



# Quantification of sustainability

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## Measuring resource flows

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University and other Uzbek and Central Asian universities

**Part 1**  
**Challenges and Principal Approaches**

UN 2015



# SUSTAINABLE DEVELOPMENT GOALS

**1** NO POVERTY

An icon representing a family of four people: a man, a woman, and two children.

**2** ZERO HUNGER

An icon of a white bowl with three wavy lines above it, representing steam or food.

**3** GOOD HEALTH AND WELL-BEING

An icon showing a white heartbeat line with a heart symbol at the end.

**4** QUALITY EDUCATION

An icon of an open book with a pencil resting on it.

**5** GENDER EQUALITY

An icon of a female symbol with an equals sign inside a circle.

**6** CLEAN WATER AND SANITATION

An icon of a water tap with a single drop of water falling from it.

**7** AFFORDABLE AND CLEAN ENERGY

An icon of a sun with a power button symbol in the center.

**8** DECENT WORK AND ECONOMIC GROWTH

An icon of a bar chart with an upward-pointing arrow.

**9** INDUSTRY, INNOVATION AND INFRASTRUCTURE

An icon of three stacked cubes.

**10** REDUCED INEQUALITIES

An icon of an equals sign inside a circle.

**11** SUSTAINABLE CITIES AND COMMUNITIES

An icon of several city buildings of varying heights.

**12** RESPONSIBLE CONSUMPTION AND PRODUCTION

An icon of an infinity symbol.

**13** CLIMATE ACTION

An icon of an eye with a globe as the pupil.

**14** LIFE BELOW WATER

An icon of a fish swimming in waves.

**15** LIFE ON LAND

An icon of a tree with birds flying around it.

**16** PEACE, JUSTICE AND STRONG INSTITUTIONS

An icon of a dove holding an olive branch and a gavel.

**17** PARTNERSHIPS FOR THE GOALS

An icon of three interlocking circles.

The United Nations logo is at the top.  
**SUSTAINABLE DEVELOPMENT GOALS**

# **Not only Climate – ”New” Global Threats**

**UN Report May 2019: Nature’s Dangerous Decline  
‘Unprecedented’; Species Extinction Rates  
‘Accelerating’**

**Current global response insufficient; Transformative changes’  
needed to restore and protect nature; Opposition from vested  
interests can be overcome for public good; Most comprehensive  
assessment of its kind; 1,000,000 species threatened with extinction**

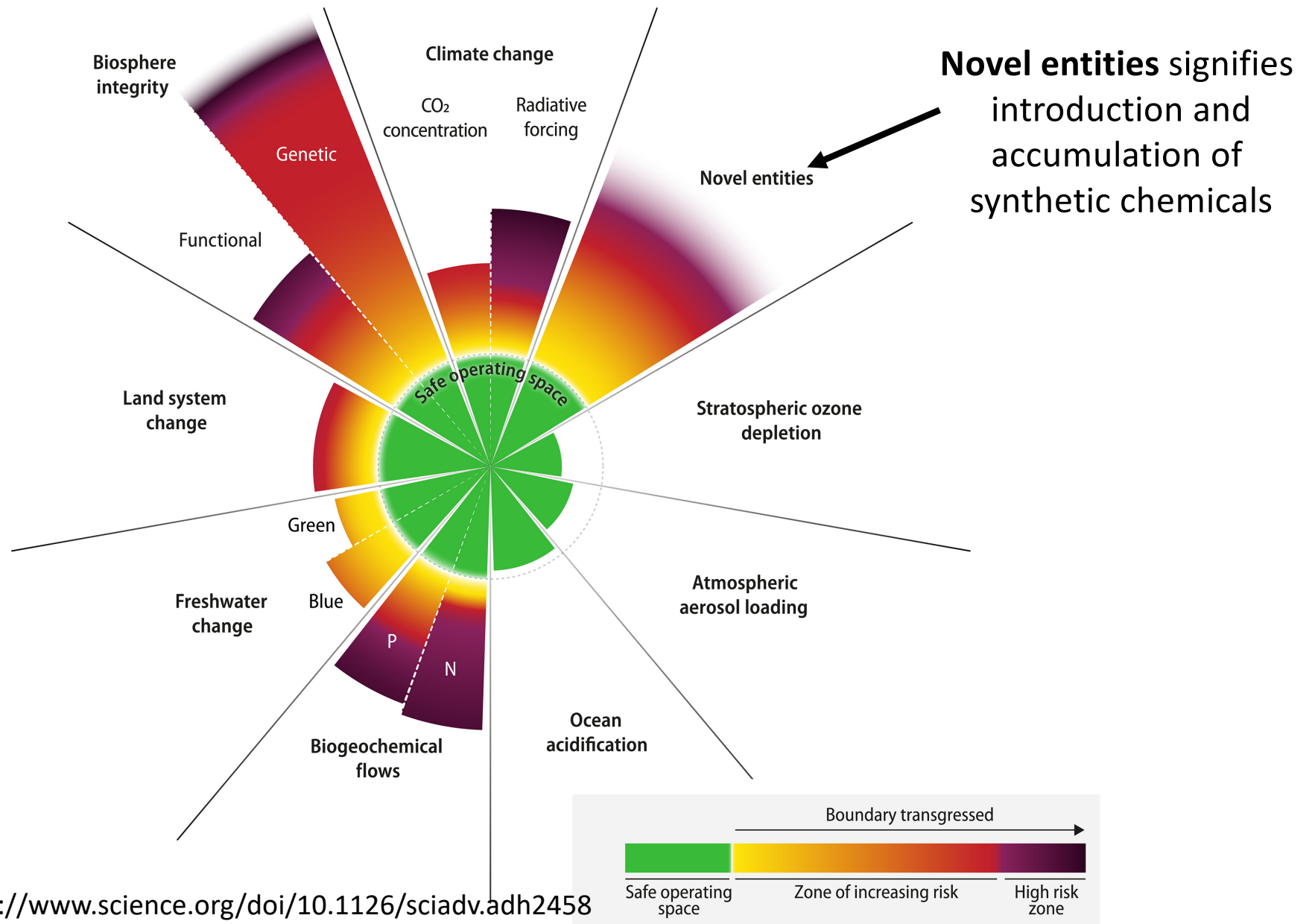
<https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/>

**60 Per cent of all Vertebrates Extinct since 1970 - ”A New  
Global Deal for Nature and People Urgently Needed”**

[https://assets.worldwildlife.org/www-prd/documents/5gc2qerb1v\\_2024\\_living\\_planet\\_report\\_a\\_system\\_in\\_peril.pdf](https://assets.worldwildlife.org/www-prd/documents/5gc2qerb1v_2024_living_planet_report_a_system_in_peril.pdf)

# The Planetary Boundaries Concept – updated 2023

The 2023 update to the Planetary Boundaries framework indicates that six of nine global environmental boundaries are transgressed, **placing humanity well outside the safe operating space**. The breached boundaries include climate change



# **Limitations of the Planetary Boundary Concept**

**The Planetary Boundaries Concept focuses on emissions from the Human Activity System and does not consider primary resource supply and manmade stocks that have been built up in cities and other infrastructure. Thus, a comprehensive approach requires that both inflows to, outflows from and stocks being built up (or are being eroded) are considered in discussions of human physical resource demand & use and ecologic sustainability**

