Ch2. Metrics: Ecological footprint and biocapacity
Part 1: Introduction

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PART I: Discussion

1. What do you understand by **ecological footprint**? and by **biocapacity**?

2. Which **variables** should be used to measure ecological footprint? and biocapacity?

- Should we include **fisheries**? **crop lands**? food **imports**(**exports**)?
- Should we include **carbon emissions**?

Chapter structure

1. **Define** the concepts ecological footprint and biocapacity

2. Present the **methodology** to work out the ecological footprint and the biocapacity

3. Study the **historical trends** of the ecological footprint and the biocapacity

The main text that we use in this chapter is Lin et al. (2019).

Definition 1. Ecological footprint

Ecological footprint provides an **integrated**, **multiscale** approach to

- Tracking the **use** (and overuse) of **natural resources**
- Study consequent **impacts** on ecosystems and biodiversity

How much of the planet's (or a region's) regenerative capacity does a defined activity require from nature? Understanding activity in a **broad sense**:

- The entire consumption metabolism of **humanity**
- The consumption of a given population (such as a **city**)
- A **production process**
- Something as small and discreet as producing **1 kilogram of wheat spaghetti**

Definition 2. Ecological footprint

The **Ecological Footprint** is derived by tracking how much biologically productive area it takes to provide for all the competing demands of people

These demands **include** space for food growing, fiber production, timber regeneration, absorption of carbon dioxide emissions from fossil fuel burning, and accommodating built infrastructure

A country's consumption is calculated by adding **imports** to and subtracting **exports** from its national production.

All commodities carry with them an embedded amount of bioproductive land and sea area necessary to produce them and sequester the associated waste → International trade flows can thus be seen as flows of embedded Ecological Footprint

Definition. Biocapacity

Biocapacity is measured by calculating the amount of **biologically productive land and sea area** available to provide the resources a population consumes and to absorb its wastes, given current technology and management practices

To make biocapacity comparable across space and time, **areas are adjusted proportionally to their biological productivity** $\rightarrow$ These adjusted areas are expressed in **"global hectares"**

Countries **differ in the productivity of their ecosystems**, and this is reflected in the Accounts.

Ecological footprint vs. biocapacity

A country has an **ecological reserve** if its footprint is smaller than its biocapacity; otherwise it is operating with an **ecological deficit**

Over 85% of the world population lives in countries with an ecological deficit

The **world's ecological deficit** is referred to as **global ecological overshoot**

> Earth Overshoot Day.
>
> Earth Overshoot Day marks the date when humanity has exhausted nature's budget for the year
>
> For more information about the Earth Overshoot Day visit: Earth Overshoot Day (Global Footprint Network link).

Footprint and carbon emissions calculators

Footprint calculators:

There exist different online calculators to work out your personal footprint. To work out your footprint, and to know more about the methodology that they use to work out that footprint, you can visit:

- Global Footprint Network calculator
- WWF calculator

Carbon calculators:

To work out your carbon emissions and to know more about projects to reduce carbon emissions visit: Carbon Footprint calculator.

To work out your **flight** carbon emissions visit: ICAO Carbon Emissions Calculator.

PART II. Presentation structure

1. **Video** to frame the methodology and the analysis
2. **Footprint** definition and components
3. **Biocapacity** definition and components
4. **Yield factors** (auxiliary instrument used to work out Footprint and Biocapacity)
5. **Equivalence factors** (auxiliary instrument used to work out Footprint and Biocapacity)

Video to frame the methodology

To frame the **methodology** (part 2), and the **analysis** (part 3), we start the lecture watching a video that summarizes the main aspects of the National Footprint Accounts (NFA): **National Footprint Accounts – Ecological Balance Sheets for 180+ Countries** (link).

