



Flows and Stocks of Resources in the Form of Energy and Materials

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Lecture 2 in the Master Course
Sustainable Development and Sustainability Science
Spring 2025

Introduction

- The lecture has many slides and little time
- The slides will therefore in many cases just be introduced and require further individual study by going through them again and consulting provided Internet links
- All lectures will be available at the following link
 - <https://www.aralsjon.nu/en/>.

What are resources?

- a stock or supply of money, materials, staff, and other assets that can be drawn on by a person or organization in order to function effectively (Source: Oxford languages, 2024)
- A useful or valuable possession or quality of a country, organization or person (Source: Cambridge Dictionary 2024)

The concept resource has a quality of being something positive (normally of value for humans in a historical context). Here, the concept has a shortcoming in discussing energy and material flows that can both be of value and of harm for the physical ecologic reality we live in.

Here, we use the term resources in a broader sense of Energy and Materials



Our most important resource

The Sun

The Sun

Our Nuclear Reactor

Radiation reaching the Earth

$$= 4,4 * 10^{10} \text{ MW}$$

$$= 1,39 * 10^{24} \text{ J/yr}$$

Current Global Human Energy Use

$$= 620 * 10^6 \text{ TJ}$$

$$= 0,62 * 10^{21} \text{ J/yr}$$

Our Nuclear Reactor the Sun gives us 2240 times more energy than current global human energy use => Harvest the Sun



The Great Acceleration and the Growth Dilemma

<https://ourworldindata.org/energy-production-consumption>

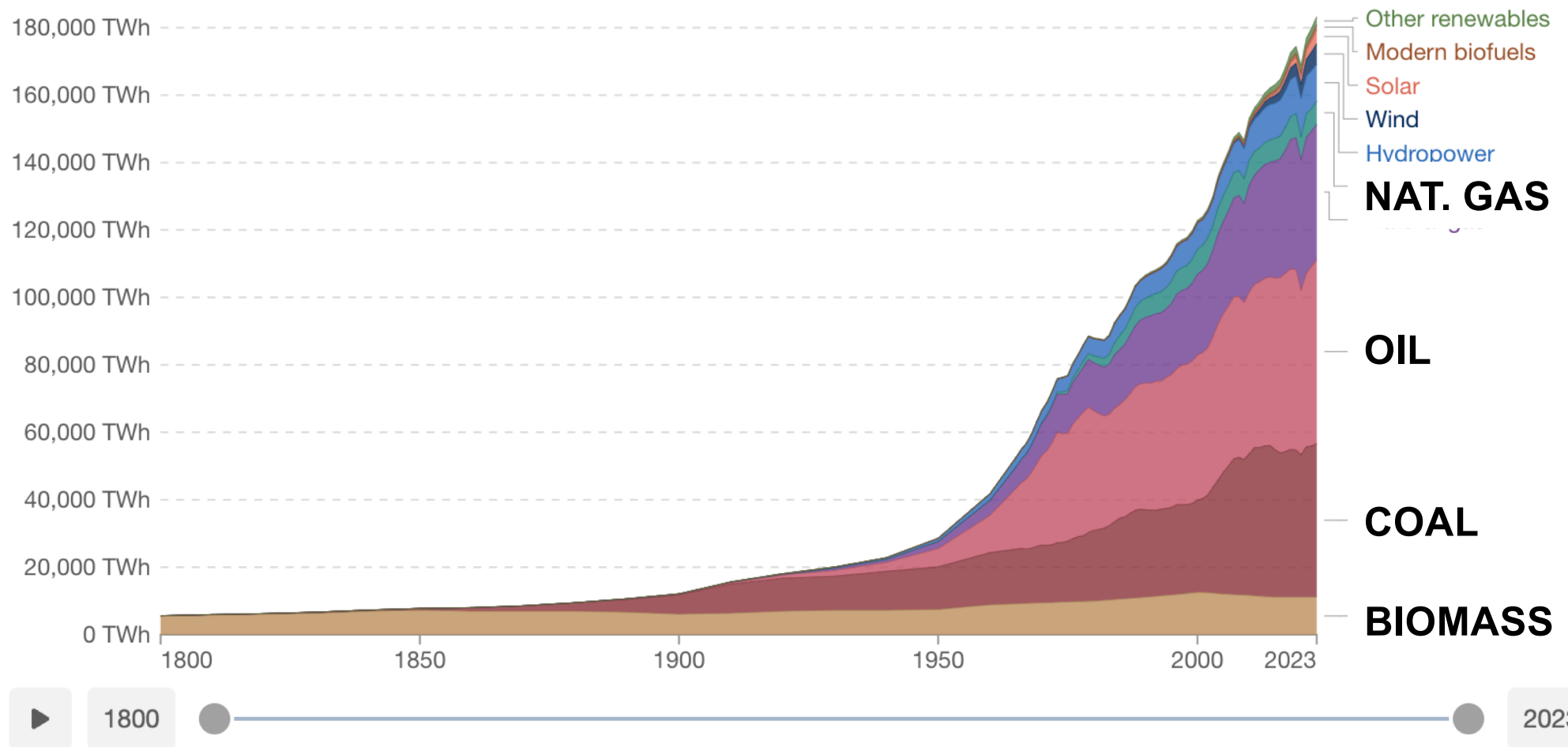
Global primary energy consumption by source

Our World
in Data

Primary energy is based on the substitution method and measured in terawatt-hours.

Table Chart

Settings



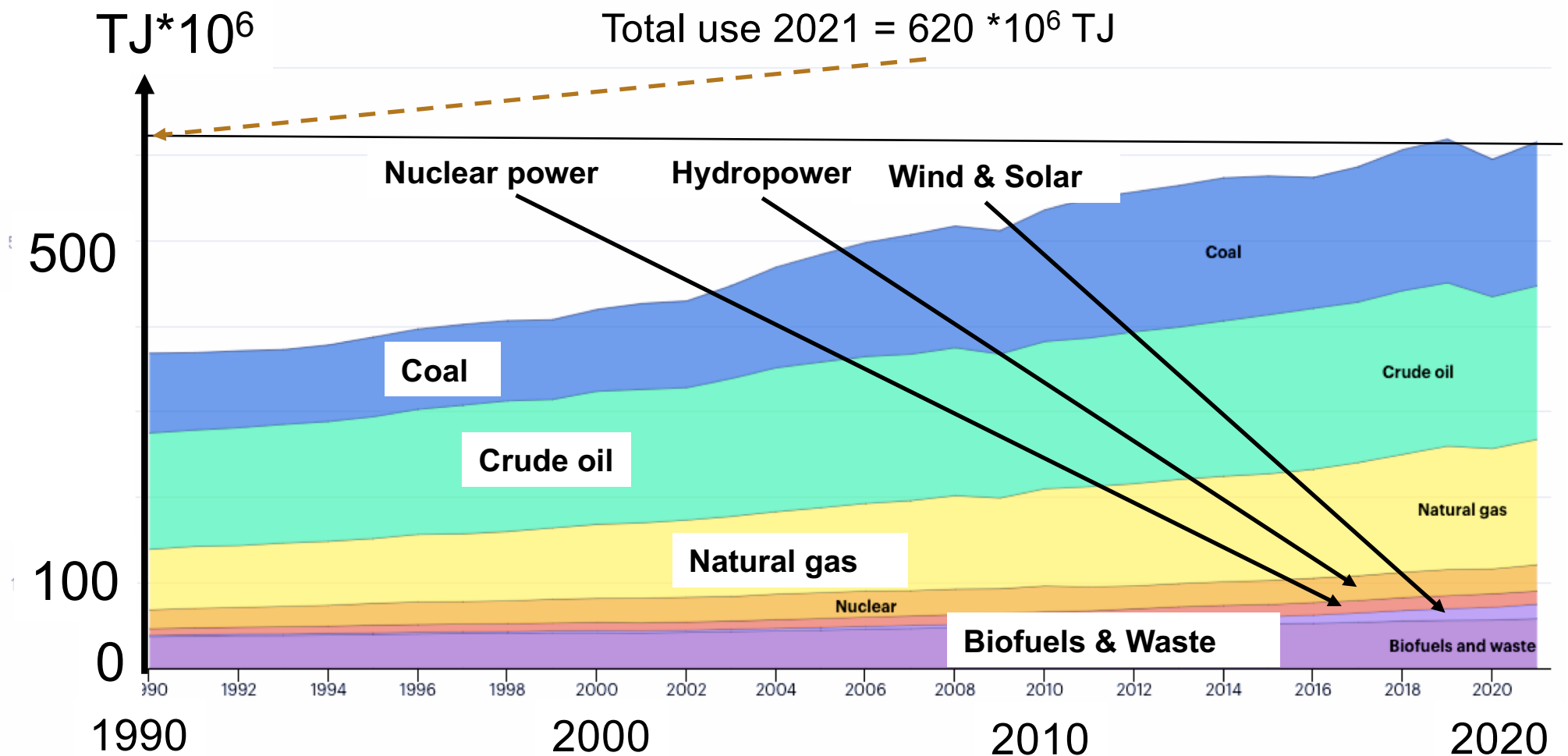
Data source: Energy Institute - Statistical Review of World Energy (2024); Smil (2017) – [Learn more about this data](#)

Note: In the absence of more recent data, traditional biomass is assumed constant since 2015.