# Some sustainability issues on the agenda

## Resource supply challenges (economic challenges)

- Food Supply
- Water Supply
- (Sustainable) Energy Supply
- Goods and Services Supply

## Ecologic challenges

- Climate change
- Biodiversity
- Waste and wastewater management
- Toxicity (biochemical interference)
- Plastics

## Social Challenges

- Income distribution
- Gender challenges
- Education

Challenges  
with  
considerable  
connection to  
engineering

Broad  
sustaina-  
bility  
oriented  
challenges

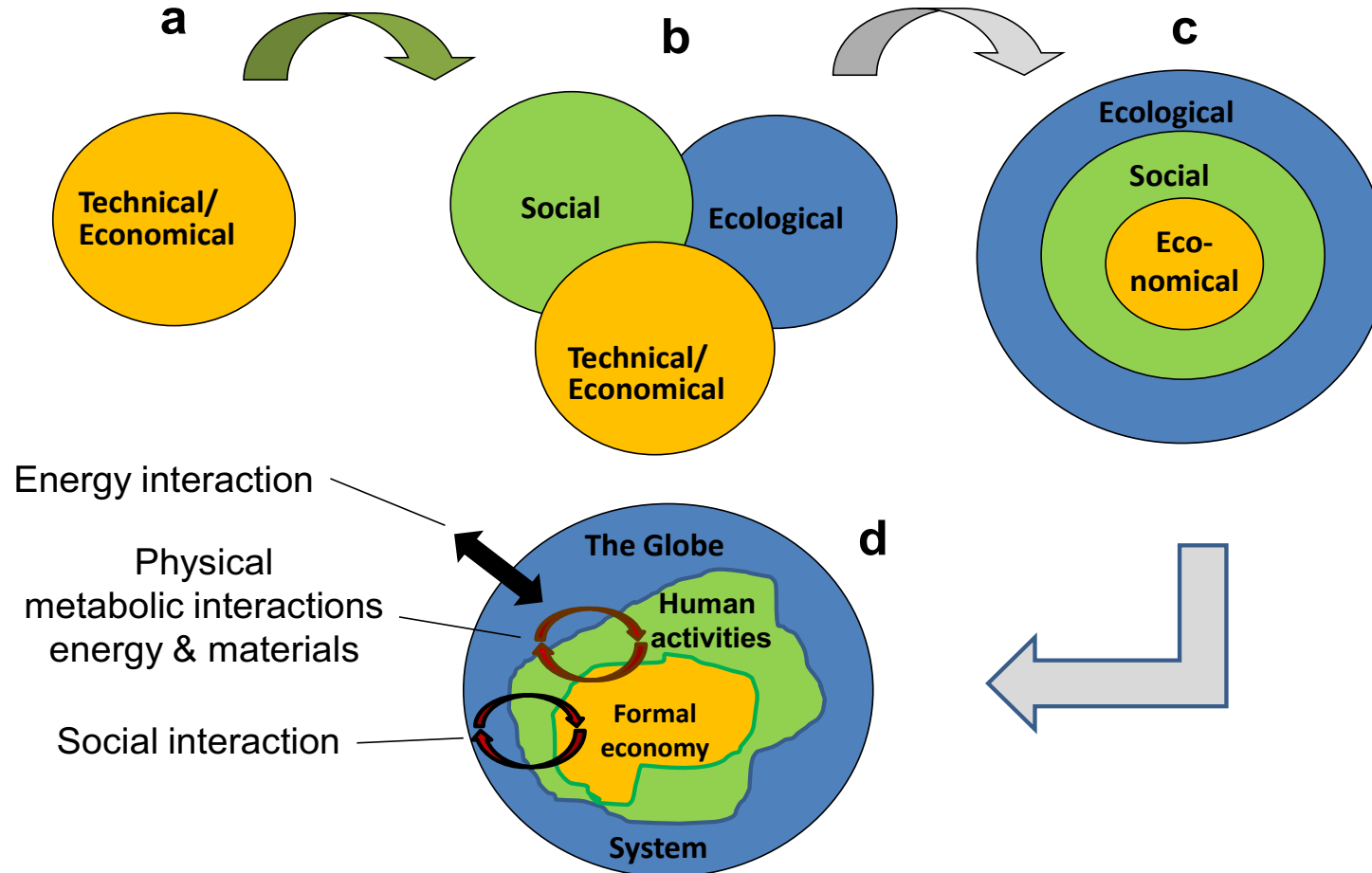
**How do we measure?**

# **Follow-up of sustainability- current approaches**

- **Countries typically have established national sustainable development goals and make national (annual) reports to the UN on how the actual national performance is developing. More and more, countries start to follow-up against the UN SD goals for 2030.**
- **There is still very much to do at other administrative levels (than the national), such as provincial, municipal, corporate and family/individual level in order to support and verify the national follow-up procedures. Methods, standards and reporting varies a lot from country to country.**
- **Still, financial accounts dominate the discussion, since economic development is still the main focus in essentially all countries on earth**

**Ecological sustainability as a platform  
for human activity, as well as social and  
economic sustainability**

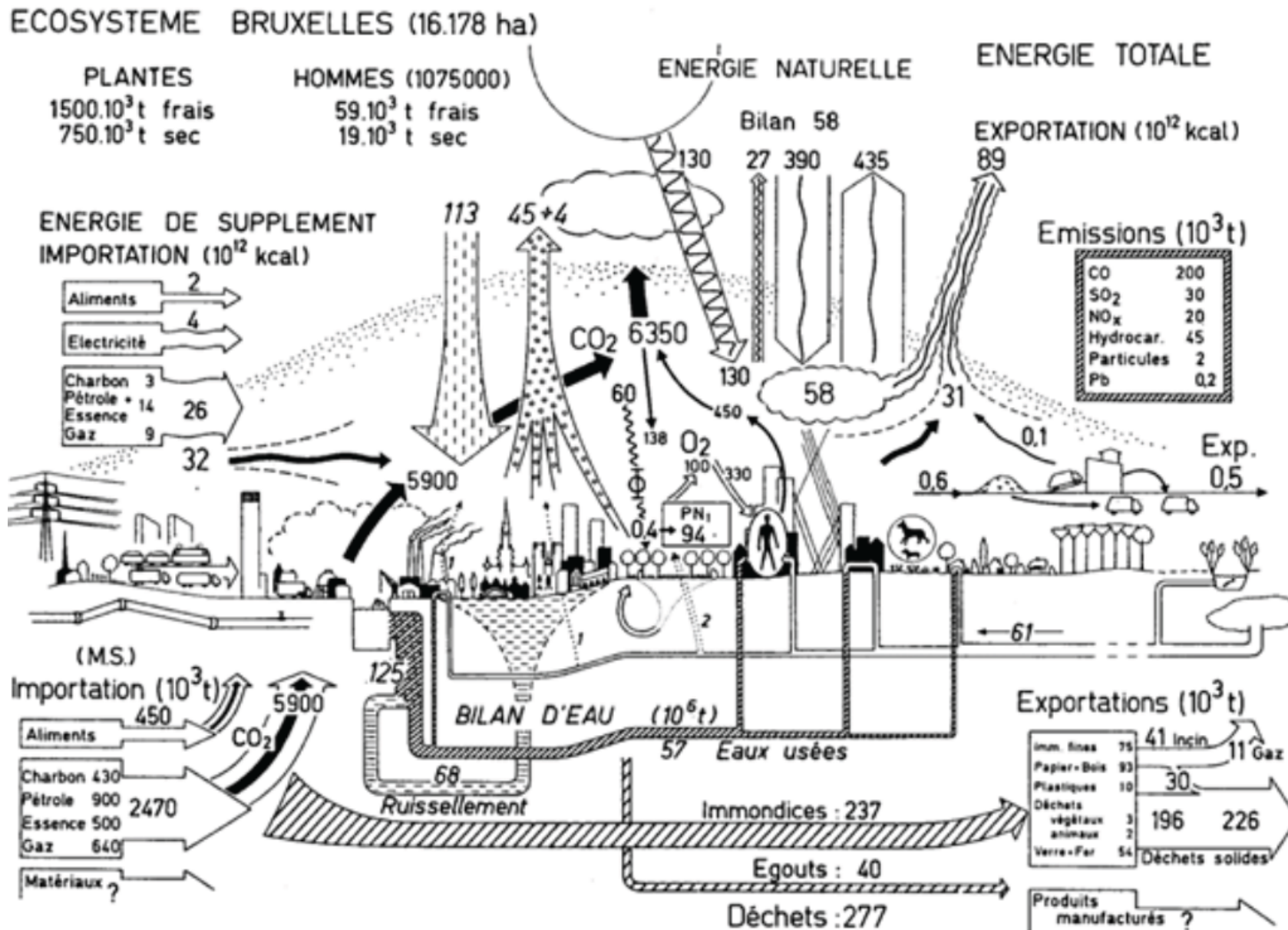
# Sustainable Development – A thought Path



