The Ecological Footprint emerged as a response to the challenge of sustainable development, which aims at securing everybody's well-being within planetary constraints. It sharpens sustainable development efforts by offering a metric for this challenge's core condition: keeping the human metabolism within the means of what the planet can renew. Therefore, Ecological Footprint accounting seeks to answer one particular question: How much of the biosphere's (or any region's) regenerative capacity does any human activity demand? The condition of keeping humanity's material demands within the amount the planet can renew is a minimum requirement for sustainability. While human demands can exceed what the planet renews for some time, exceeding it leads inevitably to (unsustainable) depletion of nature's stocks. Such depletion can only be maintained temporarily. In this chapter we outline the underlying principles that are the foundation of Ecological Footprint accounting.

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16

Ecological Footprint accounts

Principles[1]

Mathis Wackernagel, Alessandro Galli, Laurel Hanscom, David Lin, Laetitia Mailhes, and Tony Drummond

1. Introduction – addressing all demands on nature, from carbon emissions to food and fibres

Through the Paris Climate Agreement, nearly 200 countries agreed to keep global temperature rise to less than 2°C above the pre-industrial level. This goal implies ending fossil fuel use globally well before 2050 (Anderson, 2015; Figueres et al., 2017; Rockström et al., 2017).

The term "net carbon" in the agreement further suggests humanity needs far more than just a transition to clean energy; managing land to support many competing needs also will be crucial. If the human economy moves out of fossil fuel fast and furiously, demand for substitutes – for instance, forest products for fuel – could place tremendous new pressures on planet Earth if improperly managed (Smeets and Faaij, 2007). The agreement also references "sustainable management of forests" (page 23) to absorb CO_2 and "aims to strengthen the global response to climate change in a manner that does not threaten food production" (page 22). This combination of forces – consumption, deforestation, food production, emissions, and population – stresses more than ever the need for comprehensive resource accounting tools like the Ecological Footprint, which tracks the competing demands on the biosphere.

The carbon Footprint is an important component of the Ecological Footprint. Yet it is one that will vanish if we put the Paris Climate Agreement into practice. The all-encompassing Ecological Footprint helps countries better understand competing needs such as reforestation for carbon sequestration, food, and timber for everything from heat, to furniture, to paper.

Humanity will succeed when we address these competing demands on our planet's ecosystems as a whole, and this is the underlying purpose of the Ecological Footprint accounts.

To this end, this chapter documents and discusses the role of Ecological Footprint accounting. It covers the purpose of the Ecological Footprint accounts, explains their role in sustainability and economic assessments, describes how the robustness and rigour of these accounts are being improved, and reveals the answers to common issues raised about the Footprint in scientific and policy literature.

Ecological Footprint accounting is driven by one key question: *How much of the biosphere's (or any region's) regenerative capacity does any human activity demand?* Or more specifically: How much of the planet's (or a region's) regenerative capacity[2] does a defined activity demand in order to provide all the ecosystem services that are competing for mutually exclusive space? Such activities could be supporting the consumption metabolism of the humanity, a particular population, a production process, or something as small and discreet as producing 1 kg of durum wheat spaghetti. These services include provision of all the resources that the population or a process consumes and absorption of that population's or process's waste, using prevailing technology and management practice (Wackernagel, 1991; Rees and Wackernagel, 1994; Wackernagel and Rees, 1996; Wackernagel et al., 2002; Wackernagel et al., 2014). The ability of ecosystems to provide for these resources – its renewable capacity – we call "biocapacity".

As financial "profit and loss" statements track both "expenditure" and "income", or as balance sheets document "assets" and "liabilities", the Ecological Footprint accounts typically also have two sides; demand on biocapacity (Footprint) against availability of biocapacity.

The Ecological Footprint emerged as a response to the challenge of sustainable development, which aims at securing human well-being within planetary constraints. By staying within what the planet can provide, one makes sure that biocapacity, the essential ingredient for any value chain, is available now and for future generations. This is what the "planetary boundary" community calls humanity's "safe operating space" (Rockström et al., 2009; Steffen et al., 2015). The underlying objective of Ecological Footprint accounts is to provide motivational, managerial, and monitoring capacity for assessing and dealing with biocapacity and its biophysical constraints.

Keeping humanity's Ecological Footprint within the biocapacity of the planet is a minimum threshold for sustainability. While this threshold can be exceeded for some time, exceeding it leads inevitably to (unsustainable) depletion of nature's stocks. In other words, such depletion can only be maintained temporarily.

Each ecosystem reacts differently to overuse. Forests can be overharvested significantly compared to their renewal rate, because standing stocks of a middle-aged or mature forest can easily be 50 fold of annual growth rates (FAO, 2015). With the Paris declaration that defines an upper global warming limit, the amount of additional carbon that can be added to the atmosphere becomes defined. For example, a calculator by the Mercator Research Institute on Global Commons and Climate Change, based on IPCC's 2014 Synthesis Report, concludes that at current emission rates, the carbon budget for staying within 1.5°C would be eaten up by 2021, using an upper estimate, and generously assuming that non-CO_2 greenhouse gases have no additional impact (which of course they have) (accessed 2017). Overused fisheries also can lead quite rapidly to lower yields as demonstrated for instance by the 1992 cod-fish collapse in Canada (Frank et al., 2011). These examples all underline that, while it is possible to harvest beyond regeneration, this cannot persist.