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Ecological Footprint of consumption

The **Ecological Footprint of consumption** is calculated as:

$$EF_{consumption} = EF_P + EF_I - EF_E$$

where:

- EF_P is the is the Ecological Footprint of production
- EF_I is the Ecological Footprint of imports
- EF_E is the Ecological Footprint of exports

The Footprint of consumption of individual products or wastes are summed to obtain an **aggregate Footprint of consumption** for **a given land use category**

Adding together the Footprints of all of the major land use categories gives the Footprint of a country, or of the world

$EF_{production}$

Human-harvest or waste-production flow, imports, and exports are quantified in mass per time and translated into global hectares through the following equation:

$$EF_{production} = \frac{P}{Y_N} \cdot YF \cdot EQF \cdot IYF \tag{1}$$

where:

- $EF_{production}$ = Ecological Footprint associated with a product or waste, (gha)
- P = Amount of product extracted or waste generated, (t, yr^{-1})
- YN = National-average yield for product extraction or waste absorption, (t, nha^{-1}, yr^{-1})
- YF = Yield factor of a given land use type within a country, (wha, nha^{-1})
- EQF = Equivalence factor for given land use type, (gha, wha^{-1})
- IYF= Intertemporal Yield factor of a given land use type, no units.

$EF_{production}$

Notation:

- t: Metric tones
- nha: National-average hectares
- wha: World-average hectares
- gha: Global hectares

For each country, the Ecological Footprint of production (EF_P) of a single footprint category is calculated by **summing all products of that footprint category** (such as rice, wheat, corn for cropland). The total EF_P of a country is the sum of the Ecological Footprint of all product categories combined.

$EF_{production}$

Note that in Equation 1, because the yield factor is defined as national divided by world yield, the national-average yields cancel out. Thus, the basic **Ecological Footprint formula** can be expressed more succinctly in the following form:

$$EF_{production} = \frac{P}{Y_W} \cdot EQF \cdot IYF \tag{2}$$

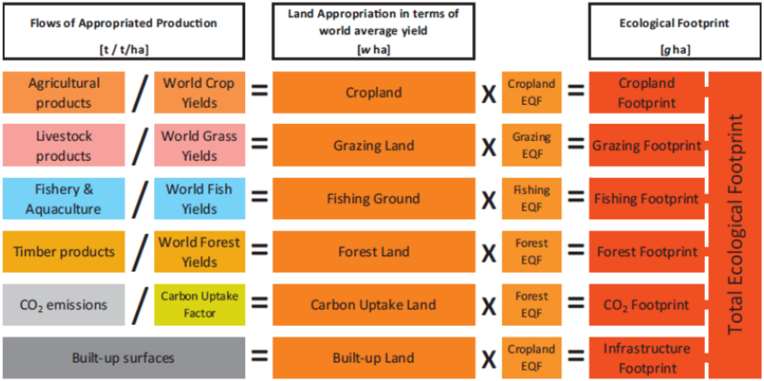
where:

- Y_W = World-average yield for product extraction or waste absorption, (t, wha^{-1}, yr^{-1})

Footprint: Components

Overview of the components and calculations that comprise the National Footprint Account

Figure: Footprint methodology



Footprint: Carbon

The carbon Footprint represents the area of forest land required to **sequester anthropogenic carbon dioxide emissions**

The total amount of carbon dioxide allocated to each country is converted into global hectares based on the **Footprint intensity of carbon.** This conversion factor is derived from the following:

- The yield of the productive land that is required to absorb the carbon dioxide emissions
- The amount of carbon absorbed by oceans
- An equivalence factor for carbon as a land type
- An adjustment factor for temporal changes in yield from the forest

Footprint: Carbon

The International Energy Agency (IEA) tracks carbon dioxide emissions from fossil **fuel combustion across 45 different economic sectors**

The IEA also publishes the total world emissions in **international transport** in the form of International Aviation bunker fuel and International Marine bunker fuels which are aggregated to “international transport emissions”

These emissions are allocated to countries according to their respective **domestic fossil fuel combustion** by the proportion of national to world imports

Emissions from **cement** are attributed to the producing country

Footprint: Cropland

The cropland Footprint reflects the amount of land necessary to grow **all crops consumed by humans and livestock**

This includes agricultural products, market animal feed, and cropped grasses used as livestock feed.