Source: Frostell, 2013

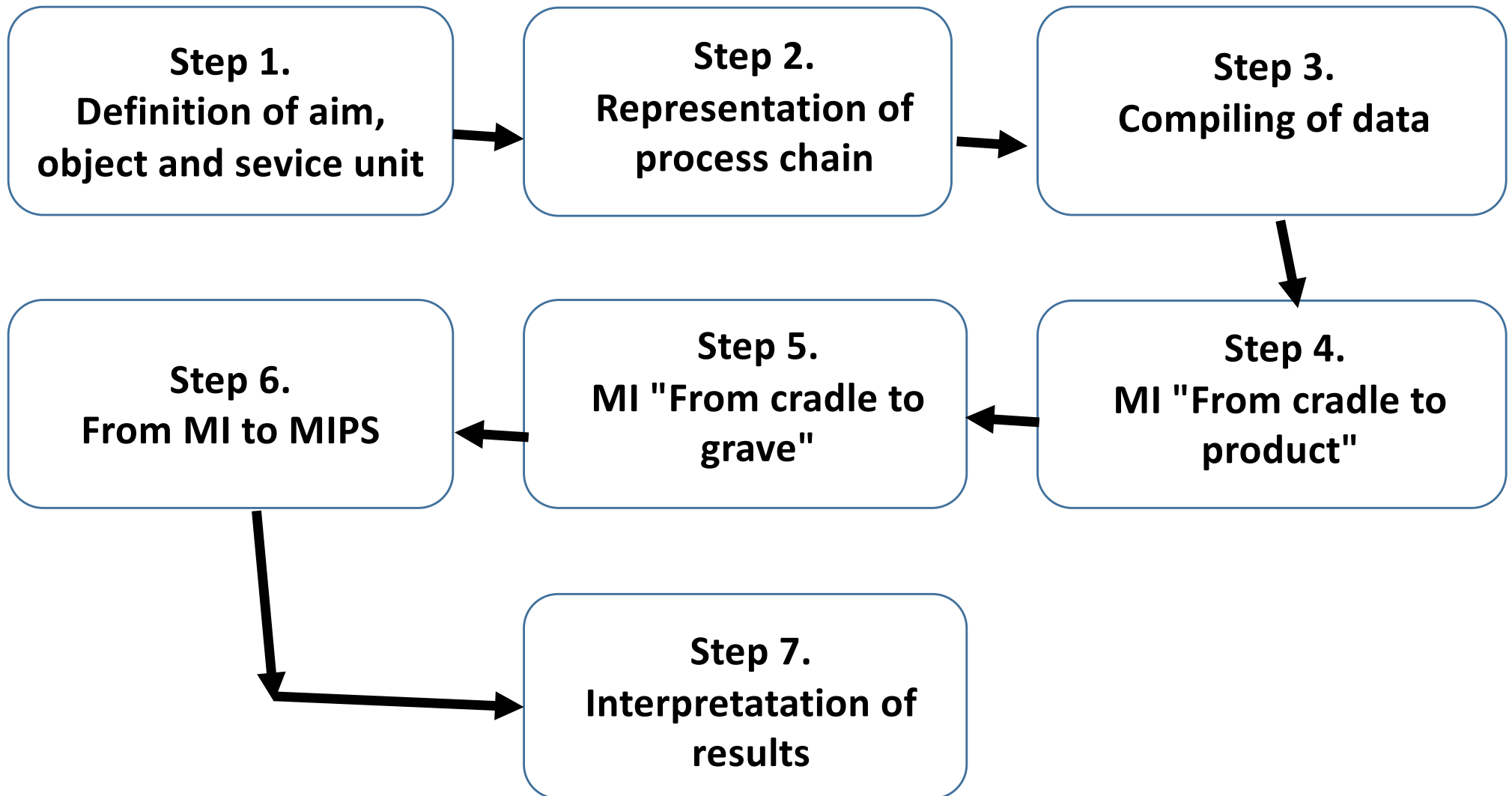
## Life on Earth Rests on Ecosystem Functionality!

# Early attempt to a metabolic approach



Source: Duvigneaud and Denaeyer-De Smet 1977. *The urban metabolism of Brussels, Belgium in the early 1970s.*

# MIPS - Material Input Per unit of Service - principle



# MIPS - Material Input Per unit of Service - example

MI factors for electric power are, for example:

	Abiotic Resources [t/MWh]	Biotic Resources [t/MWh]	Water [t/MWh]	Air [t/MWh]	Earth movements [t/MWh]
Electric power (public supply, FRG)	4.7	–	83.1	0.6	–
Electric power (industrial generation, FRG)	2.67	–	37.9	0.64	–
Electric power (European OECD-countries)	1.58	–	63.8	0.425	–