OurWorldinData.org/energy | CC BY



World total Energy use 1990-2021, TJ



Source: International Energy Agency data browser, 2023

Something New Under the Sun

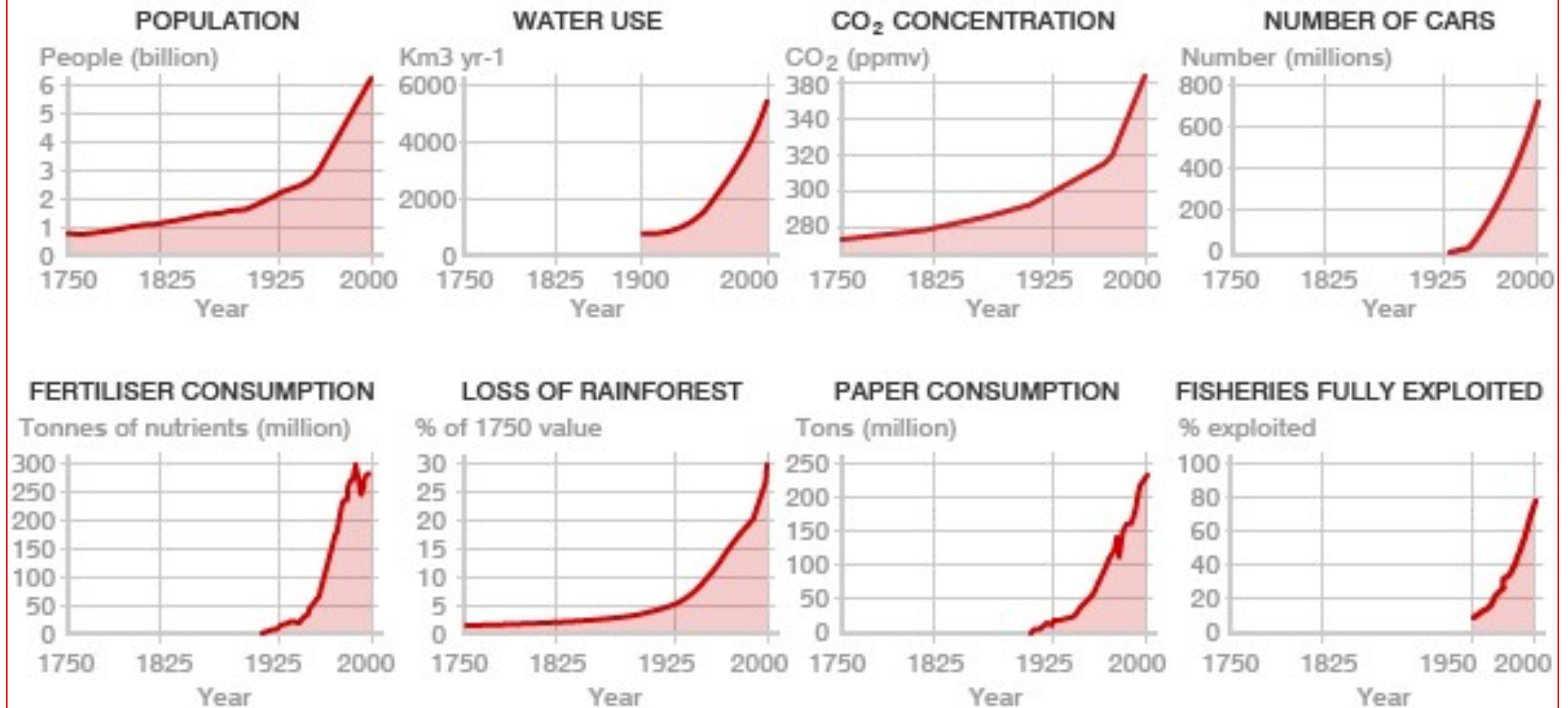
John McNeill, 2000

Development 1900 – 2000

- global population 4 x
- global economy 14 x
- industrial production 40 x
- energy use 16 x
- carbon dioxide emissions 17 x
- sulphur dioxide emissions 13 x
- ocean fishing catches 35 x
- number of pigs 9 x
- forests 0.8 x
- agricultural fields 2 x
- blue whale 0.0025 x



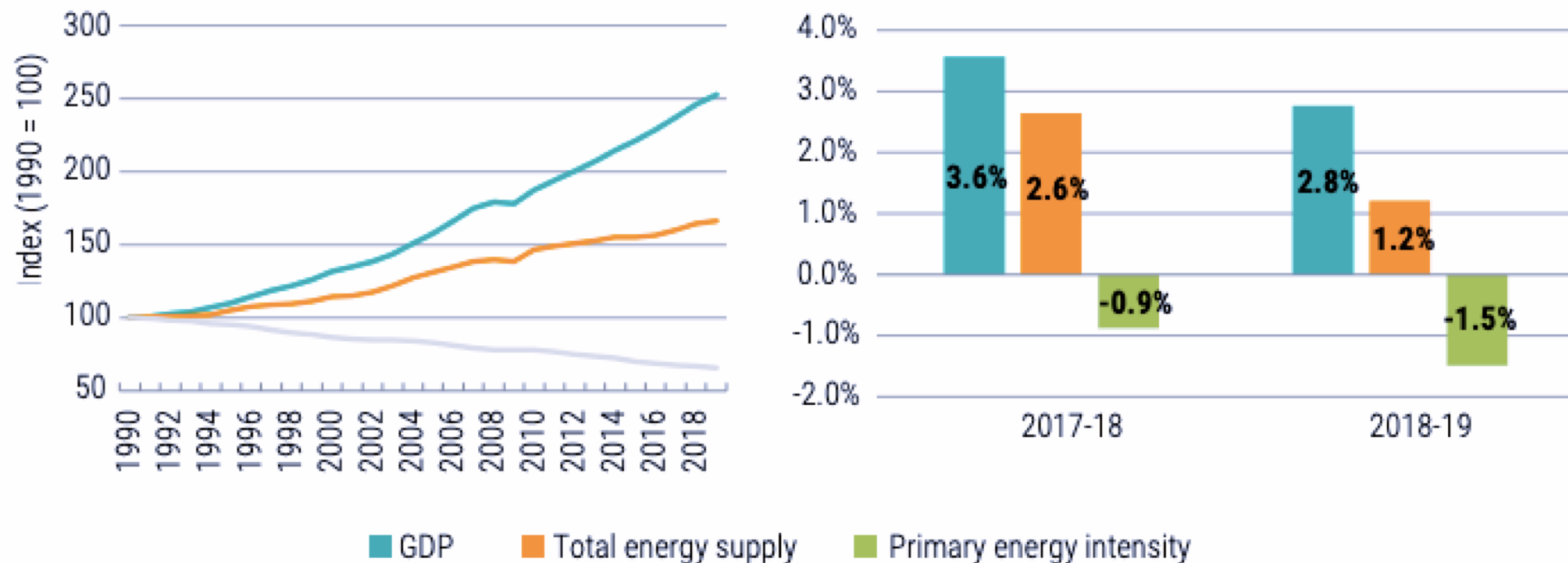
Exponential Growth



SOURCE: International Geosphere-Biosphere Programme (Steffen et al 2004)

A Growth Dilemma

Figure 4.3 • Trends in underlying components of global primary energy intensity, 1990-2019 (left); and growth rates of GDP, total energy supply, and primary energy intensity, 2017-19 (right)



Source: IEA, UN, and World Bank (see footnote 6).

Note: GDP = gross domestic product.

With annual GDP Growth substantially larger than improvement in energy intensity and with 80 % energy of fossil origin, overall climate pressure increases!



Non-renewable resources

**Mined from the crust of the earth
They are slowly emptied**

**The environmental consequences
of the accumulation of the end product
will often appear before the resource is emptied.**

