **Note**: Ecological Footprint accounting builds on the NPP approach by taking a more agricultural perspective. This means it focuses not on all plant matter but on the

[27] This is based on the calculation that the global Food Footprint as assessed by Global Footprint Network's MRIO analysis indicates that Food consumption occupies a Footprint of slightly more than half of the planet's biocapacity.

[28] Haberl, H.; Erb, K.-H.; Krausmann, F. Global human appropriation of net primary production (HANPP). Encycl. Earth 2013. https://editors.eol.org/eoearth/wiki/Global_human_appropriation_of_net_primary_production_(HANPP)

[29] Odum, H.T. Environmental Accounting: Emergy and Environmental Decision Making; Wiley: Hoboken, NJ, USA, 1996; ISBN 978-0-471-11442-0. Or Brown, M.T.; Ulgiati, S. Emergy and Environmental Accounting. In Encyclopedia of Energy; Cleveland, C., Ed.; Elsevier: New York, NY, USA, 2004.

[30] The numbers provided in the eMergy literature estimate the embodied solar energy in various flows through ecosystems and the human economy. Given the massive energy cascade from sun to product, assumptions for such calculations are often heroic, For instance, the eMergy attributed to wind seems excessively high.

[31] Haberl, H., Wackernagel, M., Krausmann, F., Erb, K.-H., Monfreda, C., 2004. "Ecological Footprints and Human Appropriation of Net Primary Production: A Comparison." Land Use Policy, 21 (2004) 279–288.

[32] Rojstaczer, S.; Sterling, S.M.; Moore, N.J. Human Appropriation of Photosynthesis Products. Science 2001, 294, 2549–2552. https://science.sciencemag.org/content/294/5551/2549

[33] Measuring in addition to Footprint extension the intensity of use of those areas complements Ecological Footprint accounting, which only tracks mutually exclusive areas. In other words, it would be valuable, once an Ecological Footprint assessment is done, to further evaluate each component on the intensity of use. One particular "intensity" angle could be "biodiversity friendliness" of the occupied area. For instance, a mono-cropping area may be highly productive, but devastating for biodiversity. In contrast, sustainably harvested forest that also include high biodiversity value as part of their management scheme may represent a benign use of areas. The former could be colored a red Footprint, and the latter a green one.

particular kind that is demanded by people. For instance, timber demand can be compared with sustainable yields for timber of forests. By using this agricultural lens, it is possible to offer sharper comparisons between demand and regeneration. Ecological Footprint accounts can also be more comprehensive than NPP assessments as they also include greenhouse gases (or at least CO_2 from fossil fuel and cement production in the case of the National Footprint and Biocapacity Accounts). Agricultural comparisons also become more meaningful across land types. For instance, crop land is typically the most productive land, but it is not managed for highest net primary productivity, therefore undervalued in NPP accounts.

- **Hectares** can be used to compare human demand for productive hectares to hectares available. Unfortunately, not every hectare represents the same biological productivity: just consider the biological productivity of one hectare of a rocky mountain slope, a tundra forest, a tropical rain forest, or a highly fertile cropland in river basin.

- **Global hectares** are productivity adjusted hectares. Each unit represents a biologically productive hectare with world average productivity. This equivalence makes the unit convenient for biocapacity accounting.[34] Biocapacity is the biologically productive area that provides ecological services. All human demands on those surfaces that compete for space can therefore be added up. This more agriculturally-based metric is straightforward. It builds on established agronomical practices to measure harvested crops and yields. As productivity changes annually (because of technological innovations, climate change, shifts in management practices, etc.), the global hectare changes accordingly. The sum-total of productivity-adjusted areas representing all of people's competing demands on nature can then be compared against available areas (also expressed in productivity adjusted hectares).

In conclusion: among all the discussed approaches that map human demand on nature using differing lenses, biocapacity accounting based on "global hectare units" seems to be the most relevant metric for comparing human demand against ecosystem regeneration. In fact, the ability to map human demand ***against*** ecosystem regeneration stands out as Ecological Footprint accounting's particularly useful advantage.

There are also several complementary approaches, two of which are discussed in section 3d below.

[34] Wackernagel, M., A. Galli, L. Hanscom, D. Lin, L. Mailhes, T. Drummond (2018), CHAPTER 16: Ecological Footprint Accounts: Principles" p244-264, in Simon Bell and Stephen Morse (Editors) 2018*. Routledge Handbook of Sustainability Indictors*, Routledge International Handbooks. For a draft see here.

3d) Complementary approaches: Planetary Boundaries and Doughnut Economics

The **Planetary Boundaries**[35] approach identifies key physical conditions that are needed to maintain the integrity of the biosphere. It identifies nine environmental areas where transgressions could lead to shifts that would irreversibly move the biosphere out of the stable conditions which characterized the Holocene ("tipping points"). They are:

- Stable climate
- Intact biodiversity
- Sufficient nutrients (but no overload)
- Protective ozone layer
- Absence of pollutants
- Clean and sufficient fresh water
- Stable and fertile soils
- Absence of acidification in both water and soils

These are the necessary conditions for healthy, productive ecosystems that can maintain their integrity. Hence, they enable the biosphere's ability to regenerate, i.e., its "biocapacity". For each condition (or each of the 9 "planetary boundaries"), the Planetary Boundaries approach employs metrics. Typically, they compare flows, but they can also address stocks – like current concentration of greenhouse gases compared to what is tolerable by the biosphere without triggering a phase shift. This means that these metrics do not measure regeneration *per se*, but attempt to identify the distance from "a safe zone".

In contrast to Ecological Footprint accounts, the Planetary Boundaries approach does not offer an aggregate measure to show the compound effect, or trade-offs among those nine domains. Nor is this approach geographically explicit. While biocapacity can be scaled down to every single hectare, Planetary Boundaries makes the case for the biosphere as a whole system.

Still, the Planetary Boundaries approach is related to the question of how big the human demand is compared to ecosystem regeneration. Yet it does not offer an overarching metric to provide an overarching quantification beyond warning signs for each domain, and that only at the planetary level.

Doughnut Economics, introduced by Kate Raworth, has playfully advocated for a "safe and just operating space". This refers to a way of living that is ecologically safe by not overusing the

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[35] Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin, F.S., III; Lambin, E.F.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; et al. 2009. A safe operating space for humanity. *Nature*, 461, 472–475. www.nature.com/articles/461472a **Also**: Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; de Vries, W.; de Wit, C.A.; et al. 2015. Planetary boundaries: Guiding human development on a changing planet. *Science*, 347, 1259855. https://science.sciencemag.org/content/347/6223/1259855

planet, while also providing a fair and equitable opportunity for all to thrive. She depicts the sustainable development challenge as a two-dimensional doughnut, the inner edge representing the minimal social foundation and the outer edge the upper ecological ceiling.[36] Therefore, the inner part of the doughnut corresponds to the "safe and just operating space," the same space depicted as the blue "global sustainable development" box in the upper right corner of the HDI-Footprint diagram. The clever depiction of a doughnut inspired Raworth to proclaim "doughnut economics," an economic theory that has the goal of supporting human wellbeing within the constraints of our planet.

There is no specific metric associated with Kate's doughnut. Often, she refers to Planetary Boundaries as the upper one and a multi-dimensional wellbeing metric for the inner one. The HDI-Footprint diagram is useful as it allows to depict results for cities, individuals, or countries, as well as trends over time.[37] It also represents all four possibilities (low/high Footprint, low/high wellbeing), while the doughnut only shows three of those (inside inner circle, between circles, outside outer circle). The fourth one (high Footprint, low well-being), potentially the most tragic one in the context of securing wellbeing for all within planetary constraints, does not appear in the doughnut.

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[36] Kate Raworth. 2017. Doughnut Economics: Seven Ways to Think Like a 21st Century Economist. Chelsea Green Publishing.

[37] Note that the simplicity of the doughnut leaves out some possible combinations. In reality, there are four possible states: low/high Footprint, low/high wellbeing makes four possible combinations. In this case, low Footprint per person would be one lower than the biocapacity available on the planet per person.
The doughnut only depicts three of them given its geometric nature (inside inner circle = low well-being & low Footprint; between circles = high well-being & low Footprint; outside outer circle = high well-being & high Footprint). The fourth one (high Footprint, low well-being), as explained above, does not appear in the doughnut. However, according to the HDI-Footprint analysis, it is increasingly common for countries to be in that quadrant. This is the most challenging and ultimately heartbreaking quadrant to address as it already depends on a resource dependence that is not globally replicable, yet its human development is not high.