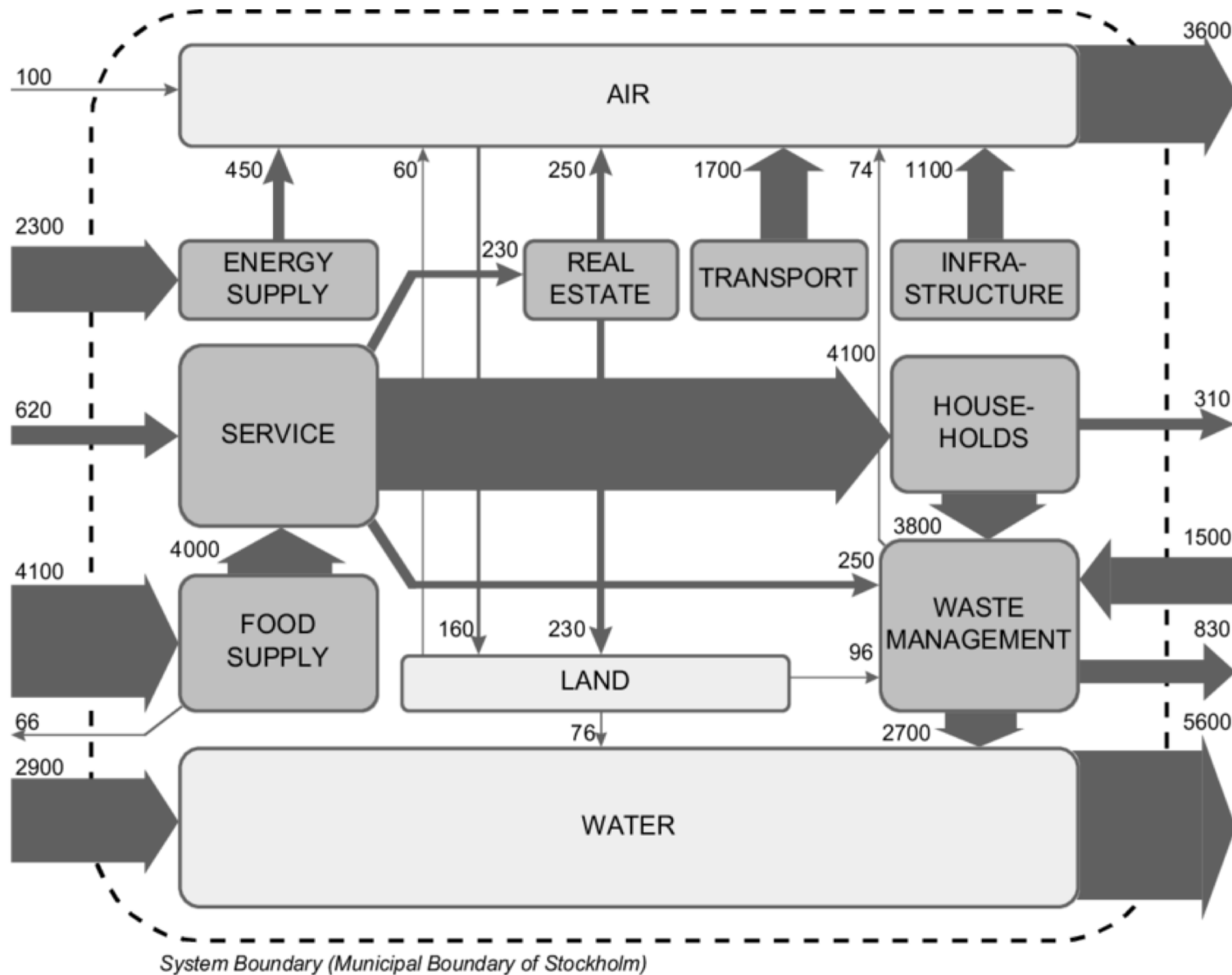
Source: Ritthof, Rohn and Liedtke (2002);

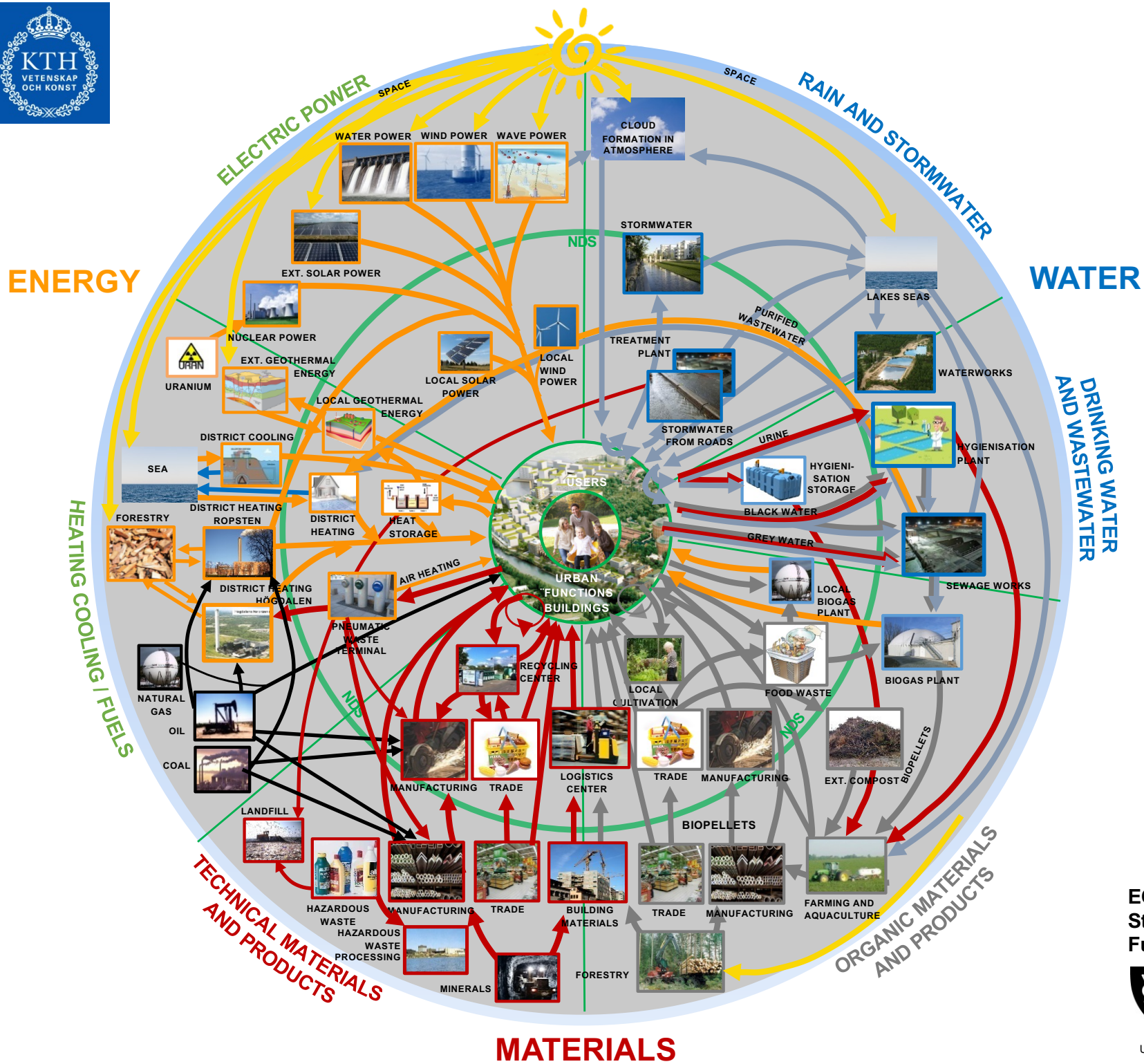
<https://epub.wupperinst.org/frontdoor/deliver/index/docId/1577/file/WS27e.pdf>

# Material flow accounts for municipalities

## The ComBox Model

Nitrogen flows in the city of Stockholm 1995





- █ SPACE
  - █ ECOSPHERE
  - █ INCOMING SUNLIGHT (solar energy)
  - █ RENEWABLE ENERGY – plants and flows
  - █ NON-RENEWABLE ENERGY TYPES
  - █ TECHNICAL, INORGANIC MATERIALS AND PRODUCTS
  - █ ORGANIC MATERIALS AND PRODUCTS
  - █ WATER of different types
  - █ FLOWS OF MINOR IMPORTANCE OR REDUNDANT
  - █ SYSTEMS BOUNDARIES NDS – OUTER WORLD
  - █ BOUNDARIES BETWEEN DIFFERENT TYPES OF RESOURCES
- NDS = ROYAL SEAPORT (Norra Djurgårdsstaden)