The Ecological Footprint makes apparent the gap between human demand and regeneration. In its applications, Ecological Footprint accounts typically underestimate human demand as not all aspects are measured, and overestimate biocapacity because it is difficult to measure how much of current yield is enabled by reduced future yield (for instance as in the case of overuse of groundwater, or erosion).

Therefore, Ecological Footprint accounts are metrics that merely define minimal conditions for sustainability. They do not cover all material aspects of sustainability. Ecological Footprint accounts focus on the minimal condition of living within the planet's ecosystem's regenerative capacity.

It is important to note that reducing the human Footprint to "one planet Earth" is still insufficient, since wild species compete for the fruits of the planet's biocapacity as well. E.O. Wilson, in his recent book *Half-Earth*, argues that half of the Earth should be left for wild species to "to stave off the mass extinction of species, including our own" (Wilson, 2016, jacket quote, and www.half-earthproject.org/book/).

If the basic condition of human demand staying within the available biocapacity is not met, Ecological Footprint accounting becomes a metric for "unsustainability". Therefore, by providing this bottom-line condition for sustainability, Ecological Footprint accounts provide a foundation upon which many other sustainable development metrics and strategies can be built.

2. What Ecological Footprints do and how they are measured

When people catch more fish than fishing grounds can regenerate, fisheries eventually collapse; when people harvest more timber than forests can re-grow, they advance deforestation; when people emit more CO_2 than the biosphere can absorb, CO_2 accumulates in the atmosphere and contributes to global warming. The overuse of these and other renewable resources is called "overshoot". Biocapacity is shorthand for biological capacity, which is the ability of any ecosystem – hence the whole biosphere – to produce useful ecosystem services for humans. This includes regeneration of biological materials and absorption of wastes generated by humans. Biocapacity is not fixed. It represents the availability of natural, renewable resources and waste absorption services that can be used by humanity in a given year. The abundance and productivity of natural capital changes each year.[3] For instance natural disasters such as forest fires or landslides, or human-induced degradation such as deforestation, soil loss, climatic impacts, or acidification can reduce biocapacity. On the other hand, careful agricultural and forestry management can also magnify biocapacity.

Box 16.1 The two principles underlying Ecological Footprint accounting

Life, including human life, competes for biologically productive areas. These areas represent nature's ability to renew itself. This fundamental capacity or material resource ultimately limits the metabolism of animal species, including humans. It is called biocapacity.

For instance, the amount of fossil fuel still underground is not the most limiting factor for its use. Rather, what limits fossil fuel use even more is the planet's capacity to absorb its CO_2 emissions. Also, rare elements (key metals/minerals used for industrial purposes) are not in themselves significantly limiting for the human economy. With more energy, deeper mines can be built to access them. The availability of these materials is only limited by the energy availability to concentrate these metals and minerals from more dispersed ores. Energy, in turn, cannot rely on fossil fuel sources, since the absorptive capacity for carbon is limited. While shifting away from fossil fuels could reduce CO_2 absorption needs, it could also potentially add new biocapacity demands elsewhere through the use of different energy sources.

To map human dependence on biocapacity, Ecological Footprint accounting is based on two basic principles:

1 **Additivity:** Given that human life competes for biologically productive surfaces, these surface areas can be added up. The Ecological Footprint (or Footprint) therefore adds up all human demands on nature that compete for biologically productive space: providing biological resources, accommodating urban infrastructure or absorbing excess carbon from fossil fuel burning. (Surfaces that serve multiple human demands are counted only once.) The Footprint then becomes comparable to the available biologically productive space (biocapacity).

2 **Equivalence:** Since not every biologically productive surface area is of equal productivity, areas are scaled proportionally to their biological productivity. Therefore, the measurement unit for Ecological Footprint accounting, global hectares, are biologically productive hectares with world average productivity.

> Both Footprint and biocapacity can be calculated at global, national, local, household, and individual levels.