SECTION 4: Strengths and limitations

Main Advantages of Ecological Footprint Accounting

- Ecological Footprint accounts are an established methodology: they are based on simple accounting principles. The accounts have been produced and updated for over 25 years. During that time, both the accounting framework and the underlying datasets have matured significantly, resulting in increasingly robust and consistent assessments.
- One of the greatest strengths of Ecological Footprint accounting is its use of biology as the organizing lens for sustainability. Like Planetary Boundaries and related approaches, Ecological Footprint accounting starts from a simple observation: human demand has grown so large that it increasingly exceeds the biosphere's regenerative capacity. Climate change, biodiversity loss, water stress, and other environmental challenges are different manifestations of this same underlying imbalance. Viewing sustainability through the lens of regeneration offers several advantages:
  - **This biological approach joins all the human pressures**, from water, climate, biodiversity, food, energy, etc., under one roof. This enables us to solve them all together (rather than one at the cost of another). This all-encompassing view also helps build the needed bridge between conservation and climate change.
  - **Biological metrics are understandable**. Very few relate to 2°C, ppm, or tons of carbon (or is it CO_2?). In contrast, even primary school kids understand biological balances (how much we take compared to how much is being renewed), or as done in the case of Ecological Footprint accounting, expressing results in number of Earths, number of countries (Switzerland uses four Switzerlands), the Earth Overshoot Day date, or hectares.
  - **The biological lens reveals "skin in the game"**. In contrast to the 'carbon-only' view, a biological approach makes the company, city, or country's economic best interest clear and obvious. It emphasizes resource security and the risk of not being prepared for each country as resource availability diminishes. To use a blunter analogy, visualizing the emergency as a "storm", it makes little sense to argue: "I will only fix my boat if others fix their boat first", yet that is the dominant strategy in the current climate negotiations. A more comprehensive biological approach helps see climate action as necessary for one's own success, rather than merely noble, i.e., a good deed for humanity. The current climate debate is based overwhelmingly on a "noble argument" ("it is our responsibility to humanity and the future"), leading to timid action. In reality, a country's competitiveness and success depend on aggressive climate action, preparing itself for an inevitable carbon-free future, thereby strengthening its own

resource security (and also, as a side benefit, supporting humanity's sustainability).

- The accounts are of policy relevance because they focus on the most limited resources (biological regeneration or biocapacity) and indicate the overall biocapacity demand of societies compared to resource availability on the planet, or in a region. They directly respond to the European Commission's goal of "living well, within the limits of our planet." Given the climate goal of the Paris Agreement and IPCC's recognition of the need to rapidly phase out of fossil fuel use, the only viable pathway for the future is a regenerative economy that lives off the planet's biocapacity rather than off further depletion. Planning for such an economy requires careful accounting of biocapacity for each country. Recent IPCC and IPBES reports confirm the importance of looking at climate in the context of all demands on the biosphere.
- Geographical and temporal coverage: the indicator has a global coverage and data is available over a long timescale (1961–2023, and updated annually – for some countries, now-casts are available too on request). The core data, strictly based on UN and UN-affiliate sources, is national and allows for aggregations at different physical scales. The indicator can be disaggregated to provide information on specific resources or ecosystems.
- The accounts have been tested by over ten national government agencies. For instance, in 2018 the Swiss Ministry of Environment released its latest review where they recalculated the Swiss results for the time period of 1996 to 2015 and replicated Global Footprint Network results within 1-3% (BAFU, p. 87).
- The Ecological Footprint has reached a wide range of audiences to increase understanding of the size of the human economy compared to the planet. It has also helped to identify the options that exist to reduce people's demand on nature. For example, Earth Overshoot Day 2019 (www.overshootday.org), based on Ecological Footprint accounting, generated over 4 billion documented media impressions, with much reporting on how people can #MoveTheDate.

Main Limitations of Ecological Footprint and Biocapacity Accounting[38]

Several important aspects of sustainable use and management are not measured by the Ecological Footprint or by biocapacity, largely because they are not part of the research question driving the accounts:

[38] For a discussion of limitations also consult European Environment Agency (2020): Ecological footprint of European countries. Its 2024 version is archived here.

- **Non-ecological aspects of sustainability**: Having an Ecological Footprint smaller[39] than the biosphere is a minimum necessary condition for a sustainable society, but it is not sufficient. For instance, the Ecological Footprint does not consider social well-being. In addition, on the resource side, even if the Ecological Footprint is within biocapacity, poor management still can lead to depletion. An Ecological Footprint smaller than biocapacity is merely a necessary condition for making quality improvements replicable and scalable.
- **Depletion of non-renewable resources**: The Ecological Footprint does not track the amount of non-renewable resource stocks such as oil, natural gas, coal, or metal deposits. The Footprint associated with these materials is based on the regenerative capacity used or compromised by their extraction and, in the case of fossil fuels, the area required to assimilate the wastes they generate.
- **Inherently unsustainable activities**: Activities that are inherently unsustainable, such as the release of heavy metals, radioactive materials, and persistent synthetic compounds (e.g., chlordane, PCBs, CFCs, PVCs, dioxins, etc.) do not enter directly into Footprint calculations. These are activities that need to be phased out independent of their quantity (there is no biocapacity budget for using them). Where these substances cause a loss of biocapacity, however, their influence is tracked by complete Footprint and biocapacity accounts, as long as data picks up this damage.
- **Ecological degradation**: The Ecological Footprint does not directly measure ecological degradation, such as deforestation, soil loss, or increased soil salinity from irrigation, which could affect future bioproductivity. However, if degradation leads to reductions in biological productivity, then this loss is captured in subsequent annual measurements of biocapacity. Aggregate numbers also hide local overexploitations in one area that are compensated by 'under exploitation' in another one.
- **Resilience of ecosystems**: Footprint accounts do not identify where and in what way ecosystems are vulnerable or resilient. The Footprint is merely an outcome measure documenting how much people demand compared to what the biosphere regenerates.

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[39] The question also his how much smaller than the entire regenerative capacity of the planet human demand should be. For instance, Prof. E.O. Wilson and his team suggest leaving half the planet's capacity to wild species which might give us a chance to safeguard 85% of the world's biodiversity. For more details see: E.O. Wilson, 2016. *Half-Earth: Our Planet's Fight for Life*. Liveright Publishing Corporation, New York. Or https://www.half-earthproject.org or https://eowilsonfoundation.org/half-earth-our-planet-s-fight-for-life

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SECTION 5: How the robustness of the accounts is being improved

As discussed in the introduction, the Ecological Footprint approach, and the National Footprint and Biocapacity Accounts in particular, have gained from feedback, suggestions, and criticisms. This section explains some additional improvements that have emerged from such feedback.

It also explains how the National Footprint and Biocapacity Accounts are being taken to the next level of rigor and robustness. An essential part of that was the creation of an independent organization dedicated to being the stewards of the National Footprint and Biocapacity Accounts: the Footprint Data Foundation (FoDaFo - https://www.fodafo.org/data)

Examples of improvements in the past and hopes for the future

The National Footprint and Biocapacity Accounts are constantly evolving. Many of the changes are minor, reflecting better data, small improvement in accounting procedures, etc. In fact, the research team is maintaining a database on all possible improvements, including minor ones that are making the implementation cleaner and clearer.

In addition to the introduction of global hectares or the shift on how nuclear energy is included in the National Footprint and Biocapacity Accounts (as discussed in Section 1), there have been many other methodological improvements. They include:

- revising the world average carbon sequestration by forests (which turned out to be lower than what we previously estimated),[40]
- detailing trade flows, and
- changing procedures in fish trade to reduce the noise in the data.

There are also many aspects that need attention and refinement.

- **Equivalence Factors:** There are several legitimate criticisms related to this key aspect of Ecological Footprint accounting. For instance, it would take more research to verify how well pixels of land with high suitability from GAEZ match with crop land. It may not be totally accurate to assume that the most suitable land must be used as cropland. More research could be done to compare and contrast the suitability index map with land cover map. Our preliminary assessments indicated that there is room for improvement. Also, when assessing the relative value of built-up area, the assumption that for most cities, built up area sits on (potentially the best) crop land, holds in many places. But

[40] Mancini, M.S., Galli, A., Niccolucci, V., Lin, D., Bastianoni, S., Wackernagel, M., Marchettini, N., 2016. Ecological Footprint: Refining the carbon Footprint calculation. Ecological Indicators, 61, 390-403. http://dx.doi.org/10.1016/j.ecolind.2015.09.040

there are also many modern cities, such as the ones in the gulf states or in the US Southwest, where cities are built on desert areas. In those cases, adjustments should be made (as the National Footprint and Biocapacity Accounts already do for the UAE, based on more detailed local analyses with UAE counterparts).

- **Potential vs. Actual Biocapacity:** One ongoing area of discussion concerns the definition of **biocapacity** itself. Biocapacity can be viewed in several ways, including:
    - The ecosystem's inherent productive potential;
    - Current observed productivity;
    - Productivity adjusted for resource depletion;
    - Long-term regenerative capacity enhanced through human management; or
    - Productivity under changing climate conditions.

  A related debate is whether biocapacity should reflect productivity under **sustainable management practices** or under **current, real-world management conditions**. Both perspectives have merit, and different definitions serve different analytical purposes. Beyond these conceptual questions, translating any definition of biocapacity into reliable measurements remains a significant methodological and data challenge.