**ECO-CYCLE MODEL 2.0 for Stockholm Royal Seaport – Future Vision 2030**

# **Quantification of sustainability - an outlook**

- Recent work to quantify sustainability increasingly takes a metabolic approach, seeing human activities in the global economy as a very large organism metabolizing materials and energy. This is reflected in words such as circular economy, eco-cycles, ecologic approach, life cycle thinking and systems thinking**
- It is important to understand that present-day (financial) economy not has been able to adequately address sustainability. This should be ascribed to its narrow focus on humans and human activities and neglecting a broader approach and broader system boundaries**
- There is a fantastic task for students to change this...!**

# **Lecture break discussion questions**

**What types of knowledge could in your opinion best foster an improved monitoring of physical resource flows and stocks (energy and materials) for improved management of environmental and climate challenges?**

**Which are in your opinion the most relevant parameters to monitor at the individual and household level in order to support sustainable development?**

**End of first lecture part**

# **Part 2**

## **Basic Practical Approaches**

# Important basic practical approaches to quantification of Sustainable Development

- A Basic Issue – The question of social scale
- Development and introduction of indicator frameworks with indicators, indices and composite indices
- The Importance of Complementing the Human Development Index with a Sustainable Development Index
- The Ecological Footprint Approach - High Degree of Pedagogy
- Other practical Approaches – Life Cycle Assessment, Cost-Benefit Analysis and other Methods

# **The Question of Scale**

# The question of scale

- An important issue in quantifying sustainability is the question of scale. Important scales are
  1. the global scale,
  2. the international regional scale,
  3. the national scale,
  4. the national regional scale,
  5. the municipal scale,
  6. company/organisational scale and
  7. the individual/household scale

The importance of these seven levels of scale from the global to the individual level is that they represent system scales that are strongly connected to the ability to exert control – to take decisions on goals and implement action

# Challenges associated with different scales

- The ability to mobilise knowledge and expertise varies
- The availability of data varies
- The challenge to reach consistency over system scales
- The possibility to create broad participation varies

So far, quantification of sustainability has been dominated by developments covering larger system scales – from the global scale to the national: There is a lack of efforts at smaller system scales except for the company/organisation scale

**Development and introduction of indicator frameworks with indicators, indices and composite indices**

# Indicator framework semantics

- An **indicator framework** can be defined as a structured, organized tool that brings together a set of statistical measures to track progress, evaluate performance, or monitor conditions, often within projects, policies, or sustainability initiatives
- An **indicator** is a quantitative or qualitative measure, sign, or signal that shows the state, level, or progress of something, making complex realities easier to understand
- The word **index** (plural indexes or indices) can have many different definitions depending on circumstances. In quantification of sustainability it may be defined as a number (such as a ratio) derived from a number of indicators and used as an integrated indicator or measure
- Related to indicator frameworks are **composite indexes, which aggregate multiple indicators into a single numerical value**
- Indicator frameworks represent **mechanisms to compress quantitative information** into single numbers characterizing a development or a trend

# Composite Indices

## Advantages

Composite indices are particularly useful for ranking countries or regions and tracking progress over time

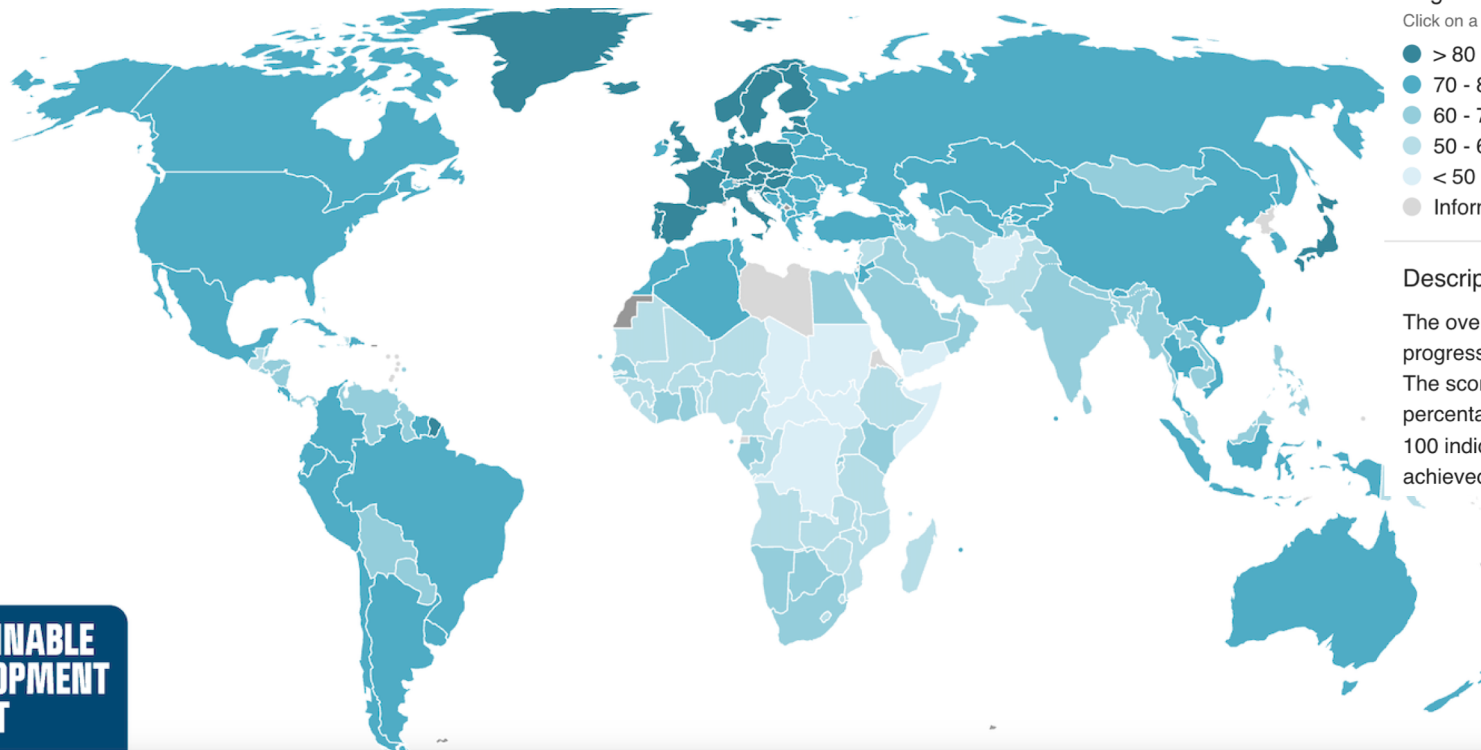
They can highlight trade-offs and synergies between different sustainability dimensions

## Challenges

Composite indices face methodological challenges, such as the weighting of indicators and the normalization of data

Choices in weighing indicators and methods for data collection can significantly influence results and may reflect subjective judgments rather than objective realities

# How well do different countries fulfil all 17 SDGs



## Legend

Click on a country to see its performance.