Fossil fuels coal, oil, gas

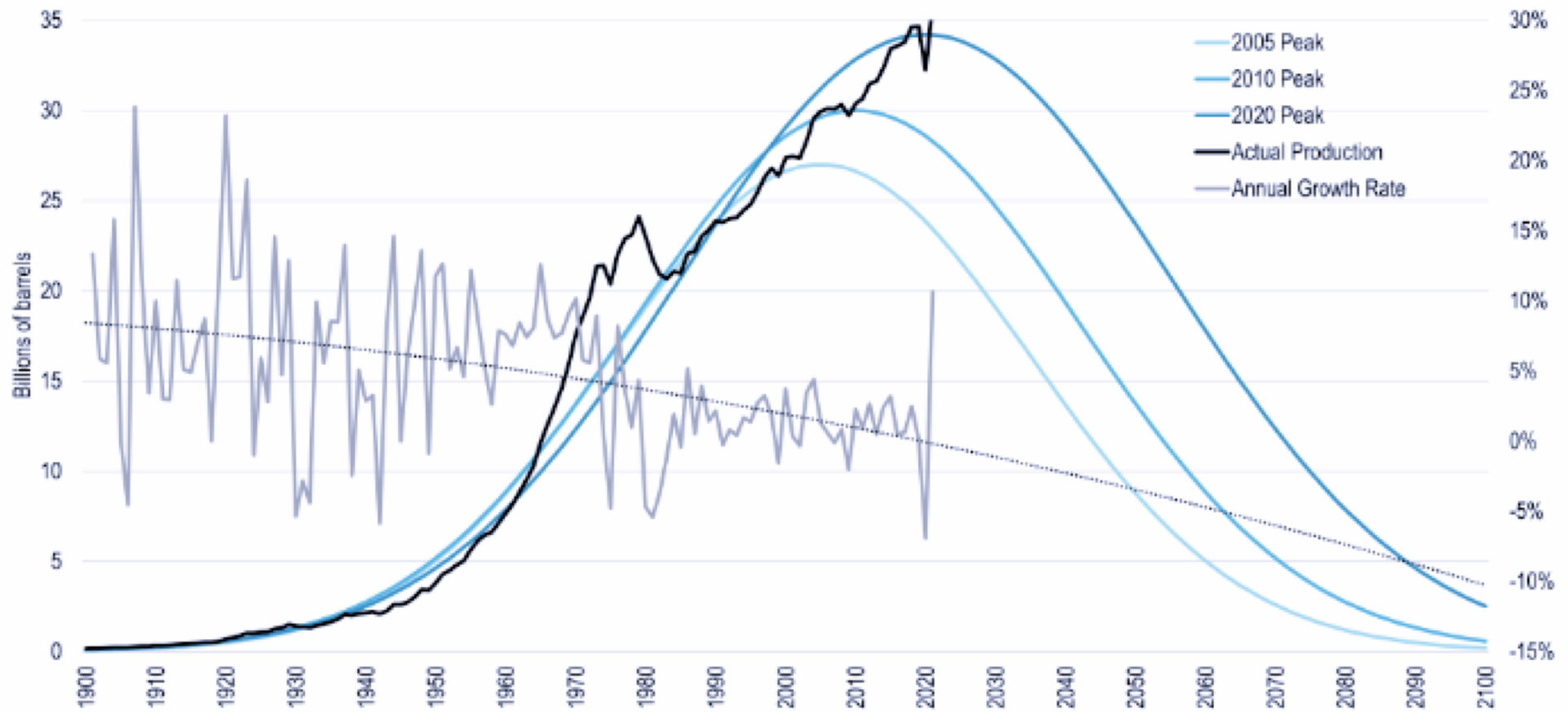


Lignite mining
Germany

Lignite Power Plant Belchatow, Poland



World Annual Oil Production and Expected Peak Oil Curves 1900-2100

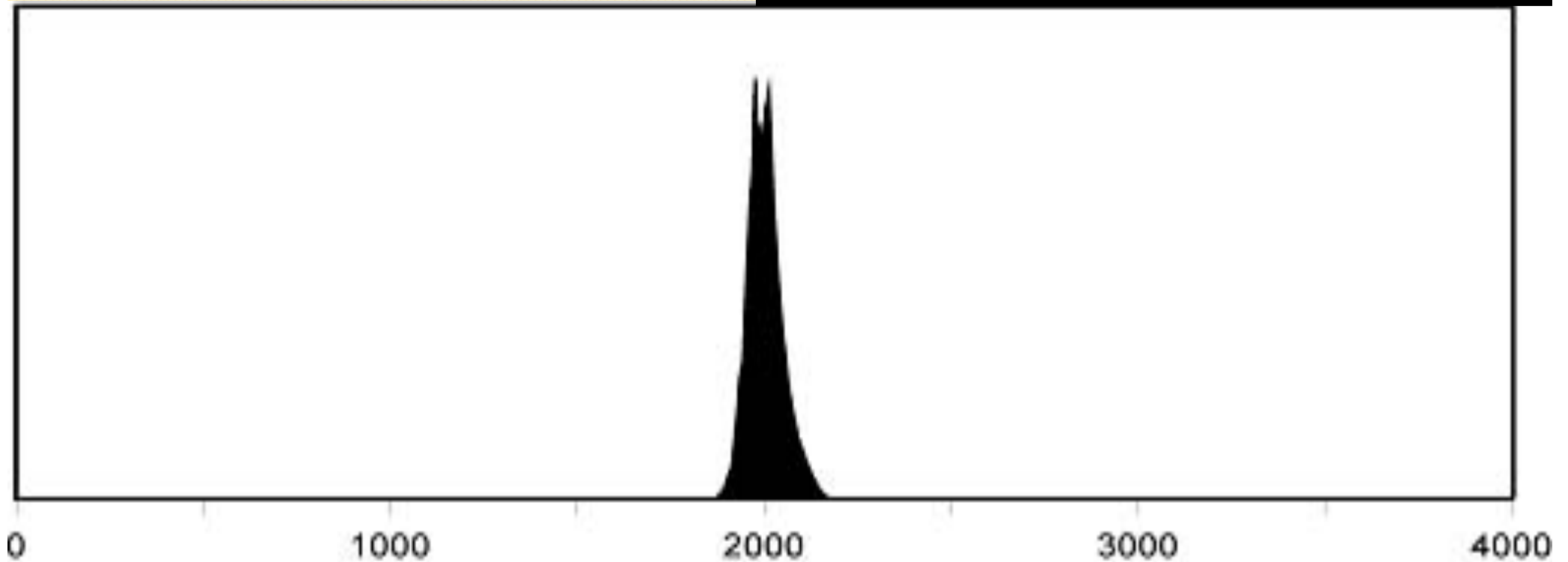


World Annual Oil Production 1900 2021 and Peak Oil 2005 2020 Scenarios

The future of energy

The
Economist

The end of the Oil Age?

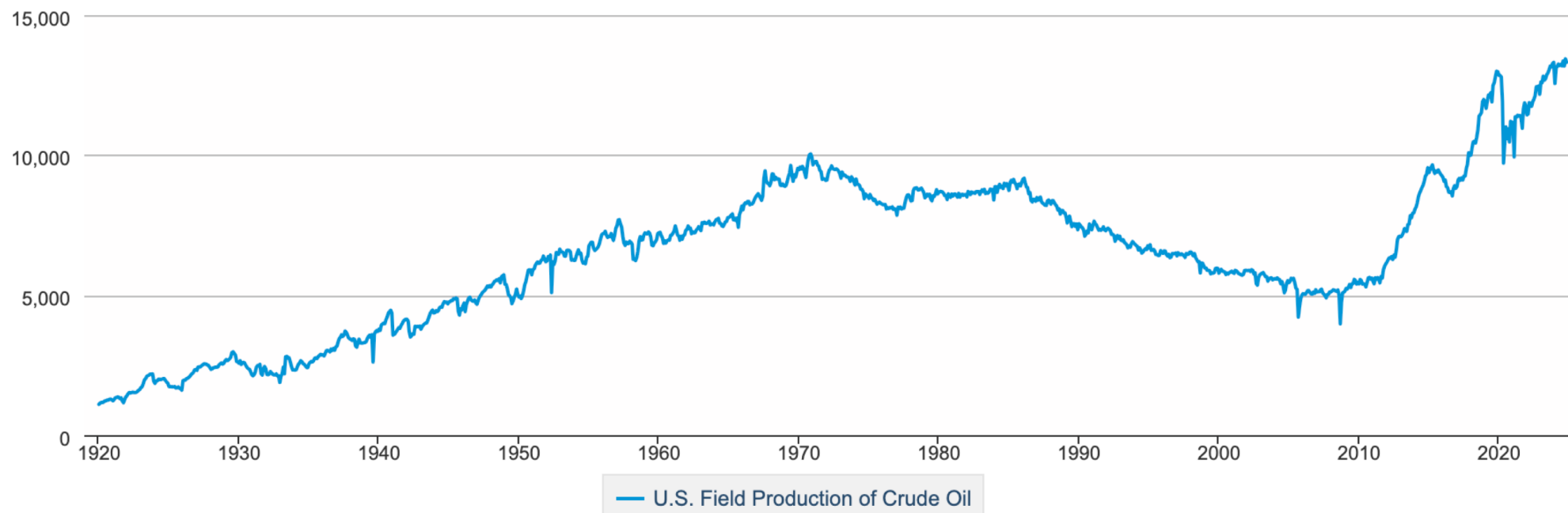


US Production of Crude Oil from 1920 to 2024

U.S. Field Production of Crude Oil

DOWNLOAD

Thousand Barrels per Day



Data source: U.S. Energy Information Administration

Source: <https://www.eia.gov/dnav/pet/hist/leafhandler.ashx?n=pet&s=mcrfpus2&f=m>

Efforts to out-phase fossils are ongoing in building sector, transport sector by developing new energy sources to combat climate change



Iron mine Kiruna Sweden



Looming crisis in rare earth metals

China produces and exports almost 70 % of the rare earth metals in the world. Virtually every developed nation in the world imports REM. Rare earths are vital to new technologies such as mobile phones, flat screen televisions and green energy technology.

Lately, REM faces declining worldwide supply and skyrocketing prices. This has worried Western governments, as rare earth metals are also key to high tech military applications.