There is an important debate regarding biocapacity: Are current levels of biocapacity sustainable? Can biocapacity ever reach a maximum, or is there still a lot of room to increase the biocapacity of specific land? As currently measured in national assessments based on the United Nations (UN) data, biocapacity only captures what is being regenerated, not whether this level of bioproductivity – or ability to maintain its level of potential net primary productivity – can be maintained forever. If this level of bioproductivity cannot be maintained, one could consider the biocapacity to be fragile. Within the domain of Ecological Footprint research, “fragility of biocapacity” has not been researched in detail. Such research would provide deeper insight into how much of the currently assumed biocapacity may not last, for instance due to water, energy, or soil constraints. However, a preliminary investigation of this aspect (Moore et al., 2012) has revealed that the world’s biocapacity could potentially rise through 2030, peaking at 12.5 billion gha (1.5 gha per capita – assuming the UN’s medium population projection) because of the effects of increased availability of land suitable for agriculture (this being a result of the initial effects of climate change). As the climate warms further, soil becomes depleted, groundwater is compromised, land becomes constrained, and agricultural land would with high likelihood be given preference over forests in an attempt to fulfil the food requirements of a growing world population. As a result, world biocapacity could then decrease. One estimate is a drop to 11.7 billion gha in 2050 (1.3 gha per capita), or less if yields drop (Challinor et al., 2014).

Biologically productive regions represent the area, both land and water, that supports significant photosynthetic activity and biomass accumulation that can be utilized by humanity. To achieve sustainable development, it is crucial to have information regarding humanity’s demand and material dependence on the biosphere as well as the complementary information: what the biosphere does provide, in any given year. Hence Ecological Footprint accounting compares the actual amount of biological resources produced and the wastes absorbed by the planet in a given year to the total human demand on nature for that year. This demand is defined by the biological resources humans extract and the subsequent waste generated in a given year.

This accounting can be done at any scale, from the resource demand of a single activity or a single individual, to that of a city, country, or the entire world (see Section 3 for more detail). Global Footprint Network's most recent national and global accounts – its National Footprint Accounts (Global Footprint Network, 2017) – show that, in 2013 (the most recent year for which UN data is available) humanity continued to be in overshoot,[4] demanding in 2013 over 64 per cent more than what the biosphere renewably provided in that year.

We emphasize that Footprint assessments are accounts, not indices, such as the Environmental Sustainability Index (Global Leaders of Tomorrow Environment Task Force, 2002), or the Dow Jones sustainable development index (www.sustainability-index.com). Accounting is systematically distinct from an index or a composite, which combines various incommensurable elements into a single number. By contrast, accounts start from a clear research question, and they use a common unit as their measurement. Therefore, accounting-based metrics are standardized and readily compared and generalizable. Each unit is comparable if not largely substitutable.[5] Examples include financial accounting, which includes GDP, where dollars are the unit, or greenhouse gas accounts, where the unit is CO_2 equivalents. In the case of Ecological Footprint accounting, the unit is global hectares.[6]

However, composite indices, such as a Mercer Quality of Life Ranking (Mercer, 2016; Mercer, 1994) which compares the liveability of cities, or the World Economic Forum competitiveness measures (WEF, 1974-2018) comparing national economies, company performances as measured by the Dow Jones Sustainable Develoment Index (2016), Transparency International's corruption perceptions index (Transparency International, 2015) measuring the perceived levels of public sector corruption, or the Environmental Performance Index which rates country status and performance against sustainability target (Dahl, Chapter 3; Dahl, Chapter 23; Esty and Emerson, Chapter 5; Conrad and Cassar, Chapter 19) are a somewhat arbitrary aggregation of diverse indicators into an index, with the indicators being averaged out according to a particular weighing framework. The upside of indices is that they can be as broad as their authors wish and cover various topic areas. The downside is that the results depend on the arbitrary architecture of the index, with assumed or implied trade-offs. In other words, composite indices lack a clear, method-independent research question, a prerequisite for scientific inquiry. In spite of their limited scientific robustness, indices may still serve practical functions. For instance, they can be used as alarm bells, but they cannot be used for determining the quantitative implications of trade-offs. They can also be constructed as proxies for quick or standardized assessments or diagnostics, such as those carried out in psychology or healthcare. They are helpful diagnostic short-cuts once the index is extensively tested in statistically rigorous ways against measureable outcomes. Indices in public policy typically lack the sample size needed for such statistical testing. Short of that, they are not a scientifically reliable diagnostic tool.

The underlying premise of the Footprint accounts is based on the recognition that the ecosystem services required for human activities compete for biologically productive space. Meaning, these areas support processes such as the harvest of rain, provision of nutrients, and capture of sunlight. Then, the Footprint is the sum of all the mutually exclusive areas needed for all the demanded services.

The area demanded is calculated by turning the formula for yield on its head. Since yield is defined as:

$$Yield = \frac{Amount\ per\ year}{Area\ occupied}$$

It follows that

$$Area\ occupied = \frac{Amount\ per\ year}{Yield}$$

Rather than expressing the area results in hectares, each hectare is adjusted for its respective biocapacity. These adjusted hectares are called *global hectares.* These global hectares are defined as biologically productive hectares with world average bioproductivity. They are the standard measurement units for both Ecological Footprint and biocapacity. One global hectare worth of any area is (in theory) able to produce a similar amount of biomass regeneration. It is a "similar" amount, because different hectares across the world do not provide identical kinds and amounts of biomass. Even so, hectares across biomes and vastly different plant communities – from tropical to boreal, from wet to dry – can be compared for productivity of meat, cereals, timber, or carbon sequestration capacity. The intent of the accounts is to base the comparison on the area's potential Net Primary Productivity. Because of data limitations, the national assessments provided by Global Footprint Network's National Footprint Accounts approximate measuring equivalence by using data on differences in agricultural potential as the basis for comparison. More on Net Primary Productivity is discussed below.

