Living Planet Report 2016

Technical Supplement: Ecological Footprint

Prepared by Global Footprint Network

Contents

Ecological Footprint at a glance

Living within the Earth's environmental limits requires, at minimum, global consumption patterns in balance with these limits. However, defining and measuring environmental limits is not an easy task. Furthermore, no super-indicator exists, which can both comprehensively define limits and operationalize them. Identifying minimum conditions for sustainability becomes of key importance (Lin et al., 2015a). Daly's two core sustainability principles – that a) renewable resources should not be used faster than they can be regenerated, and b) pollution should not be emitted faster than it can be assimilated – can be referred to as minimum sustainability criteria. Ecological Footprint accounting can be used to provide a first quantitative proxy assessment of these conditions (Galli et al., 2012a), by means of two metrics: *Ecological Footprint* and *biocapacity*. Annually, national Ecological Footprint and biocapacity values are calculated by Global Footprint Network for approximately 200 countries, using data over a period of 5 decades (Bastianoni et al., 2013; Kitzes et al., 2009). These results are called the National Footprint Accounts (NFAs).

The first metric - Ecological Footprint - measures the amount of biologically productive land and water area (biocapacity) required to produce the food, fibre and renewable raw materials an individual, population or activity consumes, and to absorb carbon dioxide emissions they generate, given prevailing technology and resource management. The six demand categories considered are: cropland, grazing land, fishing grounds, forest products, carbon and built-up land Footprints.

The other metric - biocapacity - measures the bioproductive areas available to provide food, fibre, and renewable raw materials as well as sequester carbon dioxide. Biocapacity is measured for five categories of bioproductive surfaces: cropland, grazing land, fishing grounds, forest land, and built-up land, which satisfy human demands in the six Footprint categories described above. Because forest land biocapacity can be used either to generate forest products to harvest or to sequester carbon, this land type satisfies two demand categories (Wackernagel et al., 2014; Mancini et al., 2016).

Ecological Footprint and biocapacity are expressed in a common hectare-equivalent unit called global hectare (gha), where 1 gha represents a biologically productive hectare with world average productivity (Galli, 2015; see also section "what is a global hectare?").

Interpreting results

What do Ecological Footprint Accounts indicate?

Ecological Footprint Accounting addresses one key question: *How much of the biosphere's regenerative capacity (or biocapacity) for natural resources and ecological services do human activities demand?* The Ecological Footprint framework is thus most useful to account for 1) the magnitude of humanity's biophysical metabolism, and 2) the competing demand such metabolism places on the Earth's ecosystems (Galli et al., 2016).

As reported in Galli et al., (2015), a country's Ecological Footprint of consumption is determined by three main factors: the average consumption of each person, how resource intensive this consumption is, and the population of the country. Conversely, a country's biocapacity is determined by two factors: the areas of biologically productive land and water available, and their biological productivity levels (Galli et al., 2012b; Niccolucci et al., 2011). A country's Ecological Footprint and biocapacity represent two sides of an ecological balance sheet: if a country's consumption of natural resources and services is greater than the capacity of its ecosystems to supply them, it creates a situation of ecological deficit in the same way that a situation of financial budget deficit occurs when spending is greater than revenue (Monfreda et al., 2004). The reasons for such deficit are threefold (Niccolucci et al., 2011):

1. A country can import the natural renewable resources it consumes but does not produce. This indicates the extent to which a country's metabolism depends on ecosystem services from outside its boundaries.
2. Through national production activities, a country can overharvest its own resources for a time (e.g., unsustainable agricultural practices, overgrazing, overfishing, or deforestation). This provides an indication of the pressures a national economy generates on its ecosystems.
3. A country can be in ecological deficit due to its carbon Footprint if it emits CO_2 in the atmosphere faster than the natural absorption rate.