- > 80
- 70 - 80
- 60 - 70
- 50 - 60
- < 50
- Information unavailable

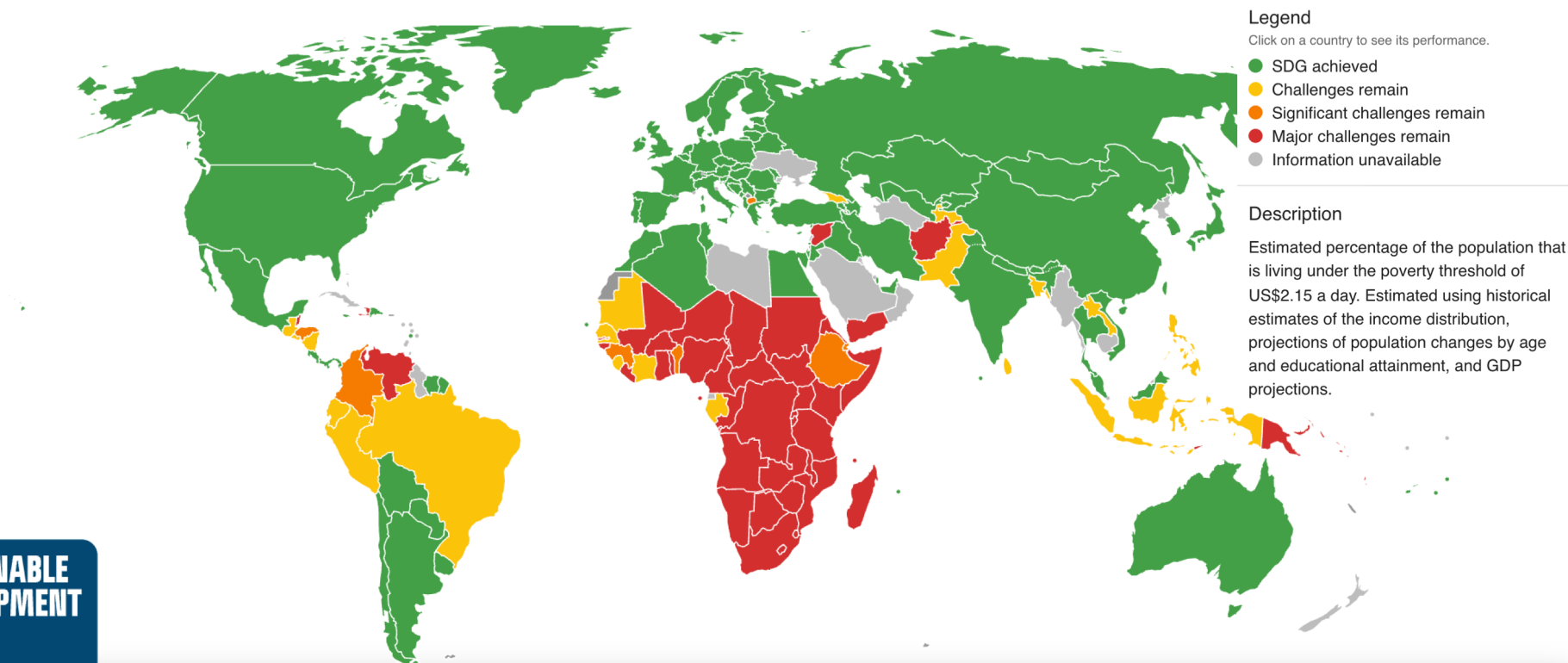
## Description

The overall score measures the total progress towards achieving all 17 SDGs. The score can be interpreted as a percentage of SDG achievement. A score of 100 indicates that all SDGs have been achieved.



All data presented on this website are based on the publication Sachs, J.D., Lafortune, G., Fuller, G., Iablonski, G. (2025). Financing Sustainable Development to 2030 and Mid-Century. Sustainable Development Report 2025. Paris: SDSN, Dublin: Dublin University Press. DOI: <https://doi.org/10.25546/111909>

# Global Extreme Poverty – less than USD 2.15/day income



All data presented on this website are based on the publication Sachs, J.D., Lafortune, G., Fuller, G., Iablonski, G. (2025). Financing Sustainable Development to 2030 and Mid-Century. Sustainable Development Report 2025. Paris: SDSN, Dublin: Dublin University Press. DOI: <https://doi.org/10.25546/111909>

# **The Importance of Complementing the Human Development Index with a Sustainable Development Index**

# The Sustainable Development Index

## Measuring Human Development in the Anthropocene

- The Human Development Index (HDI) has long been criticized for not taking account of ecological sustainability. This limitation is becoming increasingly problematic given a growing crisis of climate change and ecological breakdown in the 21st century.
- All of the HDI top performers are notable for dangerously high levels of ecological impact, which is driving a global crisis.

Source: Hickel, Jason. 2020. "The Sustainable Development Index: Measuring the Ecological Efficiency of Human Development in the Anthropocene," Ecological Economics vol 167 [PDF].

# The Sustainable Development Index (SDI)

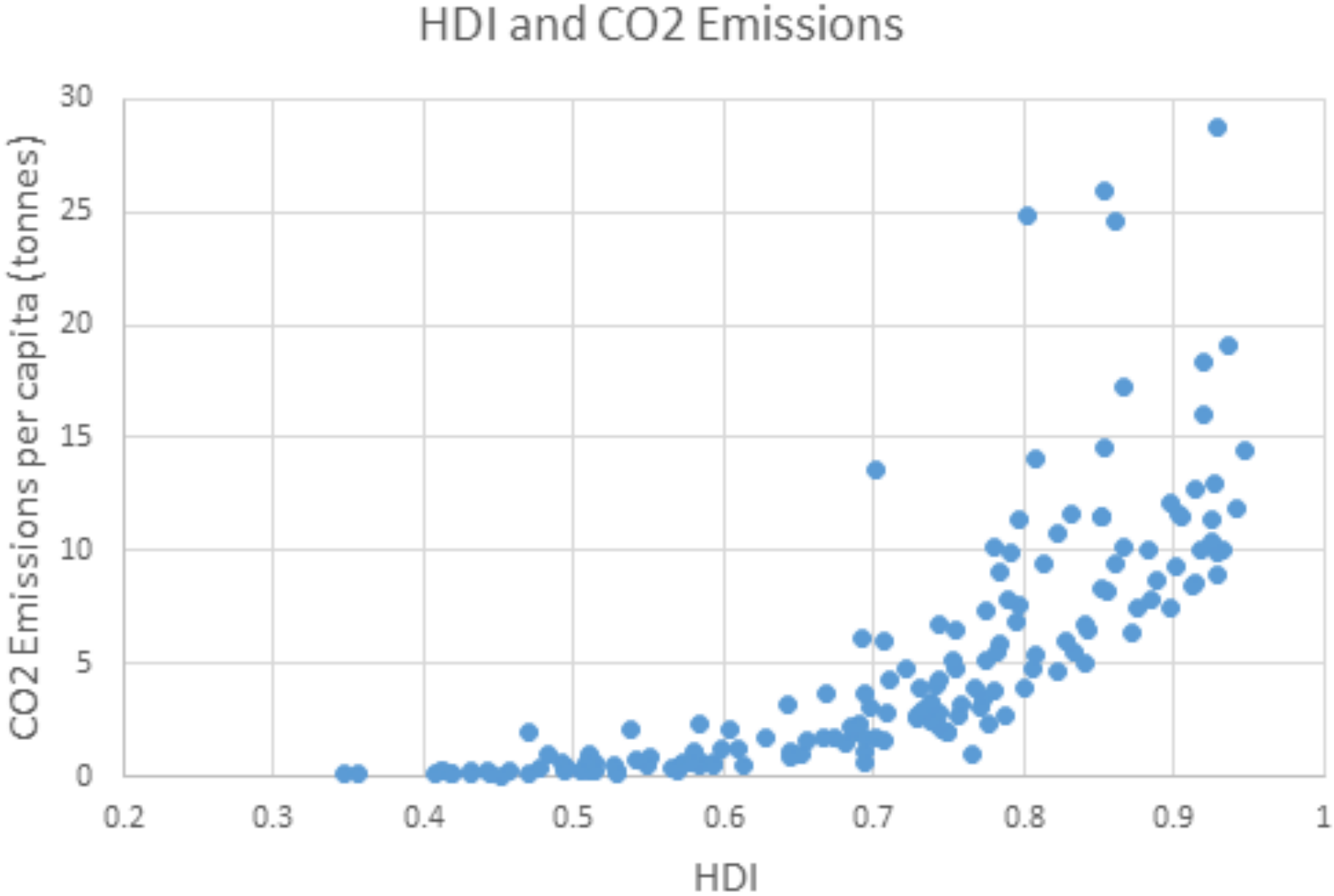
The Sustainable Development Index measures a country's ecological efficiency in delivering human development, calculated as the geometric mean of education, life expectancy, and income, divided by its per-capita carbon emissions and material footprint.