- **Time-delay in results:** The National Footprint and Biocapacity Accounts rely primarily on official UN datasets. While this strengthens consistency and transparency, it also creates a delay between the reporting year and the availability of results. At present, this gap is roughly four years, which can reduce the usefulness of the accounts for timely policy discussions. To address this limitation, Global Footprint Network and FoDaFo, with the help of York University, have developed now-casting approaches that provide more current estimates. These methods continue to improve and could become even more robust through the integration of additional relevant datasets alongside official UN statistics.

- **Data standards:** To maintain a consistent time series back to 1961, the accounts currently rely on the **SITC Revision 1** trade classification system. While this provides valuable historical continuity, it is no longer aligned with modern trade reporting systems. As a result, Footprint categories do not always correspond directly to the classifications used in contemporary trade analyses. Updating and harmonizing these classifications would improve compatibility with current economic and trade datasets.

- **Trade and its embodied biocapacity:** Trade remains one of the most challenging areas of Footprint accounting. Compared with production statistics, trade data is often less complete, less consistent, and more difficult to interpret. Additional challenges include matching traded products with the corresponding production categories and tracing the embodied biocapacity contained in complex supply chains. These issues can introduce large uncertainty into national results, particularly for economies where imports and exports are large relative to domestic production. Given the growing importance of global supply chains, improving trade accounting represents one of the most promising opportunities for future methodological development.

- **Forest Footprint:** Forest Footprint assessments could also be refined in several important ways. Potential improvements include:
    - Distinguishing more explicitly between hardwood and softwood production;
    - Incorporating changes in forest productivity over time rather than relying on static productivity estimates;
    - Better accounting for the impacts of pests, disease, and forest degradation; and
    - More accurately capturing the effects of increasingly frequent and severe wildfires.

  These factors are becoming especially important as climate change alters forest growth patterns and resilience in many regions. A more dynamic representation of forest productivity would strengthen both the accuracy and policy relevance of Footprint accounts.

- **Grazing Footprint**: Estimating the intensity by which grazing areas are used (or overused) could also be improved, including finding more adequate data sources.

- **Fisheries Footprint**: Even though it is well recognized that fisheries around the world are under stress, and data is getting richer, it is still difficult to robustly estimate harvest against regeneration for all fisheries around the world. The National Footprint and Biocapacity Accounts use www.SeaAroundUs.org data, which is the leading source.

The list continues, and clearly there are many additional arenas that would benefit from further research. This includes finding ways to track forest productivity over time, to distinguish between hard soft wood, to map water use against biocapacity, to develop ways to capture grazing land overuse, track erosion or groundwater depletion. Greenhouse gases could be included more fully; deeper assessments could help evaluate the margin of errors the accounts inherently carry.

Building a new organization for the National Footprint and Biocapacity Accounts (I)

Global Footprint Network and York University have joined forces to establish FoDaFo (Footprint Data Foundation) – Footprint Initiative with York University. It was legally established in Canada in 2019.

The rationale is simple: By establishing the National Footprint and Biocapacity Accounts within an independent and respected academic network, the Accounts will become neutral and robust. This means they need to be more robust through increased scientific engagement, better governed to have a clean process of improving the accounts, and more transparent so all can test them. All this is needed if those accounts should become an even more effective and trusted reference for decision making in support of sustainability.

To overcome misconceptions and skepticism, the world needs a credible, neutral body that develops and makes these national results available. This body also needs to be able to engage with potential criticism and learn from it.

FoDaFo aims at:

1. Producing and maintaining, with the help of academic institutions, the National Footprint and Biocapacity Accounts derived from solid and trusted data sources and assembled with academic rigor, to ensure they are robust, objective, independent. They should be released on an annual basis.
2. Establishing an international collaboration of researchers who drive the Accounts' improvements. This enables tapping into creative research minds from around the world in order to improve weaknesses of the accounts and find innovative ways to better address the research question of the Ecological Footprint accounts.
3. Gathering a consortium of governments and institutions who contribute to and draw upon the Accounts and adopt them as a key tool in their own decision-making.
4. Training a growing pool of researchers skilled in Footprint accounting who can apply their skills and knowledge to advance a world where all can thrive within the means of our planet.
5. Building robust governance, both for the organization itself and for the scientific decision-making needed to manage and improve the National Footprint and Biocapacity Accounts. For this reason, FoDaFo has established a science advisory committee that has as its primary task to evaluate potential improvements proposed by scientists and then to recommend, after testing, which ones are fit for implementation. Such a set up allows for open academic engagement as outside researchers can freely engage in research on methodological improvements, employing their fullest creativity. At the same time, by carefully selecting which improvements are truly fit for implementation,

the science advisory committee also makes sure that the actual accounts stay consistent and stable. In addition, the science committee will also develop a research agenda to help researchers focus on the most critical tasks that need to be improved.

The website www.FoDaFo.org provides more background on the effort.

SECTION 6: List of common criticisms, including “Why not just focus on carbon?”

There have been many criticisms that have led to important methodological improvements. These include using better data (for example, on carbon sequestration), introducing the **global hectare** to reflect differences in biological productivity across areas, and more strictly separating description from interpretation (for instance, avoiding labels such as “fair earthshare” for available biocapacity per person). Critiques have also helped refine how we address the link to biodiversity, including the need to account for biocapacity required by wild species and the intensity of human use.

At the same time, many recurring criticisms stem from misunderstandings about what Ecological Footprint accounts actually measure and what their underlying research question is.

This section responds to 21 specific criticisms we have received. These examples are representative of similar critiques we have encountered both before and after.

Below, we respond to each in turn:

1) CRITICISM: “The Ecological Footprint of a person to satisfy his or her consumption includes demands for food, fiber, timber, space occupied for built infrastructure, and the space required to assimilate waste, including emissions from burning fossil fuels. Currently, the most significant component of humanity’s Ecological Footprint is the carbon footprint.” This is highly misleading [because] you say “the space required to assimilate waste, including emissions from burning fossil fuels, but, in fact, the only thing the ecological footprint calculates is the fossil fuels component. It considers no other waste” (from e-mail correspondence). In essence, critics argue that claiming that Ecological Footprint is comprehensive is misleading because, in practice, the accounts, on the waste side, only quantify the fossil-fuel carbon component and do not explicitly account for most other waste streams.

OUR RESPONSE: To address this criticism, it is helpful to distinguish between three different levels of Ecological Footprint accounting:

1. **The Ecological Footprint in theory**: the full conceptual framework, which would include all competing (or mutually exclusive) human demands on biocapacity if complete data were available. This means all waste streams, not just CO_2 from fossil fuel.
2. **General Ecological Footprint accounting in practice:** the application of this framework using currently available datasets and methodologies.
3. **The National Footprint and Biocapacity Accounts (NFBA):** the most widely used implementation, which is intentionally restricted to official UN and UN-affiliated

datasets to ensure transparency, consistency, and independence from selective data choices.

These distinctions matter because data availability currently limits what can be measured. Also, by design, the accounts are highly likely to underestimate overshoot.

As documented in the literature, the National Footprint and Biocapacity Accounts are likely to underestimate ecological deficits, not exaggerate them. For instance, **on the biocapacity side**, several forms of ecological degradation are not fully captured, including:

- Soil erosion
- Groundwater depletion
- Forest degradation
- Other losses of ecosystem productivity

As a result, actual biocapacity may be lower than the estimates reported in the accounts.

On the demand or Footprint side, some human pressures on ecosystems are also omitted because they are not consistently documented in UN datasets. This means that humanity's true demand on nature is likely higher than what current accounts record. Together, these limitations create a systematic tendency toward understating rather than overstating ecological overshoot.

So what waste is included in the accounts? The criticism is correct in one important respect: Within the National Footprint and Biocapacity Accounts, the largest and most explicitly quantified waste stream is carbon dioxide emissions from fossil-fuel combustion. However, this does not mean that all other waste-related activities are ignored.

Many of the resource demands associated with waste management are included indirectly in National Footprint and Biocapacity Accounts when they are captured in official statistics. Examples include:

- Wastewater treatment
- Drinking-water treatment
- Waste collection and disposal
- Waste incineration
- Infrastructure required for these activities

These demands are reflected primarily through their carbon and built-up land requirements. In addition, some waste-absorption functions are already embedded within productive systems. For example, agricultural land absorbs and recycles manure from livestock. Because the same land simultaneously produces feed and food, counting this absorption function separately would constitute double counting.

The Real Question

The limitations identified by critics are real and worth discussing. The key question, however, is not whether the accounts capture every waste stream perfectly. The more important question is: *Do these omissions make the results fundamentally misleading?*

Answering this requires assessing the magnitude of the gap. Is the missing component likely to change the results by 5%, 50%, or 500%? How much of humanity's total demand remains unmeasured, and what empirical evidence supports that estimate?

