



# Framework for National Footprint targets: technical document

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This technical report was prepared by Chris West and Jonathan Green (Stockholm Environment Institute - York University) and Steve Jennings (Alauda Consulting) for WWF to provide the necessary technical and scientific basis to develop the [Policy Guidelines on National Implementation of Target 16 of the Kunming-Montreal Global Biodiversity Framework](#). Please note that this publication does not necessarily reflect WWF official position.

## Executive Summary

### Background

The climate crisis, disruption of global nutrient and water cycles, conversion of natural ecosystems, overfishing and pollution are all driven by overconsumption, unsustainable extraction rates, and by the methods we use to produce and consume material goods. These activities are driving biodiversity loss on a scale that is unprecedented over the last 10 million years.

The Global Biodiversity Framework (GBF) of the Convention on Biological Diversity (CBD) recognises the role of unsustainable consumption within its targets. Specifically, Target 16 calls for Parties to ‘by 2030, reduce the global footprint of consumption in an equitable manner’. The challenge is for countries to define the specific aspect(s) of overconsumption to be reduced; set an equitable but ambitious target for them; determine indicators for measuring progress; and develop the mechanisms for translating the target into action at a national level.

This document provides the scientific background on footprints that can be adopted by Parties to enable national progress towards Target 16 of the GBF. It is intended as the technical companion to [WWF’s Policy Guidelines on National Implementation of Target 16 of the Kunming-Montreal Global Biodiversity Framework](#).

### The utility of consumption footprints

There are many ways of measuring the impacts that human activities have on the natural world. Footprints (see Annex 1 for key definitions) are a particular subset of these measures, ones that can link consumption to pressures on the environment. The explicit link between consumption and environmental harm is key to the utility of footprints:

- The most urgent environmental issues, including climate change and biodiversity loss, have for several decades been more closely associated with global changes in production, trade and consumption than to purely local or regional environmental factors.
- By measuring the impact of consumption, footprints directly respond to Target 16’s agreement to reduce overconsumption.
- It is now self-evident that the impact of a national economy on the natural world extends far beyond the physical boundaries of that nation. Consumption-based footprints allocate responsibility to the consuming country, so that the ‘offshoring’ of environmental impacts becomes transparent.
- Many footprints include a scientifically estimated point at which the risk of global bio-geo-physical breakdown becomes more likely – a planetary boundary or threshold. This is a useful attribute for setting national targets that are both adequate and equitable (see Section 6).
- Footprints are already well established and used in setting targets and monitoring progress for several national, regional and international processes, including SDG 12, and environmental reporting within the EU.

These points are further elaborated in Section 2 of the report.

### Footprint assessments

No single footprint is perfect, and none should be used without thoughtful interpretation and an understanding of their respective strengths and weaknesses. Here we assess nine footprints in detail (from a longlist of sixteen, see Annex 2). The footprints assessed are Material footprint; Biomass footprint; Greenhouse Gases; Nitrogen use; Phosphate use; Water use; Land use change (deforestation); Biosphere footprint (including biodiversity footprints) and the Ecological Footprint.

In Section 4 of the report, these footprints are assessed against a range of technical, policy and practical criteria, which were largely adapted from the CBD's principles for selecting indicators. The assessment includes consideration of data availability, scientific robustness of the footprint, how changes to the footprint relate to changes in biodiversity and whether they provide relevant and meaningful information for policy decisions. It provides detailed information on each of the footprints, to allow informed choices about which can be adopted for setting national targets, developing policies, and monitoring progress towards GBF Target 16.

Wider considerations that apply to all footprints are discussed in Section 5.

## National targets

At a national level, the key steps to begin implementing this commitment are updating National Biodiversity Strategies and Action Plans (NBSAPs) by defining the specific aspect(s) of 'overconsumption', to be reduced; set a fair but ambitious reduction target for them; determine indicators for measuring progress and determine the mechanisms for translating Target 16 into action. Section 6 of the report provides technical considerations involved in this process.

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## 1. Introduction

The climate crisis, disruption of global nutrient cycles, conversion of natural ecosystems, overfishing and pollution are driven by overconsumption, unsustainable extraction rates, and by the methods we use to produce and consume material goods. These activities are driving biodiversity loss on a scale that is unprecedented over the last 10 million years,<sup>1</sup> and the rate of loss is accelerating.<sup>2</sup> With more than half of the global economy being dependent on nature,<sup>3</sup> the degradation of our natural world is increasingly being considered as a major risk to economies and businesses, and ultimately, to human wellbeing.

Urgent and transformative action needs to be taken to address how we produce and consume materials if further irreversible global biodiversity loss and failure of earth systems is to be avoided.<sup>4</sup> This transformation must recognise and address global inequalities: people living in high income countries consume more than thirteen times the quantity of materials per year than those in developing countries.<sup>5</sup> To put it another way, we need to return to within safe planetary limits<sup>6</sup> whilst meeting basic human needs as a minimum.<sup>7</sup> Transforming our economies to reduce our impact on the environment does not imply that economies have to shrink. It will almost certainly require some reductions in consumption (e.g., meat and dairy, where the current level of consumption is both unhealthy and unsustainable in many populations), but significant footprint reductions can be made by doing things differently.

The notion that we need to reduce our consumption footprint equitably is now embedded within multilateral policy instruments. Target 16 of the Kunming-Montreal Global Biodiversity Framework, commits signatories to “... by 2030, reduce the global footprint of consumption in an equitable manner, including through halving global food waste, significantly reducing overconsumption and substantially reducing waste generation”, and SDG 12 aims to achieve sustainable production and consumption.<sup>8</sup> The need to reduce consumption and in some cases, overconsumption, is also supported by growing high-level policy dialogues, such as the Global Resource Outlook.<sup>9</sup>

The immediate tasks to begin implementing this commitment are to define the specific aspect(s) of ‘overconsumption’ to be reduced; continue to improve - and in many cases start - monitoring

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<sup>1</sup> IPBES (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. Settele, E. S. Brondízio E.S., H. T. Ngo, M. Guèze, J. Agard, A. Arneeth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J., Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany. 56 pages.

<sup>2</sup> Ceballos, G. & Paul R. Ehrlich, P.R., 2023. Mutilation of the tree of life via mass extinction of animal genera. PNAS 120 (39) e2306987120 <https://doi.org/10.1073/pnas.2306987120>

<sup>3</sup> World Economic Forum (WEF), 2020, Global Risks Report, Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy: [www.weforum.org/reports/the-global-risks-report-2020](http://www.weforum.org/reports/the-global-risks-report-2020)

<sup>4</sup> Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019). Global Assessment Report on Biodiversity and Ecosystem Services. <https://ipbes.net/global-assessment>; WWF (2020) Living Planet Report 2020 - Bending the curve of biodiversity loss. Almond, R.E.A., Grooten M. and Petersen, T. (Eds). WWF, Gland, Switzerland; Secretariat of the Convention on Biological Diversity (2020) Global Biodiversity Outlook 5. Montreal.

<sup>5</sup> IRP (2019). Global Resources Outlook 2019: Natural Resources for the Future We Want. Oberle, B., Bringezu, S., Hatfield-Dodds, S., Hellweg, S., Schandl, H., Clement, J., and Cabernard, L., Che, N., Chen, D., Droz-Georget, H., Ekins, P., Fischer-Kowalski, M., Flörke, M., Frank, S., Froemelt, A., Geschke, A., Haupt, M., Havlik, P., Hüfner, R., Lenzen, M., Lieber, M., Liu, B., Lu, Y., Lutter, S., Mehr, J., Miatto, A., Newth, D., Oberschelp, C., Obersteiner, M., Pfister, S., Piccoli, E., Schaldach, R., Schüngel, J., Sonderegger, T., Sudheshwar, A., Tanikawa, H., van der Voet, E., Walker, C., West, J., Wang, Z., Zhu, B. A Report of the International Resource Panel. United Nations Environment Programme. Nairobi, Kenya

<sup>6</sup> Rockström, J., Steffen, W., Noone, K. et al. A safe operating space for humanity. Nature 461, 472–475 (2009).

<https://doi.org/10.1038/461472a>

<sup>7</sup> Raworth, K. (2017). Doughnut economics: seven ways to think like a 21st century economist. White River Junction, Vermont, Chelsea Green Publishing; O'Neill, D. W., Fanning, A. L., Lamb, W. F., & Steinberger, J. K. (2018). A good life for all within planetary boundaries. Nature sustainability, 1(2), 88-95.

<sup>8</sup> <https://sdgs.un.org/goals>

<sup>9</sup> For example, United Nations Environment Programme (2024). Global Resources Outlook 2024 Summary for Policymakers: Bend the Trend – Pathways to a liveable planet as resource use spikes. International Resource Panel. Nairobi.

<https://wedocs.unep.org/20.500.11822/44902>;

consumption-driven impacts; set reduction targets for them; develop indicators, and determine the mechanisms for translating Target 16 into action at a national level as part of updated National Biodiversity Strategies and Action Plans (NBSAPs).<sup>10</sup> The purpose of this paper is to provide technical assessment of the opportunities and challenges associated with these steps. It will be accompanied by and underpins [policy guidelines](#), which will seek to make clear the choices available to policy makers in setting and measuring consumption targets.

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<sup>10</sup> WWF (2023). Walk lightly on the Earth: Footprint of OECD countries, planetary limits and urgent action needed by all for nature and people. Discussion paper. [https://www.fint.awsassets.panda.org/downloads/wwf-discussion-paper\\_walk-lightly-on-earth\\_footprint-of-oecd-countries\\_october-2023-final.pdf](https://www.fint.awsassets.panda.org/downloads/wwf-discussion-paper_walk-lightly-on-earth_footprint-of-oecd-countries_october-2023-final.pdf)

## 2. Narrative for global footprints and national targets

### 2.1 Why global footprints?

Human activities have many different impacts on the natural world. These can be measured in numerous ways and for different purposes. Footprints (see Annex 1 for key definitions) are a particular subset of these measures, ones that denote the link between production and/or consumption and environmental impacts, or more commonly, pressures on the environment. This is distinct from the large set of environmental measurements that essentially measure environmental degradation without any inherent link to the cause of the degradation, such as measuring air pollution within a city, or water quality within a river.

The explicit linking of production and/or consumption to impact is critical in understanding the utility of footprints. The most urgent environmental issues, including climate change and biodiversity loss, have for several decades been more closely associated with global changes in production, trade and consumption than to purely local or regional environmental factors.<sup>11</sup> Footprints therefore link cause and effect in a way which environmental monitoring alone does not. Only by understanding the internationally-relevant links between cause and effect can we design solutions for tackling such systemic problems, in other words, developing this understanding is critical to addressing the cause, rather than the symptoms of our impact on the planet.

A corollary of consumption-driven environmental impacts is that it is now self-evident that the impact of a national economy on the natural world extends far beyond the physical boundaries of that nation.<sup>12</sup> Although the scope of footprints can vary (see Annex 1), those that include consumption explicitly incorporate the impacts that an economy has abroad. This is important in two regards. Firstly, it reveals a tendency of many economies towards ‘offshoring’ of impacts,<sup>13</sup> by which an economy (that may also be seeking to reduce its domestic impacts) can simply displace impacts to another part of the globe. In sum, this results in no net reduction in the impact of consumption, despite impact within the reporting territory being reduced. Such effects clearly interrelate with the concept of ‘just transitions’ for sustainable development.<sup>14,15</sup> Secondly, it reveals the real-world complexity of where responsibility for environmental degradation lies, which in turn opens the door for realistic policies to reduce them, as well as suggesting collaboration between importer and exporter countries and blocs to jointly construct effective and equitable solutions. It is also in the interests of importer countries to do so: continuing degradation of ecosystems will at some stage lead to the footprint no longer being sustained, threatening resource security.

A further subset of footprints relate to defined points (defined with varying degrees of scientific rigour) at which the risk of global bio-geo-physical breakdown becomes likely – a planetary boundary or

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<sup>11</sup> Giljum, S., Burger, E., Hinterberger, F., Lutter, S., & Bruckner, M. (2011). A comprehensive set of resource use indicators from the micro to the macro level. *Resources, Conservation and Recycling*, 55, 3, 300-308. ISSN 0921-3449, <https://doi.org/10.1016/j.resconrec.2010.09.009>; Giljum S, Hak T, Hinterberger F, & Kovanda J. (2005). Environmental governance in the European Union: strategies and instruments for absolute decoupling. *International Journal of Sustainable Development*, 8, :31–46;

Schmidt-Bleek F. (1992). MIPS – a universal ecological measure. *Fresen Environmental Bulletin*, 2, 407–12.

<sup>12</sup> Carmenta, R., Barlow, J., Bastos Lima, M.G., Berenguer, E., Choiruzzad, S., Estrada-Carmona, N., França, F., Kallis, G., Killick, E., Lees, A., Martin, A., Pascual, U., Pettorelli, N., Reed, J., Rodriguez, I., Steward, A.M., Sunderland, T., Vira, B., Zaehring, J.G., & Hicks, C. (2023). Connected Conservation: Rethinking conservation for a telecoupled world. *Biological Conservation*, 282, 110047, ISSN 0006-3207, <https://doi.org/10.1016/j.biocon.2023.110047>; Tukker, A., Bulavskaya, T., Giljum, S., de Koning, A., Lutter, S., Simas, M., Stadler, K., Wood, R. (2014). *The Global Resource Footprint of Nations. Carbon, water, land and materials embodied in trade and final consumption calculated with EXIOBASE; 2.1.* Leiden/Delft/Vienna/Trondheim. ISBN: 978-3-200-03637-6

<sup>13</sup> West, C., Green, J., Croft, S. & Gardner, T. (2023). Monitoring Offshore Environmental Impacts of Trade. Task Force 6 Accelerating SDGs: Exploring New Pathways to the 2030 Agenda. <https://t20ind.org/research/monitoring-offshore-environmental-impacts-of-trade/>

<sup>14</sup> ILO (2015). Guidelines for a just transition towards environmentally sustainable economies and societies for all. ISBN 978-92-2-130627-6

<sup>15</sup> Dasgupta, P. (2021), *The Economics of Biodiversity: The Dasgupta Review*. London: HM Treasury

threshold.<sup>16</sup> These include greenhouse gas emissions, nitrogen and phosphorus use, land use, amongst others. This is a useful attribute for both international processes, such as the CBD, as it suggests an overall numerical global target for that process, but can equally be useful for setting national targets that are both adequate and equitable (see Section 6). Furthermore, the concept that environmental thresholds or tipping points exist helps to facilitate absolute (as opposed to relative) target setting, which both reflect impact on the natural world more clearly and allows for policy choices to evaluate and monitor the contribution of various options (e.g., reductions in consumption, increased efficiency, and circular economy measures). In addition, analysis of environmental thresholds has advanced our understanding of the synergies and trade-offs between environmental and social outcomes<sup>17</sup>.

The ability to estimate a global footprint (with threshold) and nested national consumption footprints has another important attribute in that it allows equity to be front and centre of national target setting. The contribution to most global footprints is not equal between citizens and nations, with a few nations dominating the footprint and the resultant overshoot of planetary limits. If this is (for example), calculated as a per capita footprint, the national targets that combine to reduce the global footprint will vary significantly, with some nations (typically developed countries) having to drastically reduce their footprints, whilst others (typically lower income nations) may actually be able to grow their footprints in the medium term.

Finally, footprints are already well established and used in setting targets and monitoring progress for a number of national, regional and international processes. For example, the material footprint is used as an indicator for SDG 12<sup>18</sup>, and is embedded within national and regional environmental reporting within the EU.<sup>19</sup> There is clear support for resource use targets elsewhere.<sup>20</sup> This means that there is a degree of commitment and practice in using footprints which partly circumvents potential arguments about the practicalities of their implementation.