Cropland yields are calculated for each crop type by dividing the amount of crop produced by the amount of area harvested

This differs from other land use types in that yields for cropland reflect an actual harvest yield, whereas other yields are calculated based on regeneration rates

Footprint: Cropland

Harvest yields and regeneration rates for crops are equal by definition, as humans manage all growth on cropland for harvest

The National Footprint Account (NFA) 2019 workbook tracks the production of **177 categories of agricultural products**

The list of products, including both names and codes, has been generated from a complete list of all agricultural goods included in the **UN's FAOSTAT ProdSTAT database**

Footprint: Grazing Land

The grazing land Footprint assesses **demand for grazing land to feed livestock** and the **embodied demand for grazing land in traded goods**

The calculations estimate the **total feed requirements of all livestock produced** and the percentage of livestock energy requirements derived from concentrate feeds, forage crops, and crop residues

The difference between total feed requirement and total cropped feed supply is taken to equal the demand for grazing land

Footprint: Grazing Land

The grazing land section of NFA 2019 relies on the methodology and data proposed by Haberl et al. (2007) for calculating **human appropriation of net primary production (NPP)**

The calculation starts with the **number of livestock in a country and their feed requirements**

These feed requirements are partially filled through **market feed** (crops grown specifically to be fed to animals), **residues** (crop scraps that can be fed to livestock but not to humans), and **cropped grasses** (grasses that are grown on cropland and cut specifically to be fed to livestock)

Once the feed demand satisfied by the above sources has been accounted for, the **remaining amount of feed required is assumed to be provided by grazing land**

The amount of grazing land required is based on dividing the grass feed required by the average grass yield of rangeland

Footprint: Fishing Grounds

The Fishing Grounds Footprint represents the demands of fisheries on aquatic ecosystems as the **equivalent surface area required to sustainably support a country's catch**

The Fishing Grounds Footprint is calculated by dividing the amount of primary production consumed by an aquatic specie over its lifetime by an estimate of the harvestable primary production per hectare of marine area

This **harvestable primary production** is based on a global estimate of the sustainable catch of several aquatic species (Pauly and Christensen, 1995)

These sustainable catch figures are converted into **primary production equivalents**, and **divided by the total area of continental shelf**

This same calculation is currently used for **inland fish** as well

Footprint: Fishing Grounds

NFA 2019 tracks the production of **1941 marine and freshwater species**, including fish, invertebrates, mammals, and aquatic plants. The complete list of species corresponds to all species tracked in FishSTAT (FAO FishSTAT Fisheries Statistical Database)

Note 1:

Calculations of the yield for fish are extremely sensitive to the estimated **trophic level of the species**

These estimates are drawn from average values from Froese and Pauly (2016), many of which have large standard errors

The **uncertainty in the fisheries yields** for individual species is thus large compared to other products in NFA 2019

Footprint: Fishing Grounds

Note 2:

A **discard rate** is used to scale the yield of each species downward to reflect the discarded primary production related to their harvest

This discard rate is currently assumed to be **constant** across all species

Future research is looking into ways to incorporate **species** and **geographic variability**, based on new data available through SeaAroundUs

For more information about **fisheries** visit: Sea Around Us webpage (link).

Footprint: Fishing Grounds

<u>Note 3:</u>

The Footprint of production of wild fish species uses data that track the **total catch landed within a country**, rather than of the **fish caught within the waters of that country**

This **differs from the definition of Footprint of production for the other land use types**, where the Footprint of production refers to all products extracted from land physically located within the country

The Footprint of production calculated for fishing grounds thus **cannot be compared** to the biocapacity of fishing grounds for a specific country to determine whether that country's own waters are, according to world average, **over-fished**

Footprint: Forest Products

The forest products Footprint of production is comprised of **two broad types of primary product**: wood used for fuel; and timber and pulp used as a raw material to produce derived wood products

The forest products Footprint represents the **area of world average forest land needed to supply wood for fuel, construction, and paper**

To **calculate** the Footprint of forest products, timber harvests are compared against the net annual growth rates of the world's forests

The **complete list of products** is generated from a list of all forest products included in the UN's FAOSTAT ForeSTAT database

Footprint: Built-up land

The built-up land Footprint represents **bioproductive land that has been physically occupied by human activities**