Until evidence demonstrates that these omissions fundamentally alter the overall conclusion, the central finding remains unchanged: Human demand on nature exceeds the biosphere's capacity to regenerate, and the National Footprint and Biocapacity Accounts most likely underestimate rather than overstate that imbalance.

2) CRITICISM: "The most significant component of humanity's Ecological Footprint is the carbon footprint", which is a drastic understatement, because it is the change in the carbon footprint that exclusively generates overshoot." (from e-mail correspondence).

OUR RESPONSE: According to the National Footprint and Biocapacity Accounts, carbon currently represents the largest share of humanity's Ecological Footprint. Two centuries ago, this share was effectively zero. To meet the goals of the Paris Agreement, it would need to return to zero before mid-century, requiring a net-zero carbon footprint. Currently, 60% of humanity's Ecological Footprint is the carbon portion.

It is important to distinguish between **local** and **global** overshoot. Local overshoot has occurred throughout human history, for example when a forest is harvested faster than it can regenerate. Global overshoot occurs when **humanity's total demand exceeds the Earth's total regenerative capacity**. By definition, it is the sum of all demands that matters, not any single component in isolation.

Consider a hypothetical example. If humanity used only half as much fossil fuel as it does today, while all other resource use remained unchanged, the biosphere would likely still be able to absorb the resulting carbon emissions. In that case, carbon emissions alone would not place humanity in overshoot. Yet humanity would still require food, fiber, timber, and other biological resources. Even at half of today's fossil fuel use, the carbon component would still occupy a substantial share of global biocapacity. This illustrates why it is misleading to argue that one part of the Ecological Footprint contributes to overshoot while the others do not. Overshoot results from the **combined total**.

A financial analogy helps clarify this point. If your spending exceeds your income, it makes little sense to say, “These dollars contributed to my deficit, but those dollars did not.” The deficit arises because **total expenditures exceed total earnings**. Ecological overshoot works in the same way: it occurs because humanity’s **total demand exceeds nature’s capacity to regenerate**.

Finally, it is worth noting that Global Footprint Network does not advocate reducing human demand merely to “one planet.” As the late biologist E.O. Wilson argued, safeguarding a large portion of biodiversity, possibly 85%, may require setting aside roughly half of the Earth’s biologically productive area for nature (2016). If that is the goal, humanity’s resource demand would need to remain well below one planet. The key question is therefore not only how to eliminate overshoot, but also how much ecological space should be reserved for the preservation of biodiversity.

3) CRITICISM: “The fact that footprint articles appear in the scientific literature does not prove that they are of quality, given that the peer review process is highly fallible. To find out the real arguments, we must go to the critical articles like:

Van den Bergh, J. C., & Verbruggen, H. (1999). Spatial sustainability, trade and indicator‘: an evaluation of the ‘ecological footprint‘. *Ecological Economics*, 29(1), 61-72.

Ayres, R. U. (2000). Commentary on the utility of the ecological footprint concept. *Ecological Economics*, 32(3), 347-349.

Fiala, N. (2008). Measuring sustainability: Why the ecological footprint is bad economics and bad environmental science. *Ecological Economics*, 67(4), 519-525.

Galli, A., Giampietro, M., Goldfinger, S., Lazarus, E., Lin, D., Saltelli, A., Wackernagel, M. & Müller, F. (2016). Questioning the ecological footprint. *Ecological Indicators*, 69, 224-232. “ (from e-mail correspondence).”

OUR RESPONSE: Yes, we are familiar with these criticisms, and the last paper in the list includes us as co-authors. To be fair, the same concern about the fallibility of the peer-review process also applies to criticism published in the scientific literature.

Rather than focusing on “who said what,” we suggest evaluating the validity of arguments based on their substance. Given the limitations of peer review, Global Footprint Network has also encouraged independent reviews of the National Footprint and Biocapacity Accounts by key users, particularly national governments. We have invited national statistical agencies to test whether the results are robust and internally consistent. These reviews have generally confirmed the consistency of the accounts and reproduced the results within small margins of error.

4) CRITICISM: "A press release stated: 'If every person on the planet lived as a Portuguese average person, humanity would demand more than 2 planets to sustain its resource needs. This would imply that the productive area available to regenerate resources and absorb waste globally.' But the ecological footprint does not in fact consider 'natural resources' (implying that it considers them all or at least the generality), but only and exclusively the area directly used for human activities (agriculture, forestry, urbanization, etc.) and the potential area needed to remove excess carbon dioxide from the atmosphere." (from e-mail correspondence).

OUR RESPONSE: That is correct in part: Ecological Footprint accounting focuses specifically on biological resources. It aggregates all competing human demands on biocapacity, including the biophysical impacts of using non-biological resources (such as fossil fuels or minerals) insofar as they require regenerative capacity, for example, through carbon sequestration.

We would not describe the carbon component as "potential area needed." It represents actual biocapacity required if emissions are to be absorbed without increasing atmospheric CO_2. When there is overshoot, this required biocapacity exceeds what is available. The demand itself still exists, even if it cannot be fully met by current regeneration.

5) CRITICISM: "It is primarily this misleading aspect of the way in which the ecological footprint is reported that undermines its credibility." (from e-mail correspondence).

OUR RESPONSE: This is an important point, and we agree that clarity of communication matters greatly. At the same time, there is often a trade-off between accessible language and technical precision. Highly detailed explanations can obscure key messages, while simplified communication may not capture all the nuance of the underlying accounts.

Even so, statements such as "humanity is using 73% more than Earth regenerates" or "it would take two Earths if everyone lived on average like Portuguese residents" are both accurate and, if anything, conservative. They translate complex accounting results into intuitive terms without distorting the core finding.

6) CRITICISM: "Whenever I have seen criticisms (or have made them myself) of the ecological footprint, the answer is based on its communication effectiveness. This raises several fundamental questions for me, including: when the environmental movement's rallying call is "listen to the scientists" do we really want to use an indicator whose only (undeniable) merit is its communicability?" (from e-mail correspondence).

OUR RESPONSE: It would indeed be problematic if communication were the sole strength of the Ecological Footprint. However, that is not our argument. The case for the Ecological Footprint is based first and foremost on a clear research question and a consistent, well-defined accounting framework.

Strong communication is a valuable additional benefit, but it is not the foundation. The primary requirement is that the underlying methodology is transparent, internally coherent, and grounded in physical reality. We argue that Ecological Footprint accounting meets these criteria.

In fact, it is worth examining how other sustainability indicators perform on both dimensions: conceptual rigor and communicability. Many widely used composite indices, for example, lack a clearly defined research question altogether. Others rely on units that are ambiguous or less suitable for comparing human demand with ecological regeneration than global hectares. These issues are discussed in more detail in section 2.1 of this open-access paper.

For a deeper treatment, that paper also outlines how Ecological Footprint accounting is explicitly tied to a specific research question and built on simple, robust principles, while still remaining communicable.

7) CRITICISM: "Why not use each country's carbon budget consumption - also clearly communicable (allowing us to communicate whether we are above or below the border, and also allowing us to identify a carbon overshoot day), but without distortions and with much greater scientific basis?" (from e-mail correspondence).

OUR RESPONSE: Of course, one can focus solely on carbon, and many do. The key question is: what do you want to understand?

If your goal is to compare human demand with planetary availability, focusing only on carbon is limiting. Emissions are relatively straightforward to track, at least conceptually. But the harder question is: what is the carbon budget, and how much emission capacity is actually available?

Answering that requires a series of assumptions. Do you base the budget on policy targets set by a specific jurisdiction? Or on a global temperature goal such as the Paris Agreement, in which case you need to determine how to allocate that budget across countries? And even then, is there a remaining budget at all? For example, 450 ppm CO_2-equivalent corresponds to a roughly 66% chance of staying below 2°C of warming (IPCC 2014) yet NOAA data indicate that atmospheric concentrations have exceeded 539 ppm CO_2-equivalent in 2024. This raises the likely possibility that the budget is already exhausted.

Given that the only viable future is a regenerative one, why not track human demand against the regenerative capacity of the planet? This is what we call **biocapacity**. It also raises an important question: is it realistic to decarbonize without increasing pressure on other parts of the biosphere?
In Ecological Footprint accounting, both sides of the equation are explicit: how much demand is there, and how much regeneration is available? In a carbon-only framework, the second part is far less clear, for the reasons outlined above.

In essence, whether humanity decarbonizes proactively or eventually exhausts fossil fuels (leaving a large greenhouse gas debt in the atmosphere), we will ultimately need to live within Earth's regenerative capacity rather than rely on its liquidation. The sooner this transition happens, the more regenerative capacity remains available. In other words, the faster we reduce and eliminate fossil fuel dependence, the more feasible it becomes to operate within the planet's biocapacity.