Conversely, if a country's Ecological Footprint of consumption is smaller than its biocapacity, this country is running an *ecological remainder*. Such remainder is not sufficient to determine whether the country is sustainable (Galli et al., 2012a), notably because a full use of biocapacity for human consumption would leave no biocapacity for use by other species (Galli et al., 2014; Kitzes et al., 2008, 2009; Kitzes and Wackernagel, 2009). Moreover, the share of a country's consumption Ecological Footprint not met by production on its own ecosystems – its Ecological Footprint of production – reveals, in net terms, the burden that a country's demand for renewable natural resources and ecosystem services displaces on foreign ecosystems. This is useful to understand the overall demand for biocapacity of a country's consumption and how that demand may affect other countries' ecosystems (see Galli et al., 2014; 2015).

Like any measure, Ecological Footprint accounting is subject to misinterpretation. Therefore, it is important to point out that this metric does not impose goals or suggest what might be the ideal Footprint levels for countries or cities. There are no "shoulds" in Ecological Footprint accounting; it documents only "what is" and helps to identify the consequences of choices.

What is a global hectare?

A global hectare is a hectare-equivalent unit representing the capacity of a hectare of land with world-average productivity (across all croplands, grazing lands, forests and fishing grounds on the planet). More specifically, it is a measure of the inherent capacity of the biosphere to produce useful biomass that is appropriated by humans. As technology, climate, environmental conditions and management change every year, so differs the global hectare for every year. Dividing the total biocapacity of Earth by the total number of bioproductive hectares yields the value of an average productive hectare – a "global hectare". Each global hectare represents the same biological productivity – a fraction of the earth's total biocapacity.

A parallel with the unit CO_2-equivalent (CO_2eq) can further clarify the nature of this unit. The release of one ton of CO_2eq does not mean that this amount has actually been released, as there is no molecule called CO_2eq. Rather, it means that various greenhouse gases with the equivalent global warming potential of one ton of CO_2 have been released. Similarly, when a world-average resident is said to have an Ecological Footprint of 2.8 gha, it does not mean that 2.8 hectares of physical land in the world are used.

It means that the equivalent capacity of 2.8 hectares of productive land with world average productivity is needed to produce (via photosynthesis) the resources and services that such world resident demands – this biocapacity could be anywhere in the world and could be originating from an actual land area smaller or larger than 2.8 hectares.

Is the Ecological Footprint a sustainability indicator?

During the last decade, the Ecological Footprint has helped reopen the sustainability debate (e.g., Wiedmann and Barrett, 2010) by communicating the scale of humanity's overuse of Earth's natural resources and ecosystem services in simple and powerful terms. However, as a biophysical measure, Footprint accounts do not evaluate the social and economic dimensions of sustainability. Ecological Footprint should be complemented with other indicators and tools to arrive at comprehensive sustainability assessments (Galli et al., 2012a). Moreover, even within the environmental pillar of sustainability, National Footprint Accounts are not capable to quantify human environmental damage or pollution, nor do they indicate the intensity with which a biologically productive area is being used or whether current resource management practices can be sustained. Biocapacity and Ecological Footprint accounts document the supply and demand of natural resources and services based on historical datasets. Persistent or harmful environmental practices, which reduce the ability of our ecosystems to provide these natural resources and services, are reflected in biocapacity accounts only during the time period in which reduction in productivity has occurred and is recorded – not before (Goldfinger et al., 2014; Lin et al., 2015a).

Historically, human economies have increased the biocapacity of their existing environment by investing in practices such as fertilizer-use and the improvement of technology, some of which come at a high Footprint cost. The use of fossil fuels, for example, has enabled societies to improve their economic and resource situations, however, the resulting anthropogenic emission of CO_2 at rates faster than our ecosystems can sequester has led to damaging levels of CO_2 accumulation in our atmosphere. It is very difficult to determine the balance between additional biocapacity gained relative to the additional Ecological Footprint cost.

Nevertheless, current Footprint accounts tell us that humanity's annual demand has overshot the earth's ability to supply natural resources and services and can be interpreted as a proxy for the minimum magnitude of human demand on nature. These accounts also show that the impact of current policies to promote sustainable use of resources is insufficient to address resource limitations and trends highlighted by Ecological Footprint accounts (Goldfinger et al., 2014; Lin et al., 2015b).