The calculations assume that **infrastructure area covers former cropland**, and apply the yield and equivalence factors for cropland to the calculation of the Footprint

<u>Note 1:</u>

Since low-resolution satellite images are not able to capture dispersed infrastructure such as roads and houses, estimates of infrastructure areas have **high levels of uncertainty**

Footprint: Built-up land

Note 2:

Based on the fact that human settlements historically developed and congregated on the **most agriculturally fertile land**, infrastructure areas are assumed to occupy former cropland and yield and **equivalence factors** for cropland are thus used in the Footprint calculation

This assumption will **overestimate** both the Footprint and biocapacity of infrastructure areas located on areas of formerly low productivity

Footprint: Built-up land

Note 3:

The methodology **does not track imports and exports of built-up land**, although built-up land is embodied in goods that are traded internationally (e.g., the physical area of a factory producing a given product for export) and thus should be counted as an export of Footprint embodied in that product

This omission likely causes an **overestimate** of the built-up Footprint of exporting countries, and an underestimate of the built-up Footprint of importing countries

Definition. Biocapacity

Biocapacity is measured by calculating the amount of **biologically productive land and sea area** available to provide the resources a population consumes and to absorb its wastes, given current technology and management practices

To make biocapacity comparable across space and time, **areas are adjusted proportionally to their biological productivity** $\rightarrow$ These adjusted areas are expressed in **"global hectares"**

Countries **differ in the productivity of their ecosystems**, and this is reflected in the Accounts.

Biocapacity. Equation

Biocapacity is calculated at the national level for each biocapacity land-use category by using the following formula:

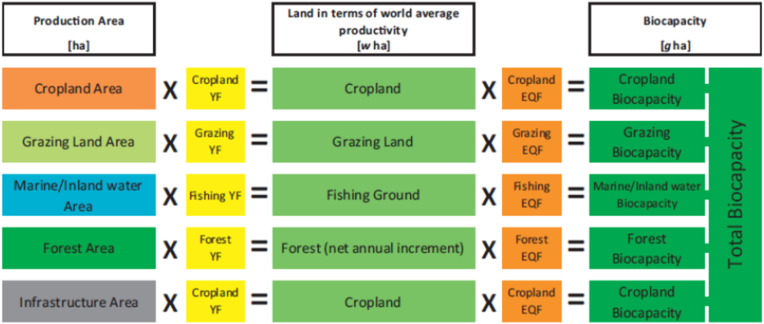
$$BC = A_n \cdot YF \cdot IYF \cdot EQF \tag{3}$$

where:

- BC= biocapacity of a given land use type, (*gha*)
- A = Area of a given land use type within a country, (*nha*)
- YF = Yield factor of a given land use type within a country,(wha, nha^{-1})
- IYF = Intertemporal Yield factor of a given land use type for that year, no units
- EQF = Equivalence factor for given land use type, (gha, wha^{-1})

Biocapacity. Components

Figure: Biocapacity methodology



Biocapacity. Notes

There is **no biocapacity figure for carbon uptake**

All other land use types have a corresponding biocapacity calculation

Biocapacity for cropland is equal to the cropland Footprint of production because the yields are defined by human use.

Yield Factors

Yield factors reflect the relative **productivity of national and world average hectares of a given land use type**

Each country, in each year, has a yield factor for each land use type

Yield Factors

For land use types for which there are data on the average growth for primary production, yield factors are calculated using Equation 4 (Yield Factors Simple Calculation)

This equation applies to **grazing land**, **fishing grounds**, and **forest**

$$YF_N^L = \frac{Y_N^L}{Y_W^L} \tag{4}$$

where:

- $YF_N^L =$ Yield factor for a given country and land use type, (wha, nha^{-1})
- Y_N^L = Yield for a given country and land use type, (t, nha^{-1})
- $Y_W^L =$ World-average yield for a given land use type, (t, wha^{-1})

Yield Factors

Cropland produces more than one primary product. For this land use type, equation 5 (**Yield Factors Extended Calculation**) is used

$$
\begin{aligned}
YF_N^L &= \frac{\sum A_W}{\sum A_N}, \text{ where} \\
A_N &= \frac{P_N}{Y_N}, \text{ and} \\
A_W &= \frac{P_W}{Y_W}
\end{aligned}
\tag{5}
$$

where:

- $YF_N^L =$Yield factor for a given country and land use type, (wha, nha^{-1})
- $A_N =$ Area harvested for a given quantity of product in a given country, (nha^{-1})
- $A_W =$ Area that would be required to produce a given quantity of product using world average land, (wha^{-1})
- $P_N =$ Amount of given product extracted or waste generated in a country, (t, yr^{-1})
- $Y_N =$ National yield for product extraction, (t, nha^{-1}, yr^{-1})
- $Y_W =$ World-average yield for product extraction, (t, wha^{-1}, yr^{-1})

Equivalence Factors

Equivalence factors reflect the **relative productivity** of world average hectares of different land use types

Equivalence factors are the **same for all countries**, and change slightly from year to year

Equivalence factors are calculated using suitability indexes from the **Global Agro-Ecological Zones (GAEZ) model**

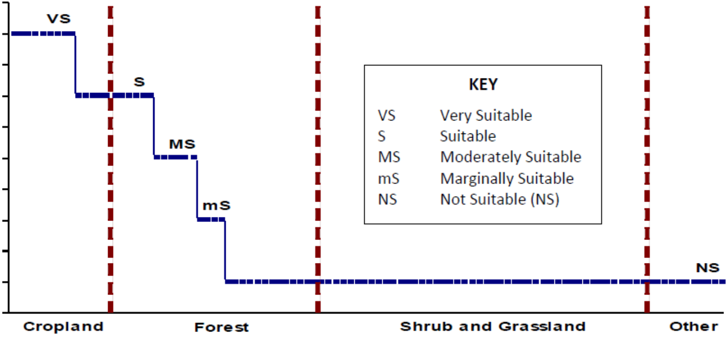
The GAEZ model divides all land globally into **five categories**, each of which is assigned a suitability score:

- Very Suitable (VS): 0.9
- Suitable (S): 0.7
- Moderately Suitable (MS): 0.5
- Marginally Suitable (mS): 0.3 ìtem Not Suitable (NS): 0.1

For more information about the Global Agro-Ecological Zones (GAEZ) model visit: GAEZ model webpage (link).

Equivalence Factors

Figure: Equivalence factors



Equivalence Factors

The equivalence factor calculation assumes that the **most productive land is put to its most productive use**

The calculations assume that the most suitable land available will be planted to **cropland**, the next most suitable land will be under **forest**, and the least suitable land will be **grazing area**

The equivalence factor is calculated as the ratio of the average suitability index for a given land use type divided by the average suitability index for all land use types.

Equivalence Factors

The equivalence factor for **built up area** is set equal to the equivalence factor for cropland, reflecting the assumption that built up areas occupy former cropland.

The equivalence factor for **marine area** is calculated such that a single global hectare of pasture will produce an amount of calories of beef equal to the amount of calories of salmon that can be produced on a single global hectare of marine area

The equivalence factor for **inland water** is set equal to the equivalence factor for marine area

Summary

1. **Video** to frame the methodology and the analysis
2. **Footprint** definition and components
3. **Biocapacity** definition and components
4. **Yield factors** (auxiliary instrument used to work out Footprint and Biocapacity)
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PART III: Global trends: Aggregate analysis

Humanity's total **Ecological Footprint** has been increasing steadily at an average of 2.1 percent per year (SD = 1.9) since 1961, nearly tripling from 7.0 billion gha in 1961 to 20.6 billion gha in 2014

The increase in Ecological Footprint has been **outpacing biocapacity** increases, which have increased at an average of 0.5 percent per year (SD = 0.7), from 9.6 billion gha in 1961 to 12.2 billion gha in 2014

Together, these results indicate that Earth's **ecological overshoot** began in the 1970s

Global trends: Per capita analysis

During the same period, **per capita Ecological Footprint** increased by 24 percent (2.29 to 2.84 gha per person), while **per capita biocapacity** decreased by 46 percent (3.13 to 1.68 gha per person)

The increase in total biocapacity and decrease in per capita biocapacity are indicative of a **growing global population**

More recently, the world **Ecological Footprint per person** decreased by 1.1 percent between 2010 and 2014, while **biocapacity per person** decreased by 2.4 percent over the same time period

In other words, although our individual share of the world's biocapacity is decreasing, we are also reducing our individual demand on nature.