This transition will require both focus and commitment, because fossil fuels have allowed us to extend beyond the limits of biological income. Their influence is pervasive. For example, fossil fuels:

- increase food and feed production through fertilizers, irrigation, and mechanization, and enable global transport and processing that bypass local limits;
- replace biological fibers, with synthetics now accounting for roughly 70% of fiber use;
- provide heating without reliance on wood; and
- enable mobility without working animals which depend on animal feed.

8) CRITICISM: "The lack of caveats in Ecological Footprint dissemination is worrying and has led to the most serious criticism of the method to date, that of it fulfilling the criteria for pseudo-science for failing to disclose uncertainties in calculations and results" (Johannesson et al. 2020).

OUR RESPONSE: It is indeed important to be transparent about what is being measured, including the precise research question and the limitations of both the methodology and its implementation.

In our scientific publications, Global Footprint Network addresses issues of accuracy and reliability as thoroughly as possible. However, like many users of official statistics (including national or UN datasets), the input data we rely on are typically provided without explicit confidence intervals. This is common across many indicators. For example, GDP, life expectancy, and unemployment figures are generally reported without margins of error.

Estimating the overall uncertainty in National Footprint and Biocapacity Accounts is challenging. We have reasons to believe (as explained above) that biocapacity is often overstated and Ecological Footprints understated. However, quantifying the exact margin of error remains an open area for further research.

9) CRITICISM: “For instance, it is not clear why it is useful to convert greenhouse gases to land as methane and nitrous oxide are already aggregated into CO_2 equivalent indicators of greenhouse gases.” (Fiala 2008)

OUR RESPONSE: As documented elsewhere, we consider biological regeneration to be the fundamental physical constraint on the human economy. This is analogous to the climate argument that warming is driven not only by CO_2 but by the combined effect of all greenhouse gases. In the same way, ecological overshoot is not driven by a single factor such as food, energy, or timber use, but by the cumulative demand of all these pressures together.

If one recognizes that the challenge is broader than climate change alone and encompasses total ecological overshoot where all demands compete for our planet’s biocapacity, then Ecological Footprint accounting becomes particularly useful.

CO_2 equivalent is already a valuable tool for comparing the impacts of different greenhouse gases. Converting these emissions into global hectares further enriches the analysis by relating them to the Earth's limited biocapacity and the competing demands placed upon it. This creates a more complete picture of how human activities contribute to pressure on planetary boundaries.

10) CRITICISM: “For land degradation though, the benefits of looking directly at soil erosion rates are obvious as the ecological footprint gives no information on this.” (Fiala 2008)

OUR RESPONSE: If the goal is to measure soil erosion specifically, Ecological Footprint accounting is not the appropriate tool. Moreover, the National Footprint and Biocapacity Accounts do not currently capture the effect of soil erosion on biocapacity directly (except insofar as it affects agricultural productivity over time), because the underlying UN datasets are not sufficiently detailed.

However, in more detailed Ecological Footprint studies, erosion can be incorporated when suitable data are available. The advantage is that it places erosion within a broader context of competing demands on the biosphere.

In general, Ecological Footprint accounting is not the appropriate tool for tracking narrowly defined aspects of environmental impacts. Its strength lies in addressing interconnected challenges that require a systemic, cross-sectoral perspective.

11) CRITICISM: "The Ecological Footprint converts flows of energy and matter to and from economic activities in **hypothetical** land area (in ha or kilometers [km2]) that would be needed to sustain these flows. Yet, the possibility exists that this is interpreted as realistic or, worse even, actual land area. We refer to this first concern about the Ecological Footprint method as 'false concreteness'." Van den Bergh and Grazi, 2013

OUR RESPONSE: The Ecological Footprint quantifies human demands on biologically productive space and compares them to available biocapacity. When demand exceeds regeneration, overshoot occurs, and the gap is met through depletion of natural capital.

One major demand on this productive space is the absorption of CO_2 from fossil fuel combustion. This is modeled in current National Footprint and Biocapacity Accounts by assessing forest space needed to absorb CO_2 in the long-run.

Maintaining natural capital requires that emissions be absorbed at the same rate they are produced. The fact that they are not indicates overshoot. In principle, more biocapacity could be allocated to carbon sequestration, and mechanisms such as carbon credits or REDD+ schemes aim to do this.

This demonstrates that the "hypothetical" land is not fictitious. Rather, it represents actual regenerative capacity that is either available or already overused. Overshoot is therefore a real condition, not an abstract construct.

For example, the biocapacity required to produce a potato can be expressed in global hectares, even if the specific land is not identified. That capacity exists somewhere, even if it is distributed across regions.

Similarly, if timber is harvested faster than a forest regenerates, the demand exceeds the forest's biocapacity. The forest is real, but it is being depleted. This is not hypothetical; it is a measurable physical process.

Different units can describe the same reality. A field can be measured in hectares (area) or in global hectares (productivity). Likewise, oil can be measured by weight, volume, or energy content. These are complementary physical descriptions, not "false concreteness."

12) CRITICISM: "Please separate the carbon Footprint from the remainder of the Footprint."

OUR RESPONSE: Ecological Footprint results are available both as an aggregate and by component. Users can therefore disaggregate results if that is more useful.

However, the main value of the framework lies in aggregation: it shows total human demand relative to total biocapacity. This integrated view makes trade-offs visible that would otherwise be missed.

For instance, increasing land dedicated to carbon sequestration reduces the land available for food or fiber production. Climate change is ultimately a biophysical issue: it depends on how effectively the biosphere can absorb accumulated greenhouse gases. The IPCC itself recognizes the tight coupling between land use and climate dynamics (see www.ipcc.ch/srccl).

Historically, the carbon Footprint accounted for roughly 0% of humanity's total Footprint, up to about 200 years ago. Achieving the Paris Agreement targets would require it to approach zero again well before 2050. Yet decarbonization may increase pressure on other biocapacity demands. For example, if biomass is used as an energy substitute for fossil fuels. In such a transition, reductions in the carbon Footprint could be offset by increases elsewhere.

This is why the carbon Footprint alone cannot represent the full picture. Only by considering all competing demands together can we identify solutions that improve system outcomes rather than shift burdens. If we solve one problem by exacerbating another, we risk undermining the broader goal of living within planetary limits.

13) CRITICISM: "Doesn't technological progress make resource accounting obsolete?"

OUR RESPONSE: Resource accounting is highly relevant for anyone who recognizes that the economy depends on a physical planet.

Because all value chains ultimately rely on natural capital, some advocate for "**strong sustainability**", meaning that, in net terms, natural capital should not decline. Under this view, harvests must remain below sustainable regeneration, and stocks such as groundwater and biodiversity must be maintained.

Others take a "**weak sustainability**" perspective, arguing that declines in natural capital can be offset by gains in other forms of capital. This reflects the "technology argument": as efficiency improves, an economy can reduce its reliance on natural capital and substitute it with other inputs. Even under this assumption, however, decision-makers still need to monitor whether natural capital is being depleted faster than it is being replaced. Otherwise, they cannot judge whether other capital gains make up for it.

For weak sustainability to hold in practice, resource efficiency must continuously outpace the loss of natural capital. If that condition is met, the economy can, in principle, avoid consequences by reducing its physical dependence faster than it depletes ecological stocks. Yet this assumes that efficiency gains can keep up indefinitely—a strong assumption. In reality, there may be diseconomies of scale, where maintaining economic activity becomes increasingly difficult as inputs become scarcer. Put differently, the ratio between human demand and regeneration cannot rise year after year; otherwise, weak sustainability collapses. This is precisely why monitoring biocapacity and ecological footprints remains essential even under a weak sustainability framework.

At the far end of the spectrum, some argue that resource availability is not a binding constraint on economic performance and therefore does not need to be tracked. This is analogous to a pilot refusing to use a fuel gauge. Even if one believes that fuel is unnecessary, the aircraft will still eventually run out of fuel.

Further, technology is not a homogeneous property. Some technology increases efficiencies (bicycles let people move faster using the same amount of energy, LEDs produce equal amount of light on far less electricity), while other technologies increase resource demand to achieve their promises (more powerful jet engines let us fly faster, air-conditioning enables people to live in more hostile environments). When analyzing resource use over the last half century, it seems to be that shifts were driven more by resource-intensifying technologies than efficiency-increasing technologies, as explained in a lecture by Mathis Wackernagel (2025).

14) CRITICISM: "Doesn't the drop in resource prices indicate that resource limitations are overplayed?" (from e-mail correspondence).

OUR RESPONSE: Ecological Footprint accounting does not make an economic argument *per se*. It simply compares human demand with ecological regeneration.

Resource prices, however, measure neither demand nor regeneration. They reflect market conditions, not biophysical limits. As a result, prices may fall even in the context of significant global ecological overshoot, and therefore cannot be taken as evidence that resource constraints are absent.

15) CRITICISM: "The Ecological Footprint is a great communication tool. But it is not policy relevant." (common criticism)

OUR RESPONSE: Ecological Footprint accounts measure both the available biocapacity and the amount being used. The results communicate effectively, including when expressed as an Earth Overshoot Day date.