How does the Ecological Footprint relate to biodiversity?

Ecological Footprints accounts do not represent the resource needs to maintain biodiversity but can provide insights into the level of pressure from human metabolism on ecosystems and the biodiversity that inhabit them.

Direct anthropogenic threats to biodiversity include habitat loss or damage, resource overexploitation, pollution, invasive species and climate change. These direct threats are the result of more distant, indirect drivers of biodiversity loss arising from consumption of resources and the generation of waste. The ultimate drivers of threats to biodiversity are human demands for food, fibers and timber, water, energy and land area on which to build infrastructure. As the human population and global economy grow, so do the pressures on biodiversity (Galli et al., 2014).

An increase in the Ecological Footprint represents an increase in humanity's demand on the biosphere's regenerative capacity, which in turn equates to increased pressure on ecosystems and biodiversity and greater risks of biodiversity loss. If humanity's Ecological Footprint exceeds the world's biocapacity, then a minimum condition for sustainable consumption is not being met. This means that ecosystem stocks are being depleted, and/or CO_2 is accumulating in the atmosphere and oceans. When this is the case, competition for biological resources and quantitative or qualitative reductions in area for biodiversity are likely to result in pressure on species populations and, ultimately, biodiversity loss. A reduction in the Ecological Footprint, and especially the elimination of overshoot, would indicate reduced pressure on the world's biological resources and a lower risk of biodiversity loss.

Applied at the national level, the Ecological Footprint also captures indirect pressure on biodiversity. Through international trade, consumption of resources in one country can be associated with the use of the ecosystems of another country. Footprint accounts identify which countries are driving global, human-induced pressure and in which countries such displacement of human-induced pressures is taking place (Galli et al., 2014); they can help identify policy responses to reduce the ultimate drivers of threats to biodiversity and the consequent risk of losing habitats (Lazarus et al., 2015).

The Ecological Footprint is utilized by the Convention on Biological Diversity for assessing progress towards Aichi Biodiversity Target 4 of the Strategic Plan for Biodiversity 2011-2020: *By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.*

How can the EF be projected to 2020 if it is a descriptive rather than a predictive indicator?

Ecological Footprint accounting is a descriptive methodology because it uses historical data inputs (harvest of natural resources and emissions of waste CO_2) and quantifies the productive land required to produce these natural resources and assimilate waste emissions. By necessity, projections must make assumptions about future conditions of the environment and the economy. The simplest short-term projection is a business as usual scenario, where we assume that humanity's consumption will continue to grow as it has in the past. The projected Ecological Footprint describes a likely future if humanity does not undergo considerable shifts in technology, infrastructure, and behaviour, in order to support less resource-intensive production and lifestyles (for further information please refer to Moore et al., 2012).

Calculating the Ecological Footprint

Improvements made in the NFA 2016 edition

A total of 23 improvements were implemented in the NFA 2016 edition. These improvements aimed at increasing the robustness and scientific rigor of the Ecological Footprint accounts from previous editions. The improvements include methodological changes, and improved conversion factors and data parameters. This has allowed for more accurate and robust calculations.

One of the most significant data parameters of the accounts is the estimate of how much carbon can be sequestered by one global hectare. With improved data, this was recalculated. After a two-year research process, Global Footprint Network concluded (Mancini et al., 2016; see also section below) that the sequestration rate is about 25% lower than what was previously estimated. This increases the carbon Footprint component of all countries. The other 22 improvements made to the Ecological Footprint accounts had relatively small impact on NFA results for most countries; detailed descriptions of each of these 22 improvements will be published by research scientists from Global Footprint Network in a forthcoming updated method paper (Lin et al, forthcoming).

Results from the NFA 2016 edition should not be compared to previous editions because the above mentioned improvements are applied to recalculate the entire time series. So, actual changes in humans' demand on the planet's biocapacity over the last few years can be seen by looking at time series data from the NFA 2016 edition. Conversely, the effect of the improved methodology can be assessed by comparing results from the same year across different editions. For example, to see differences between NFA 2015 and NFA 2016, one could compare the results for 2010 in each.