Hybrid technology is totally dependent on Rare Earths

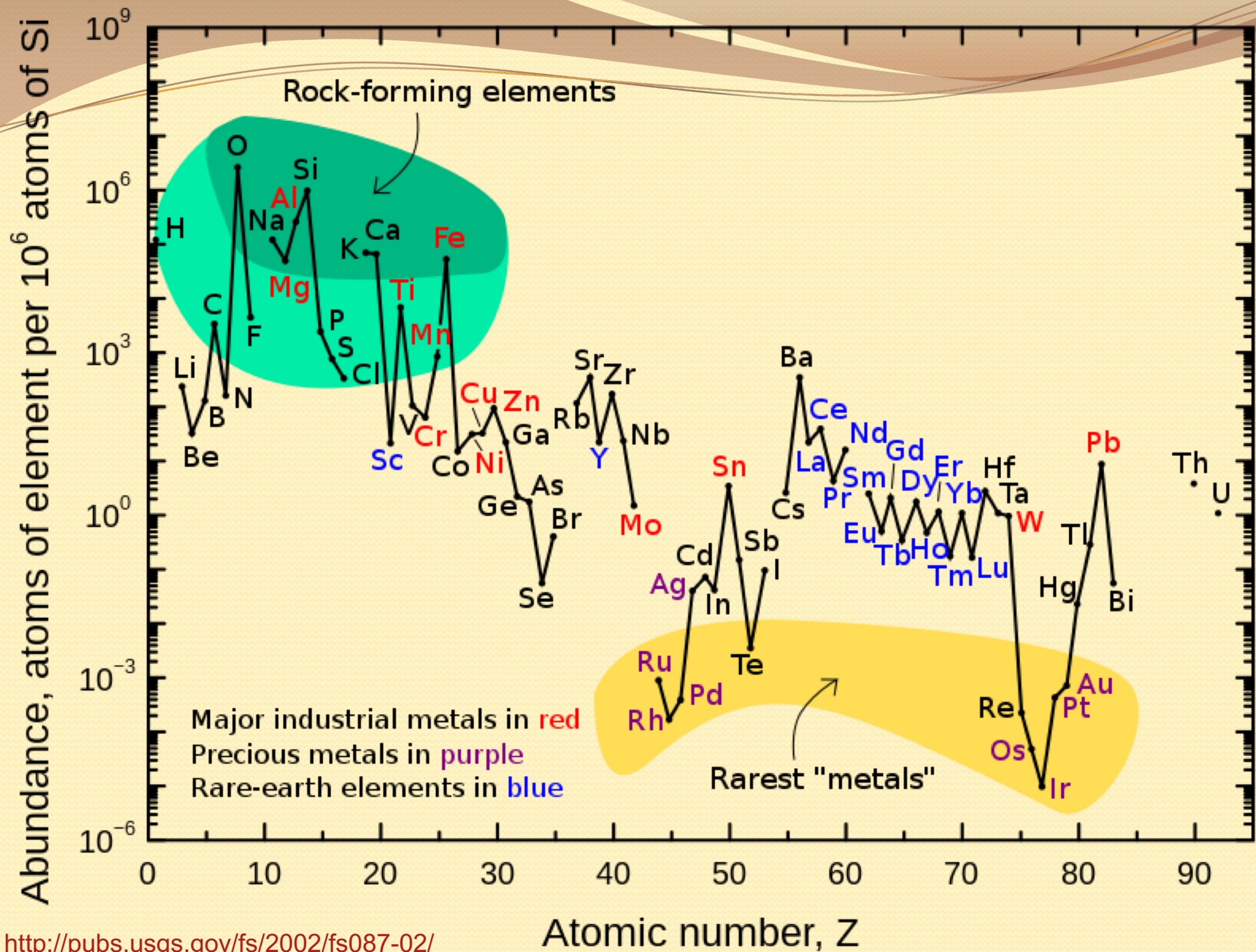
HYBRID electric motor and generator

- Neodymium
- Praseodymium
- Dysprosium
- Terbium

HYBRID NiMH battery

- Lanthanum
- Neodymium
- Cerium





World mine production of rare-earth oxides 1960-2012

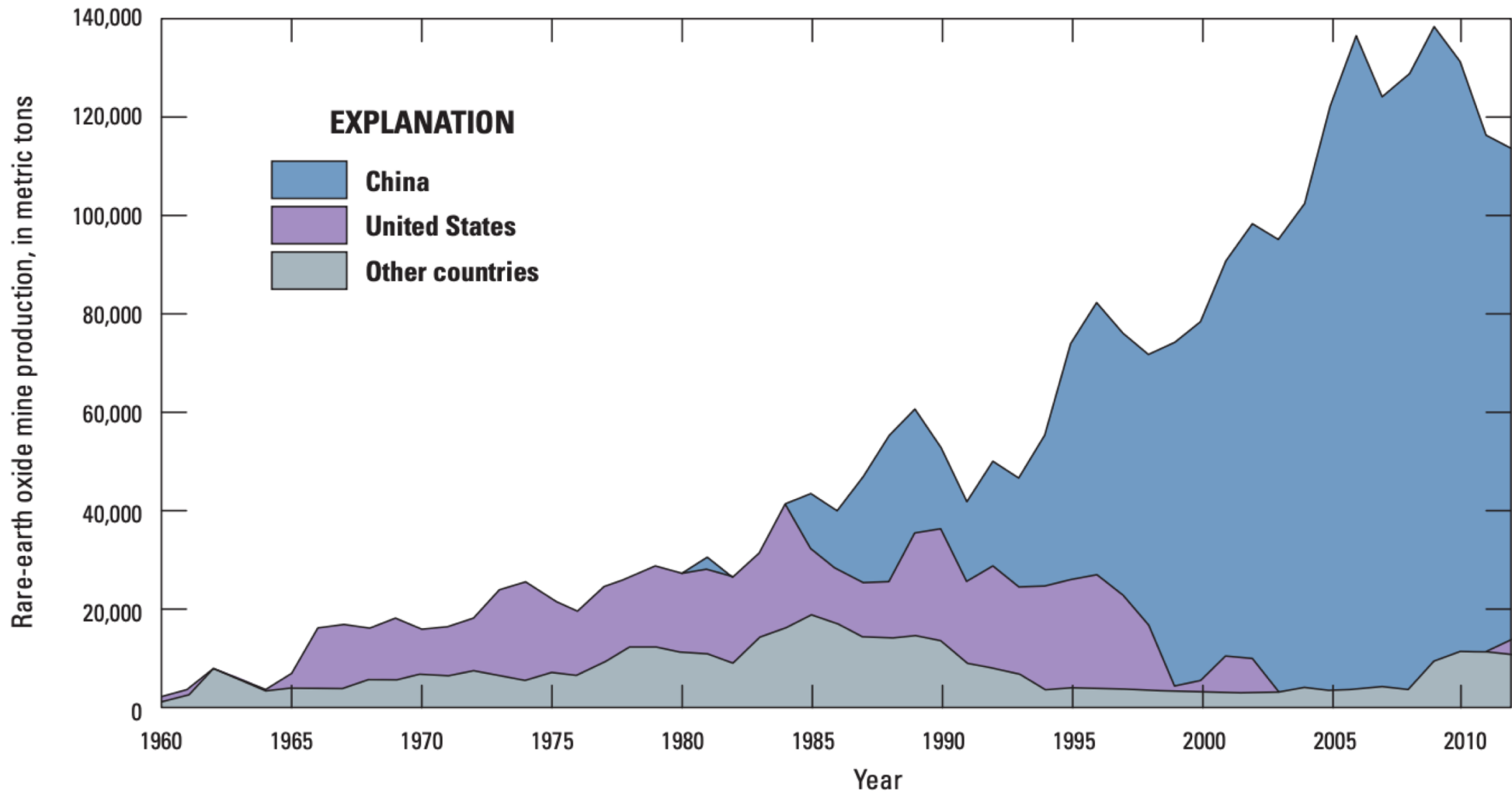
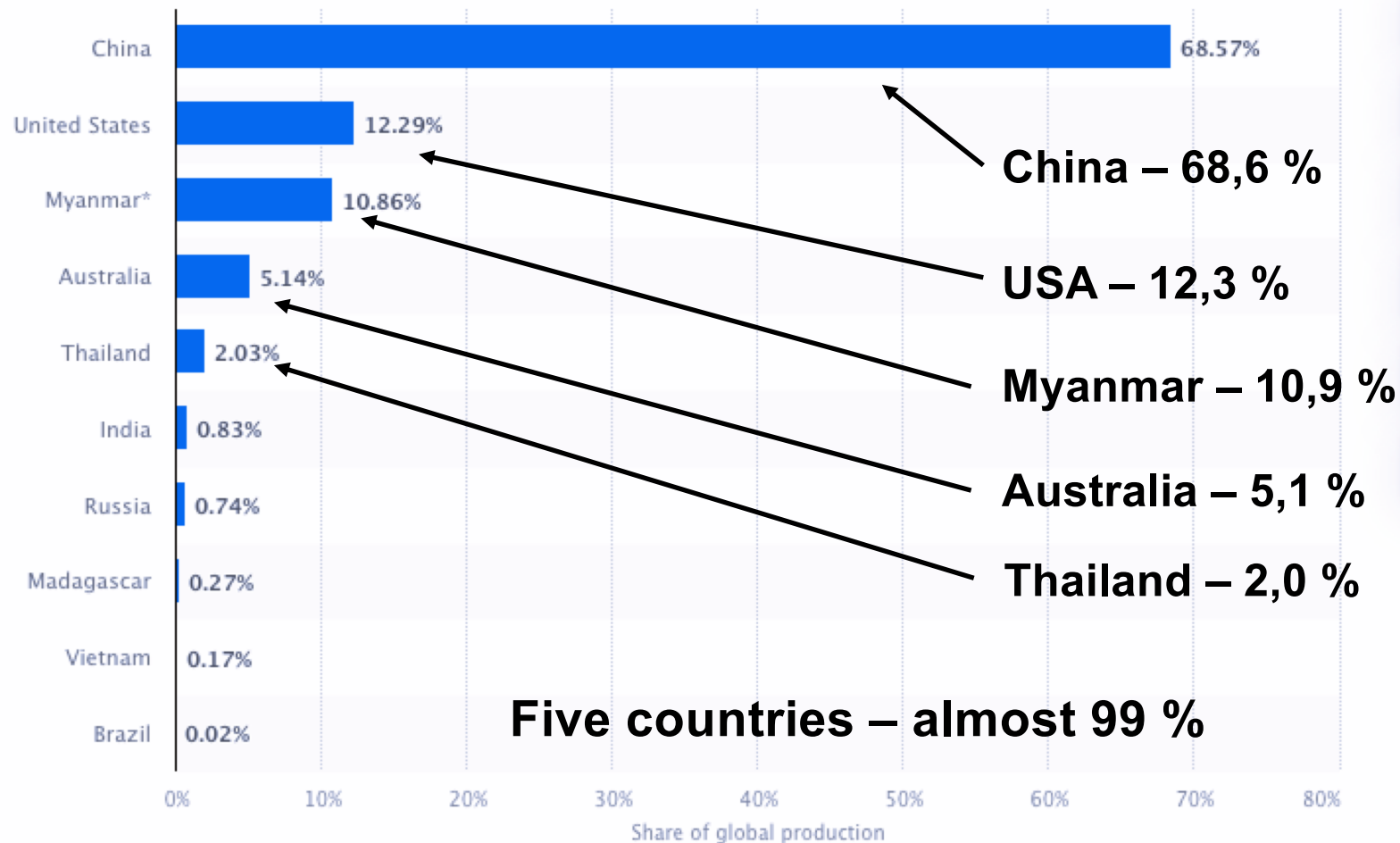