There are valid criticisms of global footprints. No single footprint is perfect, and none should be used without thoughtful interpretation and an understanding of their respective strengths and weaknesses. There are also choices and limitations with footprints in general, including the availability of global data sets that are up to date, which reflect national or subnational variations adequately, that are sufficiently sensitive to changes in production activities, and - as a consequence of a lack of global supply chain transparency - the impact of using modelling approaches to link metrics to consumption. These are discussed in Section 5, whilst issues with specific footprints are highlighted in Section 4. However, these issues should not mask the utility of footprints in linking cause and effect.

## 2.2 ... and why national footprint targets?

In common with any other type of target, a national footprint target allows policies to be assessed against likely impact, and progress to be monitored to understand whether action is effective, too little or too much. There are, in addition, some specific advantages of consumption-based footprints.

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<sup>16</sup> Rockström, J., Steffen, W., Noone, K. et al. A safe operating space for humanity. *Nature* 461, 472–475 (2009).

<https://doi.org/10.1038/461472a>; Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., (2015). Sustainability. Planetary boundaries: guiding human development on a changing planet. *Science*, 347 (6223), p. 1259855, [10.1126/science.1259855](https://doi.org/10.1126/science.1259855)

<sup>17</sup> Raworth, K. (2017). *Doughnut economics: seven ways to think like a 21st century economist*. White River Junction, Vermont, Chelsea Green Publishing; O'Neill, D. W., Fanning, A. L., Lamb, W. F., & Steinberger, J. K. (2018). A good life for all within planetary boundaries. *Nature sustainability*, 1(2), 88-95.

<sup>18</sup> <https://sdgs.un.org/goals/goal12>

<sup>19</sup> EUROSTAT (2023). Domestic Material Consumption. <https://ec.europa.eu/eurostat>

<sup>20</sup> For example, United Nations Environment Programme (2024). *Global Resources Outlook 2024 Summary for Policymakers: Bend the Trend – Pathways to a liveable planet as resource use spikes*. International Resource Panel. Nairobi. <https://wedocs.unep.org/20.500.11822/44902>

The notion of setting national footprint targets (see Section 6) has many of the same strengths and weaknesses as global footprints. Fundamentally, however, a national footprint denotes the impact of an economy on the natural world, wherever those impacts occur, and hence a national footprint target denotes the responsibility that a nation has for reducing global environmental degradation. A national footprint target allows the potential for an equitable national share of global resources whilst taking into account the country's responsibility for global environmental issues.

The data on which footprints are constructed typically allows evaluation of which sectors are the main contributors to a national footprint, which is important for developing effective policy instruments. For example, material footprints are based on data that have a high level of product detail, and so it is possible to identify the main contributors to the overall footprint. In this example, fossil energy and carriers (oil, natural gas, coal, and derived products) comprise the largest share of the material footprint of most countries. The sectors responsible for fossil fuel use within each economy are already known from climate change research, enabling sector specific policies to reduce their material to be created, balancing issues of supply chain resilience and security, and hotspots of environmental exposure.

### 3. A high-level guide to understanding footprints and metrics

#### 3.1 Introduction

Target 16 of the GBF commits signatories to ‘by 2030, reduce the global footprint of consumption in an equitable manner, including through halving global food waste, significantly reducing overconsumption and substantially reducing waste generation, in order for all people to live well in harmony with Mother Earth’. The specific footprints we are considering in this document are therefore indicators linked to ‘consumption’ activities, not (necessarily) of biodiversity *per se*. That being said, biodiversity and consumption are clearly interconnected – hence the existence of Target 16 – and the more responsive biodiversity is to changes in a footprint the better the selected footprint(s) will serve the overarching purpose of the GBF.

This section describes a limited number of criteria that can be used to assess the utility of footprints, and their underlying indicators and metrics.

#### 3.2 Footprints' characteristics that are appropriate for GBF Target 16

For the purposes of the GBF’s Target 16, we suggest that footprints should meet a number of technical, practical and policy considerations. These are largely adapted for the specific issue of footprints from the CBD’s Principles for Selecting Indicators (denoted by “CBD”) amongst other sources<sup>21</sup>:

##### 3.2.1 Technical considerations

**Measurable:** Footprints should be composed of indicators and metrics that can be measured in an unambiguous way (e.g., are based on empirical data and not subjective views).

**Scientifically robust:** Footprints must be based on clearly defined, verifiable and scientifically acceptable data, which are collected using standard methods with known accuracy and precision, or based on traditional knowledge that has been validated in an appropriate way. If two groups estimate the same footprint at the same time using the same methods, they should get the same result. (CBD)

**Technical relevance:** For footprints relevant to the GBF, this has two distinct aspects:

- The footprint should reflect an important aspect of consumption (directly or indirectly) to reflect Target 16 of the GBF;
- The footprint should have a clear (direct or indirect) impact on biodiversity such that a reduction in the footprint would – all else being equal – result in a reduction in the rate of biodiversity loss or ultimately an increase in biodiversity. (CBD)

**Sensitive:** A measured change in the footprint should relate to a real-world change in the (direct or indirect) impacts on biodiversity in time frames and on scales that are relevant to decision making. For example, some chemical pollutants may remain environmentally harmful many decades after release, so a footprint indicating a reduction in their release would provide little knowledge if being used as an indicator of their current impacts. Secondly, the underlying data used to construct footprints is varied in its ability to detect changes in consumption. (CBD)

**Scope:** the truest picture of a nation’s footprint on the natural world is its consumption footprint, which includes both domestic and imported resources (see ‘Definitions’) and so it must be possible to assign the

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<sup>21</sup> CBD (2007). Principles for selecting indicators. <https://www.cbd.int/indicators/indicatorprinciples.shtml>. Other sources, including Kaye-Blake et al. (2017). Signs to look for: criteria for developing and selecting fit for purpose indicators. New Zealand Institute of Economic Research, were also used.

footprint in that way. A second aspect of scope is understanding what aspects of consumption are covered by a footprint.

**Operates at multiple spatial scales:** Ideally, a footprint would remain relevant (and calculable) at multiple spatial scales: globally, nationally and preferably, to different sectors within a national economy and/or sub-nationally.

### 3.2.2 Practical and policy considerations

**Available:** Footprints should be based on data and/or modelling that is readily available, or that can be conducted with reasonable effort and cost. (CBD)

**Policy relevant and meaningful:** Footprints should send a clear message and provide information at a level appropriate for policy and management decision making by assessing changes in the status of biodiversity (or pressures, responses, use or capacity), related to baselines and agreed policy targets if possible. (CBD)

**Threshold:** The footprint should ideally have a threshold through which human activity cannot safely pass (a 'planetary boundary' or 'planetary limit'). This allows global and subsequent national targets to be set with a degree of rigour. The threshold should be based on robust science.

**Broadly accepted:** The power of a footprint depends on its broad acceptance, with policy makers, major stakeholders and experts involved in its development. In the case of the GBF, the methodology should have been endorsed by relevant intergovernmental bodies and there should be adequate mechanisms to ensure data quality. One useful indicator of acceptance is the presence of a footprint existing in policy commitments or endorsements by relevant intergovernmental bodies. Indicator provision should also be accompanied by transparency around quality assurance processes. (CBD)

**Limited in number:** Having too few footprints (or underlying indicators) risks missing important aspects of change, and trade-offs, whereas large numbers of indicators may make clear communication of progress towards targets – or even the reasons for progress or lack of progress – difficult to ascertain.

## 4. Assessing footprints

### 4.1 Introduction

This section provides a brief review of the footprints that were chosen for assessment against the criteria outlined in the preceding section.

Sixteen footprints – and their major variants – were initially examined. All of these footprints are well established in the scientific literature, are global in nature and can be estimated nationally, which are essential prerequisites for application of footprints for the CBD. We have not attempted to assess the availability of particular estimates of resource extraction/emissions that might reside in LCA databases and/or have been created for particular products/regions. This is because they are typically not comparable across different products/regions and are not really 'accessible' for global footprint assessments.

Nine of these were selected for further assessment: Material footprint; Biomass footprint (which is also a subset of the Material Footprint); GHGs; Nitrogen use; Phosphate use; Water use; Land use change (deforestation); Biosphere footprint (including biodiversity footprints) and the Ecological Footprint.

Those not selected for further analysis (see Annex 2) were excluded either because they are in effect sub-categories or specific cases of other footprints (e.g., ocean acidification is a consequence of GHG concentrations) or because there is uncertainty about the impacts on the environment and/or they are already the subject of significant national and/or international legislation and monitoring – this is particularly the case with pollution-focused footprints (e.g., the novel entity footprint is composed of multiple compounds that have different, complex and often unknown environmental impacts, meaning that the environmental impacts of a change in the overall footprint is essentially unknown).

### 4.2 Material footprint

#### 4.2.1 Introduction

##### **Description of the footprint**

The Material Footprint is the attribution of global material extraction (mining, harvesting, etc) to final consumption by a country's or region's economy. It is the balance of the biomass, fossil fuels, metal ores and non-metal ores entering and leaving an economy, measured in tonnes. Note that biomass is also considered as a separate footprint below.

The most standardised method for calculating the Material Footprint is based on established Economy-Wide Material Flow Accounting procedures (EW-MFA).<sup>22</sup> According to these procedures, the Material Footprint is the domestic production and import of these materials minus exports, inclusive of the materials needed to produce the imported goods. Domestic Material Consumption (DMC) is a similar and more widely used measure, but only encompasses the mass of the traded materials themselves, and not the total weight of materials used to produce them. Consumption-based accounting (CBA), which relies Multi-Regional Input-Output (MRIO) models, can also be used to provide material footprint estimates (see Section 5 for more detailed explanation of these accounting techniques and associated considerations that cut across footprint measures). Ideally, the material footprint is estimated in terms of 'Raw Material Equivalent' (RME) which reflects the raw materials that are extracted to produce traded and consumed products, rather than the traded products themselves, and hence is a closer reflection of

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<sup>22</sup> <https://seea.un.org/>

environmental pressures. RME is therefore closer to the source of the major environmental impacts (production).

### Planetary limit

At global level, similar limits have been proposed for the Material Footprint: 50 Gt per year<sup>23</sup> or 50.8 Gt per year<sup>24</sup>, which represent a return to the global material footprint of 1992 and 2000 respectively. These and other formulations of a planetary limit are often articulated as a *per capita* limit of between 5-8 tonnes per year.<sup>25</sup>

#### 4.2.2 Technical considerations

**Measurability.** The Material Footprint is highly and relatively easily measurable. Estimates are commonly based on standardised and verifiable customs data which are available globally and annually with at most a 1-year lag (e.g., UN Comtrade, which also publishes monthly data with less consistent coverage) and with a shorter lag in some national customs databases, and national production data (typically available annually with a c. 1 year lag). UNEP also collates data for all countries.<sup>26</sup> Material Footprint versions based on MRIO may be updated less often.

**Scientific robustness of footprint.** Highly standardised. Methodologies for compiling material flow data and calculating indicators on material use and material productivity have been standardised for > 20 years by organisations such as UNDP and EUROSTAT.

**Scientific robustness of planetary limit.** Although the planetary limit is established in the literature, the scientific underpinning is not clearly tied to the risk of breakdown in planetary systems functioning. Instead, it is typically based on an arbitrary reference year in the past and/or the notion that material flows indirectly measure many of the environmental changes that have created the Holocene.<sup>27</sup>

**Technical relevance (reflects consumption).** Very high: the footprint directly reflects the majority of material resources consumed by economies.

**Technical relevance (directness of relationship with impacts on biodiversity).** The material footprint is an indirect indicator of impacts on biodiversity. As impacts are largely associated with the exact nature of production/extraction of materials, it is possible to have two countries with similar material footprints that have different levels of environmental impact. It also does not explicitly account for the lack of comparability of different materials in terms of their environmental impact, and so, for example, changes in extraction technology or substitution between materials (e.g., substituting fossil fuels for biomass in electricity production) can lead to different aggregate impacts. The material footprint does not explicitly account for these impacts. Note that although material footprint in RME is available for some countries (e.g., the EU<sup>28</sup>), it is not yet a global standard.

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<sup>23</sup> O'Neill, D.W., Fanning, A.L., Lamb, W.F. et al. (2018). A good life for all within planetary boundaries. *Nature Sustainability*, 1, 88–95. <https://doi.org/10.1038/s41893-018-0021-4>; Dittrich, M., Giljum, S., Lutter, S. & Polzin, C. (2012). Green economies around the world? Implications of resource use for development and the environment. Sustainable Europe Research Institute, Vienna.

<sup>24</sup> Bringezu, S. (2015). Possible target corridor for sustainable use of global material resources. *Resources* 4, 25-54, doi:10.3390/resources4010025.

<sup>25</sup> O'Neill, D.W., Fanning, A.L., Lamb, W.F. et al. (2018). A good life for all within planetary boundaries. *Nature Sustainability*, 1, 88–95. <https://doi.org/10.1038/s41893-018-0021-4>; Dittrich, M., Giljum, S., Lutter, S. & Polzin, C. (2012). Green economies around the world? Implications of resource use for development and the environment. Sustainable Europe Research Institute, Vienna; Hoekstra, A. Y. & Wiedmann, T. O. (2014). Humanity's unsustainable environmental footprint. *Science* 344, 1114-1117, doi:10.1126/science.1248365; UNEP (2014). Managing and Conserving the Natural Resource Base for Sustained Economic and Social Development (United Nations Environment Programme, Nairobi; Bringezu, S. (2015). Possible target corridor for sustainable use of global material resources. *Resources* 4, 25-54, doi:10.3390/resources4010025.

<sup>26</sup> <https://www.unep.org/explore-topics/sustainable-development-goals/why-do-sustainable-development-goals-matter/goal-12-1>

<sup>27</sup> Bringezu, S. (2015). Possible target corridor for sustainable use of global material resources. *Resources* 4, 25-54, doi:10.3390/resources4010025.

<sup>28</sup> Eurostat (2023). Material flow accounts statistics - material footprints. [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Material\\_flow\\_accounts\\_statistics\\_-\\_material\\_footprints#Raw\\_material\\_consumption\\_by\\_final\\_use\\_of\\_products](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Material_flow_accounts_statistics_-_material_footprints#Raw_material_consumption_by_final_use_of_products)

**Sensitivity.** Data is available annually, and hence should broadly reflect annual changes in the pressures that material consumption puts on the natural world. The caveat here is that the material footprint (in tonnes) may not directly relate to environmental impact (See Technical relevance section, above).

**Scope.** The material footprint (and most of its variants) have a highly appropriate scope in that the footprint directly reflects consumption of the majority of goods that are consumed (exceptions include water).

**Operates at multiple scales.** The footprint is relevant at global and national scales, with no change in accuracy between these scales. In addition, the high level of product level detail captured in the underlying data makes it relatively straightforward to estimate at subnational and sectoral levels with limited assumptions/additional data and/or modelling.

#### 4.2.3 Practical and policy considerations

**Availability.** Very high – the basic data is available globally and at least annually (with a c. 1 year time lag at most, other than variants that use RME which are based on estimates that may not always be updated annually) and the methods for estimating material footprint are well established and are in practice conducted by many nations. This also means that skills and knowledge on the footprint exist within many organisations.

**Policy relevant and meaningful.** The material footprint and its variants include defined sub-categories of materials, allowing clear feedback mechanisms between policy and the footprint. Furthermore, additional policy-relevant indicators can be readily derived from the basic Material Flow Account, such as resource use efficiency.