**It indicates which nations achieve high development without exceeding planetary boundaries.**

It was created to update the Human Development Index (HDI) for the ecological realities of the Anthropocene.

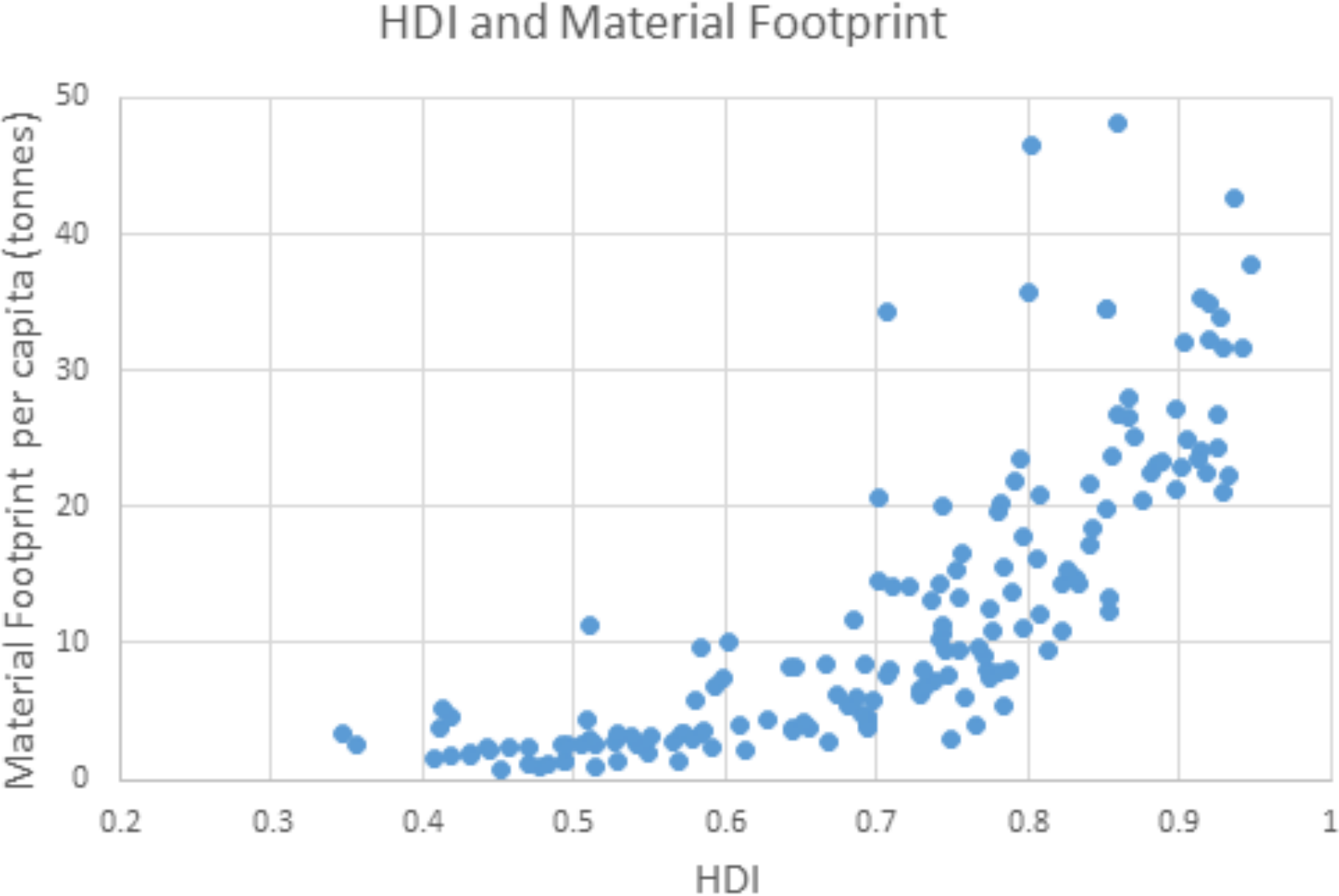
<https://www.sustainabledevelopmentindex.org/>

# Is the Human Development Index Appropriate for Quantification of Sustainable Development 1?



Source: <https://www.sustainabledevelopmentindex.org/about>

# Is the Human Development Index Appropriate for Quantification of Sustainable Development 2?



Source: <https://www.sustainabledevelopmentindex.org/about>

# The Sustainable Development Index for different countries – data from 2022



# **The High Degree of Pedagogics in the Ecological Footprint Approach**

# The Ecological Footprint

- The ecological footprint is a very pedagogic and illustrative indicator of ecologic sustainability. It is calculated as the land area needed to provide current social products and services in a sustainable way - with the best available technology

Source: Wackernagel, M. and Rees, W. (1996) Our Ecological Footprint Reducing Human Impact on the Earth. New Society Publishers, Philadelphia

- The EF calculated is compared with the available land area and if the latter is smaller than the EF, the current situation is unsustainable
- According to the EF indicator , the world grand EF is larger than the available productive land area on earth (appr 1.8 times larger) and increasing each year
- The EF methodology has been criticized as being non-scientific and thus not a reliable indicator (cf. e.g. van den Bergh and Verbruggen 1999, Ayres 2000)



# The Ecological Footprint

This is the way the Ecological Footprint is explained on their homepage according to the reference below

## ***How the Footprint Works***

The Ecological Footprint accounting measures the ***demand*** on and ***supply*** of nature. On the demand side, the Ecological Footprint adds up all the biologically productive areas for which a population, a person or a product competes. It measures the ecological assets that a given population or product requires to produce the natural resources it consumes (including plant-based food and fiber products, livestock and fish products, timber and other forest products, space for urban infrastructure) and to absorb its waste, especially carbon emissions.

Source: <https://www.footprintnetwork.org/our-work/ecological-footprint/>

# The Ecological Footprint

## MEASURES

how fast we consume resources and generate waste



Energy



Settlement



Timber & Paper



Food & Fiber



Seafood

COMPARED TO  
how fast nature can absorb our waste and generate new resources.