Figure 01. Graph showing world mine production of rare-earth oxides, by country and year, from 1960 to 2012. The layers of the graph are placed one above the other, forming a cumulative total. Data are from U.S. Bureau of Mines (1961–96) and U.S. Geological Survey (1997–2016).

Global Production of Rare Earth Metals in 2023 – most important countries



Recycling of non-renewable resources – metals

- **Steel** is today increasingly produced from scrap iron and some virgin metal
- Recycled **copper** is paid well
- **Lead** recycling is requested by law and is >99 %
- **Mercury** is taken out of use and stored
- Recycling of **REM** has to be improved

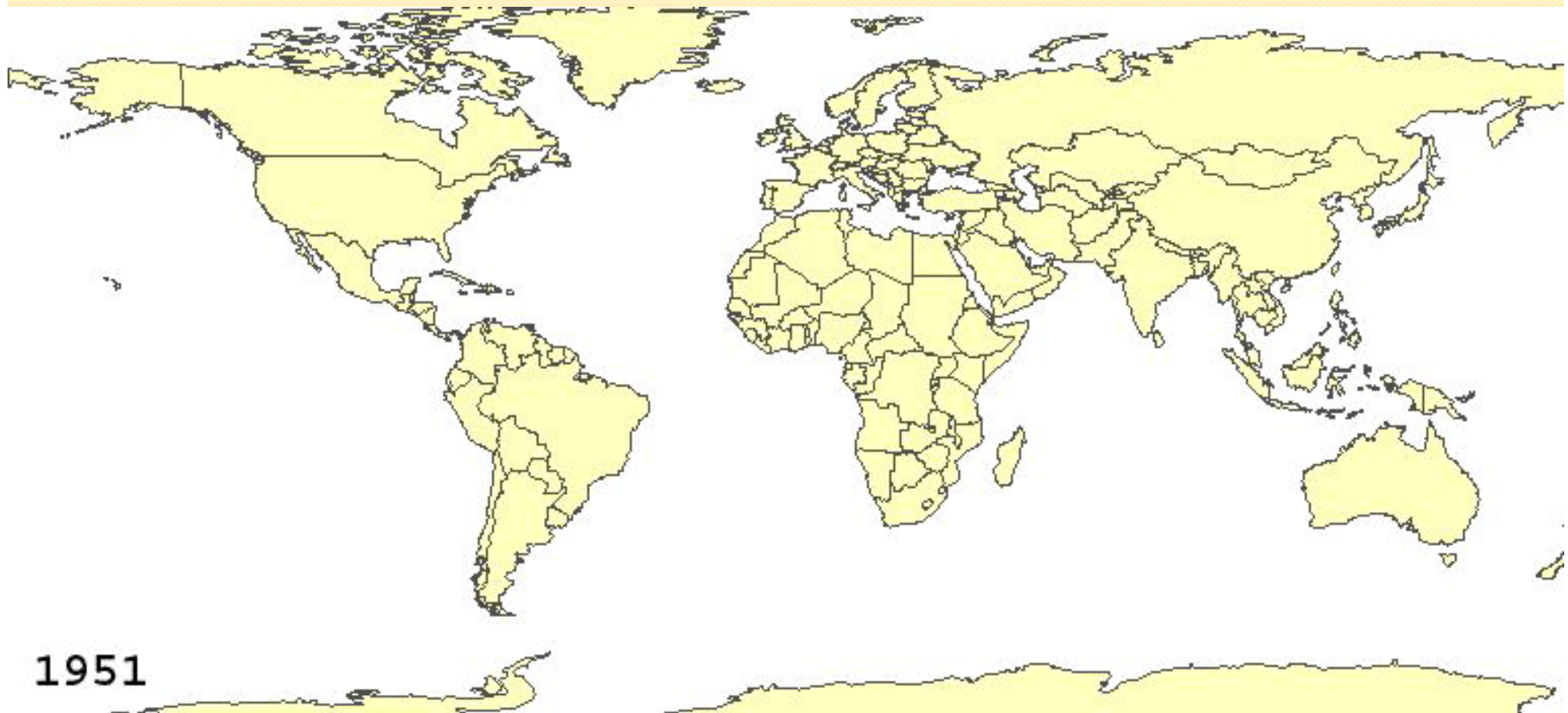
Renewable resources

These resources cannot be harvested faster than the reproduction rate; also renewable resources can be depleted and emptied!