Whether these results are policy relevant is ultimately for decision-makers to determine. Our working assumption is that regenerative capacity (biocapacity) is the primary material constraint, and that competition for biocapacity is a particularly useful lens for understanding overall resource dependence. We also hold that physical reality inevitably shapes policy outcomes.

Regardless of the analytical framework, physical limits ultimately determine whether policy conclusions are realistic. In that sense, when analysts find the Ecological Footprint irrelevant to certain policy questions, it may be because those questions are not directly related to ecological constraints.

The more closely our assumptions align with physical reality, the more likely our policy choices are to succeed.

16) CRITICISM: "…it doesn't distinguish between sustainable and unsustainable uses of crop and grazing land, and doesn't account for other means of carbon sequestration, like ocean and soil." Richardson in NYT, 2020[41]

OUR RESPONSE: The term "sustainable" is inherently ambiguous, as it often refers to multiple dimensions at once. Global Footprint Network therefore avoids using it as a descriptor. Instead, the Ecological Footprint metric is designed to define and measure specific aspects of what people often may mean by "sustainability."

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[41] Susan Shain and John Schwartz (2020) 'Earth Overshoot Day' Is This Week," Climate and Environment, Climate Fwd: newsletter, New York Times. https://www.nytimes.com/2020/08/19/climate/earth-overshoot-day.html

We also treat "sustainable" not as an intrinsic property of an object or activity, but as a question of system compatibility: how well something fits within its ecological context. For example, whether a horse is "sustainable" depends not only on the horse itself, but on how many horses exist relative to available biocapacity. For instance, 1 trillion horses on planet Earth would clearly not be sustainable. In other words, the adjective "sustainable" is a relational rather than absolute attribute.

For this reason, we prefer more precise terms such as regenerative versus depleting use. What is often described as "sustainable" or "unsustainable" is, in our terminology, whether a use can be regenerated by the biosphere.

The Ecological Footprint directly addresses this by measuring how much regenerative capacity is required to replenish human demand. The focus is therefore fundamentally on regeneration.

In practice, however, measurement is constrained by data availability. For instance, the National Footprint and Biocapacity Accounts rely on UN datasets that do not fully capture some forms of ecological degradation, such as soil loss. As a result, certain relevant aspects are currently underrepresented. This limitation reflects data gaps, not methodological intent. The core principle of Ecological Footprint accounting remains to compare all human demands against the biocapacity required to regenerate them.

Regarding the second point, ocean sequestration is included in the National Footprint and Biocapacity Accounts (see the workbook and related publications). Likewise, if CO_2 is sequestered through mechanisms other than forests, or avoided through alternative sequestration techniques, these can be incorporated into Ecological Footprint calculations.

17) CRITICISM: "The use of ecological footprints at the national level has been challenged as a measure of a country's own sustainability because of the antitrade bias implicit in the methodology."[42]

OUR RESPONSE: Ecological Footprint accounting, and Global Footprint Network more broadly, do not take a position on trade. The accounts simply measure how much biocapacity people or activities use, compared to how much biocapacity is available in a region, a country, or globally.

One clear implication is purely mathematical: not everyone on our planet can be a net importer of biocapacity. If one actor imports, another must export.

[42] Page 259 in the *Human Development Report 2020* of UNDP: http://hdr.undp.org/en/2020-report. Supposed antitrade bias has been raised by numerous critics, including van den Bergh & Verbruggen (1999)., Stiglitz et al (2009), and Blomqvist et al. (2013).

Trade can be beneficial when a country has the financial means to access biocapacity elsewhere. However, this ability depends on having sufficient purchasing power to compete with other countries seeking the same resources. As global overshoot persists, competition for remaining biocapacity will inevitably intensify, putting any entity with a biocapacity deficit at a disadvantage.

It is also worth noting that financial accounting and mainstream economics are often more prescriptive about trade than Ecological Footprint accounting. Many monetary economists caution against persistent trade imbalances. In contrast, Footprint accounts do not recommend for or against biocapacity trade imbalances. They just make them visible.

For this reason, claims that Ecological Footprint accounting has an anti-trade bias are misplaced. They do not reflect the methodology and are irrelevant to its scientific validity for describing resource balances.

18) CRITICISM: "Criticism on [Ecological Footprint accounting] is gradually accumulating (Gordon and Richardson, 1998; van den Bergh and Verbruggen, 1999; VROMraad, 1999; Ayres, 2000; Moffatt,2000; Opschoor, 2000; van Kooten and Bulte, 2000; EAI, 2002; Grazi et al., 2007; Lenzen et al., 2007; Fiala, 2008; van den Bergh and Grazi,2010; Blomqvist et al., 2013a, 2013b). These various studies seem to agree on the main shortcomings, summarized recently in van den Bergh and Grazi (2014a) in the form of 8 main points:

1. False concreteness
2. Global hectares: Adding to the hypothetical character of the ecological footprint
3. A case of "land value theory": Land use as a proxy of environmental pressure
4. Incompleteness in terms of capturing relevant environmental pressures
5. Aggregation through unfounded, implicit weights
6. Carbon sink land resulting from an arbitrary "sustainable energy scenario"
7. Countries versus "bioregions"
8. Ecological deficit and antitrade sentiments"

van den Bergh and Grazi, 2015

OUR RESPONSE: Van den Bergh and his colleagues have raised many of these critiques consistently since their first publication on the topic in 1999. As noted in previous responses, several of these criticisms arise from interpreting Ecological Footprint accounting as a social theory, policy framework, or prescription for action. It is none of these. Ecological Footprint accounting is a metric: it measures the extent to which human activities compete for the planet's regenerative capacity.

Its purpose is straightforward. Ecological Footprint accounts document humanity's dependence on biological resources, much as a fuel gauge documents the amount of fuel available to a vehicle. A fuel gauge does not explain how a car operates, nor does it prescribe where the driver should go. It simply tracks a critical parameter. Likewise, Ecological Footprint accounting does not explain the entire economy or dictate policy choices. It tracks a fundamental reality: the relationship between human demand for biological regeneration and nature's capacity to provide it. Just as a vehicle is at risk when it repeatedly runs on empty, economies that depend on depleting ecological assets place themselves at increasing risk.

1. "False Concreteness": Every model simplifies reality. Ecological Footprint accounting does not claim to measure "sustainability" in its entirety, nor does it capture all environmental impacts. Its objective is more specific: to estimate how much of nature's regenerative capacity is occupied by human activities.

Achieving this requires methodologies that are necessarily influenced by available data. For example, the *National Footprint and Biocapacity Accounts* provide a country-level assessment based largely on internationally reported UN datasets. As better data and more robust methods become available, the accounts can and should improve accordingly.

The purpose of Ecological Footprint accounting is precisely to make regeneration measurable, transparent, and understandable. Rather than leaving regenerative capacity as an abstract concept, it seeks to quantify it in ways that can inform analysis, decision-making, and public understanding.

2. Global Hectares: Adding to the hypothetical character of the ecological footprint: They characterize global hectares as an example of Ecological Footprint accounting being overly hypothetical. In reality, a global hectare is simply a standardized measurement unit: one hectare of biologically productive area with world-average biological productivity.

This is no more hypothetical than expressing economic values in inflation-adjusted dollars or greenhouse gas emissions in CO_2-equivalent units. Standardized units are commonly used whenever diverse phenomena must be compared consistently. While global hectares represent average productivity, average productivity itself is a measurable characteristic, making the unit both practical and scientifically meaningful.

3. A "Land Value Theory": Land use as a proxy of environmental pressure: Ecological Footprint accounting is not a theory of economic value, nor does it attempt to explain how economies function. It is an accounting framework designed to measure how much regenerative capacity is embodied in human activities and consumption patterns.

Researchers may use Footprint results in economic analyses, but the accounting system itself contains no underlying theory of value. It simply quantifies biological resource demand relative to biological regeneration.

4. Incompleteness in Capturing Environmental Pressures: Ecological Footprint accounting intentionally focuses on demands that compete for biocapacity. It does not claim to represent every environmental concern.

The scientific literature has long acknowledged this focus. A focus is always a limitation, because some pressures, outside of the metric's focus, are not included. Ecological Footprint results are generally understood as conservative estimates of total human pressure on the biosphere. Other important challenges, such as persistent toxic pollution, noise, infectious disease risks, or certain ecosystem disruptions, fall outside the specific question that Ecological Footprint accounting is designed to answer. This is readily acknowledged.

A metric should be evaluated based on the question it seeks to address, not on whether it answers every possible environmental question simultaneously.

5. Aggregation Through Unfounded Implicit Weights: The aggregation principle is explicit, not implicit. Different resource demands are combined according to the amount of biocapacity required to support them.

This principle is transparent and consistently stated throughout the methodology. While implementation can always be refined as data and methods improve, there is no hidden weighting system. The weighting factor is clear: embodied biocapacity. The accounting framework is built around making this relationship visible rather than obscuring it.