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Figure 16.1 Humanity's Ecological Footprint, 1961–2013

Source: Global Footprint Network (2017)

This graph shows the ratio between human demand and the Earth's biocapacity, and the components of the human demand, from 1961 to 2013. In other words, the Footprint in this Figure 16.1 is not expressed in global hectares, but in number of planets. It does not imply that biocapacity does not change over time – just that the number of planets available has been constant, even though the planet itself has changed over the time period.

Ecological Footprint accounts attempt to track all competing demands for biologically productive surfaces. These demands include regenerating harvested renewable resources and absorbing wastes generated by human processes, as well as accommodating urban infrastructure and roads.

These simple and visual principles make the Footprint accounts easy to communicate and understand, as for instance also explained in the example of the Ecological Footprint of one person (Box 16.2).

Box 16.2 Calculating the Ecological Footprint of Gérard Depardieu in 6 easy steps

Let's take the case of the actor Gérard Depardieu to illustrate how Footprints are calculated. Say Depardieu's coffee comes from Guatemala, the wheat to feed the chickens that lay his eggs comes from Iowa, and the wool used for his suit is from New Zealand. Thus his Footprint is spread all across the world.

To assess his Footprint, we ask:

1 How much pasture does it take to feed the cows for the dairy and meat he consumes?

2 How large are the fields needed to produce all his beans, cotton, rubber, sugar, cereals – not only for his bread and spaghetti, but also for feeding his share of chickens and pigs?

3 How much ocean area is necessary to produce the fish that he eats?

4 How much land does his home (or portion of it, if he shares his home with others), his garden, and his share of the roads, city squares, and parks occupy?

5 How much forest area is necessary to absorb the CO_2 from fossil fuel he uses – for heating and cooling his homes, producing the goods and services he consumes, driving and flying him around, etc.?

6 How much area is needed for the energy and resources used to provide Gérard’s share of social expenditures like hospitals, police forces, government services, educational facilities, and military activities?

To get Gérard Depardieu’s Footprint, we first translate all the areas from the above questions into the actual areas needed. Then, we translate actual areas needed into standardized “global hectares” with world average productivity or growing potential (global hectares becomes the common currency). Then we simply add them up. This is the area Depardieu occupies from the beginning to the end of his life. Of course, this area fluctuates over the years, depending on his level of consumption in each year, but also on the efficiency of production in that given year and the changing productivity of the biosphere.

3. Data for National Footprint Accounts and testing results

National Footprint Accounts use over one billion data points to track the Footprint and biocapacity of 200 countries from 1961 until today. The input data for the Ecological Footprint comes from a variety of international data sets, predominantly the UN, FAO, and IEA. Therefore, the quality, i.e., accuracy and precision, of the National Footprint Accounts is dependent upon the level of accuracy and availability of these data. The primary inputs are detailed in Appendix 16.2. Of course, both the accuracy and detail of the Footprint results need further development. Global Footprint Network builds on 20 years of methodological development and continues to refine and develop the tool with inputs from its partner organizations and the advisory board.

Most of the methodological improvements are a reflection of better data becoming available. For instance, the 2016 National Footprint Accounts introduced 21 improvements, most significantly a recalculation of the world average ability of forests to absorb CO_2. The conclusion of this recalculation was that the initial absorption rate of 0.97 t C $ha^{-1}yr^{-1}$ absorption may in light of new data be much lower, possibly as low as 0.73 t C $ha^{-1}yr^{-1}$ (Mancini et al., 2016).

UN data limitations prevent national calculations from capturing all resource flows. Particularly on the waste side, current accounts only include CO_2 emissions from burning fossil fuel. Demand on nature, i.e., the Ecological Footprint, is categorized into six different area types: cropland, grazing land, forest products, carbon Footprint, built-up land, and fishing grounds (see Figure 16.1). Biocapacity is categorized by only five categories, since forest land is used both for carbon Footprint and forest products. Forests require long-term protection from harvest in order to be used for effective carbon sequestration. Current national accounts do not distinguish or identify which portions of forests are under such protection.

Ecological Footprint accounts focus on the biosphere's annual resource flows. Fossil fuel deposits (or underground ores) are not considered to be biocapacity. Rather, they are economic assets in the lithosphere. They are similar to gold deposits in the bank's safe, with which the owners can buy products and services, such as biocapacity or services thereof. Lithosphere assets are thus included only to the extent that they place a demand on biosphere resources, such as in the process of mining, or when fossil fuels are burned and CO_2 is emitted. Therefore, the effects of oil exploration, refining and final use are directly accounted for.