FISHERIES

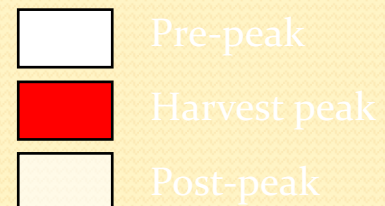


Fisheries

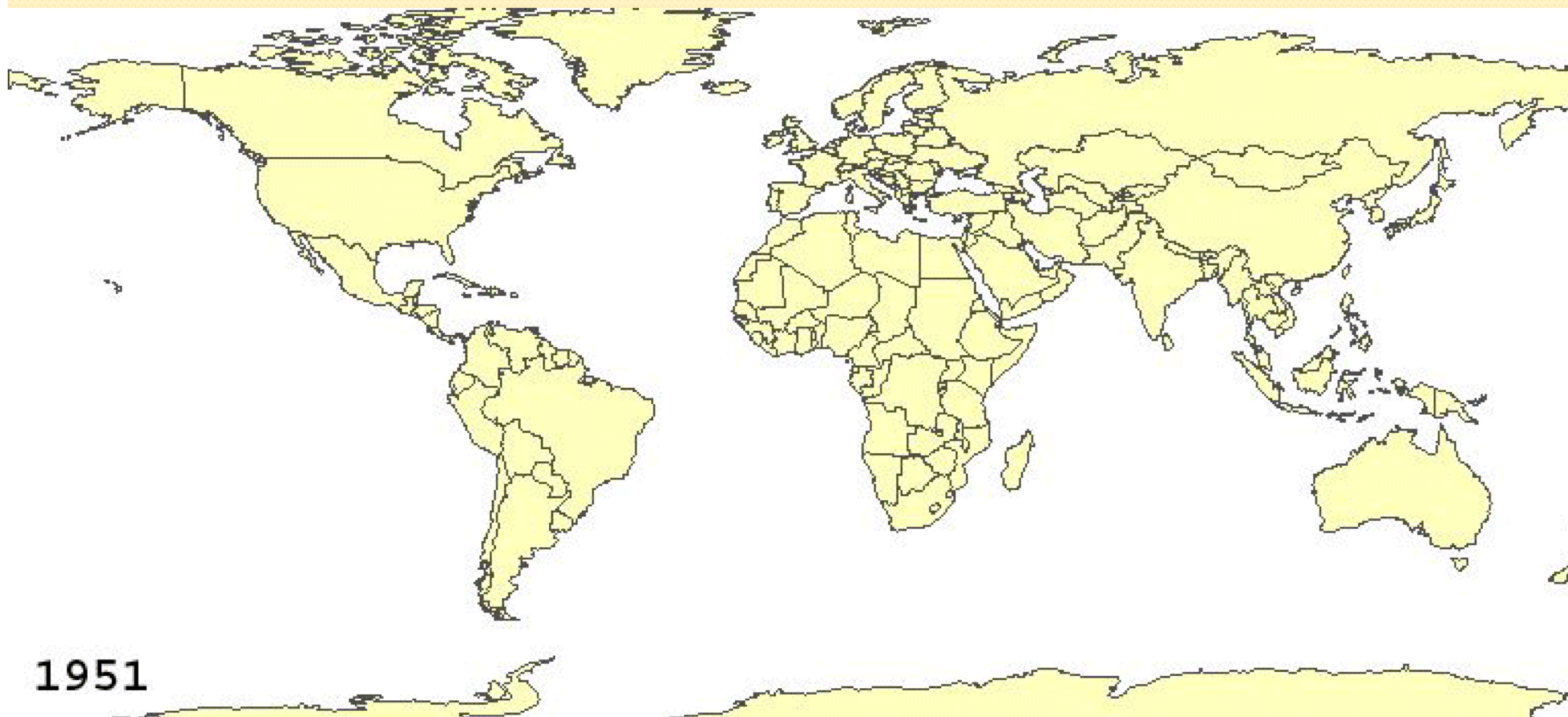


1951

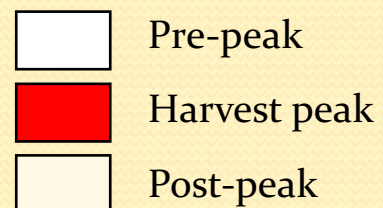
Year of Peak Fish Harvest



Source: Millennium Ecosystem Assessment and Sea Around Us project



Year of Peak Fish Harvest



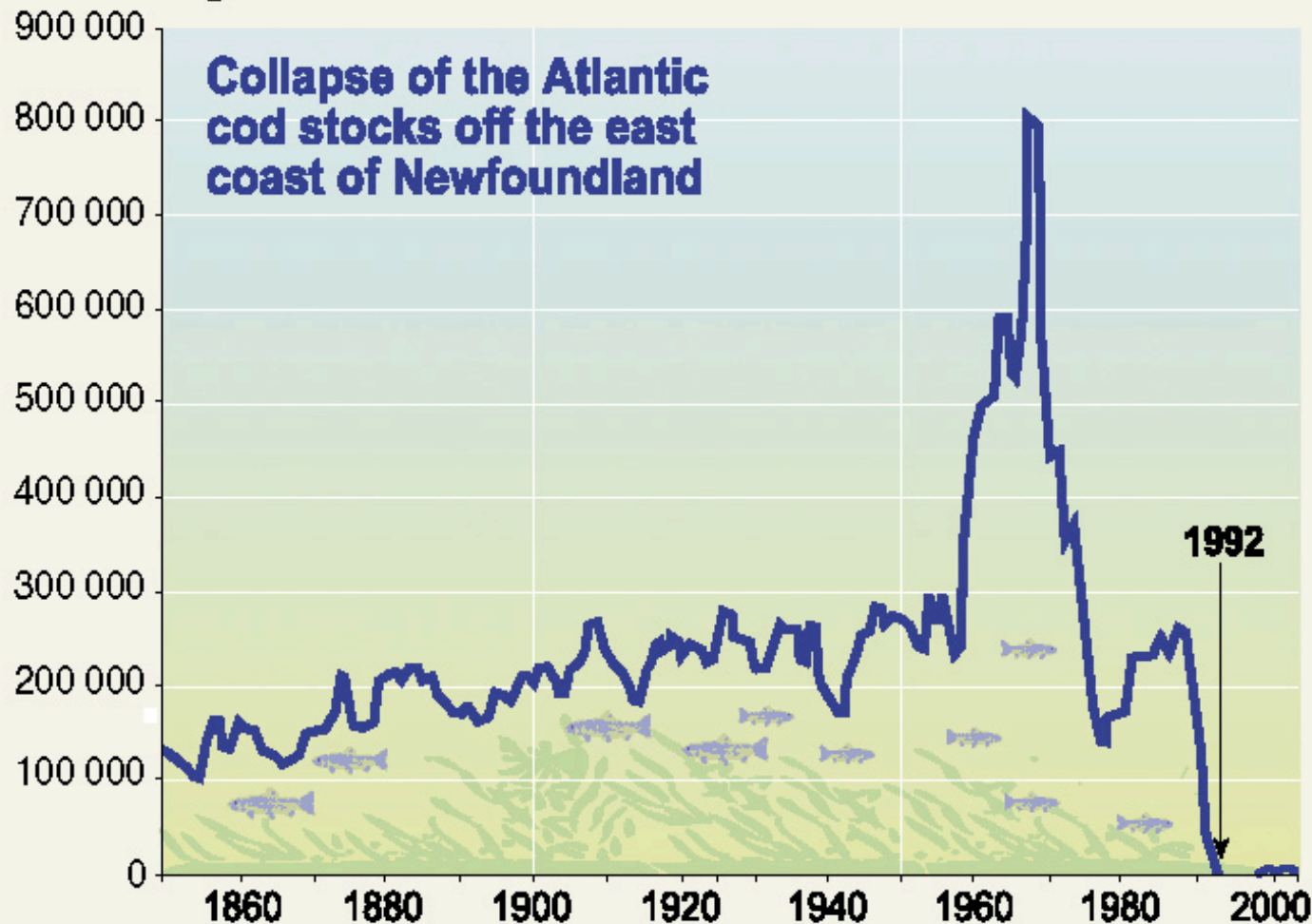
Source: Millennium Ecosystem Assessment and Sea Around Us project

MARINE FISHERIES

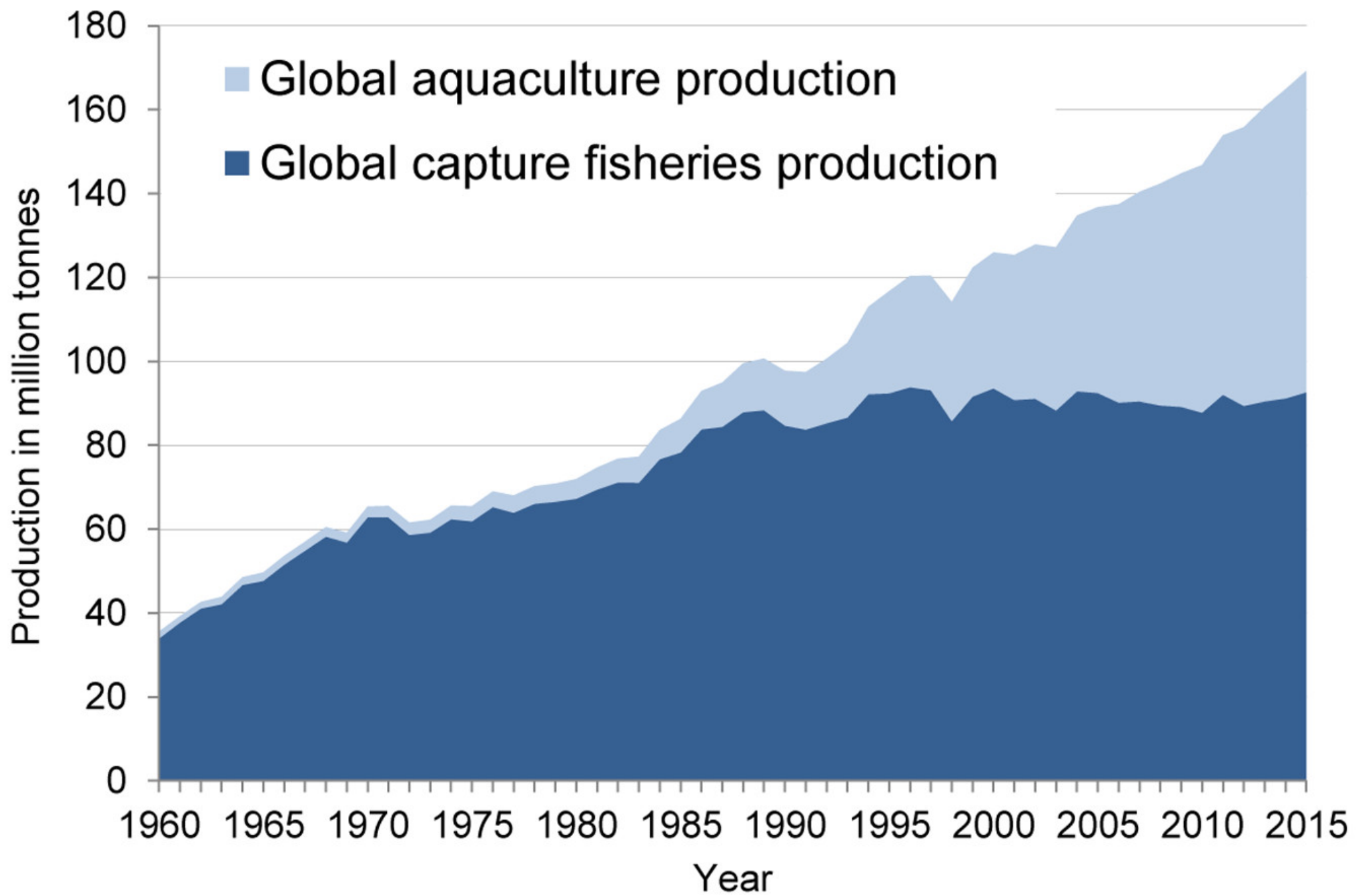
Global
Footprint
Network

The dramatic collapse of cod stocks off Newfoundland illustrates how quickly the services of an ecosystem can disappear when its resources are overexploited.