6. Carbon Sink Land and a Supposed "Sustainable Energy Scenario": Ecological Footprint accounting does not rely on a hypothetical sustainable energy scenario.

The carbon component estimates the amount of biological capacity that would be required to absorb anthropogenic CO_2 emissions. In fact, the approach is conservative because it does not assign all observed carbon uptake, such as that performed by the oceans, to the Footprint calculation. The calculation simply translates a measurable demand, CO_2 emissions, into the corresponding demand on regenerative capacity. And even that is conservative, as the estimate errs on the side of optimistic long-term sequestration rates of forests (Mancini et al. 2016).

7. Countries Versus Bioregions: Ecological Footprint accounting is not restricted to countries. The methodology can be applied to virtually any entity for which meaningful data are available: nations, cities, regions, companies, products, watersheds, farms, or bioregions.

National accounts are particularly prominent because national data are generally the most comprehensive and internationally comparable. Where sufficient data exist, bioregional analyses are entirely possible. The primary constraint is data quality and availability, not the accounting framework itself.

8. Ecological Deficits and Alleged Anti-Trade Bias: Ecological Footprint accounting contains no prescription regarding trade. It simply documents the embodied biocapacity associated with production, consumption, imports, and exports.

The metric can therefore be used to analyze trade flows, but it does not imply that trade is good or bad. The only mathematical constraint is that, at the global level, total imports must equal total exports.

One may reasonably argue that heavy dependence on biocapacity imports could represent an economic risk in a world where ecological overshoot is widespread. However, that interpretation is external to the metric itself. The accounting framework merely provides the information needed to conduct such analyses.

A useful analogy is a scale. A scale measures weight; it does not express a preference for heavier or lighter people. Similarly, a height chart measures height without implying that being taller or shorter is desirable. Ecological Footprint accounting measures biocapacity demand without prescribing particular economic or political conclusions.

A Broader Observation

A recurring challenge in the critique by van den Bergh, Grazi, and colleagues is that they often attribute particular interpretations to Ecological Footprint results and then criticize those interpretations. Yet those interpretations are not inherently built into the accounts themselves.

Accounting and interpretation are distinct activities. Ecological Footprint accounting provides a set of biophysical accounts that quantify human demand relative to nature's regenerative capacity. What those findings mean, how they should be interpreted, and what actions may or may not follow are separate questions.

The value of the accounts lies in providing a transparent empirical foundation for addressing questions such as:

- Are human activities demanding more regenerative capacity than nature can renew?
- If so, by how much?
- What are the implications of that relationship?
- If ecological overshoot is considered undesirable, what response options are available?

Ecological Footprint accounting does not attempt to answer all of these questions. Its contribution is to provide a consistent, measurable basis from which they can be explored.

19) CRITICISM: "We could add here a large number of studies applying the ecological footprint that include (minor or major) changes in its methodological assumptions. In effect, such studies implicitly levy criticism on certain aspects of the footprint method. Major studies in this respect are mentioned in van den Bergh and Grazi (2014a). Note further that over time Wackernagel and his Global Footprint Network have frequently altered the assumptions of the method. All this means that much care is needed in comparing footprint estimates between studies or over time." Van den Bergh and Grazi, 2015 (footnote 1)

OUR RESPONSE: Ecological Footprint accounting begins with a straightforward observation: our planet's annual biocapacity is finite (even though it can change from year to year), and human demand for it can exceed nature's ability to regenerate it. As a result, there is competition for available biocapacity. While the methodology has evolved over time, the core research question has remained remarkably consistent for more than 30 years: **How does humanity's demand on nature compare with nature's capacity to renew itself?**

Like any scientific framework, the approach continues to be refined. For example, researchers may debate how regeneration should be defined and measured, including distinctions between potential and actual regeneration, or how much biocapacity may be at risk because of degrading underlying conditions such as groundwater depletion or soil erosion. These are important methodological discussions, but they do not alter the fundamental question being assessed.

The best-known application of this work is the **National Footprint and Biocapacity Accounts**, which were launched in 1997. WWF's *Living Planet Report 2000* presented the first global time series of humanity's Ecological Footprint, highlighting the emergence of ecological overshoot. This work was later documented in a PNAS publication on overshoot.

Readers can compare the timeline published in the *Living Planet Report 2000* with the current results available at data.footprintnetwork.org. Back then, the estimate was 20% overshoot for 1999. The current accounts estimate 33% overshoot for 1999. Yet the principles underpinning those analyses remain the same today. While there is a difference in results, these changes reflect scientific progress, including methodological refinements, improved data sources, and occasional adjustments in scope. For instance, nearly 20 years ago, the accounts stopped including nuclear power impacts beyond associated CO_2 emissions, but this change had only a minor effect on global results.

For that reason, characterizing the methodology as one whose assumptions are “frequently altered” overstates the case. The evidence shows a framework that has maintained a consistent conceptual foundation while continuously improving the quality and precision of its measurements, as robust scientific systems are expected to do.

20) CRITICISM: “The Ecological Footprint has as much scientific merit as astrology, phrenology, and flat-earth theories.” Michael Shellenberger in Forbes Magazine.

OUR RESPONSE: Michael Shellenberger’s comparison makes for a striking headline, but it does not engage with the actual scientific question: **Is Ecological Footprint accounting a scientifically grounded method for measuring human demand on nature’s regenerative capacity?**

Science is not defined by whether everyone agrees with a particular method. Rather, scientific inquiry depends on several fundamental principles:

1. **A clear and testable research question.**[43]
2. **Methods that generate measurable results that can be challenged and scrutinized.**
3. **Independent evaluation, replication, and critique by other researchers.**

Ecological Footprint accounting meets these criteria.

Its central research question is straightforward:
How much of the Earth’s regenerative capacity is required to support human activities?

This question is neither ideological nor speculative. It seeks to measure the relationship between human demand for biological resources and ecological services, and the amount of biologically productive capacity available to regenerate them. Because human demands compete for biologically productive areas, those demands can be expressed in a common accounting framework and aggregated into a consistent measure.

The challenge, as in any scientific endeavor, is translating a research question into a measurable methodology. Ecological Footprint accounting does exactly that. It uses available data to estimate both human demand on biocapacity and the regenerative capacity of ecosystems. The resulting estimates can then be tested, challenged, refined, and compared against other evidence.

[43] Typically, defining a clear, method-independent, testable research question leads to a falsifiable hypothesis. In the case of a metric, the hypothesis for a metric’s results is that they are not implausible anomalies. If they are, they would be clearly false.

Importantly, the validity of the methodology does not rest on assertion alone. The results can be subjected to **triangulation** using independent approaches and related indicators. Researchers can ask whether the findings are consistent with observed patterns of resource depletion, land-use pressures, carbon accumulation, declining ecological stocks, or other biophysical trends. In other words, the methodology can be challenged through efforts to determine whether its results are implausible, inconsistent, or anomalous.

The National Footprint and Biocapacity Accounts represent one application of this approach at national and global scales. Over many years, Global Footprint Network and numerous research partners have repeatedly reproduced broadly consistent patterns of Ecological Footprint and biocapacity accounting. Like all scientific metrics, the methodology continues to evolve as better data and improved techniques become available. Yet the underlying research question and accounting logic have remained remarkably stable.

If there is a criticism to be made, it is not that Ecological Footprint accounting is mystical, arbitrary, or opaque. If anything, the opposite is true. The approach is intentionally simple and transparent. It asks a basic accounting question: how much regenerative capacity is available, and how much is being used? The science may be debated, refined, and improved, but it is grounded in explicit assumptions, measurable quantities, and published methods.

Comparisons to astrology, phrenology, or flat-earth theories therefore miss the mark.

- **Phrenology** began with predetermined conclusions and attempted to justify them through flawed reasoning and biased assumptions.
- **Astrology** is not based on a testable biophysical mechanism and generally does not operate within the framework of modern scientific validation.
- **Flat-earth theories** are contradicted by overwhelming empirical evidence.

Ecological Footprint accounting is fundamentally different. It starts with a clearly defined empirical question, applies a transparent methodology, generates quantifiable results, and invites ongoing testing and critique.

Reasonable scientists may disagree about particular assumptions, data sources, aggregation methods, or interpretations. Such debates are an ordinary and healthy part of scientific progress. However, disagreement over methodology is very different from claiming that an entire field of inquiry belongs in the same category as pseudoscience.

Indeed, from the perspective of the philosophy of science, the more relevant question is not whether Ecological Footprint accounting can be criticized, but whether its claims can be tested, challenged, and improved. They can. And that is precisely what has been happening for more than three decades.

The real issue, therefore, is not whether Ecological Footprint accounting is scientific. The more productive question is how accurately it measures human demand on regenerative capacity and how the methodology can continue to be improved. That is a scientific debate. Comparing it to astrology or flat-earth theories is not.