**Potential to set targets against a threshold.** A global threshold has been proposed (see above) and is typically tied to a return to material use of a particular historic reference year (e.g., 2000) rather than being tied to the risk of breakdown in planetary system functions

**Broadly accepted.** The Material Footprint (and its variants) are mature and established at national levels in many countries, and at international levels via the UN<sup>29</sup> and the EU.<sup>30</sup> It is already used as a measure by various international commitments (e.g., SDG Targets 8.4 and 12.2)<sup>31</sup> and embedded within the discourse of the sustainable and equitable transition that the global economy needs to make in order to secure a sustainable future.<sup>32</sup> For example, the UNEP's Global Resource Outlook argues for the need to 'Institutionalise resource governance, including embedding resources in the delivery of multilateral environmental agreements on climate change, biodiversity loss, land degradation and others. Defining resource use paths aligned with the goals of these agreements and the creation of an international resource agency are some of the ways that resources could be prioritised at all levels of governance.'<sup>33</sup> Further, the underlying data is published by national government agencies, giving it meaningful national status.

**Few in number.** The Material Footprint is arguably the single most comprehensive indicator of an economy's consumption – though less so of the *impact* of consumption – is based on a discrete set of metrics and has relatively few variants.

#### 4.2.4 General considerations and footprint-specific recommendations

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<sup>29</sup> <https://www.resourcepanel.org/global-material-flows-database>

<sup>30</sup> [https://ec.europa.eu/eurostat/databrowser/view/ENV\\_AC\\_MFA/default/table?lang=en](https://ec.europa.eu/eurostat/databrowser/view/ENV_AC_MFA/default/table?lang=en)

<sup>31</sup> <https://unstats.un.org/sdgs/report/2019/goal-12/#:~:text=%E2%80%9CMaterial%20footprint%E2%80%9D%20refers%20to%20the,the%20material%20needs%20of%20people>

<sup>32</sup> United Nations Environment Programme (2024). Global Resources Outlook 2024 Summary for Policymakers: Bend the Trend – Pathways to a liveable planet as resource use spikes. International Resource Panel. Nairobi. <https://wedocs.unep.org/20.500.11822/44902>

<sup>33</sup> United Nations Environment Programme (2024). Global Resources Outlook 2024 Summary for Policymakers: Bend the Trend – Pathways to a liveable planet as resource use spikes. International Resource Panel. Nairobi. <https://wedocs.unep.org/20.500.11822/44902>

The material footprint (at least conceptually) underpins most of the other footprint measures which in some form or other rely on estimates of raw material extraction to then link through to environmental pressures or impacts. In addition, for many countries, the largest contributor to the Material Footprint is fossil fuels and carriers. There is therefore potential synergy between reducing the material footprint and achieving climate targets.

## 4.3 Biomass footprint

### 4.3.1 Introduction

#### **Description of footprint**

Biomass consumption relates to the consumption of agricultural products, animal products, forestry products and fishery products. It is a subset of the broader Material Footprint which comprises biomass, fossil fuels, metal ores and non-metal ores. It also is treated separately here<sup>34</sup> due to its particularly close link with the food system, which is one of the major drivers of the global climate<sup>35,36</sup> and biodiversity crises<sup>37</sup>.

The biomass footprint can be based on established Economy-wide Material Flow Accounting procedures, which sums the biomass entering and leaving an economy (in tonnes). Biomass footprints are dominated by food and animal feed in many economies, but also include timber products, fibres and biomass used for energy production.

#### **Planetary limit**

This has received relatively little attention as biomass is usually bound up in the estimates for a planetary limit for material consumption (see above). A threshold has been derived as a proportion of the Material Footprint<sup>38</sup>, and one could be derived from global net primary productivity<sup>39</sup> or the human appropriation of that (see biosphere integrity) but neither approach is without significant pitfalls. Limits to the use of bioenergy – a subset of the biomass footprint – are more commonly estimated, for example 1.2 billion tonnes carbon of potentially harvestable energy per year.<sup>40</sup>

### 4.3.2 Technical considerations

**Measurability.** Highly measurable and based on standardised data which is commonly available and accessible, including via national statistics submissions (see Material Footprint for details).

**Scientifically robustness of footprint.** Highly standardised. Methodologies for compiling material flow data and calculating indicators on material use and material productivity have been standardised for > 20 years by organisations such as UNDP and EUROSTAT.

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<sup>34</sup> See also Metabolic & WWF (2020). Halving the footprint of production and consumption.

[https://wwfint.awsassets.panda.org/downloads/halvingfootprint\\_report\\_wwf\\_metabolic.pdf](https://wwfint.awsassets.panda.org/downloads/halvingfootprint_report_wwf_metabolic.pdf)

<sup>35</sup> Mbow, C., C. Rosenzweig, L.G. Barioni, T.G. Benton, M. Herrero, M. Krishnapillai, E. Liwenga, P. Pradhan, M.G. Rivera-Ferre, T. Sapkota, F.N. Tubiello, & Y. Xu (2019). Food Security. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)].

<sup>36</sup> Crippa, M., Solazzo, E., Guizzardi, D. et al. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food* 2, 198–209. <https://doi.org/10.1038/s43016-021-00225-9>

<sup>37</sup> Benton, T. G., Bieg, C., Harwatt, H., Pudasain, R., & Wellesley, L. (2021). Food system impacts on biodiversity loss. Chatham House. Available at: [https://www.chathamhouse.org/sites/default/files/2021-02/2021-02-03-food-system-biodiversity-loss-benton-et-al\\_0.pdf](https://www.chathamhouse.org/sites/default/files/2021-02/2021-02-03-food-system-biodiversity-loss-benton-et-al_0.pdf)

<sup>38</sup> For example, Jennings, S., McCormack, C. & Stoll, G. (2021). Thriving within our planetary means: reducing the footprint of production and consumption. WWF-UK. <https://www.wwf.org.uk/what-we-do/uk-global-footprint>

<sup>39</sup> Erb, K-H & Gingrich, S. (2022). Biomass—Critical limits to a vital resource. *One Earth*, 5 (1), 7-9. ISSN 2590-3322, <https://doi.org/10.1016/j.oneear.2021.12.014>.

<sup>40</sup> Field, C.B., Campbell, J.E. & Lobell, D.B. (2008). Biomass energy: the scale of the potential resource. *Trends in Ecology & Evolution*, 23 (2), 65-72. ISSN 0169-5347, <https://doi.org/10.1016/j.tree.2007.12.001>.

**Scientific robustness of planetary limit.** Low – very few estimates have been undertaken, and none that clearly tie biomass consumption to a heightened risk of planetary system failure.

**Technical relevance (reflects consumption).** Very high - the footprint directly reflects consumption of (biological) goods, and includes both materials extracted domestically, and those imported from overseas, with exports excluded.

**Technical relevance (directness of relationship with impacts on biodiversity).** In general, the biomass footprint is an indirect indicator of impacts on biodiversity, as described for the Material Footprint (above). However, a significant part of the Biomass Footprint is composed of plants and animals that are harvested from the wild, especially marine wild capture fisheries and timber harvested from natural forests. These elements of the footprint have direct impacts on the species involved and on their habitats, particularly if the methods of harvesting are environmentally destructive (e.g., bottom trawling). Secondly, the terrestrial portion of biomass derives from the way land is used, which has direct implications for biodiversity (see Land Use Change and Biosphere integrity footprints, below). Like the material footprint, the biomass footprint would be best estimated in terms of 'Raw Material Equivalent' (RME).

**Sensitivity.** Data is available annually, and hence should reflect changes in the pressures that biomass consumption put on the natural world. The caveat here is that changes in production techniques or substitution between materials can lead to different aggregate impacts.

**Scope.** The footprint directly reflects consumption of biological goods which only comprise a subset (albeit highly important) of the impacts to biodiversity linked to total consumption activity.

**Operates at multiple scales.** Relevant at global and national scales. Relatively straightforward to estimate at subnational and sectoral scales with straightforward assumptions/additional data and/or modelling.

#### 4.3.3 Practical and policy considerations

**Availability.** Very high - data is available globally and annually (with a c. 1 year time lag at most) and the methods for estimating material footprint are well established and are conducted by many nations. This also means that skills and knowledge on the footprint exist within many organisations.

**Policy relevant and meaningful.** The footprint includes defined sub-categories of biomass materials, allowing clear feedback mechanisms between policy and the footprint. Furthermore, additional policy-relevant indicators can be readily derived, such as resource use efficiency.

**Potential to set targets against a threshold.** A threshold can be derived but the basis is not tied to the risk of a breakdown in planetary system functions (see above).

**Broadly accepted.** It is widely accepted as an element of the Material Footprint, but less commonly used alone.

**Few in number.** Reflects an important but incomplete aspect of consumption but may not reflect sufficient aspects of consumption to be ideal as a sole footprint.

#### 4.3.4 General considerations and footprint-specific recommendations

The Biomass Footprint has a significant advantage of being closely tied to the food system, which is a major contributor to biodiversity loss and an area with existing international commitments relating to sustainability and equity (e.g., SDGs). However, it is probably best viewed as a part of the wider Material Footprint, albeit one that requires specific analysis (and arguably specific targets) given its direct relation to global environmental issues.

## 4.4 Nitrogen Footprint

#### 4.4.1 Introduction

##### Description of footprint

Anthropogenic input of reactive nitrogen into earth systems occurs through industrial fixation of nitrogen from atmospheric nitrogen via the Haber-Bosch process, intended biological N fixation; and unintended nitrogen fixation due to the emission of nitrogen oxides (NO<sub>x</sub>) from transport and industry. Nitrogen fixation via the Haber-Bosch process is by far the largest of these. The combined input of nitrogen from intended human fixation processes is used as to quantify the global footprint<sup>41</sup>, national consumption footprints,<sup>42</sup> and to define the planetary limit.<sup>43</sup> An alternative approach estimates nitrogen *losses* into the environment from consumption (rather than use) but has so far largely been focused on individual consumers or organisations.<sup>44</sup> Target 7 of the Global Biodiversity Framework explicitly refers to “reducing excess nutrients lost to the environment by at least half”.<sup>45</sup>

##### Planetary limit

Application rate of intentionally fixed nitrogen to the agricultural system of 62 million tonnes of nitrogen per year.<sup>46</sup>

#### 4.4.2 Technical considerations

Measurability. The underlying data on industrially fixed and applied nitrogen is from the International Fertilizer Industry Association, which includes nation- and crop-specific data for 88 countries (which account for an estimated 90% of global fertiliser use) and represents an expert consensus on data from the Food and Agriculture Organisation of the United Nations (FAO).<sup>47</sup> The FAO data is based on the response to national questionnaires. The data can therefore be considered to have a subjective element. In developing consumption footprints, O’Neil et al. (2018)<sup>48</sup> further mediate the data through the EORA MRIO database.

**Scientific robustness of footprint.** The data and processes used to create nitrogen footprints are defined and use standardised data collection methods. However, the precision and accuracy of the estimates are less clear.

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<sup>41</sup> Rockström, J., Steffen, W., Noone, K. et al. A safe operating space for humanity. *Nature* 461, 472–475 (2009).

<https://doi.org/10.1038/461472a>; W. de Vries, J. Kros, C. Kroeze, S. P. Seitzinger (2013). Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. *Current Opinion in Environmental Sustainability*, 5, 392–402. 10.1016/j.cosust.2013.07.004; Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., (2015). Planetary boundaries: guiding human development on a changing planet. *Science*, 347 (6223), p. 1259855, [10.1126/science.1259855](https://doi.org/10.1126/science.1259855)

<sup>42</sup> O’Neill, D.W., Fanning, A.L., Lamb, W.F. et al. (2018). A good life for all within planetary boundaries. *Nature Sustainability*, 1, 88–95. <https://doi.org/10.1038/s41893-018-0021-4>

<sup>43</sup> Rockström, J., Steffen, W., Noone, K. et al. A safe operating space for humanity. *Nature* 461, 472–475 (2009).

<https://doi.org/10.1038/461472a>; W. de Vries, J. Kros, C. Kroeze, S. P. Seitzinger (2013). Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. *Current Opinion in Environmental Sustainability*, 5, 392–402. 10.1016/j.cosust.2013.07.004; Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., (2015). Sustainability. Planetary boundaries: guiding human development on a changing planet. *Science*, 347 (6223), p. 1259855, [10.1126/science.1259855](https://doi.org/10.1126/science.1259855)

<sup>44</sup> University of Virginia <https://n-print.org/CountryNFootprints>

<sup>45</sup> <https://www.cbd.int/gbf/targets/7>

<sup>46</sup> Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., (2015). Planetary boundaries: guiding human development on a changing planet. *Science*, 347 (6223), p. 1259855, [10.1126/science.1259855](https://doi.org/10.1126/science.1259855); Fanning, A.L., O’Neill, D.W., Hickel, J. et al. (2022). The social shortfall and ecological overshoot of nations. *Nat Sustain* 5, 26–36 (2022). <https://doi.org/10.1038/s41893-021-00799-z>

<sup>47</sup> Potter, P., Ramankutty, N., Bennett, E. M. & Donner, S. D. (2010). Characterizing the spatial patterns of global fertilizer application and manure production. *Earth Interactions* 14, 1–22, doi:10.1175/2009EI288.1 (2010); O’Neill, D.W., Fanning, A.L., Lamb, W.F. et al. (2018). A good life for all within planetary boundaries. *Nature Sustainability*, 1, 88–95. <https://doi.org/10.1038/s41893-018-0021-4>; Dittrich, M., Giljum, S., Lutter, S. & Polzin, C. (2012). Green economies around the world? Implications of resource use for development and the environment. Sustainable Europe Research Institute, Vienna.

<sup>48</sup> O’Neill, D.W., Fanning, A.L., Lamb, W.F. et al. (2018). A good life for all within planetary boundaries. *Nature Sustainability*, 1, 88–95. <https://doi.org/10.1038/s41893-018-0021-4>

**Scientific robustness of planetary limit.** The planetary boundary is set to avoid eutrophication.<sup>49</sup> However, in practice the local application of nitrogen fertiliser (or more specifically, its loss into the environment) is the critical impact. This localisation is particularly important as a few agricultural regions of very high nitrogen application rates are the main contributors to the transgression of this planetary boundary.<sup>50</sup>

**Technical relevance (reflects consumption).** As the footprint and planetary boundary are tied to agricultural practices, the footprint indirectly reflects food consumption (or, more precisely, food consumption under the prevailing norms of the food system, such as the high levels of animal protein consumed in many developed nations).

**Technical relevance (directness of relationship with impacts on biodiversity).** Excess nitrogen has a known and deleterious impact on freshwater ecosystems and biodiversity, and can also act in concert with excessive phosphorus in freshwater and marine ecosystems.

**Sensitivity.** In theory, this footprint should be highly sensitive in that a measured increase or decrease in the footprint should relate to rapid changes in ecological impacts. However, nitrogen input data is essentially based on generic average factors/estimates and therefore not well suited to picking up rapid or localised changes in usage. In addition, the importance of local effects means that a general (global or national) increase or decrease in nitrogen application may not result in changes to specific places.

**Scope.** Several variants of the nitrogen footprint have a highly appropriate scope in that the footprint directly reflects consumption, albeit food consumption rather than a broader economy-wide notion of consumption.