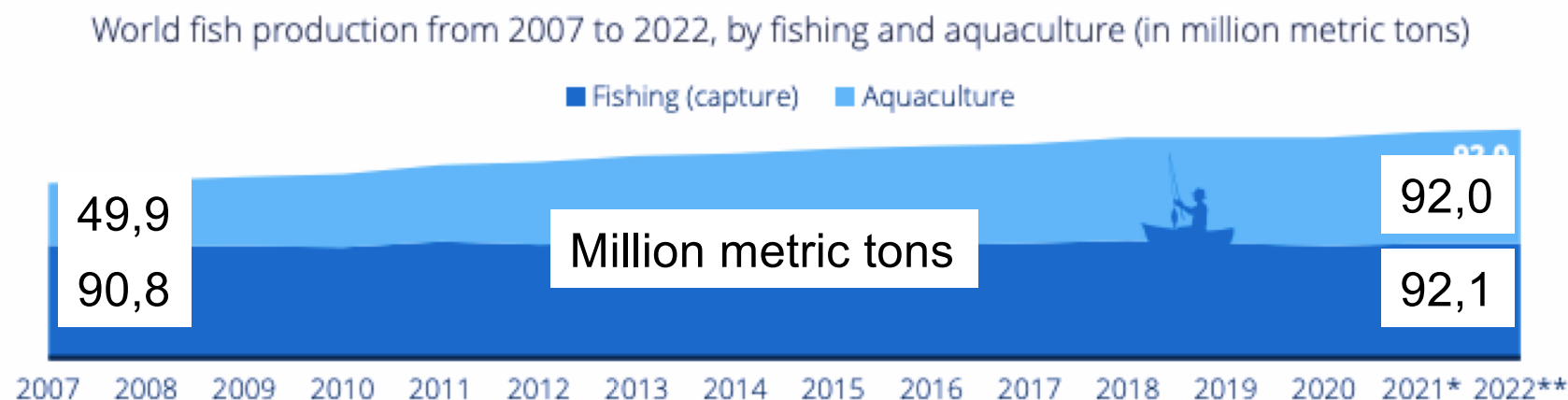
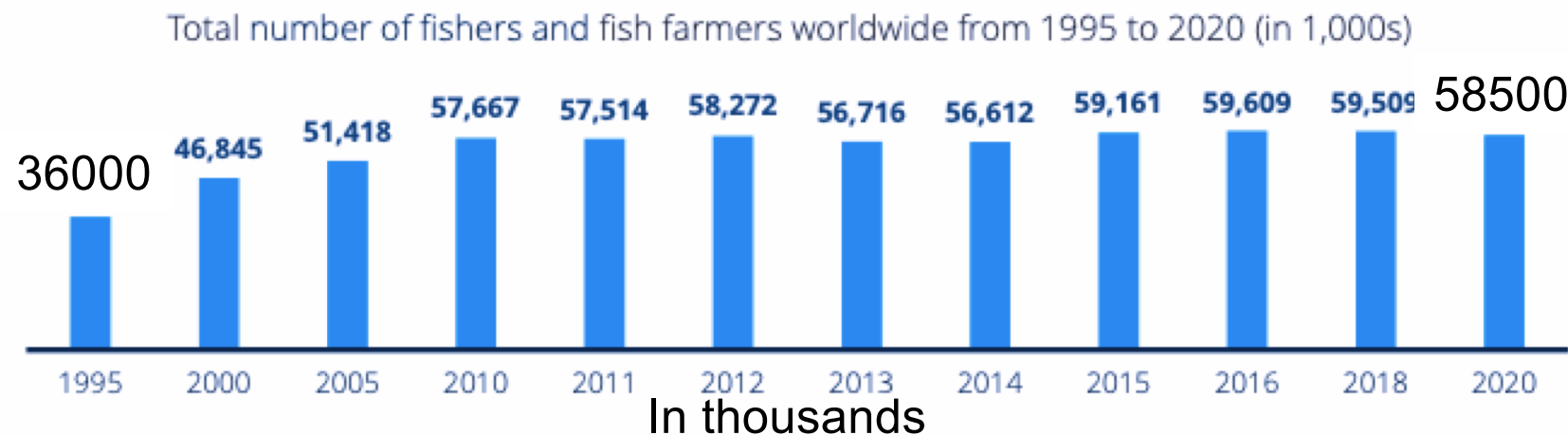
Fish landings in tons



Source: Millennium Ecosystem Assessment



Fishers and fish farmers 1995-2020 plus world fish production 2007-2020



(1) Note(s): Worldwide; 1995 to 2020; 2017 and 2019 were not provided by the source
Source(s): FAO; [ID_248767](#)

(2) Note(s): Worldwide; 2007 to 2022; *estimated; **projected
Source(s): FAO; [ID_272311](#)

FORESTS

Sustainable Forest governance is a main concern in Sustainable Development

1. Ecosystem services

- Habitat for billions and billions
- Biodiversity
- Photosynthesis & respiration
- Water retention & treatment
- Air filtration & treatment
- Recreation for humans

2. Human resource base

- Wood/timber
- Paper
- Chemicals
- Drugs
- Bioenergy

TOP SOIL



WATER



30 minutes break

- Discuss what you consider as the most important material resource for a sustainable development. Motivate your answer...

After 20 minutes we gather to listen to results of the discussion.



Concepts of identifying Unsustainability

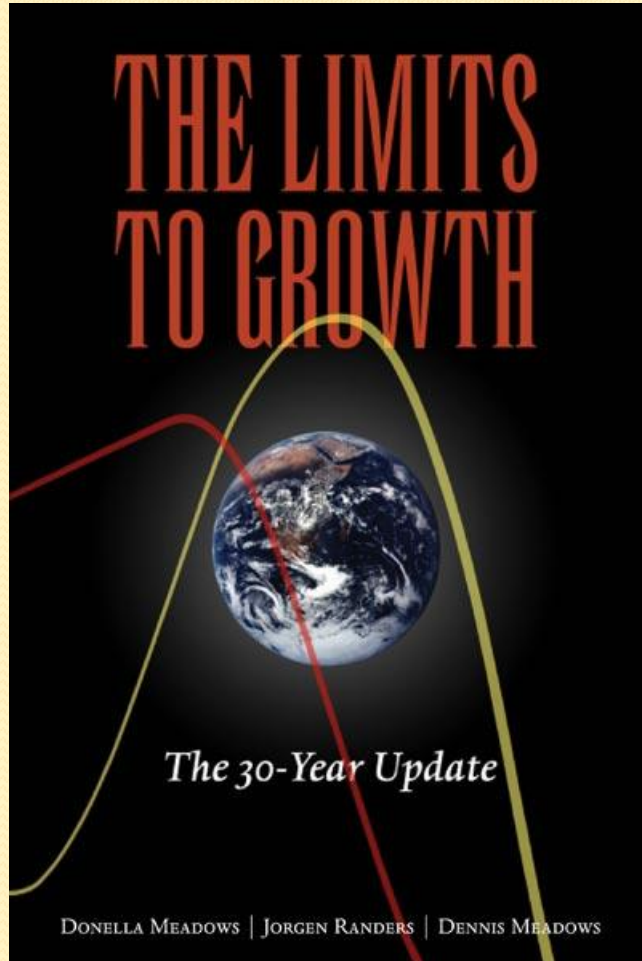
The study of the limits of global resources

1. *Limits To Growth*, Meadows et al (1972) first computer model; the Limits To Growth a 30 year update (2003).
Jörgen Randers 2052 (2012)
2. *Material flows* Wuppertal Institute and the ecological rucksack, *MIPS and Factor 10*. 1990s (Schmidt-Bleek).
3. *Ecological footprint network* and biocapacities, 1990s (Rees and Wackernagel).
4. *The Planetary Boundaries Concept*, Stockholm Environment Institute, Stockholm Resilience Centre, 2009.

Limits to Growth (1972):

The 30 year update (2003)

We are Witnessing a Terrible Validation



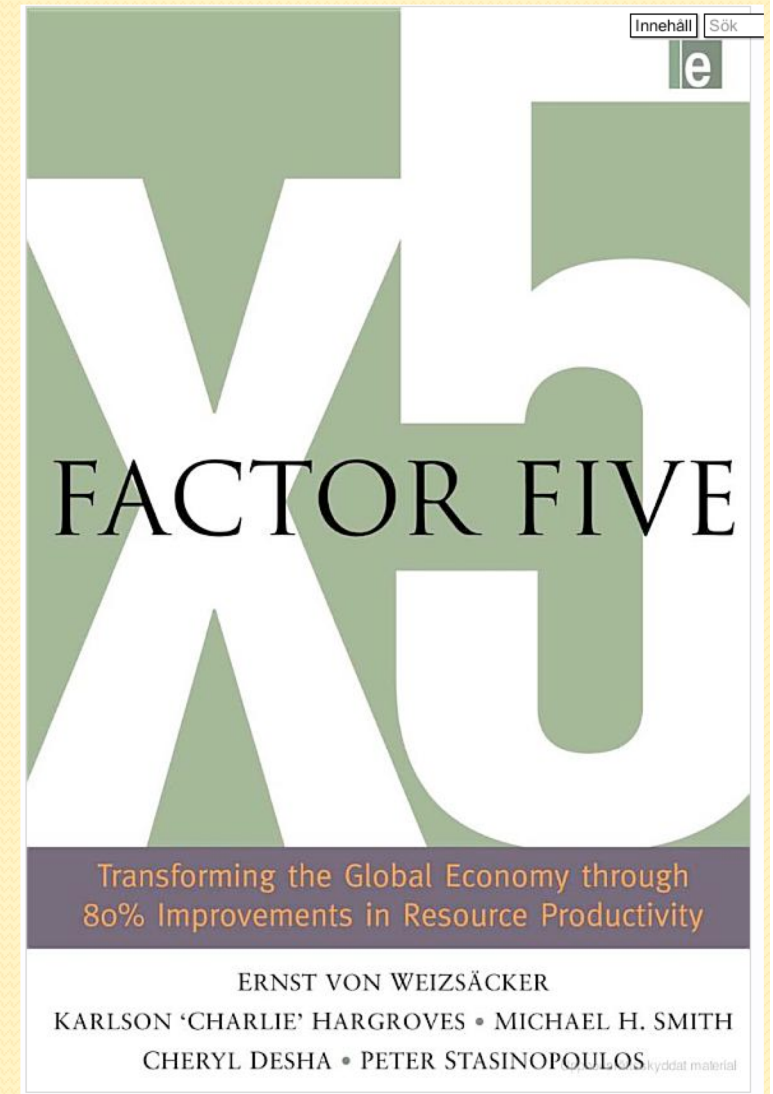
- Original “Club of Rome Report” alerted world to the dangers of continued **exponential growth against natural limits in a finite system**
- Noted that humanity had the capacity to create **systems that were sustainable**
- Vehemently attacked at the time, especially by economists
- Now validated — unfortunately — by over 50 years of data