A focus on the Carbon component

There are many different ways of categorizing the release of carbon compounds into the atmosphere and their impacts on our planet. The term carbon Footprint in relation to the Ecological Footprint method refers to the equivalent amount of forest land required to sequester the anthropogenic emissions of carbon dioxide not absorbed by oceans (see Borucke et al., 2013; Mancini et al., 2016). This is different from the use of the same term in the climate debate, where it usually refers to emissions of a number of different greenhouse gases, rather than just solely CO_2, and expresses them as quantities of CO_2 equivalent, which are often called "CO_2-e emissions" or "GHG emissions" (see Galli et al., 2012a; Wiedmann and Minx, 2008).

Within the Ecological Footprint methodology, anthropogenic CO_2 emissions are tracked in three categories: emissions from fossil fuel combustion, emissions from non-fossil fuel sources (gas flaring, anthropogenic forest fires and cement production), and emissions from international marine and aviation transport (bunker fuel). While the carbon cycle involves the natural sequestration and emission of CO_2 between the terrestrial ecosystems, the ocean, and the atmosphere, increasing anthropogenic emissions continue to contribute to rising atmospheric CO_2 concentrations. The carbon Footprint thus accounts for the bioproductive area of forest needed to absorb the portion of the atmospheric CO_2 emitted by humans after deducting the portion that is absorbed by oceans and sequestered through other measures (e.g., carbon capture and storage). No gas other than carbon dioxide is accounted for by the Ecological Footprint methodology (see Galli et al., 2012a; Kitzes et al., 2009; Mancini et al., 2016).

The carbon Footprint includes CO_2 emissions within a country, as well as "embodied CO_2 emissions" or "embodied carbon Footprint" of imports and exports. Embodied carbon is based on the energy used during a product's entire life cycle in order to manufacture, transport and use the product. This concept is used in relation to trade as a way to attribute the demand for CO_2 emissions to final users.

A key parameter in calculating the carbon component of the Ecological Footprint is the Average Forest Carbon Sequestration (AFCS). This parameter's calculation has been recently revised to capture different rates of carbon sequestration depending on the degree of human management of forests, the type and age of forests and to include the emissions related to forest wildfires, soil and harvested wood (see Mancini et al., 2016). In summary, carbon emissions related to forest wildfires and soil, as well as harvested wood products have been included for the first time in this update of the AFCS calculation. Thus, AFCS was obtained by accounting for:

- sequestration through net dry matter accumulation in above ground (i.e. all the above ground, visible surfaces of the trees: trunk, branches and leaves) and below ground (i.e. roots) biomass; and carbon embedded in harvested wood products.
- emission through dry matter lost in wildfires (as subtraction from the biomass growth); and soil respiration (thus as loss of carbon from the ecosystem).

The new AFCS value represents a measure of forests' NEP (Net Ecosystem Production) rather than NPP (Net Primary Production) as in previous calculations (Mancini et al., 2016). This resulted in an AFCS value of 0.73 t C ha^{-1} yr^{-1}. Replacing the previously used AFCS value (0.97 t C $ha^{-1}yr^{-1}$) with the value calculated using the recent findings of the AFCS study (0.73 t C $ha^{-1}yr^{-1}$) in the calculation of the NFA 2016 edition, caused the carbon Footprint and the total Ecological Footprint of the World to increase by 15% and 8%, respectively in the year 2012, everything else held constant.

Due to this methodological change, humanity's Ecological Footprint is 1.6 planets and its carbon component's share approximately 60%, in the latest year of the current NFA 2016 edition.

A focus on the fishing grounds component

The fishing grounds Footprint and biocapacity are based on primary production, the ability of aquatic primary producers, such as algae or other autotrophs, to produce biomass through photosynthesis. Primary production forms the base of the food chain: fishes at higher trophic levels eat fishes at lower levels and these, in turn, eat plankton, which is generated out of photosynthesis.