**Operates at multiple scales.** The nitrogen footprint has been estimated at global and national scales.<sup>51</sup> As mentioned previously, even more localised footprints based on nitrogen loss into the environment (which is the critical path to ecological impact) have been developed.<sup>52</sup>

#### 4.4.3 Practical and policy considerations

**Availability.** The data (FAO) and modelling approach (MRIO) are widely available. However, there is a lag of c. 2 years in FAO data availability on the nitrogen content of applied fertilisers, and the accuracy of FAO questionnaire data is not clear.

**Policy relevant and meaningful.** The footprint is highly policy-relevant in that it can be used as the basis for detailed agricultural policy and monitoring the impacts of such policies. However, from a policy perspective, there is likely to be a perception in many countries and with various stakeholders that reducing nitrogen application will negatively affect food production and food security. Although the planetary limit has been estimated to be sufficient for global food production<sup>53</sup>, this may elicit complications at national levels. Furthermore, nitrogen application is extremely unevenly distributed

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<sup>49</sup> W. de Vries, J. Kros, C. Kroeze, S. P. Seitzinger (2013). Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. *Current Opinion in Environmental Sustainability*, 5, 392–402. [10.1016/j.cosust.2013.07.004](https://doi.org/10.1016/j.cosust.2013.07.004)

<sup>50</sup> Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., (2015). Planetary boundaries: guiding human development on a changing planet. *Science*, 347 (6223), p. 1259855, [10.1126/science.1259855](https://doi.org/10.1126/science.1259855)

<sup>51</sup> Fanning, A.L., O'Neill, D.W., Hickel, J. et al. The social shortfall and ecological overshoot of nations. *Nat Sustain* 5, 26–36 (2022). <https://doi.org/10.1038/s41893-021-00799-z>

<sup>52</sup> Dukes E, Cheng S, Mogen S, Galloway J, Leach A, Trimble AR, Pettit A, Compton J, Pennino M. Footprints in Action: How UVA Is Managing Its Sustainability Stewardship. *Sustain Clim Chang*. 2023 Feb 1;16(1):48-63. doi: 10.1089/scc.2022.0067. Epub 2023 Feb 23. PMID: 36910689; PMCID: PMC9994435.

<sup>53</sup> O'Neill, D.W., Fanning, A.L., Lamb, W.F. et al. (2018). A good life for all within planetary boundaries. *Nature Sustainability*, 1, 88–95. <https://doi.org/10.1038/s41893-018-0021-4>

between nations, meaning that some nations would have to make extremely radical cuts which may not be politically acceptable.

**Potential to set targets against a threshold.** The planetary threshold represents a global risk of freshwater eutrophication, but this may not reflect the often-localised nature of impacts, which means that any agreed global threshold would be as much a policy agreement (also considering issues such as inequality in nitrogen use) as one based on scientific evidence.

**Broadly accepted.** GBF Target 7 explicitly refers to reducing nutrients lost into the environment. However, despite its relevance to many global commitments (e.g., the SDGs), excess nitrogen use lacks broad visibility within other international processes.

**Few in number.** As the footprint and planetary boundary are tied to agricultural practices, the footprint indirectly reflects food consumption. Although the food system is a key driver of biodiversity loss, the nitrogen footprint is most likely to be useful as one of a stable of footprints that together reflect broader aspects of consumption.

#### 4.4.4 General considerations and footprint-specific recommendations

The key limitation on adoption may well be political rather than technical (see ‘Policy relevant and meaningful’, above). For example, proposed cuts in nitrogen losses from agriculture into the environment in the Netherlands have proven highly politically contentious.<sup>54</sup>

## 4.5 Phosphorus Footprint

### 4.5.1 Introduction

#### Description of footprint

Phosphate is a key plant nutrient that is widely applied to agricultural soils. Sources of primary phosphorus (mined phosphate rock) are finite and are being depleted. Meanwhile, an estimated 80-95% of primary phosphate is lost throughout the stages of P production and use. The use of phosphorus in agriculture is used to quantify the global footprint<sup>55</sup>, national consumption footprints,<sup>56</sup> and to define the planetary limit.<sup>57</sup> Target 7 of the Global Biodiversity Framework explicitly refers to “reducing excess nutrients lost to the environment by at least half”.<sup>58</sup>

#### Planetary limit

O'Neill *et al.* (2018) give the planetary boundary for phosphorus as 6.2 million tonnes per year of phosphorus mined and applied to erodible (agricultural) soils.<sup>59</sup>

### 4.5.2 Technical considerations

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<sup>54</sup> Tullis, P. (16 Nov 2023). Nitrogen wars: the Dutch farmers’ revolt that turned a nation upside-down. The Guardian. <https://www.theguardian.com/environment/2023/nov/16/nitrogen-wars-the-dutch-farmers-revolt-that-turned-a-nation-upside-down>

<sup>55</sup> Rockström, J., Steffen, W., Noone, K. et al. A safe operating space for humanity. *Nature* 461, 472–475 (2009). <https://doi.org/10.1038/461472a>; W. de Vries, J. Kros, C. Kroeze, S. P. Seitzinger (2013). Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. *Current Opinion in Environmental Sustainability*, 5, 392–402. 10.1016/j.cosust.2013.07.004; Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., (2015). Planetary boundaries: guiding human development on a changing planet. *Science*, 347 (6223), p. 1259855, [10.1126/science.1259855](https://doi.org/10.1126/science.1259855)

<sup>56</sup> O’Neill, D.W., Fanning, A.L., Lamb, W.F. et al. (2018). A good life for all within planetary boundaries. *Nature Sustainability*, 1, 88–95. <https://doi.org/10.1038/s41893-018-0021-4>

<sup>57</sup> Rockström, J., Steffen, W., Noone, K. et al. A safe operating space for humanity. *Nature* 461, 472–475 (2009). <https://doi.org/10.1038/461472a>; W. de Vries, J. Kros, C. Kroeze, S. P. Seitzinger (2013). Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. *Current Opinion in Environmental Sustainability*, 5, 392–402. 10.1016/j.cosust.2013.07.004; Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., (2015). Planetary boundaries: guiding human development on a changing planet. *Science*, 347 (6223), p. 1259855, [10.1126/science.1259855](https://doi.org/10.1126/science.1259855)

<sup>58</sup> <https://www.cbd.int/gbf/targets/7>

<sup>59</sup> O’Neill, D.W., Fanning, A.L., Lamb, W.F. et al. (2018). A good life for all within planetary boundaries. *Nature Sustainability*, 1, 88–95. <https://doi.org/10.1038/s41893-018-0021-4>

**Measurability.** The underlying data on applied phosphorus is the same as for Nitrogen (see above).

**Scientific robustness of footprint.** The data and processes used to create phosphorus footprints are defined and use standardised data collection methods. However, the precision and accuracy of the estimates are less clear.

**Scientific robustness of planetary limit.** The planetary limit is the point at which global ocean anoxia (when large expanses of Earth's oceans become depleted of dissolved oxygen, creating toxic waters) caused by inflow of Phosphorus into the oceans becomes a significant risk.<sup>60</sup> Ocean anoxia has happened in geological times, which provides some information on the risk caused by the current increasing levels of Phosphorus loss into the ocean.

**Technical relevance (reflects consumption).** As the footprint and planetary boundary are tied to agricultural practices, the footprint indirectly reflects food consumption.

**Technical relevance (directness of relationship with impacts on biodiversity).** Excess phosphate has a known and deleterious impact on marine ecosystems and can also act in concert with excessive nitrogen in freshwater and marine ecosystems.

**Sensitivity.** This footprint should be considered sensitive in that a measured increase or decrease in the footprint should relate to changes in ecological impacts (and risks of impacts). However, the partly subjective nature of the underlying data makes it difficult to judge how responsive the estimated footprint would be to changes in application.

**Scope.** The phosphorus footprint has a highly appropriate scope in that the footprint directly reflects consumption, albeit food consumption rather than a broader economy-wide notion of consumption.

**Operates at multiple scales.** The phosphorus footprint has been estimated at global and national scales.<sup>61</sup> We are not aware of more local estimates.

#### 4.5.3 Practical and policy considerations

**Availability.** The data (FAO) and modelling approach (MRIO) are widely available. However, there is a lag of c. 2 years in FAO data availability on the phosphate content of applied fertilisers, and the accuracy of FAO questionnaire data is not clear.

**Policy relevant and meaningful.** The footprint is highly policy-relevant in that it can be used as the basis for detailed agricultural policy and monitoring the impacts of such policies. However, from a policy perspective, there is likely to be a perception in many countries and with various stakeholders that reducing phosphorus application will negatively affect food production and food security. Although the planetary limit has been estimated to be sufficient for global food production<sup>62</sup>, this may elicit complications at national levels. Furthermore, phosphate application is unevenly distributed between nations (e.g., use patterns mean that the Phosphorus levels of many African countries are depleting, whilst it is accumulating in Oceania, Europe, the Caribbean and Central America<sup>63</sup>), meaning that some nations would have to make extremely radical cuts, which may not be politically acceptable in those countries.

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<sup>60</sup> Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., (2015). Planetary boundaries: guiding human development on a changing planet. *Science*, 347 (6223), p. 1259855, [10.1126/science.1259855](https://doi.org/10.1126/science.1259855)

<sup>61</sup> Fanning, A.L., O'Neill, D.W., Hickel, J. et al. The social shortfall and ecological overshoot of nations. *Nat Sustain* 5, 26–36 (2022). <https://doi.org/10.1038/s41893-021-00799-z>

<sup>62</sup> O'Neill, D.W., Fanning, A.L., Lamb, W.F. et al. (2018). A good life for all within planetary boundaries. *Nature Sustainability*, 1, 88–95. <https://doi.org/10.1038/s41893-018-0021-4>

<sup>63</sup> Lun, F., Liu, J., Ciais, P., Nesme, T., Chang, J., Wang, R., Goll, D., Sardans, J., et al. (2018). Global and regional phosphorus budgets in agricultural systems and their implications for phosphorus-use efficiency. *Earth System Science Data Discussions* 10, 1, 1-18. 10.5194/essd-2017-41.

**Potential to set targets against a threshold.** The planetary threshold represents the risk of global ocean anoxia.

**Broadly accepted.** GBF Target 7 explicitly refers to reducing nutrients lost into the environment. However, despite its relevance to many global commitments (e.g., the SDGs), excess nitrogen use lacks broad visibility within other international processes.

**Few in number.** As the footprint and planetary boundary are tied to agricultural practices, the footprint indirectly reflects food consumption. Although the food system is a key driver of biodiversity loss, the phosphorus footprint is most likely to be useful as one of a stable of footprints that together reflect broader aspects of consumption.

#### 4.5.4 General considerations and footprint-specific recommendations

The key limitation on adoption may well be political rather than technical, given the widespread perception that reducing phosphate inputs to agriculture would negatively affect agricultural production, food security, and food sovereignty.

### 4.6 Ecological footprint

#### 4.6.1 Introduction

##### Description of footprint

The ecological footprint measures how much nature we need to provide the goods and services that our economies consume, and to absorb the waste and emissions we produce. The ecological footprint is thus a compound indicator that measures an economy's demand for built-up land, forest, cropland and pasture, fisheries and the land that would be required to sequester its carbon footprint.<sup>64</sup> Each component can be extracted and evaluated during the assessment process, if required. The components are measured by the abstract unit, the 'global hectare' – a hectare of land with the global average productivity – which allows the indicators to be aggregated into an estimate of the total pressure that an economy is placing on the natural world.

##### Planetary limit

The planetary limit for the ecological footprint is defined by an associated concept, 'biocapacity', which is the ability of nature to produce goods and services and to absorb the waste and gases we produce. Biocapacity is also measured in 'global hectares'. The Global Footprint Network estimates global biocapacity at 12.2 billion 'global hectares' in 2023, equivalent to 1.5 global hectares per person.<sup>65</sup> Global biocapacity changes annually according to (amongst other things) changes in the intensity of agricultural and forestry activities.

#### 4.6.2 Technical considerations

**Measurability.** The Global Footprint Network has codified the measurement of the Ecological Footprint.

**Scientific robustness of footprint.** The methods used for estimating the Ecological Footprint are standardised and replicable. However, they have also been subject to a range of scientific critiques.<sup>66</sup>

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<sup>64</sup> Global Footprint Network (2023). <https://www.footprintnetwork.org/our-work/ecological-footprint/>

<sup>65</sup> <https://www.footprintnetwork.org/what-biocapacity-measures/>

<sup>66</sup> e.g., Blomqvist, L., Brook, B.W., Ellis, E.C., Kareiva, P.M., Nordhaus, T., & Shellenberger, M. (2013). Does the shoe fit? Real versus imagined ecological footprints. *PLoS Biol.* 11 (11), e1001700, <http://dx.doi.org/10.1371/journal.pbio.1001700>; van den Bergh, J. & Grazi, F. (2015). Reply to the first systematic response by the Global Footprint Network to criticism: A real debate finally? <http://dx.doi.org/10.1016/j.ecolind.2015.05.007>

**Scientific robustness of planetary limit.** The formulation of global 'Biocapacity' has the potential to produce perverse outcomes in that increasingly intensive agriculture and forestry would increase biocapacity whilst self-evidently also increasing certain types of impact on the natural world.

**Technical relevance (reflects consumption).** Reflects a range of consumption activities directly or indirectly: built-up land, forest, cropland and pasture, fisheries and carbon footprint.

**Technical relevance (directness of relationship with impacts on biodiversity).** The impacts of the component indicators of the Ecological Footprint have varied relationships (direct and indirect) with environmental harm. In addition, the footprint (and biocapacity) tend to be dominated by GHGs (converted to 'global hectares'), meaning that the footprint as a whole tends to largely reflect GHG emissions. In addition, the conversion of measures into 'global hectares' loses the direct link to environmental impacts<sup>67</sup>.

**Sensitivity.** The footprint, and its planetary limit, respond to changes in consumption patterns. It is reported annually. However, the relationship between these and impacts on biodiversity are far less transparent (see above).

**Scope.** The Ecological Footprint is a consumption footprint, incorporating a variety of different types of consumption (of marine resources, of land for urban infrastructure, etc).

**Operates at multiple scales.** Can be applied at global and national levels. However, at a national scale, it compares the domestic footprint of consumption with domestic biocapacity, and hence measuring self-sufficiency rather than sustainability.<sup>68</sup>

#### 4.6.3 Practical and policy considerations

**Availability.** The Global Footprint Network updates the footprint annually.

**Policy relevant and meaningful.** The conversion of measures into 'global hectares' is useful in the sense that it allows aggregation of a range of different human impacts on the biosphere. This provides a significant benefit in terms of communication. However, it is also an additional step between policy and the size of the footprint, which may obscure the policy choices and their impacts. The dominance of carbon in the ecological footprint may lead to the erroneous conclusion that the other consumption of the other indicators is within sustainable limits, or to put it another way, changes to the management or distribution of croplands, grazing lands, or built-up land would have virtually no effect on global ecological overshoot.<sup>69</sup> A further set of issues are present with the policy-relevance of 'biocapacity'. As the capacity of land to produce and absorb flows used by humans depends mainly on the use of human technology and the amount of fossil energy used as inputs at a given time point and location, increased (and increasingly intensive) anthropogenic use of land actually increases the threshold, irrespective of the health of natural systems.<sup>70</sup>

**Potential to set targets against a threshold.** Defined by 'biocapacity' which is an estimate of the capacity of ecosystems to provide services (e.g., sequestration of atmospheric GHGs). Unlike the thresholds for many footprints, biocapacity is in essence inherent to the footprint itself, which means that desirable states for the footprint do not have to be separately defined.