Global trends: Components

The **carbon footprint** is the fastest growing Footprint component; in 2014, it comprised 60 percent of the world's total Ecological Footprint

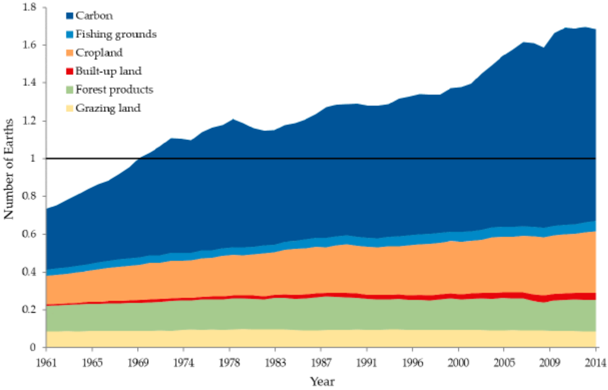
This is a significant increase from the carbon Footprint in 1961, which contributed to 44 percent of the world's Ecological Footprint, or 150 years ago, when it was less than one percent of what it is today

Cropland footprint was the next largest contributor to the world's Ecological Footprint in 2014, at 19.4 percent

Followed by **forest-product** (9.8 percent), **grazing-land** (5.1 percent), **fishing-ground** (3.3 percent), and **built-up-land** (2.3 percent)

Global trends

Figure: Footprint global trends



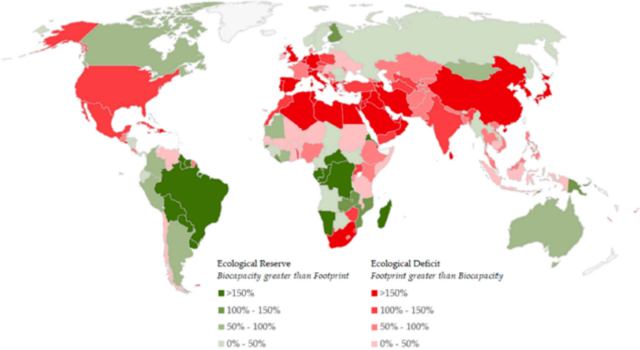
Geographical distribution

Across **individual countries**, results show that most countries run a biocapacity deficit, where they have larger Ecological Footprints than biocapacity

Countries that continue to have **biocapacity reserves** (where the biocapacity within a country's borders is greater than the Ecological Footprint of that country) tend to be located in forested regions, such as the tropics and boreal latitudes.

Geographical distribution

Figure: Ecological deficit and reserves



For more information about footprint global trends and footprint geographical distribution visit Global Footprint Network

Sustainable development trends

National progress towards sustainable development can be assessed by comparing the footprint and biocapacity results to the United Nations' **Human Development Index (HDI)**, which aggregates education, longevity, and income into a single metric

The United Nations Development Program (UNDP) defines an **HDI score of 0.7 as the threshold for high development**

The **biocapacity available on the planet is calculated as 1.7 gha per person**

Combining these two thresholds gives clear minimum conditions for globally sustainable human development.

Sustainable development trends

Countries in the light-blue section of the lower right-hand box (figure in the next slide) exhibit high levels of development with globally replicable resource demand

As of 2014, only **two countries fit these criteria**: Sri Lanka and the Dominican Republic

On average, the world is **moving closer to the Global Sustainable Development Quadrant**: HDI has increased consistently since the metric was developed in 1990, from 0.55 in 1990 to 0.69 in 2014 (weighted by the population of each country)

In addition, the **world's Ecological Footprint per person decreased from slightly** from 2013 to 2014

However, the current world Ecological Footprint of 2.8 gha per person remains far above the 1.7 gha of biocapacity available to each person.

Sustainable development trends

Figure: Sustainable development