Carbon Footprint



Built-up land



Forest



Cropland & Pasture

Fisheries

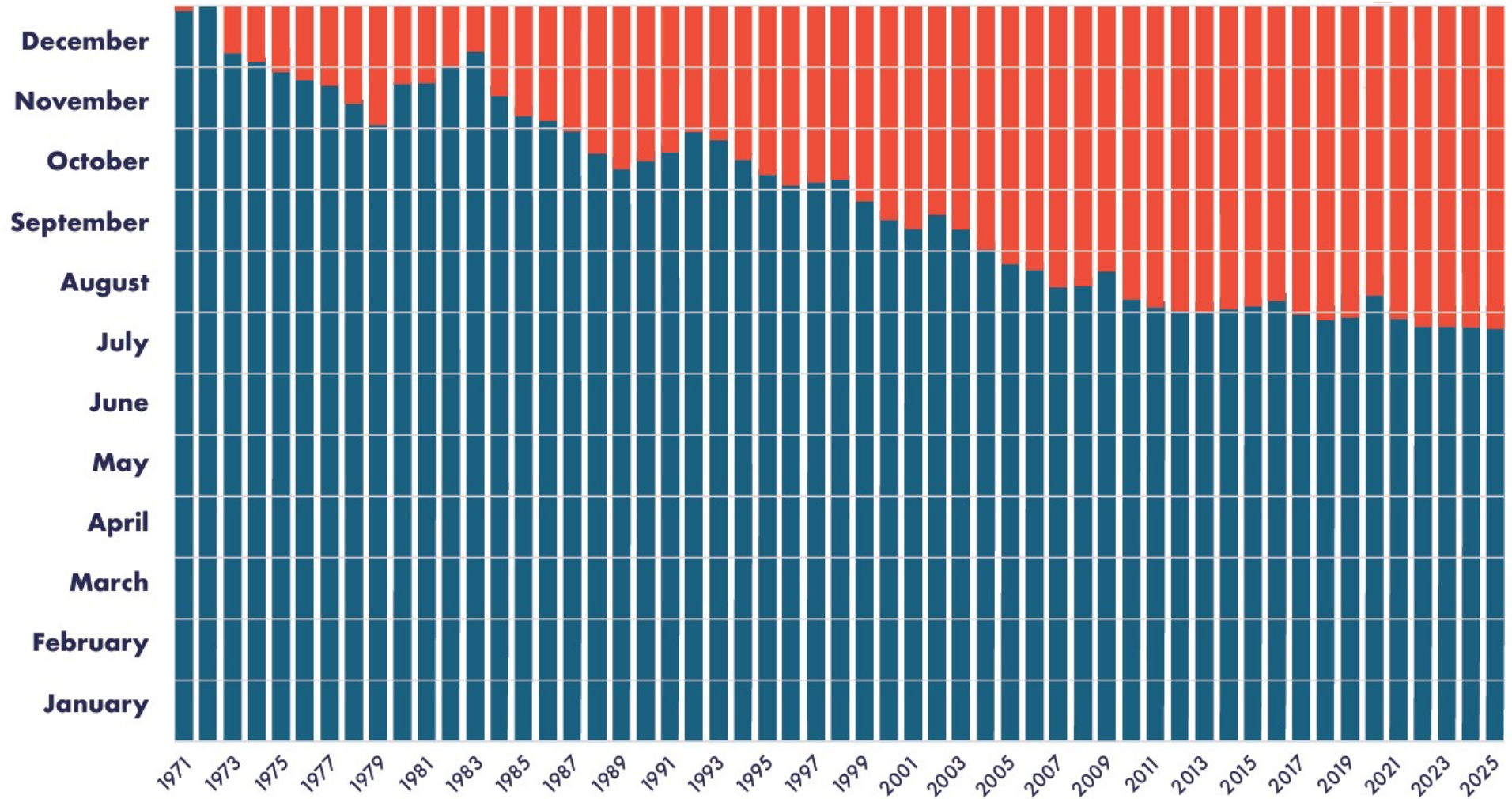
1 Earth



# Earth Overshoot Day

## 1971 - 2025

1.8 Earths



Based on National Footprint and Biocapacity Accounts 2025 Edition

# Recent alternative footprint approaches

## Energy Footprint

1. According to the EF methodology
2. According to LCI methodology
3. Other approaches

## Carbon Footprint

GFN (2026) The Carbon Footprint Network, ([www.footprintnetwork.org/en/index.php/GFN/](http://www.footprintnetwork.org/en/index.php/GFN/))

## The Water Footprint

Hoekstra A.Y. & Hung P.Q., 2005. Globalization of water resources: international virtual water flows in relation to crop trade. *Global Environmental Change* (15), pp. 45-56.

Hoekstra A.Y. (2008). Human appropriation of natural capital: A comparison of ecological footprint and water footprint analysis. *Ecological Economics*, 68, 1963-1974.

**Other practical Approaches – Life Cycle  
Assessment, Cost-Benefit Analysis and  
other Methods**

# Life Cycle Assessment and Cost-Benefit Analysis

**Life Cycle Assessment** is a very important method for assessing the environmental impacts of providing products and services for society. The method – developed in the 1990s - is now taught at more than 100 technical and natural science oriented universities in the world and has found a broad application in academia and in industry

**Cost-Benefit Analysis (CBA)** is very frequently used for economic evaluation of different alternatives. It may also be used for quantification of sustainability by assigning monetary values to environmental and social goods. So far, however, traditional economic approaches have not been able to demonstrate their versatility for quantification of sustainability

# **Environmental Systems Analysis (ESA)**

## **A large toolbox**

**Scenario Development and Evaluation**

**SEA - Strategic Environmental Assessment**

**EIA - Environmental Impact Assessment**

**LCA - Life Cycle Assessment**

**LCC - Life Cycle Costing**

**CBA - Cost/Benefit Analysis**

**MFA - Material Flow Analysis**

**SFA - Substance Flow Analysis**

**PIOTs – Physical Input-Output Tables**

**EF – (Ecological) footprints**

**ISA – Integrated Sustainability Assessment**

# Other approaches to quantification of sustainability 1

- Computer based **System dynamics models** may be used to simulate interactions between environmental, economic, and social systems over time and also explore feedback loops and tipping points. Systems modeling is especially valuable for understanding long-term scenarios and the potential impacts of different policy choices

An emerging approach is **the use of remote sensing and big data technologies**. Satellite imagery, sensor networks, and machine learning algorithms enable real-time monitoring of environmental changes, such as deforestation, air quality, and urban expansion.

# Other approaches to quantification of sustainability 2

- In a local context, there is an increased interest in **multidimensional and participatory approaches to sustainability measurements and quantification**
- Other increasingly influential approaches are based on **physical resource accounting** (material and energy flows and stocks), which focuses on accounting for the metabolic activity of society

## Final words

Since sustainability challenges become increasingly urgent, improving the robustness, transparency, and inclusivity of methods to quantify and communicate progress or challenges will become increasingly important. Here, physical resource accounting of energy and material flows and stocks in different System scales will become a foundation for better decisions regarding the environment and climate

# One way of valuing sustainability

Björn Frostell's friend Lars Sörenson hugging a 400 year (?) old Scots Pine tree on Björn's Hälsingland farm, circumference appr. 4 metres, March 2021



**Thank you for your attention!**

**[bjornfrostell@gmail.com](mailto:bjornfrostell@gmail.com)**