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<sup>67</sup> e.g., Giljum, S., Hammer, M., Stocker, A., Lackner, M., Best, A., Blobel, D., Ingwersen, W., Naumann, S., Neubauer, A., Simmons, C., Lewis, K., Shmelev, S., 2007. Scientific assessment and evaluation of the indicator "Ecological Footprint". Project Z 6–FKZ: 363 01 135, Final Report. German Federal Environment Agency, Dessau

<sup>68</sup> van den Bergh, J. & Grazi, F. (2015). Reply to the first systematic response by the Global Footprint Network to criticism: A real debate finally?, <http://dx.doi.org/10.1016/j.ecolind.2015.05.007>.

<sup>69</sup> Blomqvist, L., Brook, B.W., Ellis, E.C., Kareiva, P.M., Nordhaus, T., & Shellenberger, M., (2013). Does the shoe fit? Real versus imagined ecological footprints. *PLoS Biol.* 11 (11), e1001700, <http://dx.doi.org/10.1371/journal.pbio.1001700>

<sup>70</sup> Galli, A., Giampietro, M., Goldfinger, S., Lazarus, E., Lin, D., Saltelli, A., Wackernagel, M. & Müller, F. (2020). Questioning the Ecological Footprint. *Ecological Indicators*, 69, 224-232, ISSN 1470-160X, <https://doi.org/10.1016/j.ecolind.2016.04.014>

**Broadly accepted.** Well known and promoted, and can be used for effective communications (e.g., ‘Earth overshoot day’). It is not without critics, who, (amongst other issues) cite the dominance of carbon in the footprint of middle- and high-income countries; assumptions about the productivity of both natural ecosystems and anthropogenic ones; and the use of an abstract measure (‘global hectares’).

**Few in number.** As a compound footprint, the Ecological Footprint incorporates several data sources and footprint indicators.

#### 4.6.4 General considerations and footprint-specific recommendations

The Ecological Footprint is probably best used as a symbolic parameter representing the problem of resource consumption.

### 4.7 Biosphere Footprint

#### 4.7.1 Introduction

##### Description of footprint

Within the Planetary Boundaries framework, biodiversity is directly captured under “biosphere integrity”, which references the ability of the biosphere to deliver myriad interactions with the geosphere that ultimately sustain life on earth.<sup>71</sup> The framework suggests that measurement of biosphere integrity can be usefully split into two underpinning dimensions: genetic diversity, and functional biosphere integrity. Whilst this is how the planetary boundaries framework captures it, biodiversity is broad and complex and covers many other aspects. This complexity is one of the key challenges of dealing with biodiversity and measuring its loss - for example under the CBD 23 targets have been set for 2030, each with multiple metrics for measurement, reflecting the myriad aspects of biodiversity and our interactions with it.

##### Planetary limit

*Genetic diversity* is suggested to be above safe limits if extinctions exceed the rate of that experienced over the last 10 million years (estimates of this rate are variable, but a figure of <10 extinctions per million species years<sup>72</sup> is used). This level is exceeded.

*Functional biosphere integrity* is measured as the Human Appropriated Net Primary Production (HANPP) is suggested, and the safe operating limit defined according to a Holocene baseline (<10% of Holocene NPP is within safe limits, >20% is within high risk zone). This level was exceeded in the late 19<sup>th</sup> century.

#### 4.7.2 Technical considerations

##### Measurability.

*Genetic diversity*: At this stage, it isn’t possible to calculate extinction dynamics below species level (i.e. losses of genetic diversity that precede species extinction events), although advances anticipated within the next decade may provide this information,<sup>73</sup> this future is too uncertain and too far off to suggest when, how and whether they will be usefully applied in footprinting methods. Alternative proxies for this do exist for footprinting methods at the species level – most notably STAR and LIFE methods.<sup>74</sup> Although suffering from taxonomic and geographic biases (they are underpinned by IUCN Redlist and BirdLife data, which whilst the best available for this purpose, are inevitably biased towards certain regions,

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<sup>71</sup> Richardson et al. 2023. Earth beyond six of nine planetary boundaries. *Science Advances* 9(37).

<https://www.science.org/doi/10.1126/sciadv.adh245>

<sup>72</sup> The ‘species-year’ unit references the persistence of one species for one year, and is helpful for understanding extinction rates. For example, 1 extinction per million species-years means that if you have one million species, we expect one of them, on average, to become extinct over the course of a year.

<sup>73</sup> Richardson et al. 2023. Earth beyond six of nine planetary boundaries. *Science Advances* 9(37).

<https://www.science.org/doi/10.1126/sciadv.adh245>

<sup>74</sup> Mair et al. (2021). A metric for spatially explicit contributions to science-based species targets. *Nature Ecol. & Evol.* 5:836-844.

<https://www.nature.com/articles/s41559-021-01432-0>; Eyres et al. (2024). LIFE A metric for quantitatively mapping the impact of land-cover change in global extinctions. <https://www.cambridge.org/engage/coe/article-details/662f651491aefa6ce1b9bb6a>

habitats and taxonomic groups), they provide spatial information that is directly relevant to losses of terrestrial vertebrates (i.e. extinction likelihood) and, thereby, both loss of genetic diversity and reductions/losses of species functions within ecosystems.

*Functional biosphere integrity:* The use of HANPP was at least partly motivated by the desire for a more universal metric than could be offered by more conventional measures of biodiversity, such as the biodiversity intactness index, for which significant spatial and taxonomic biases exist in the underlying data (for example few indices measure terrestrial, marine and freshwater systems, and vertebrates have received significantly more attention than other life forms) .<sup>75</sup> The use of remotely sensed data partially counters these biases. Alternatives to HANPP exist in the form of metrics that describe the intactness or integrity of the ecosystem and/or species assemblages. These include the Biodiversity Intactness Index (BII)<sup>76</sup>, which describes an ecosystem in terms of its current species assemblage and its distance from the pre-industrial state. Its more recent sister metric, Ecosystem Integrity Index (EII)<sup>77</sup> incorporates three components: structural (i.e. landcover intactness or contiguity, measured using the Human Modification Index), compositional (using BII), and functional (calculated as the difference between potential and current NPP). Another measure to estimate functional integrity is the potentially disappeared fraction (PDF) of species. This is particularly favoured by the life cycle analysis community and intended as a measure of diffuse impacts that cause local damage to ecosystems that can be attributed to specific products<sup>78</sup> or commodity production<sup>79, 80</sup>. Mean Species Abundance (MSA) is an alternative way to capture the integrity of an ecosystem - for example in the Global Biodiversity Score (GBS), which assesses the impacts that multiple pressures have on biodiversity<sup>81</sup>.

#### **Scientific robustness of footprint.**

*Genetic diversity:* Although the exceedance of a safe limit for genetic diversity is stated, it can only be estimated crudely, limiting its utility in footprinting, which requires a responsiveness not currently available. Species-level proxies are well described, though limited by spatial and taxonomic biases (i.e. only available for terrestrial vertebrates).

*Functional biosphere integrity:* HANPP is modelled based on remotely sensed data and provides a practical approach for a global surface. Although EII is one of the newest measures available, it incorporates several component indices, each with a peer-reviewed literature behind it.

#### **Scientific robustness of planetary limit.**

*Genetic diversity:* Within the planetary boundaries framework, the use of a background extinction rate is used. Estimates of this rate are variable, though we can say with confidence that it is exceeded. Less certain is by how much. Using a species level approach is more practicable for footprinting purposes currently, and no limit is described explicitly, though targets to halt biodiversity loss (which are often countenanced in species terms) could be translated to reducing extinctions to zero. Such a threshold is

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<sup>75</sup> Richardson et al. 2023. Earth beyond six of nine planetary boundaries. *Science Advances* 9(37).

<https://www.science.org/doi/10.1126/sciadv.adh245>

<sup>76</sup> Scholes, R.J. & Biggs, R. (2005). A biodiversity intactness index. *Nature* 434:44-49. <https://www.nature.com/articles/nature03289>;

Newbold et al. (2015). Global effects of land use on local terrestrial biodiversity. *Nature* 520, 45–50.

<https://www.nature.com/articles/nature14324>, Newbold et al. (2016). Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. DOI: 10.1126/science.aaf2201

<sup>77</sup> Hill et al. 2023. The Ecosystem Integrity Index: a novel measure of terrestrial ecosystem integrity.

<https://doi.org/10.1101/2022.08.21.504707>

<sup>78</sup> Huijbregts et al. (2017). ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. *Int. J. Life Cycle Assess.* <https://link.springer.com/article/10.1007/s11367-016-1246-y>

<sup>79</sup> Chaudhary et al. (2016). Spatially Explicit Analysis of Biodiversity Loss Due to Global Agriculture, Pasture and Forest Land Use from a Producer and Consumer Perspective. *Environ. Sci. Technol.* <https://doi.org/10.1021/acs.est.5b06153>

<sup>80</sup> Rossberg, A.G., 2022. Quantifying Biodiversity Impact - Relations amongst local and global metrics, why they matter, and how to offset impacts. Tech. rep., Queen Mary University of London, London. 16 pp.

<sup>81</sup> CDC BIODIVERSITÉ. <https://www.cdc-biodiversite.fr/le-global-biodiversity-score/>

essentially a notional 'healthy' state, and differs from those for greenhouse gas emissions, for example, where we can model the consequences of a per unit increase.

*Functional biosphere integrity*: It is difficult to quantify a planetary boundary, but the use of 10% of pre-industrial NPP is precautionary. There is no limit suggested for other measures, such as EII.

#### **Technical relevance (reflects consumption):**

For both genetic and functional, the metrics described are not explicitly linked to consumption, though a range of methods and models exist to do so, mostly using multiregional input-output models.<sup>82</sup> This link is primarily through modelling drivers of land use change and associated habitat losses allowing estimates of impacts to the biosphere, but some methods also incorporate measures of pollution: e.g. ecotoxicity and eutrophication.<sup>83</sup>

#### **Technical relevance (directness of relationship with impacts on biodiversity).**

All the methods directly pertain to biodiversity at either the species or ecosystem level. Habitat loss is a primary driver of biodiversity loss and this is reflected in the modelling work that underlies the metrics, with impacts driven (either partially or wholly) by land use change.

#### **Sensitivity.**

Metrics are sensitive to land cover changes that can be detected by satellite. The most significant limitations are around differential susceptibility of species to land use change, the inability to incorporate information pertaining to the farming system, which can be highly variable and have different impacts on species and landscape connectivity.

#### **Scope.**

The metrics described are well suited to understanding how land use change drives changes to biodiversity and biosphere integrity. Thus well suited to understanding the impacts of food systems.

#### **Operates at multiple scales.**

The metrics described are those which have been modelled globally and for all terrestrial habitat types. They can be aggregated to understand cumulative impacts. However, biosphere integrity is a wide-ranging concept and care needs to be taken to understand the results of global comparisons. Metrics related to extinction risk are well suited to such global comparison, but measures of ecosystem integrity describe changes from a historical reference point and are not directly comparable between geographies, in terms of biodiversity loss per se. They are well suited, however, to understanding how biosphere function may be altered.

### **4.7.3 Practical and policy considerations**

#### **Availability.**

*Genetic diversity*: Several biodiversity methods and/or layers are publicly and freely available. The provision of STAR metric (via the IBAT tool) is easy, though a paid service. LIFE will be available for a single 'current' year initially, with future updates anticipated.

*Functional biosphere integrity*: Estimates of NPP can be accessed at least annually for calculation of HANPP. The more 'derived' metrics, such as EII, can be calculated using published methods. However, EII is not currently provided as global and annually updated layers, although this is anticipated given its intended use in the Taskforce for Nature-related Financial Disclosures (TNFD), for example.

#### **Policy relevant and meaningful.**

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<sup>82</sup> Zhu et al. (2024). Glaring gaps in tools to estimate businesses' biodiversity impacts hinder alignment with the Kunming-Montreal global biodiversity framework. *J. Cleaner Prod.* 451: 142079. <https://doi.org/10.1016/j.jclepro.2024.142079>

<sup>83</sup> Huijbregts et al. (2017). ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. *Int. J. Life Cycle Assess.* <https://link.springer.com/article/10.1007/s11367-016-1246-y>

*Genetic diversity*: The species-level metrics will respond directly to policies around land use change and therefore can be updated annually in line with land cover/land use products. In the case of STAR, policies targeting the removal of other threats to species too (with some lag according to the frequency of assessment and update of layers).

*Functional biosphere integrity*: HANPP, EII and other habitat-related assessments of species assemblages (e.g. BII, PDF) respond to policy around land use.

**Potential to set targets against a threshold.**

*Genetic diversity*: Unclear what the threshold should be above the genetic level, making this threshold tricky to define.

*Functional biosphere integrity*: HANPP threshold is globally relevant but trickier to apply at individual company/country level. It is less obvious what is an acceptable level of integrity for EII.

**Broadly accepted.**

*Genetic diversity*: Several options here making competition and confusion between metrics an issue. STAR, in particular, is gaining increasing traction, particularly with the kudos of IUCN and the IBAT platform supporting it.

*Functional biosphere integrity*: Yes – broad acceptance of HANPP. EII likely to build on acceptance of component indices.

**Few in number.** There are a large number of metrics that report on some aspect of biodiversity, creating a confusing landscape. This is, at least partly, due to the term ‘biodiversity’ itself, which covers a range of aspects from genetic to ecosystem diversity, and for which each have multiple proxies and methods for their assessment.

#### 4.7.4 General considerations and footprint-specific recommendations

Although the variety of metrics available creates some confusion, it also provides a wealth of options for the assessment of a biodiversity footprint. Given biodiversity’s underpinning role in planetary health and human wellbeing, it is vital that policy makers include a measure that directly pertains to biodiversity (as opposed to others in this section, which are less direct proxies) and that footprinting efforts consider changes to both species and ecosystems.

## 4.8 Water footprint

### 4.8.1 Introduction

#### Description of footprint

The Planetary Boundaries framework conceptualises the human induced impacts linked to water in terms of ‘freshwater change’ (previously ‘freshwater use’) across the entire water cycle over land, with ‘streamflow’ used as a proxy to represent blue water (surface and groundwater) availability and root-zone soil moisture to represent green water (plant-available water). The ‘green’ and ‘blue’ water terminology is conceptually similar to that presented with the Water Footprint Network’s (WFN) water footprint<sup>84</sup> estimates, which have been developed for crops and (more coarsely) for industrial processes.<sup>85</sup> The WFN’s values are commonly used in water footprint assessment. Historically, they were released for a reference period of 1996-2005,<sup>86</sup> with later attempts (for crops) to annualise these using

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<sup>84</sup> <https://www.waterfootprint.org/>

<sup>85</sup> <https://www.waterfootprint.org/resources/Report16Vol1.pdf>

<sup>86</sup> Mekonnen, M.M., & Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences*, 15, 1577–1600, 2011. doi:10.5194/hess-15-1577-2011

‘fast track’ methods based on changes in crop-yields.<sup>87</sup> More recently, revised water footprint estimates have been released for 175 individual crops at national (and in some cases pixel) scale.<sup>88</sup> This data, however, conceptualises the blue water footprint as the water available to crops from irrigation and capillary-rise (from groundwater) and green water (water available from precipitation). In contrast then with the PB concept, it does not - alone - assess water availability in the environment (rather it measures the water requirements for crop production). As such, it must be combined with estimates of local water availability (such as those supplied by the WULCA AWARE dataset<sup>89</sup>) to relate through to associated environmental impacts.