The Footprint methodology is based on the assumption that it is possible to calculate how much plankton is produced every year by continental shelf areas through photosynthesis as well as how much of this plankton is needed to grow fishes (or "embedded" into each fish) and that if the demand for embedded plankton is more than the plankton supply, the photosynthetic capacity of the biosphere in this ecosystem type (i.e., fishing grounds) is being overused.

The fishing grounds Footprint calculation thus begins with species-level data on national harvests, and calculates the primary production requirement (PPR) to sustain the fish species harvested by humans, following the work of Pauly and Christensen (1995). This calculation takes into account the carbon content of fish biomass, discard rate of bycatch, the transfer efficiency of biomass between trophic levels, and the trophic levels. For a technical description, please see Borucke et al. (2013) and Lazarus et al. (2014). The PPR used to calculate the fishing grounds Footprint can then be compared to the biocapacity, which is calculated from the available primary production within the productive aquatic areas, marine and inland waters, of a country. The accounts provide an indication of harvest and regeneration at the ecosystem level based on the trophic level of harvested species, but do not provide an indication on the state of specific fisheries. In other words, Ecological Footprint and biocapacity measure annual flow of resources rather than resources' stock and their variations.

In previous editions of the National Footprint Accounts (NFAs), trade of fish commodities provided estimates of Footprint embedded in traded commodities by calculating the trophic level of each commodity. Because of poor species resolution associated with commodities, this methodology resulted in major interannual variations in the Footprint of trade. In the current NFA 2016 edition, the methodology for calculating the Footprint of traded fish commodities was improved to calculate the Footprint of imported fish products based on the average trophic level of world harvests, and calculate the Footprint of exported fish commodities based on the average trophic level of each country's harvest. This change significantly reduced data spikes and increased the precision of Ecological Footprint results.

From NFA to CLUM

National Footprint Accounts are summarized by six major Footprint (or demand) categories: cropland, grazing land, fishing grounds, forest products, carbon and built-up land Footprint. Using the NFA results as input data to a Footprint-extended Multi-Regional Input-Output (MRIO) model in the MRIO-Footprint Accounts, we can track the flow of Ecological Footprint through the entire global economy as represented by 57 economic sectors in each of 140 tracked countries and/or regions. The MRIO model used to extend Footprint results is currently GTAP-9 (Narayanan et al., 2012); additional details on how such Footprint extension of a MRIO model is performed can be found in Ewing et al., (2012) and Weinzettel et al., (2014). The final consumption of Ecological Footprint in the economic sectors can then be aggregated into five main household consumption categories - food, housing, transportation, goods, and services - as well as two additional categories (government and gross fixed capital formation), to create the consumption land use matrix (CLUM) (see Figure 1).

Figure 1:
A sample Consumption Land Use Matrix

Gha person $^{-1}$		Crop Land	Grazing Land	Forest Land	Fishing Grounds	Build-up Land	Carbon	Total
Household	Food							
	Housing							
	Transportation							
	Goods							
	Services							

The Food category refers to the Ecological Footprint necessary to provide final consumers with food products and beverages, such as the cropland Footprint needed to produce wheat, the grazing land needed to produce meat, the fishing ground needed to produce fish. It also includes the carbon Footprint from CO_2 released during the food production process and the built-up land Footprint occupied by food industries. Housing includes rental housing, maintenance and repair of housing, and utilities associated with housing. Personal transportation includes the purchase and operation of vehicles, and transportation services. Goods include a wide variety of physical goods such as clothing, textiles, appliances, electronics, and tobacco products. Services includes a number of sectors including medical services, communications services, accommodation services, personal care, education, insurance, and financial services.

A country's CLUM allows users to track how the Ecological Footprint is distributed across the five consumption components – food, housing, transportation, goods, and services – and could help prioritizing Footprint reduction interventions. By looking across each row, we see that household consumption activities, such as food, often require multiple land appropriations and a carbon Footprint component.

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