Climate change is not directly measured by Ecological Footprint accounting. Still, loss (or gain) of biocapacity is tracked by the Footprint from year to year (as long as the input data reflect these changes). Since the accounts only measure outcome, they do not determine whether these changes are directly caused by climate change. However, predictions of climate models can be translated into estimates of biocapacity changes. Annual fluctuation in the biocapacity of countries also indicates higher vulnerability to changing weather patterns.

A number of national government organizations have independently tested and reviewed the accounts. Some of the reviews are presented on Global Footprint Network's website at www.footprintnetwork.org/reviews. Some reviews suggested some methodological improvements. Many of them are now incorporated in the accounting template for all countries.

Unfortunately, underlying statistics do not identify their confidence intervals. This limits the ability to offer confidence intervals for national Ecological Footprint results. Sensitivity analyses can indicate estimated result ranges – but they cannot describe these ranges with statistical probability.

In order to prevent exaggeration of the overuse of the planet's regenerative capacity, the applied accounting method is constructed to be conservative. Therefore, the results of the National Footprint Accounts are most likely an *underestimate* of overshoot.

The approach to rather underestimate, rather than overestimate overshoot strengthens the argument for a significant and rapid reduction of the human economy's resource consumption in order to secure human well-being.

4. Ecological Footprint and climate change

Ecological Footprint and biocapacity results are also consistent with the 2015 Paris Agreement, which came into effect on November 4, 2016, stipulating that global temperature rise should remain well below 2°C, and possibly even below 1.5°C over pre-industrial levels.

Avoiding an increase over 2°C requires, according to IPCC reviewed climate models, less than 450 ppm CO_{2e} atmospheric concentration. Further, 450 ppm may be on the high side, particularly for Paris's postulated 2°C upper long-term limit. According to IPCC reviewed studies, there is only a 66 per cent probability that we will reach this goal (IPCC, 2014).

In 2017, the atmosphere contained 407 ppm CO_2 (and significantly higher (i.e., >450 ppm) when measured in CO_{2e}). Currently, humanity's emissions increase the CO_2 concentration by 2–3 ppm per year. In other words, humanity has less than 20 years of current emissions left to comply with Paris. Some climate assessments would even suggest that the emissions would have had to cease ten years ago to reach the Paris goal. meaning humanity should have stopped emitting ten years ago. Many conclude that humanity might well need net-negative carbon emissions to reach the Paris goal.

While the carbon assessment defines the maximum carbon we can emit while staying within the temperature goal, Ecological Footprint accounts compare the overall amount that people demand to what can be renewed. Still, both approaches come to similar conclusions, recognizing that the resource metabolism of the human economy has become too large compared to what the planet can provide continuously.

Ecological Footprint accounting complements and strengthens carbon considerations in a number of ways. First, Ecological Footprint accounts confirm Paris reduction requirements without depending on complex, dynamic, and assumption-prone climate models. With basic, widely understood scientific principles (as explained in Box 16.1), the accounts can be audited by anyone with a basic science education.

Second, the accounts support the Paris Agreement's use of net-emissions. The focus on net-emissions recognizes the fundamental link between the atmosphere and the biosphere. It is not only about carbon emissions, but also about how much of the carbon can be sequestered, by biological, technical, or other means.

Third, the focus on biocapacity becomes even more relevant once we acknowledge that fossil fuel will no longer be useable once the carbon budget is exhausted, and what will be left to power the economy is biocapacity, supplemented by energy that is generated on biologically non-productive areas, such as photovoltaics in deserts or windmills off-shore. Further, if humanity should still use fossil fuels beyond the carbon budget, the ensuing climate change would most likely reduce the planet's overall biocapacity, making it even more difficult to power the economy in the long run.

Lastly, by putting the climate challenge into the context of biocapacity, the resource security perspective becomes more obvious, possibly helping to overcome the common misperception that climate change is an inevitable "tragedy of the commons". The argument, that investing into an economy's resource security would be in that economy's self-interest, is still missing in the climate debate.

5. Ecological Footprint and Planetary Boundaries

The Ecological Footprint research is closely related to the concept of Planetary Boundaries (Rockström et al., 2009; Steffen et al., 2015). In simple terms, Ecological Footprint could be seen as an aggregate of Planetary Boundaries. With one important distinction: Planetary Boundaries are identified as maximum thresholds, the crossing of which would make humanity leave "the (Holocene's) safe operating zone" and bring about destructive, and potentially irreversible changes. In contrast Ecological Footprint measures demand against ecosystem regeneration. This boundary can be transgressed without immediate risks, if the transgression is time-limited and does not lead to irreversible depletion of the assets.

The Planetary Boundaries are set at a precautionary level below the threshold of lasting damage. The choice of the boundary depends on the degree of risk which decision-makers are willing to take on, which, in turn, is influenced by how resilient societies are to major environmental change. According to the authors, "normative judgements influence the definition and the position of planetary boundaries" (Rockström et al., 2009). In other words, the boundaries are also subject to human preferences and cannot be sharply and fully objectively defined. But they can be approximated scientifically.