21) CRITICISM: BP started the carbon footprint. And they did it to put all blame on individuals. One Swiss internet news article stated in 2021:

> *"BP hat den ökologischen Fussabdruck-Rechner ins Leben gerufen. Richtig gelesen. Der «Footprint Calculator», jenes Tool, das zeigt, wie viel CO_2 jeder von uns jährlich verursacht. Jenes Tool, das mittlerweile auf Websites von so ziemlich allen Umweltschutzorganisationen zu finden ist. Genau jenes Tool wurde von einer Firma ins Leben gerufen, die rund 400 Millionen Tonnen Kohlendioxid im Jahr ausstösst (zum Vergleich: Die Schweiz hat einen jährlichen CO_2-Ausstoss von rund 40 Millionen Tonnen). Damit hat BP den Kampf gegen den Klimawandel grundlegend verändert." Source Watson: https://www.watson.ch/!581184198*

IN ENGLISH: BP launched the ecological footprint calculator. That's right. The "Footprint Calculator", the tool that shows how much CO_2 each of us produces each year. The tool that can now be found on the websites of just about every environmental organization. The tool was created by a company that emits around 400 million tons of carbon dioxide a year (by comparison, Switzerland has annual CO_2 emissions of around 40 million tons). BP has thus fundamentally changed the fight against climate change.

More stories in this vein can be found here:

- https://www.theguardian.com/environment/2021/nov/18/the-forgotten-oil-ads-that-told-us-climate-change-was-nothing (by Geoffrey Supran and Naomi Oreskes).
- https://mashable.com/feature/carbon-footprint-pr-campaign-sham
- https://www.theguardian.com/commentisfree/2021/aug/23/big-oil-coined-carbon-footprints-to-blame-us-for-their-greed-keep-them-on-the-hook
- https://grist.org/energy/footprint-fantasy/

Reactions also exist:

- https://www.treehugger.com/carbon-footprint-is-not-a-sham-5202134
- https://repustar.com/fact-briefs/does-bp-deserve-all-credit-concept-carbon-footprint

OUR RESPONSE: The claim that BP invented the carbon footprint is inaccurate.

Mathis Wackernagel and Bill Rees developed the Ecological Footprint in the early 1990s, and carbon emissions have been part of the methodology from the beginning. The reason is straightforward: carbon emissions from burning fossil fuels place a demand on Earth's biocapacity. The carbon footprint was not a later addition to the Ecological Footprint framework; it was there from the outset.

What is true is that BP's highly visible 2005 carbon footprint campaign dramatically increased public awareness of the term. As climate change drew growing attention, BP embraced the concept and promoted it extensively, helping make the phrase "carbon footprint" part of mainstream conversation.

The evolution of the term was documented, for example, by the late linguist William Safire in a 2008 New York Times article tracing the history of "footprint" as an environmental concept.

The belief that BP "invented" the carbon footprint appears to have gained traction partly through work by Harvard historian of science Naomi Oreskes. We have great respect for Oreskes and her important research on how fossil fuel interests have shaped public understanding of climate change. At the same time, recognizing BP's role in popularizing the term should not be confused with inventing it. Here is a related Guardian story by her.

A simple reality check illustrates the point: searching for "carbon footprint" today yields references from thousands of organizations, including WWF, Conservation International, The Nature Conservancy, universities, governments, and many others. BP helped popularize the term, but it did not create the concept.

Beyond the BP Narrative

It is also too simplistic to suggest that BP alone is responsible for the tendency to personalize or moralize environmental challenges.

This framing is widespread across society. Environmental organizations, educators, faith leaders, policymakers, and media outlets have all often presented environmental action as an individual moral responsibility. While this perspective is understandable, it can unintentionally create a counterproductive dynamic.

When environmental action is framed primarily as personal sacrifice for the common good, people often ask: "Why should I act if others aren't doing their part?" This exemplifies the classic free-rider problem. It portrays sustainability as a burden, rather than framing overshoot as the context we live in — one where preparing yourself is strongly aligned with your own best interest and self-preservation. Free-rider narratives thereby unintentionally weaken motivation for meaningful action.

At Global Footprint Network, we believe a more constructive approach is to highlight the benefits of acting. Our work focuses on helping people, communities, businesses, and governments recognize that reducing ecological risk is in their own interest.

For example, our Earth Overshoot Day 2026 report, *Prepared for the Predictable*, shows that nations do not protect their self-interest by ignoring ecological overshoot. On the contrary, failing to prepare for foreseeable ecological constraints increases economic and social vulnerability.

The logic is simple: If others fail to prepare, my own risks become greater, not smaller. That strengthens the case for acting. The less prepared others are, the more important it becomes for my community, business, or country to build resilience and reduce exposure to predictable ecological risks. Responding to overshoot is therefore not only an act of solidarity. It is also prudent self-interest.

Does the Footprint Individualize the Problem?

Another common criticism is that footprint concepts place too much responsibility on individuals.

This is an important concern. However, both the original Ecological Footprint work and Global Footprint Network's ongoing efforts have focused primarily on systemic and national-scale assessments. Our core work centers on country-level analysis through the National Footprint and Biocapacity Accounts.

It is true that Mathis Wackernagel developed one of the first personal footprint calculators in the mid-1990s, followed by the first web-based calculator in 2002 and later versions thereafter. None of these initiatives were sponsored by fossil fuel companies.

More importantly, they were never intended to suggest that individual consumer choices alone can solve ecological overshoot. In fact, the current calculator at www.FootprintCalculator.org encourages users to think beyond personal consumption and engage with a broader question: "Which solution do you love?"

The goal is not to assign blame. It is to help people connect with solutions and become part of larger systemic change.

Many footprint and carbon calculators created by environmental organizations do focus primarily on individual consumption choices. At Global Footprint Network, we are not convinced this is the most effective message. It may even be psychologically counterproductive and can distract attention from the larger structural challenge of ecological overshoot.
At the same time, we have found no evidence that footprint calculators developed by environmental organizations were sponsored by fossil fuel companies.

Why Did BP Promote the Carbon Footprint?

While we were never able to verify BP's motivations directly, three plausible explanations stand out:

1. **Corporate repositioning.**
   BP was promoting its "Beyond Petroleum" identity and wanted to be seen as a broader energy company rather than simply an oil company.
2. **Reputational advantage.**
   Public concern about climate change was growing rapidly, and aligning with the climate conversation allowed BP to present itself as part of the solution rather than part of the problem.
3. **Confidence in continued demand.**
   BP likely understood that the global economy remained deeply dependent on fossil fuels. Raising awareness of climate impacts did not necessarily threaten demand for oil in the near term, making public engagement on the issue less risky from a business perspective.

Why Looking Beyond Carbon Matters
Global Footprint Network also believes that focusing exclusively on carbon can be limiting.

Climate change is essential to address, but carbon is only one of several demands placed on the biosphere. Reducing carbon emissions can sometimes shift pressure onto other ecological systems if broader resource demands are overlooked.

For that reason, we believe it is valuable to track all competing demands on nature, not just carbon emissions alone. A comprehensive view of ecological limits provides a more complete understanding of both risks and opportunities.

Ultimately, the most useful question is not who should be blamed for environmental challenges. The more important question is how people, communities, businesses, and countries can position themselves to thrive in a resource-constrained future.

That is the purpose of the Ecological Footprint: not to assign guilt, but to help decision-makers understand reality and meaningfully respond to it.

Further Resources

More on the Ecological Footprint

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https://doi.org/10.1016/j.ecolecon.2008.07.008 [Cited in Section 3a in support of the point that methane is not yet incorporated into the National Footprint and Biocapacity Accounts.]

Web resources

- FootprintNetwork.org — offers, as Global Footprint Network's main site, all the background on the Ecological Footprint and its applications, linking back to its origins in the early 1990s when we coined the "footprint" term and developed its metric.

- www.FoDaFo.org is the home of the National Footprint and Biocapacity Accounts. Established in 2019, it is the organization jointly set up by York University in Toronto and Global Footprint Network to be the steward of the National Footprint and Biocapacity Accounts. It works directly with York University's Ecological Footprint Initiative for details see footprint.info.yorku.ca.

- Data.FootprintNetwork.org — provides all key results for the National Footprint and Biocapacity Accounts. This is the source of the widely used statistics on how many Earths we use.

- www.FootprintStandards.org provide guidance on how to produce consistent Ecological Footprint applications at all scale, including assuring consistency with results from the National Footprint and Biocapacity Accounts.

- FootprintCalculator.org — allows individuals to estimate their own Footprint and their personal Overshoot Date. We have 3 million annual users, up from 2 million in 2017, with plans to reach 10 million per year within two years. This is the primary entry point to the #MoveTheDate map.

- OvershootDay.org — hosts Earth Overshoot Day and features solutions to #MoveTheDate (reached 2 billion media-impressions in 2017, 3 billion in 2018, and 4 billion in 2019, with ambition to reach 10 billion within 3 years).