### **Planetary limit**

The planetary boundaries framework considers deviations of blue water (streamflow) and green water (root-zone soil moisture) from pre-industrial levels, with deviations in their global assessment mapped at 30 arc-min cell level (approximately 55 km at the equator). Boundaries are expressed in terms of the percentage of cells deviating from pre-industrial levels (at ~10% from blue and ~11% for green water which equate to the 95th percentile of preindustrial variability). The authors state that current deviations are ~18% for blue and ~16% for green; thus transgressing limits.<sup>90</sup>

#### 4.8.2 Technical considerations

**Measurability.** The crop-estimates of blue and green water from the WFN are based on model-based assumptions associated with water requirements (evapotranspiration). The models will reflect requirements but do not represent direct water consumption.

**Scientifically robustness of footprint.** As above, estimates of the footprint are based on models. Whilst likely reflecting ‘average’ requirements, they will therefore not account for local variations in cropping systems. That said, the latter is relatively impractical with current data availability and model-based outputs are likely adequate proxies for assessing overall water demands.

**Scientifically robustness of planetary limit.** The planetary limit assumes that global deviations >95% from historical levels are ‘unsustainable’ but this is not a rigorously substantiated threshold.

**Technical relevance (reflects consumption).** The Planetary Boundary-linked measures are not explicitly linked to consumption, so here we consider the relevant footprint to be those measures developed by (or from) the Water Footprint Network statistics. These are directly related to consumption activities; representing the embedded water use associated with crops (and other commodities). However, changes in water flow (and therefore general availability) are highly variable due to a multitude of non-(directly)-consumption related factors (e.g. water-course modification, climate and weather).

**Technical relevance (directness of relationship with impacts on biodiversity).** Relevant to biodiversity if combined with estimates of water availability. However, in such cases the measure is only a loose proxy for biodiversity impacts.

**Sensitivity.** Model based estimates are only sensitive to updates made by modellers based on changes in yields, cropping patterns etc. It is most useful therefore for comparisons e.g. across products or - when combined with water availability data - for assessing risks associated with sourcing changes. A ‘fast track’ method has been developed to approximate changes in water consumption based on crop yields.<sup>91</sup> Estimates of water scarcity are typically not regularly updated and therefore will not reflect acute

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<sup>87</sup> Tuninetti, M. et al. (2017) Environmental Research Letters 12 074010 DOI 10.1088/1748-9326/aa6b09

<sup>88</sup> Mialyk, O., Schyns, J.F., Booij, M.J. et al. (2024). Water footprints and crop water use of 175 individual crops for 1990–2019 simulated with a global crop model. Sci Data 11, 206 <https://doi.org/10.1038/s41597-024-03051-3>

<sup>89</sup> <https://wulca-waterlca.org/aware/download-aware-factors/>

<sup>90</sup> Richardson et al. (2023). Earth beyond six of nine planetary boundaries. Science Advances 9(37).

<https://www.science.org/doi/10.1126/sciadv.adh245>

<sup>91</sup> Tuninetti, M. Tamea, S., Laio, F. & Ridolfi, L. (2017) A Fast Track approach to deal with the temporal dimension of crop water footprint. Environmental Research Letters 12 074010 DOI 10.1088/1748-9326/aa6b09

irregular water shortages which would have outsized impacts if not associated with appropriate water management.

**Scope.** Whilst water footprint metrics have been estimated for industrial processes<sup>92</sup> this information is comparatively dated and coarse and therefore this measure is best suited for agricultural crops.

**Operates at multiple scales.** Data is available at country, basin and sometimes pixel scale and the concepts of extraction/consumption and availability are amenable to application at various scales. Given use of modelling approximations, data at finer resolutions may be more uncertain, however.

#### 4.8.3 Practical and policy considerations.

**Availability.** Water Footprint Network data, and data from Mialyk *et al.* (2024)<sup>93</sup> is openly available, as is the underpinning model code.<sup>94</sup> This is provided in alignment with FAO crops and therefore is easy to directly apply.

**Policy relevant and meaningful.** Main practical relevance is in terms of comparing water consumption and resultant environmental 'risk' across sourcing regions or crop/product types. The lack of annual sensitivity limits the value as a measure of the sustainability of existing systems year-on-year. Blue water (irrigation-linked) use is typically identified as a more relevant measure, but in the latest study the authors highlight the need to consider green water more widely, given the importance of broader water availability for ecosystems (and for blue water generation).<sup>95</sup> The relevance of this metric is most acute in areas with low baseline water availability. The water footprint benefits from being relatively simple to understand from a non-technical perspective.

**Potential to set targets against a threshold.** The Planetary Boundary threshold is not meaningful at the level of individual product consumption, given the lack of direct linkage to deviations from historical baselines at landscape scale. Thresholds/targets are therefore most relevant in terms of e.g. reducing the consumptive use of water (e.g. crop efficiency, reduced irrigation) overall or seeking to redress the issue of unsustainable extraction from water-scarce areas.

**Broadly accepted.** Water footprinting is ubiquitous in studies and assessments at product and economy-wide scale. It is recommended for use within ISO14044.

**Few in number.** Blue and Green Water represent different components of the water footprint (as does the 'Grey' water component - not explored here - which links to water pollution). Blue water can be measured in terms of irrigation inputs and via capillary action from groundwater. The water footprint, applied directly, is a relatively loose proxy for biodiversity-linked impacts, even when combined with water availability information. Water extraction for crops will also not necessarily correlate with other demands on nature (e.g. water consumption varies widely by crop and therefore may not equate well to land use requirements). As such, the water footprint is best applied and analysed in conjunction with other measures to assess sustainability of production.

#### 4.8.4 General considerations and footprint-specific recommendations

There appears to be limited data available linked to the industrial use/consumption of water, meaning this is an important gap in the footprint (in terms of relevant, up to date, global data availability).

Additionally, it is important to understand the distinction between consumptive water use and water

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<sup>92</sup> Hoekstra, A.Y. (2015). The water footprint of industry. Chapter 7 in Klemeš, J.J. (Ed.): *Assessing and Measuring Environmental Impact and Sustainability*

1st Edition ISBN: 9780127999685

<sup>93</sup> Mialyk, O., Schyns, J.F., Booi, M.J. et al. (2024). Water footprints and crop water use of 175 individual crops for 1990–2019 simulated with a global crop model. *Scientific Data* 11, 206. <https://doi.org/10.1038/s41597-024-03051-3>

<sup>94</sup> [github.com/aquacropos/aquacrop](https://github.com/aquacropos/aquacrop)

<sup>95</sup> Mialyk, O., Schyns, J.F., Booi, M.J. et al. (2024). Water footprints and crop water use of 175 individual crops for 1990–2019 simulated with a global crop model. *Scientific Data* 11, 206. <https://doi.org/10.1038/s41597-024-03051-3>

which is used for industrial processes but then returned to water courses (sometimes with pollutants, i.e. 'grey' water).

## 4.9 Land System (Deforestation) Footprint

### 4.9.1 Introduction

#### **Description of footprint**

The Planetary Boundaries framework uses the concept of 'land system change' to relate to the biophysical processes within land systems that regulate the climate. The extent of forest cover remaining is used as a proxy measure, divided into tropical, temperate and boreal forest domains; justified by the outsized role that these biomes play in land-climate regulation in comparison to other biomes. As such, the 'deforestation footprint' offers the most appropriate footprint measure linked to this PB, as conceptualised.

#### **Planetary limit**

The Planetary Boundaries framework indicates that thresholds for forest extent globally are 85% for tropical and boreal forest (compared to Holocene levels), and 50% for temperate forest (with 75% as a weighted average across biomes), with these boundaries all transgressed. As such, when applied to footprinting, a 'zero-deforestation' limit is warranted and also aligns with recent policy commitments.

### 4.9.2 Technical considerations

**Measurability.** Forest extent is measured via a number of remote-sensing products, with WRI's 'Global Forest Watch' offering the most widely applied globally-relevant resource. However, monitoring tree cover, tree cover loss and classification as 'permanent' cover loss is relatively complex and estimates remain subject to uncertainties although data products are improving rapidly. A variety of remote-sensing products exist overall which may not align with one another, nor the FAO's definition of forest, but there are ongoing efforts to improve comparability.<sup>96</sup> Attribution of forest loss/deforestation to production is a complex process, but one that has been conducted by studies to incorporate approximations of real-world land use change dynamics. Despite these challenges, in comparison to other footprint measures, this footprint is relatively measurable, subject to these uncertainties being acknowledged and understood.

**Scientifically robustness of footprint.** Deforestation and associated monitoring systems are extensively studied and related datasets are typically the result of peer-reviewed research. Remote sensing products are often derived from nationally-supported global monitoring programmes (e.g. Copernicus, LandSat programmes). The science is evolving rapidly, with resultant improvements in data products.

**Scientifically robustness of planetary limit.** This is relatively low, given that the thresholds themselves are subject to low confidence, the 'land system change' boundary is only motivated by climate system concerns rather than other ecosystem service functions, and given that forest cover - whilst most important from a climate perspective - does not account for changes in other important biomes (e.g. savannahs, grasslands, wetlands etc). That said, there is little uncertainty that forest cover sits substantially below Holocene levels and that further forest loss is inherently unsustainable given the clear role that forests play in ecosystem service provision.

**Technical relevance (reflects consumption).** High. Land use change is intrinsically linked to consumption, and a primary threat to forest (particularly in the tropics) is deforestation for commodity production (primarily crops and pasture, but also e.g. mining and aquaculture).

**Technical relevance (directness of relationship with impacts on biodiversity).** Very high. Forests are a key haven for biodiversity, and land-use change more generally is the leading driver of terrestrial

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<sup>96</sup> For example, <https://www.wri.org/events/2023/2/forest-data-partnership-aligning-and-innovating-shared-data-ecosystem>

biodiversity loss. Deforestation alone, however, may not always be a good proxy for broader biodiversity-linked concerns.

**Sensitivity.** High. Biodiversity loss will be closely/directly related to natural habitat availability. Furthermore, the ability to remotely monitor forest loss (in close-to-real time in some cases) means metrics can be developed which are highly sensitive. When linked to deforestation footprints, these measures may be subject to lags of a couple of years given requirements to also incorporate land-utilisation information (e.g. crop extent), with some studies also incorporating transitional lags/amortisation steps to mirror land use dynamics.

**Scope.** Deforestation footprints are most advanced for agricultural land use (including pasture). Attribution of footprints to mining remains at an earlier stage. Tree-cover loss data is available globally, but footprints are most robust in tropical regions (given better availability of crop-specific expansion data, and lower prevalence of rotational forestry which complicates deforestation assessment).

**Operates at multiple scales.** Calculable at a variety of scales given direct use of high-resolution remote sensing information (although quality varies across the globe).

#### 4.9.3 Practical and policy considerations.

**Availability.** High - for deforestation footprints. Globally relevant estimates of deforestation linked to production/consumption are available at national scale (and in some contexts at subnational scale).

**Policy relevant and meaningful.** Conceptually, the extent of forest remaining, and the amount or percentage of forest loss over time, are readily understood. Deforestation has clear links to biodiversity and climate change agendas and therefore is highly policy relevant internationally.

**Potential to set targets against a threshold.** Whilst thresholds for forest cover are not globally accepted, there are national examples of commitments to preserving primary forest (e.g. Brazil's Forest Code). Zero-deforestation commitments are relatively widespread. Commitments to reduce land use change in general, however, are not widely present, nor are agreed thresholds on how much land requires preservation.

**Broadly accepted.** There are international commitments to reduce deforestation (to zero) and several governments are introducing 'due diligence' based measures to avoid deforestation linked to national supply chains. Existing units exist within several governments with a remit covering. Deforestation footprinting has been conducted by/for several national governments.

**Few in number.** Whilst globally-relevant data is available, only a few studies actually provide up-to-date information linked to production-to-consumption footprints, with data from the Chalmers University of Technology well established.<sup>97</sup> Deforestation footprints offer a proxy for broader environmental concerns including climate change (where emissions from deforestation are also available) and biodiversity loss.

#### 4.9.4 General considerations and footprint-specific recommendations

Whilst a widely used proxy for biodiversity loss and broader land use pressures, the deforestation footprint is not a perfect substitute for these concerns and additional attention is warranted on monitoring broader land use change footprints. Global footprint-relevant metrics covering broader land use change linked to commodity production are not readily available, but extensions of deforestation-footprint datasets to incorporate other forms of land use change are underway and therefore footprints which encompass broader natural habitat conversion are likely to be viable in the near future. Additionally, forest (and land use) degradation is also an important driver of biodiversity loss, but

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<sup>97</sup> Singh, C., Persson, U.M., Croft, S., Kastner, T., & West, C. (2024). Commodity-driven deforestation, associated carbon emissions and trade 2001-2023. <https://zenodo.org/records/10633818>

efforts to quantify degradation-linked impacts are in their infancy compared with deforestation footprints. Afforestation (i.e. planting of trees) may also take place which means an important distinction exists between net and gross deforestation. Distinctions between gross and net deforestation may be difficult to assess (e.g. in areas where tree plantations are common) and conversion from natural habitat to managed plantations is also possible and should be considered when interpreting footprint results.

## 4.10 Greenhouse gas Footprint

### 4.10.1 Introduction

#### Description of footprint

A country's GHG Footprint is the attribution of global greenhouse gas emissions to a country's activities. Under the UNFCCC and the Paris Agreement, GHG emissions accounting is based on each country's *territorial emissions* (see 'Definitions') of the six main greenhouse gases listed in the Kyoto Protocol. An alternative GHG accounting methodology includes emissions related to a country's *consumption* of goods and services.

#### Planetary limit

Two planetary limits are proposed, one based on an atmospheric CO<sub>2</sub> concentration of 350 ppm<sup>98</sup> and the second which includes all GHGs, and which is a planetary boundary of cumulative emission of greenhouse gases starting from 2018 and staying below 420 GtCO<sub>2</sub>eq.<sup>99</sup> The latter provides a two thirds chance of limiting warming to 1.5°C, according to the best available scenarios.<sup>100</sup>

### 4.10.2 Technical considerations

**Measurability.** The protocols for measuring territorial GHG emissions are established under UNFCCC and well understood.<sup>101</sup> The same protocols can in effect be used with consumption modelling to derive a consumption-based footprint, but although numerous national examples exist, the approach of linking emissions to consumption is less codified.

**Scientific robustness of footprint.** National inventories are typically a combination of empirical data and modelling, in which the uncertainties are quantified.<sup>102</sup> The metrics underlying national GHG footprints can therefore be considered robust in that they are clearly defined, verifiable and scientifically acceptable data, which are collected using standard methods with (largely) known accuracy and precision.

**Scientific robustness of planetary limit.** The implications of GHG emissions have been the subject of vastly more scientific research than any other footprint, and so the likely consequences of reaching or exceeding the planetary limit are well established. That being said, the agreement to try to contain global warming within 1.5°C of pre-industrial levels is essentially a political consensus (i.e., what degree of change is deemed acceptable given numerous trade-offs).<sup>103</sup>

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<sup>98</sup> Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., (2015). Sustainability. Planetary boundaries: guiding human development on a changing planet. *Science*, 347 (6223), p. 1259855, [10.1126/science.1259855](https://doi.org/10.1126/science.1259855)

<sup>99</sup> Metabolic & WWF (2020). Halving the footprint of production and consumption.

[https://www.int.awsassets.panda.org/downloads/halvingfootprint\\_report\\_wwf\\_metabolic.pdf](https://www.int.awsassets.panda.org/downloads/halvingfootprint_report_wwf_metabolic.pdf)

<sup>100</sup> IPCC, 2018: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 616 pp. <https://doi.org/10.1017/9781009157940>.