Both Footprint and Planetary Boundary assessments would be even more useful if they also reflected how long a boundary can be transgressed before a threshold is crossed. Also note that the Planetary Boundaries describe the global situation; the Ecological Footprint is scale independent: it can be applied to any geographic scale.

6. Conclusion: what Ecological Footprints offer

In essence, Ecological Footprint accounting answers a very simple and fundamental question: How much of the biosphere's (or any region's) regenerative capacity does any human activity demand? Because life competes for biologically productive spaces, it is possible to add those spaces up and compare them with how much productive area is available. Further, by scaling each area proportional to its productivity, it becomes possible to calculate for each activity that requires biologically productive space, what percentage of the planet's biocapacity it occupies. Also, it becomes possible to map how much of the planet's biocapacity is located where or how much of the planet's biocapacity of the planet is located in a defined region.

While simple and transparent, the accounts also come with sophistication for more detailed assessments. More on the calculation methodology underlying Ecological Footprint accounting is available through Global Footprint Network publications, including the *Working Guidebook to the National Footprint Accounts 2016* (based on the 2016 edition) and a method paper (Borucke et al., 2013). In addition to these scientific publications, a summary of the results for the general public is presented in *Living Planet Reports*, published by WWF (the Worldwide Fund for Nature), with support from Global Footprint Network, and the Zoological Society of London (see WWF et al., 2008, 2010, 2012, 2014, 2016). The 2017 Edition of the National Footprint Accounts was launched in April, 2017, and all results that are sufficiently robust are available on an open Data Platform at http://data.footprintnetwork.org.

Each edition is accompanied by a multi-regional input-output (MRIO) analysis, which provides additional insight into the components of the overall Footprint by consumption category, more details on the geography of trade flows, and Footprint intensity per major economic sector. This MRIO analysis is based on the GTAP data set from the University of Purdue, that sheds light on 57 sectors of economies. This analysis allows to construct tables that show which consumption activities are occupying how much of the overall Ecological Footprint. Such assessments allow for more detailed assessments of components of economies.

Further, both carbon calculations and Ecological Footprint accounting make a clear case that a stable human economy requires a significant reduction in resource throughput. Ecological Footprint accounting adds to the discussion the idea that there is a biocapacity budget available to power us – only the carbon Footprint needs to go down to zero.

Yet, such reductions as identified by carbon accounts and Ecological Footprint are in stark contradiction with most policies implemented today. Recognizing this contradiction, as well as the biophysical necessity to avoid staying in overshoot in order to maintain resource availability, Global Footprint Network emphasizes the need to have reliable metrics on resource demand and availability. Therefore, it is highly unlikely that humanity, or any nation, would be better off without any Footprint results, despite the current limitations of the Footprint approach. As outlined in Appendix 16.1, currently no other resource accounts exist that can comprehensively compare human demand to planetary regeneration. This makes these accounts an important complement to efforts to provide monetary assessments of the value of natural capital (Bartelmus, Chapter 15; Hueting and de Boer, Chapter 14, this volume).

The basic assessments provided by Ecological Footprint and biocapacity accounts are critical for sustainable development, because not meeting the basic condition of living within the regenerative capacity of planet Earth makes sustainable development impossible. Yet the current Ecological Footprint accounts, which most likely underestimate human demand and exaggerate long-term biocapacity document a significant global overuse of the planet's regenerative capacity. Ignoring this equates to planning for and encouraging economic and societal failure.

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Appendix 16.1

Comparing the Footprint accounts with similar approaches (after Galli et al. 2016)

Concept	Footprint and biocapacity	Planetary Boundaries	Mass flow analysis (also called "material footprint")	Carbon Footprint	WAVES/Genuine saving	Inclusive wealth	Genuine Progress Indicator (GPI or ISEW)
Organizations	Global Footprint Network	Stockholm Resilience Centre	Wuppertal Institute	IEA/IPCC	World Bank	UN University	Herman Daly, John and Cli Cobb, Redefining Progress, others
What research question is being answered?	How much of the regenerative capacity of the biosphere is occupied by human demand? (Plus, where does demand originate, and how is the biocapacity	What are Planetary Boundaries, and for each one of them, how close is humanity to those limits?	How much mass moves through an economy?	How much CO_2 from fossil fuel is released within a country? Also by a lifestyle or activity.	How much net wealth does a country have? How does it change year to year? (focus on natural capital)	How much wealth is in a country? How does it change year to year?	What is the n income of a country, including nor market benefits, and excluding defensive expenditures?