<sup>101</sup> IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories. <https://www.ipcc-nggip.iges.or.jp/public/2006gl/>

<sup>102</sup> IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories. <https://www.ipcc-nggip.iges.or.jp/public/2006gl/>

<sup>103</sup> UNFCCC (2015). Paris Agreement.

[https://unfccc.int/files/meetings/paris\\_nov\\_2015/application/pdf/paris\\_agreement\\_english\\_.pdf?gad\\_source=1&gclid=CjwKCAjw88yxBhBWEiwA7cm6pbz0opeNVyBqT18j3eg8n8oumWigdR07egeYa\\_7\\_h5IzvoCRMFqrUBoCKHgQAvD\\_BwE](https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf?gad_source=1&gclid=CjwKCAjw88yxBhBWEiwA7cm6pbz0opeNVyBqT18j3eg8n8oumWigdR07egeYa_7_h5IzvoCRMFqrUBoCKHgQAvD_BwE)

**Technical relevance (reflects consumption).** The territorial footprint required by UNFCCC does not include emissions from imported goods (or exclude emissions from exported goods) and so can obscure significant 'offshoring' of a nation's footprint. If constructed as a consumption-based footprint, the GHG footprint should measure consumption both directly - the footprint is dominated globally by fossil fuel use - and indirectly (e.g., land use change, although some formulations omit this).

**Technical relevance (directness of relationship with impacts on biodiversity).** Often complex causality but nonetheless a strong relationship between global warming and biodiversity loss: c. 1 in 6 species may be threatened by climate change.<sup>104</sup>

**Sensitivity.** High, in the sense that changes to biodiversity caused (or contributed to) by global warming are sometimes detectable over a few years. However, there are systemic lags (e.g., sea level rise; and lags caused by the range of times that GHGs remain in the atmosphere: e.g., methane 11.8 years; nitrous oxide 109 years, CO<sub>2</sub> cannot readily be represented with a single value because the gas is not destroyed over time, but instead moves among different parts of the ocean–atmosphere–land system).

**Scope.** The protocols for measuring territorial GHG emissions are established under UNFCCC, are well understood and widely implemented. This means that there is significant expertise available to measure and monitor the footprint. Protocols for measuring GHG consumption footprints are less standardised, but numerous examples exist of national consumption footprints.

**Operates at multiple scales.** GHG levels are monitored globally, and national footprints are well established (though see above). Sub-national, sectoral and footprints of individual organisations are increasingly codified.<sup>105</sup>

#### 4.10.3 Practical and policy considerations

**Availability.** UNFCCC Appendix 1 countries submit annual GHG accounts, otherwise up to date estimates are only available from unofficial modelled estimates. UNFCCC data is territorial emissions only.

**Policy relevant and meaningful.** The footprint includes sectoral estimates, which makes it attractive to specific policies (e.g., on energy production, deforestation and land use change), allowing clear feedback mechanisms between policy and the footprint.

**Potential to set targets against a threshold.** Two planetary limits are proposed, one based on an atmospheric CO<sub>2</sub> concentration of 350 ppm<sup>106</sup> and the second which includes all GHGs, which is a planetary boundary of cumulative emission of greenhouse gases starting from 2018 stay below 420 GtCO<sub>2</sub>eq.<sup>107</sup> The latter is aligned with global commitments and national policy on climate change.

**Broadly accepted.** Reducing GHG emissions is firmly embedded in international commitments and dialogue, especially the UNFCCC, and within the resulting domestic policies.

**Limited in number.** The single metric that forms the footprint (GHG emissions in CO<sub>2</sub>e, measured in tonnes) represents a wide range of direct and indirect aspects of consumption.

#### 4.10.4 General considerations and footprint-specific recommendations

Given the prominence of climate change in policy commitments and dialogue, the significant understanding of its impacts, and the existing expertise at measuring the underlying data, there is a strong case for including a GHG consumption footprint amongst a suite of footprint indicators.

<sup>104</sup> Urban, M.C. (2015). Accelerating extinction risk from climate change. *Science*348,571-573.DOI:10.1126/science.aaa4984

<sup>105</sup> For example, The Greenhouse Gas Protocol <https://ghgprotocol.org/> and the Science-based Targets Initiative <https://sciencebasedtargets.org/>

<sup>106</sup> Steffen, W., Richardson, K., Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., (2015). Sustainability. Planetary boundaries: guiding human development on a changing planet. *Science*, 347 (6223), p. 1259855, [10.1126/science.1259855](https://doi.org/10.1126/science.1259855)

<sup>107</sup> Metabolic & WWF (2020). Halving the footprint of production and consumption. [https://wwfint.awsassets.panda.org/downloads/halvingfootprint\\_report\\_wwf\\_metabolic.pdf](https://wwfint.awsassets.panda.org/downloads/halvingfootprint_report_wwf_metabolic.pdf)

## 5. Overarching issues

### 5.1 Linking production to consumption

Developing a consumption-linked footprint requires a mechanism to link the chosen environmental metric (i.e. the measure of pressure or impact) through to its proximate (often production-, sometimes processing-, linked) drivers, through to the ultimate drivers of utilisation of materials or services within economies by consumers, governments etc. As mentioned above, two typical, sometimes overlapping, approaches to making these connections are economy-wide material flow accounting (EW-MFA) and consumption-based accounting (CBA), with the latter typically relying on multi-regional input-output (MRIO) modelling. Below we describe these systems in more detail, with reference particularly to their utilisation in preparing material footprints which commonly underpin extensions to other footprint measures.

EW-MFA is arguably the most established - and certainly the most well standardised - approach for accounting for the materials which are ultimately linked to the impacts under consideration. Many national governments (such as those within the EU and OECD) undertake EW-MFA; many seeking alignment with the UN's System of Integrated Environmental and Economic Accounting. EW-MFA aims to account for the overall material inputs (imported or domestically produced) to a national economy, changes in material stocks, and the material outputs (which can include exports, but also accounts for processed output that is otherwise released back into the environment e.g. waste). A relatively high level of product detail is contained within the accounts; particularly for primary products of agriculture (and associated residues) and e.g. mining. Domestic production statistics along with trade information is critical to the compilation of MFA accounts, which is usually compiled/available at least on an annual basis.

Consumption-based accounting utilising input-output modelling instead relies (typically) on industrial-transaction information in the form of supply-and-use tables (which are then converted to input-output tables) which detail the economic outputs from one sector necessary to fulfil demand for other sectors of the economy and - ultimately - final demand from consumers. These tables are being constructed (typically by academic institutions, but e.g. the OECD also manages IO accounts) with increasing granularity/global coverage. A major advantage of MRIO-based approaches in comparison with MFA is that MRIOs allow 'total' global production-to-consumption activities to be fully accounted for whereas MFA may misrepresent the ongoing supply chains associated with downstream processing of materials which are later exported (e.g. products such as electronic goods which contain themselves contain composite materials may be combined in industry for export), and/or the use of materials that are associated with non-material products (e.g. production linked to the provision of service industries (e.g. food to support workers) which are paid for by third-countries but do not themselves involve trade of materials). In comparison with MFA, which focuses primarily on domestic utilisation, CBAs will typically provide greater detail on the origin of materials which - via their international 'whole economy' scope - also ensure that these origins detail points of production rather than assigning origins to points of transit/intermediate processing. CBAs can therefore be considered to provide a more holistic account of consumption and therefore ultimate responsibility for overseas footprints. However, sectoral detail is usually coarse in comparison to MFA accounts. Additionally, whilst several repositories/models for MRIO data exist, the compilation of MRIO data is resource intensive and often relies on IO tables which are not available annually (even if steps are taken to annualise data based on annualised GDP and/or trade information).

'Hybrid' approaches also exist. For example, the 'Global Environmental Impacts of Consumption' (GEIC) indicator (which is listed as a component indicator under the CBD GBF framework) can be considered a hybridisation of elements of MFA and MRIO in an attempt to preserve the positive attributes of both approaches. Production and trade information is first compiled based on mass-balance-based assumptions that also account for the potential for 're-exports' of products flowing through intermediate countries, before - at point of import - materials are inserted into a monetary MRIO framework to distribute materials through to final consumptive use. Equally, elements of this framework (e.g. the initial trade steps, or trade after accounting for re-exports) can be extracted, meaning that one can assess the resulting footprints from the perspective of more direct-attribution (direct trade) through to the more holistic, but often more indirect, impacts embedded in final consumption.

These approaches are not mutually exclusive, and the same - or similar - footprint metrics are typically amenable to application across approaches. Indeed, the GEIC indicator combines biomass, land use, deforestation, deforestation-linked GHG emissions, water and biodiversity footprints into a dashboard of indicators that follow a common production-to-consumption attribution approach. Importantly, however, the choice of method used, and the associated choice of data, will impact on the results obtained. For example, within the GEIC framework, the choice of MRIO model can have a marked impact on the resultant material footprint assessment. For Germany for the year 2017, using the EXIOBASE MRIO, the total material footprint (note this is for agricultural products and timber only) is estimated to be 231 million tonnes. With the Global Trade Analysis Project (GTAP), the estimate is 200 million tonnes. Further divergence is to be expected when more detailed flows (e.g. country- or commodity-specific) are assessed.

Overall, the following (non-exhaustive) factors are influential in determining the results obtained when attempting to link production impacts through to consumption:

- **Scope/perspective on consumption offered:** MFA and/or approaches accounting just for imports/exports can be considered to offer an 'apparent' consumption perspective, whereas CBA approaches offer 'total consumption'. For high-income economies it is typical for 'total consumption' estimates to be higher than apparent consumption, but the opposite is often the case for lower-income economies.
- **Scope of material/sectoral coverage:** Relatedly, the scope of economic/material coverage can vary across accounting methods. MFA is concerned with material products only, and will not explicitly account for the footprint associated with service-based industries. The GEIC indicator does not cover all materials at the current time of writing, instead having a focus on agricultural, cattle and timber-linked impacts.
- **Granularity of data:** Consumption-based accounts based on traditional MRIO will typically link environmental impact information ('intensities') to relatively coarse sectoral activities. This can have the effect of 'averaging out' impacts associated with distinct production systems and ultimately provides final footprint information which is less granular. Hybrid or full-material-based MRIO approaches attempt to address this issue. Increasingly, material flow information is becoming available at finer-resolutions (e.g. Trase) which can improve specificity of impact assessment further.
- **Data quality:** National statistics and international datasets (e.g. those from FAO) provide important information for MFA or MRIO accounting processes, but often suffer from gaps and/or imputations/estimates that can a) lower data quality and b) shift results when/if gaps are filled. FAO, for example, employs estimates for production volumes and trade flows where formal records are not available. On the one hand these estimates offer insight/allow supply chain

mapping where gaps would otherwise leave blind-spots, but on the other hand they can reduce confidence in the overall quality of results. IO accounts - whilst increasingly compiled as national statistics - are also often obtained via academic, unofficial, sources and MRIOs may contain a mix of official and unofficial sources with varying timestamps.

- **Trade/consumption modelling assumptions:** To overcome data limitations or mismatches, assumptions or model-based approaches are often employed to join/compile consistent datasets. For example, methods can prioritise preserving production records in preference for trade-flow volumes and vice versa. Publication of results from varying implementations of models is variable and studies which provide 'footprint analysis' typically provide limited, or no, intercomparison of alternative trade-model parameterisation.
- **Attribution-assumptions:** Authors can attempt to account for/quantify the dynamics of 'production-to-impact' when attributing impacts through to downstream drivers. For example, lags between land use change and productive use are common - and sometimes required - before material production can begin. Equally, productive use can take place for several years following the main/initial 'impact' and this impact can often be 'amortized' over a period of time (essentially having a smoothing effect). Studies can account for these dynamics in different ways, including by essentially ignoring them e.g. linking in-year impacts to in-year production.
- **Mass-balance approaches:** Both MFA and CBA accounts employ 'mass balance' based assumptions due to a lack of globally-applicable intra-country traceability and a lack of information e.g. on the environmental qualities of traded materials. In other words, information that would allow delineation of specific flows, qualities and impacts from point A to point B to point C are not available globally. As an example, a product (A) making up 50% of production, produced unsustainable in Country A is treated - statistically - as equivalent to a sustainably produced product (B) in Country A making up the other 50% of production. If country B imports/consumes 100 tonnes of product originating from country A, then it will be assigned the footprint associated with 50 tonnes of product A and 50 tonnes of product B. Additional spatial and/or product granularity can assist, but currently does not fully resolve such issues. Associatedly, when employing consumption-based measures, given the highly embedded nature of flows that are estimated within these methods, it is likely that indicators will never reach e.g. zero even if there is reality no unsustainable consumption arising from point A-to-B. This may be important where targets have zero-thresholds.

Overall, MFA and MRIO-based CBA approaches are best seen as complementary. An economy-wide MFA approach has the advantage of being conceptually simpler, is often amenable to the inclusion of greater product detail, and more formal guidance for data collection and presentation. CBA has the advantage of providing a more complete account of the footprint and attribution of impacts to points of origin, with hybrid-MRIO offering opportunities to increase specificity. We would recommend that the application of both approaches is explored in the development of monitoring frameworks. Countries should seek to understand their total 'material dependencies' in the first instance, with EW-MFA offering the opportunity to conduct such analysis in a standardised format. Adopting the more holistic CBA approach becomes more pertinent, however, when extension to other environmental footprints is being pursued, because information on the specific origin and total extent of impacts is often highly important in understanding the severity of potential impacts. Hybridisation can bring together the benefits of both approaches.

## 5.2 Navigating component indicators linked to Target 16 of the Global Biodiversity Framework

Under Target 16 of the Global Biodiversity Framework four component indicators are identified as:

- Food waste index
- Material footprint per capita
- Global environmental impacts of consumption
- Ecological footprint

The Material Footprint and Ecological Footprint are described above, but we now briefly cover the Food Waste Index and Global Environmental Impacts of Consumption (GEIC) indicator which are yet to be considered.

The Food Waste Index is prepared by WRAP and UNEP and measures food and inedible parts wasted by retail and consumers. Results are published in the form of an international report with country-level results. For each country, the level of food waste per annum is expressed as an index relative to the level of food waste in the baseline year. Various data points can be utilised in the preparation of a national Food Waste Index, including via direct measurement, mass balance approaches, and academic and non-academic studies. Whilst relevant to specific aspects of Target 16, where a target for halving food waste is specified, the Food Waste Index is not a 'footprint' measure and therefore is not considered further here.

The Global Environmental Impacts of Consumption (GEIC) indicator is prepared by the UK JNCC and Stockholm Environment Institute. Results are available via an interactive online tool. GEIC is best considered as a dashboard of footprint metrics covering various aspects of environmental impact, rather than a single indicator. It includes biomass, land use, deforestation (and associated deforestation-linked GHG emissions), water and biodiversity footprint information. Scope at the current time is limited to crop and wood commodities although work is ongoing to expand the breadth of materials covered (and extension and improvement to the footprint metrics). Environmental footprint information is linked via the use of physical production and trade data (from FAO and UN COMTRADE repositories) via MRIO modelling (two model versions are available) through to the countries linked to consumption. Importantly, impacts are represented on a commodity-specific basis, meaning that resolution in comparison to other footprint measures (such as the Ecological Footprint) is relatively high. Results across different environmental metrics are linked to the same underpinning material- and economic-flow information, meaning that results (impact measures and associated hotspots of environmental risk) derived from one footprint measure can be directly compared with results of another with the confidence that the underpinning estimates of supply-chain, trade- and consumption-based connections and drivers are consistently represented.

Ultimately, the component indicators selected under GBF Target 16 provide different components of information linked to the impacts of consumption on biodiversity. In contrast to the Material Footprint and Ecological Footprint, both the Food Waste Index and GEIC indicator can be considered to provide additional detail and specificity. The Food Waste Index considers the acute issue of unnecessary food waste as a contributing factor to overconsumption. The GEIC indicator allows the acute impacts associated with specific commodity-production systems and trade to be analysed across a variety of specific environmental impact categories.

## 6. Towards national targets

At a national level, the key steps to begin implementing this commitment are updating National Biodiversity Strategies and Action Plans (NBSAPs) by defining the specific aspect(s) of ‘overconsumption’, to be reduced; set a fair but ambitious reduction target for them; determine indicators for measuring progress and determine the mechanisms for translating Target 16 into action.

### 6.1 The global target

Target 16 of the Kunming-Montreal Global Biodiversity Framework commits to: ‘... by 2030, reduce the global footprint of consumption in an equitable manner, including through halving global food waste, significantly reducing overconsumption’. It therefore includes both numerical (halving) and non-numerical (‘significant reduction’) elements.

### 6.2 National targets

National footprint targets are the necessary first step to reducing the footprint of overconsumption significantly and equitably. They will need to be implemented through sectoral targets, strategy and policy and legislation, but this section focuses on the technical aspects of national target setting. It should also be noted that all of the assessed footprints can and have been estimated at a national level (although note that the Ecological Footprint takes on a different meaning at national level) and can sometimes be downscaled effectively to a sub-national and/or sectoral level (see Section 4).

#### 6.2.1 Absolute and relative targets.

The nature of GBF Target 16 leaves open two possibilities for national targets regarding overconsumption and waste: they could be formulated as *absolute* targets or as *relative* targets. Whilst both relative and absolute targets are commonly used in environmental policy, they have different characteristics that ought to be carefully considered. Progress towards relative targets (e.g., ‘an increase in the efficiency of use of resource y of x% by 2030’) are perfectly amenable to monitoring. However, even if the relationship between the footprint and environmental harm is well established (see Section 4), whilst the first of these formulations is likely to provide a positive environmental outcome, the second formulation may not, because overall use of the resource, and the environmental damage that entails, may go up in absolute terms. This issue does not occur with absolute targets (e.g., ‘an x% reduction in footprint z by 2030’).

#### 6.2.3 Political process and trade-offs

Although this document focuses on technical aspects of footprints, it is important to understand that any target is essentially a political process. The UNFCCC Paris Agreement provides a useful illustration here: the consequences of rising global temperatures are well established in science, the decision to pin the acceptable increase at 1.5°C (rather than 1°C, 1.4 °C or 2°C, etc) is essentially a trade-off between the gathering risks of increasing global temperatures and the costs and non-climate consequences of change. In this sense, the existence of a footprint threshold (and/or robust simulations of the impacts of an increasing footprint on earth systems) grounds the political decisions and perhaps allows more thorough examination of trade-offs rather than being an absolute demand.

#### 6.2.3 Equity between nations

Countries do not contribute equally to the footprints described in Sections 1 and 4, above. In some cases, a very small number of countries are primarily responsible for planetary overshoot (currently and/or historically), whilst others may use insufficient planetary resources to meet the needs of their populations. It would therefore be unfair to expect all countries to reduce their footprints equally, and this is embedded within the wording of GBF Target 16.

There is no universally agreed way of resolving this, however, we highlight two approaches here. Firstly, a simple *per capita* calculation of footprint thresholds can be used to quantify each global citizen's fair share of a planetary resource. This can then be compared with the *per capita* national footprint to assess the direction and magnitude of change required. So, for example, whilst the UK would have to *reduce* its material footprint from 22.2 to 6.9 tonnes per person per year to stay within the proposed planetary threshold, Sri Lanka could *increase* its footprint from 3.8 to 6.9 tonnes per person per year.<sup>108</sup>

It should be noted that several other ways of sharing nation responsibility for action on global issues have been proposed.<sup>109</sup> The challenge for policymaking is that the different equity definitions can lead to very different outcomes (i.e., could result in inadequate reductions or over-reduction) and there is no agreement on which underlying principles and approaches should be used.

#### 6.2.4 Downscaling planetary boundaries

As GBF Target 16 lacks a complete numerical target for overconsumption, a key issue is establishing whether national targets together constitute a 'significant' reduction, let alone a sufficient one. This problem can be overcome by taking a precautionary approach and using the planetary boundaries associated with many footprints as a starting point for estimating each nation's equitable share of planetary resource use.

Setting national targets by distributing planetary boundaries between nations is valid where the absolute magnitude of anthropogenic emissions is what determines the overall impact, and it does not substantially matter where the emissions are generated (e.g. greenhouse gases). For other 'global' issues (e.g., nitrogen use, biodiversity loss) a simple sharing of the planetary threshold between nations is sometimes considered inadequate, because the impacts are fundamentally determined by local conditions. Instead, a complex multi-scale systemic approach which involves a range of observational and modelled data, understanding interactions amongst multiple earth systems, social and economic dimensions, and international scientific governance bodies has been proposed.<sup>110</sup> Whilst this is a valid representation of earth system processes, it is difficult to see how it would operate in practice for footprints that do not already possess such data and structures. Using consumption-based footprints partially overcomes the issue, in that it reveals where national responsibility lies, irrespective of national boundaries. We suggest that national footprints and targets can - at least for the time being - be set according to the processes described in the preceding section, rather than waiting for the multilateral institutions to be formed that would potentially allow for more refined national target setting.

#### 6.2.5 Monitoring and reporting

The ease of measuring footprints is one of the key characteristics used to assess them (see Section 4, above), because monitoring progress towards a target is critical to understand whether policies are working. Regular (preferably annual) reporting also provides accountability for those policies, and, aggregated, for progress towards the global target. Having data, modelling and analysis publicly available will significantly aid transparency at all levels. It is therefore essential that national footprints are based on data and/or modelling that is readily available, or that can be conducted with reasonable extra effort and cost.

#### 6.2.6 Offshored footprints and policy

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<sup>108</sup> Fanning, A.L., O'Neill, D.W., Hickel, J. et al. The social shortfall and ecological overshoot of nations. *Nat Sustain* 5, 26–36 (2022).

<https://doi.org/10.1038/s41893-021-00799-z>, cited data for 2015 from <https://goodlife.leeds.ac.uk/national-trends/country-trends/#LKA>

<sup>109</sup> Häyhä, T., Lucas, P.L., van Vuuren, D.P., Cornell, S.E., & Hoff, H. (2016). From Planetary Boundaries to national fair shares of the global safe operating space — How can the scales be bridged? *Global Environmental Change*, 40, 2016, 60-72, ISSN 0959-3780, <https://doi.org/10.1016/j.gloenvcha.2016.06.008>

<sup>110</sup> Häyhä, T., Lucas, P.L., van Vuuren, D.P., Cornell, S.E., & Hoff, H. (2016). From Planetary Boundaries to national fair shares of the global safe operating space — How can the scales be bridged? *Global Environmental Change*, 40, 2016, 60-72, ISSN 0959-3780, <https://doi.org/10.1016/j.gloenvcha.2016.06.008>

As described in preceding sections, consumption footprints provide the clearest attribution of the environmental impacts of a nation's economy. Depending on the granularity of data, it also reveals where in the world those environmental pressures are occurring. From a policy perspective, this in turn opens the door for realistic policies to reduce a nation's environmental impacts *in toto*. However, reducing overseas impacts is self-evidently more complex than dealing with the domestic environment. Two main approaches to this conundrum are currently receiving significant attention. The first, regulating on the sustainability of imported goods, is exemplified by the EU Deforestation Regulation, the UK's Forest Risk Commodities regulations, and the FOREST Act in the US. The second approach is more based on collaboration and the transfer of resources between importer and exporter countries (or blocs) to jointly construct effective and equitable solutions (e.g., Norway's Climate Investment Fund, and the EU's Forest Law Enforcement, Governance and Trade).

## 1. Annex 1. Definition of key terms and concepts

**Footprint:** the degree of (direct and/or indirect) impact that our activities have on the natural environment (e.g., Greenhouse Gas Footprint, Material Footprint, Ecological Footprint). None of these represent a comprehensive measure of all of the “footprint” economic activity on nature. The way that these impacts are attributed can vary, for example between the impact of consumption and/or production activities (see **Scope**).

**Indicator:** Indicators are measures that are based on verifiable data that convey information beyond their own context. To become an indicator, a metric must either:

- be presented in the context of progress towards a target. For example, the proportional change in a country’s material footprint each year from a specified baseline would indicate progress towards a target to decreasing the footprint by x%, or
- be used to assess the effectiveness of another intervention. For example, the effectiveness of a policy to increase the consumption of sustainably produced food could be indicated by a change in forest cover associated with the supply base.

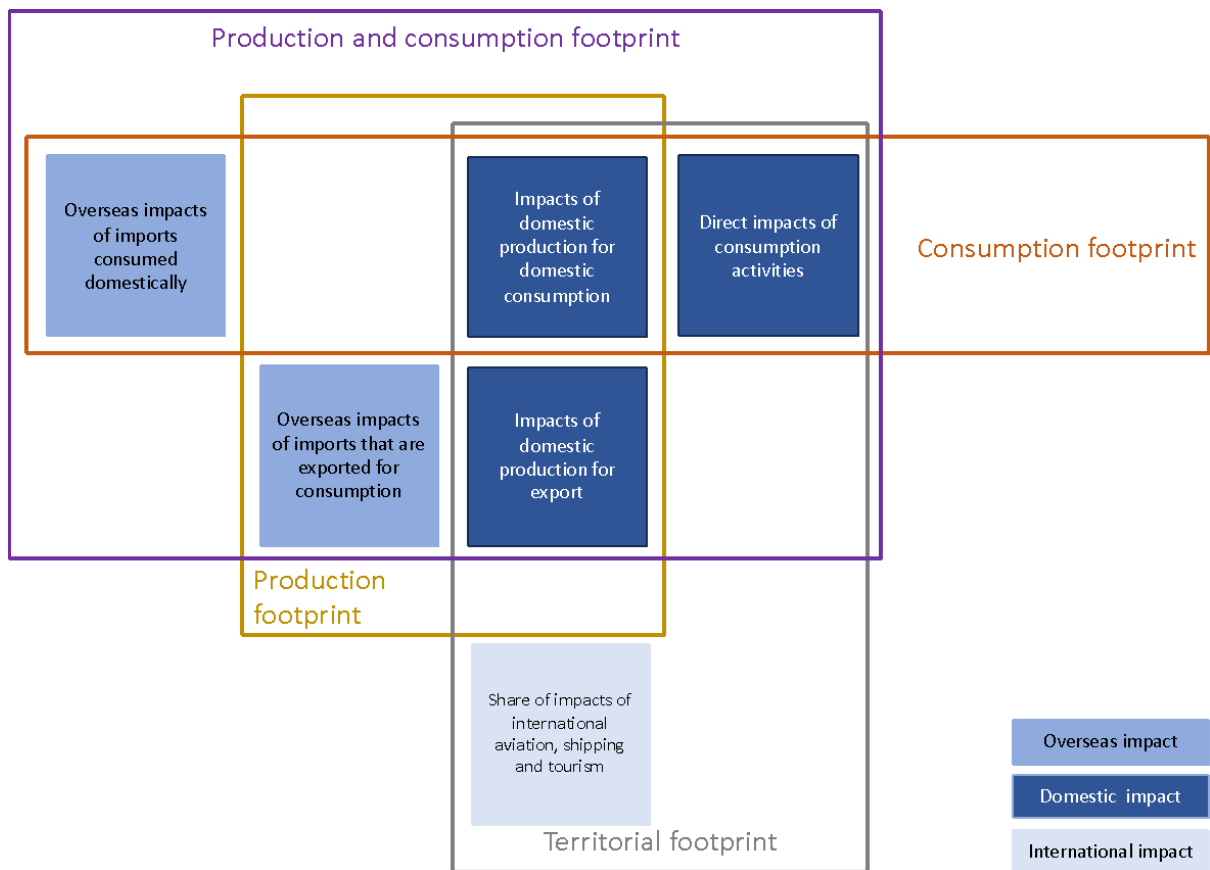
**Metric:** a system or standard of measurement. For example, observations of species numbers and abundance collected over space and/or time can be used to form a metric that provides direct information about biodiversity. Equally this could be measured indirectly via habitat extent and/or quality. Similarly, the metric for material footprint is the sum of fossil fuels, metal ores and non-metal ores (and of biomass in many definitions) produced and/or consumed, and there are defined protocols for measuring this consistently across countries and over time. The term ‘metrics’ includes indicators, indices and data that provide information on the environment.

**Multiregional Input-Output Model (MRIO):** A method that takes input-output (IO) tables, which describe monetary (or, occasionally, physical) transactions between industry sectors of an economy, and compiles them to provide a representation of the supply-chain connections between sectors of multiple regions’ (and usually the global) economy. MRIOs help elucidate the complicated relationship between consumption drivers and production (see also ‘environmental extensions’). A number of global MRIO models are available, constructed using similar - but often distinct - datasets and with differing assumptions.

**Environmental extensions:** In the context of footprinting analyses that use a multi-regional input-output (MRIO) approach, the term ‘environmental extension’ refers to the step that links the MRIO, which is in financial or physical units, to some environmental data. Typical extensions include resource use (e.g. water, land), emissions, pollutants, and forest and biodiversity loss. Ultimately, this provides information to assess the environmental consequences associated with economic activities across various sectors and regions. Environmental extensions are integral to footprinting methodologies that attempt to quantify the environmental consequences of consumption.

**Consumption:** In footprinting, consumption refers the environmental impacts from the consumption of goods and services by a national economy, irrespective of whether these are produced within or outside the country. See also ‘Footprint scope’, below.

**Footprint scope:** The scope of a footprint is one of the fundamental issues that determines how useful it will be to set targets and monitor progress against the GBF. There are numerous possible scopes for footprints, each of which allocates impacts differently. We suggest the following definitions for footprints of consumption, production, consumption and production and territorial footprint. Each type of economic activity that creates an environmental impact is within a blue box, the shade of blue indicates the location of the impact:



Note that the 'production' and 'consumption' footprint are (in theory) equivalent in terms of the impact being measured. However, they differ in how they attribute those impacts.

## 2. Annex 2. Footprints not assessed in detail

Footprint	Source	Rationale for excluding from detailed analysis
Water pollution	WWF/Metabolic (2020)	Significant uncertainty on the environmental impacts of the multitude of pollutants; already significant attention on water pollution
Marine resource	WWF/Metabolic (2020)	Part of the biomass footprint, so little to be gained by treating this out as a separate footprint
Novel entities	Steffen <i>et al.</i> (2015)	Significant uncertainty on the impacts of the multitude of novel entities, their duration in the environment, lag times, and a very limited definition, etc
Air pollution	WWF/Metabolic (2020)	Significant uncertainty on the environmental impacts of the multitude of pollutants, which also means that a combined footprint' may poorly reflect environmental impacts. Already significant policy attention on air pollution at local/national (and for a few, international) levels.
Atmospheric aerosol loading	Steffen <i>et al.</i> (2015)	Significant uncertainty on the environmental impacts; seems rather marginal for a process focused on biodiversity
Ocean acidification	Steffen <i>et al.</i> (2015)	A specific consequence of atmospheric GHG levels, therefore in effect covered by GHG footprint
Global Environmental Impacts of Consumption indicator	<a href="https://commodityfootprints.earth/">https://commodityfootprints.earth/</a>	More of an indicator than a footprint, and is mentioned in relevant parts of the text