	distributed on the planet?)						
How is this question relevant to understanding a country's (or other entity's) risk and opportunity exposure?	In the 21st century, biocapacity is increasingly a limiting factor for the human economy. It is essential to know how much you have, how much you use, and what the trends are.	Makes a scientific global case for a number of dimensions. Adds credibility to the possibility of global overshoot. May not be easily applicable at local scale. Not clear what trade-offs are among boundaries.	More mass flow is a proxy for the overall amount of resources being used.	Future climate treaties could put a limitation on this emission, through prices, or regulations. To set targets and monitor progress, metrics are needed.	Is overall wealth (measured in monetary value) building up per capita? If not, this is a risk to income generation in the future.	Is overall wealth (measured in monetary value) building up per capita? If not, this is a risk to income generation in the future.	GPI adjusts GDP for aspects that subtract from well-being, a adds those tha are missing, making the measure a more realistic assessment o what the true annual incom of a nation is.
Metric Unit	global hectares	kg/yr/kg/yr	kg/year	kg/year	$	$	$
Key websites	www.footrpint network.org Wackernagel et al. 2014	www.stockh olmresilienc e.org Rockström et al. 2009	www.wupperi nst.org www.material flows.net Fischer-Kowalski et al. 2011	www.ipcc.ch Hertwich and Peters, 2009	www.wavespartne rship.org see website for reports	inclusive wealthind ex.org see website for reports	rprogress.org ustainability_ dicators/genu e_progress_i icator.htm
Strengths	Provides the bottom-line answer to a central question: Is there enough biocapacity to maintain the metabolism of the economy?	Each one of the Planetary Boundaries can easily be communicated and are known to most	Kg easy to understand, directly links to tracked mass flows of categories. Some statistical offices now	There is a scientific effort behind carbon accounting. Public is starting to be more sensitive to	Dollars speak loudly to traditional economic analysts.	Dollars speak loudly to traditional economic analysts.	Dollars speak loudly to traditional economic analysts. GPI relates clearly to GDP, possibly the most prominent

	Area is relatively easy to understand – it is like a farm. Has been tested by 12 national governments.	publics. Can build on independent robust scientific assessments in each domain.	track mass flows.	basic climate science.			policy indicator.
Weaknesses	Many details could be improved beyond the current accounts that use 6,000 data points per country and year. The accounts, however, are constantly being refined. There is currently no direct link to financial figures, which makes it harder to communicate to finance oriented audiences. However, numbers can be interpreted for them.	Some boundaries are global (CO_2), others are local (water, nitrogen). Difficult to understand trade-offs among them. Difficult to apply at sub-planetary scale.	Mass flow accounts are at the basis of Footprint accounts. But it is less clear what question they answer. One kg of gravel has different demand on nature than one kg of wood. (Apart from weight, in what way are they ecologically equal?) How do mass flows link to supply? Which mass flows are included and which ones not, and why? While having good material statistics is fundamental, result interpretation (or how to use them to guide	CO_2 in isolation is hard to tackle since self-interest for those reducing their emission is not obvious or may be absent. Just focusing on CO_2 may detract from all other environmental pressures.	Dollars are unstable predictors of the future. Prices can fluctuate by magnitudes. They only show current human preferences in the market, not ecological necessities.	Dollars are unstable predictors of the future. Prices can fluctuate by magnitudes. They only show current human preferences in the market, not ecological necessities. Results are counterintuitive, and suggest that natural capital has extremely low value.	Dollars are unstable predictors of the future. Prices can fluctuate by magnitudes. They only show current human preferences i the market, n ecological necessities, o resource limi What is adde or subtracted from GDP to get GPI can b arbitrary, a problem whic could be overcome wit clear and widely accepted accounting standards for GPI calculations.

			policy) is not as obvious.				

Appendix 16.2

Fundamental sources and description for data used within the National Footprint Accounts

Data set	**Source**	**Description**
Production of primary agricultural products	FAO ProdSTAT	Data on physical quantities (tonnes) of primary products produced in each of the considered countries.
Production of crop-based feeds used to feed animals	Feed from general marketed crops data is directly drawn from the SUA/FBS from FAOSTAT Data on crops grown specifically for fodder is drawn directly from the FAO ProdSTAT	Data on physical quantities (tonnes) of feeds, by type of crops, available to feed livestock
Production of seeds	Data on crops used as seeds is calculated by Global Footprint Network based on data from the FAO ProdSTAT	Data on physical quantities (tonnes) of seed
Import and export of primary agricultural and livestock products	FAO TradeSTAT	Data on physical quantities (tonnes) of products imported and exported by each of the considered countries.
Livestock crop consumption	Calculated by Global Footprint Network based upon the following data sets: • FAO Production for primary Livestock • Haberl et al. (2007). Quantifying and mapping the human appropriation of net primary production in Earth's terrestrial ecosystems.	Data on crop-based feed for livestock (tonnes of dry matter per year), split into different crop categories.
Production, import, and export of primary forestry products	FAO ForeSTAT	Data on physical quantities (tonnes and m^3) of products (timber and wood fuel)[a] produced, imported, and exported by each country.

Production, import, and export of primary fishery products	FAO FishSTAT	Data on physical quantities (tonnes) of marine and inland fish species landed as well as import and export of fish commodities.
Carbon dioxide emissions by sector	International Energy Agency	Data on total amounts of CO_2 emitted by each sector of a country's economy.
Built-up/infrastructure areas	A combination of data sources is used, in the following order of preference: 1. CORINE Land Cover 2. FAO ResourceSTAT 3. Global Agro-Ecological Zones (GAEZ) Model 4. Global Land Cover (GLC) 2000 5. Global Land Use Database from the Center for Sustainability and the Global Environment (SAGE) at University of Wisconsin.	Built-up areas by infrastructure type and country. Except for data drawn from CORINE for European countries, all other data sources only provide total area values.
Cropland yields	FAO ProdSTAT	World average yield for 164 primary crop products.
National yield factors for cropland	Calculated by Global Footprint Network based on cropland yields and country-specific un-harvested percentages.	Country-specific yield factors for cropland.
Grazing land yields	Chad Monfreda (personal communication). (2008), SAGE, University of Wisconsin, Madison.	World average yield for grass production. It represents the average above-ground edible net primary production for grassland available for consumption by ruminants.
Fish yields	Calculated by Global Footprint Network based on several data including: • Sustainable catch value (Gulland, 1971) • Trophic levels of fish species (Christensen et al., 2008) • Data on discard factors, efficiency transfer, and carbon content of fish per tonne wet weight (Pauly and Christensen, 1995).	World average yields for fish species. They are based on the annual marine primary production equivalent.
Forest yields	World average forest yield calculated by Global Footprint Network based on national Net Annual Increment (NAI) of biomass. NAI data is drawn from two sources:	World average forest yield. It is based on the forests' Net Annual Increment of biomass. NAI is defined as the average annual volume over a given reference period of gross

	Temperate and Boreal Forest Resource Assessment – TBFRA (UNECE and FAO, 2000). Global Fiber Supply Model – GFSM (FAO, 1998).	increment less that of neutral losses on all trees to a minimum diameter of 0 cm (d.b.h.).
Carbon uptake land yield	Calculated by Global Footprint Network based on data on terrestrial carbon sequestration (IPCC, 2006) and the ocean sequestration percentage (IPCC, 2001). Further details can be found in Kitzes et al., (2009, p. 69).	World average carbon uptake capacity. Though different ecosystems have the capacity to sequester CO_2, carbon uptake land is currently assumed to be forest land only by the Ecological Footprint methodology.
Equivalence Factors (EQF)	Calculated by Global Footprint Network based on data on land cover and agricultural suitability. Data on agricultural suitability is obtained from Global Agro-Ecological Zones (GAEZ) (. FAO and International Institute for Applied Systems Analysis 2000). Land cover data drawn from ResourceSTAT.	EQF for crop, grazing, forest and marine land. Based upon the suitability of land as measured by the Global Agro-Ecological Zones model (FAO, 2000).

Note: [a] In Global Footprint Network's national accounts, "wood fuel" is not considered to be a derived product because fuel wood productivity is higher than timber productivity since more of a tree can be used for fuel than for timber. It is treated in a same manner as the primary products in the Footprint calculation. Therefore, it is covered under primary products in the MRIO model.

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[1] This chapter builds on Mathis Wackernagel, Gemma Cranston, Juan Carlos Morales, Alessandro Galli (2014). 'Chapter 24: Ecological Footprint Accounts: From Research Question to Application', Giles Atkinson, Simon Dietz, Eric Neumayer and Matthew Agarwala (eds.), 2014, *Handbook of Sustainable Development: second revised edition*, Edward Elgar Publishing, Cheltenham, UK.

[2] The potential of the planet's surface to provide net primary productivity.

[3] Sometimes, results are presented in terms of "number of planets". This is equivalent to showing the ratio between humanity's Footprint and the planet's biocapacity.

[4] Ecological overshoot occurs when a population's demand on an ecosystem exceeds the capacity of that ecosystem to regenerate the resources it consumes and to absorb its wastes (see also Catton, 1982).

[5] For no accounts are the units totally pure, or universally interchangeable. They are just reasonably good approximations of more or less interchangeable units. For example, one dollar to a low-income person may be worth much more than to a billionaire; yet, the

dollar is a good approximation of a comparable unit of purchasing power. Or the last cubic metre of freshwater removed from a dry area is far more damaging than the first, or the last kilogram of fish caught causes more impact on the fish stock than the first kilogram of fish. Also, depending on the species and the respective ecosystem health, the impact of consuming 1 kg of fish can vary by magnitudes. Yet it is a meaningful and scientifically robust research question to inquire: how many kilograms of fish were removed from this lake? This and all other questions based on a commensurable unit can be answered through accounting.

6 A global hectare is a common unit that encompasses the average productivity of all the biologically productive land and sea area in the world in a given year (Galli et al., 2007; Monfreda et al., 2004). Biologically productive areas include cropland, forest and fishing grounds, and do not include deserts, glaciers, and the open ocean.