Wuppertal Institute for Climate, Environment, and Energy

1. The MIPS Concept (MIPS = Material Intensity Per Service unit)
2. The Factor 4, Factor 5 and Factor 10 concepts for reduced material use in production

<https://wupperinst.org/en/topics>

Look for publications

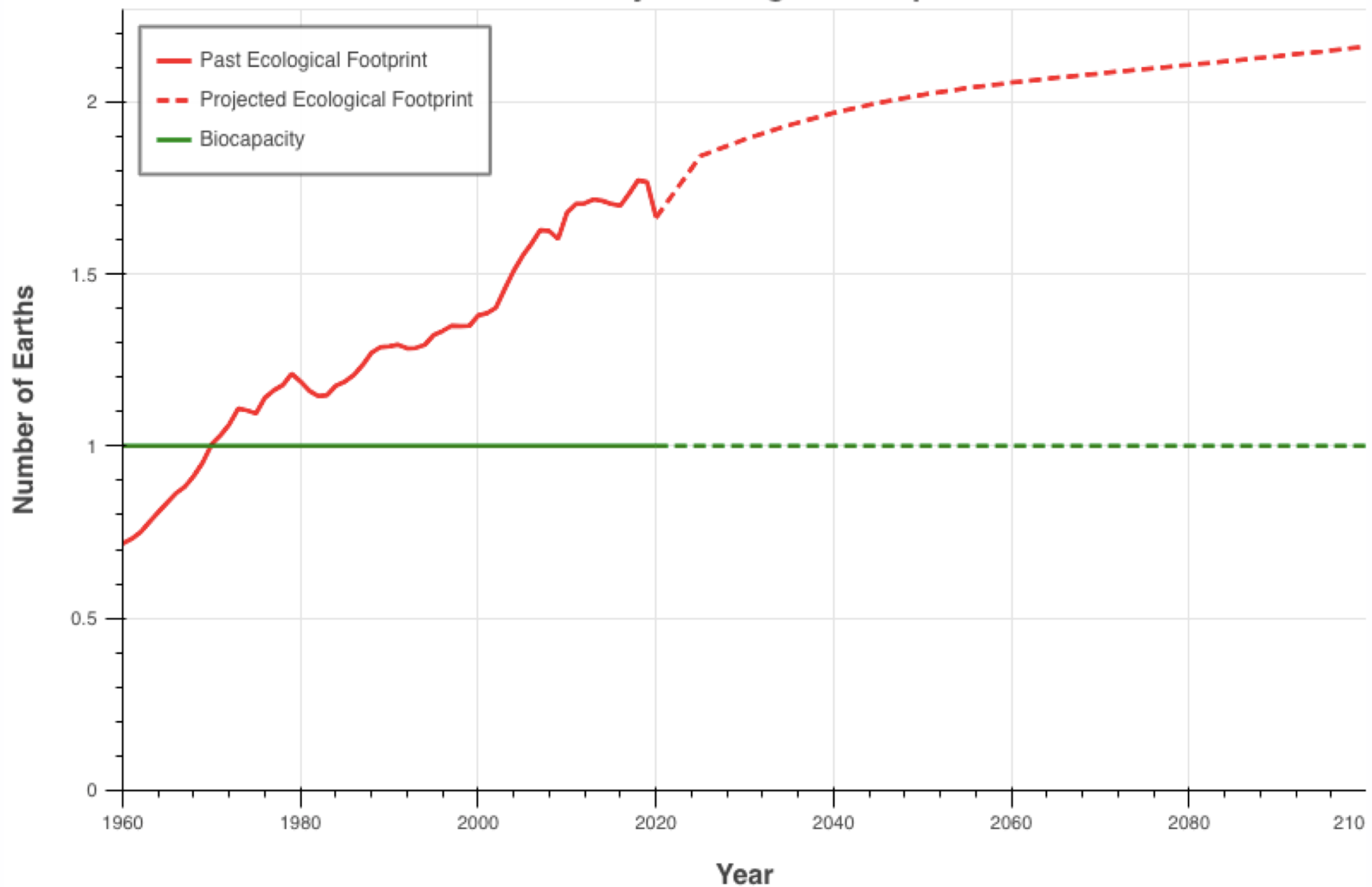


The Ecological Footprint

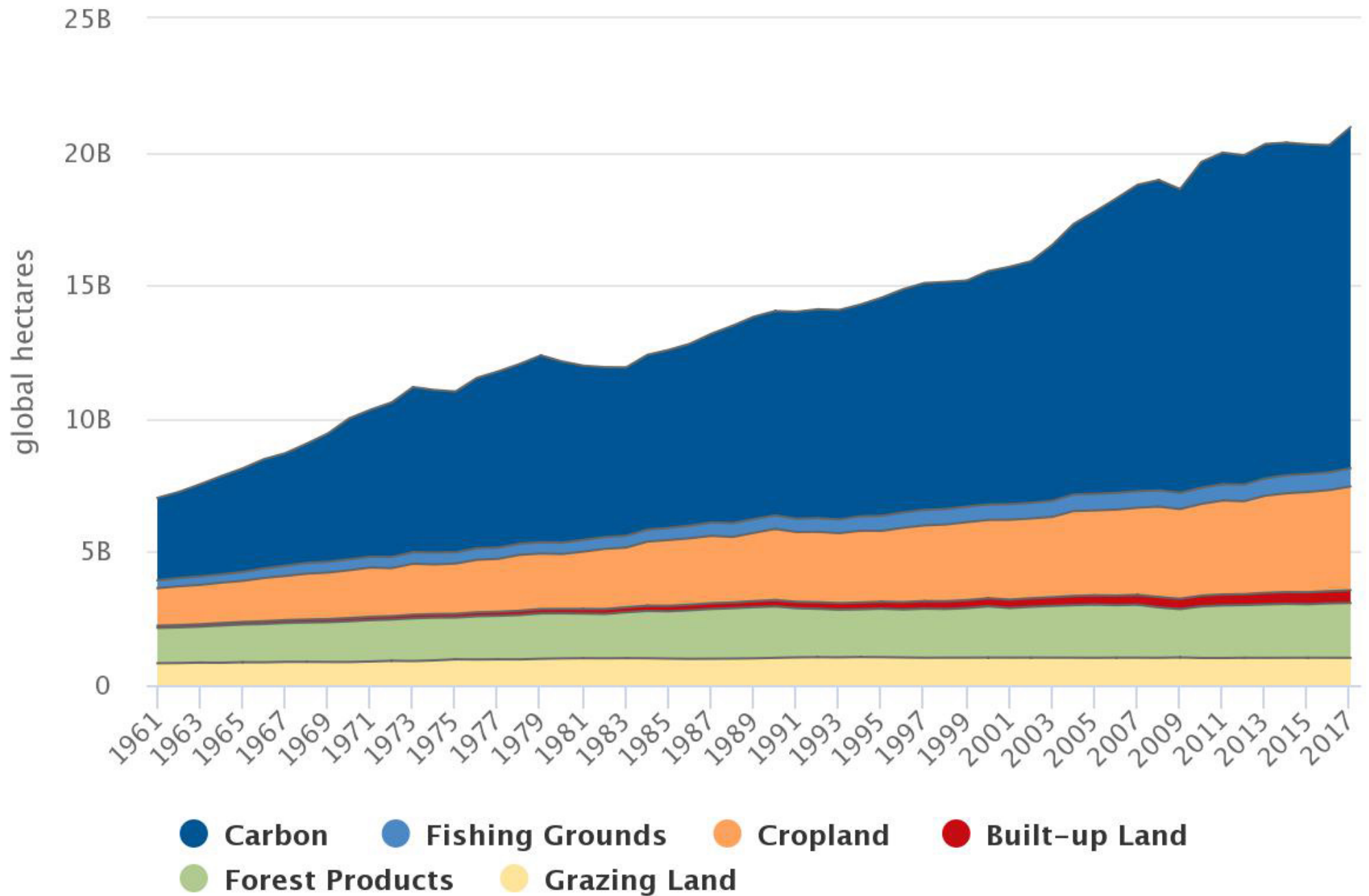
- William Rees introduced the concept of ecological footprint in 1992.
- The ecological footprint is "*the surface area a population needs to continually satisfy its needs and produce its products and services*". It is measured in so-called global ha.
- Ecological footprint is a quantitative information and not the same as environmental labelling.
- Ecological Footprint is a very pedagogical way of illustrating the unsustainability of current development, but has also been criticized
- <http://www.footprintnetwork.org>

Humanity's Ecological Footprint

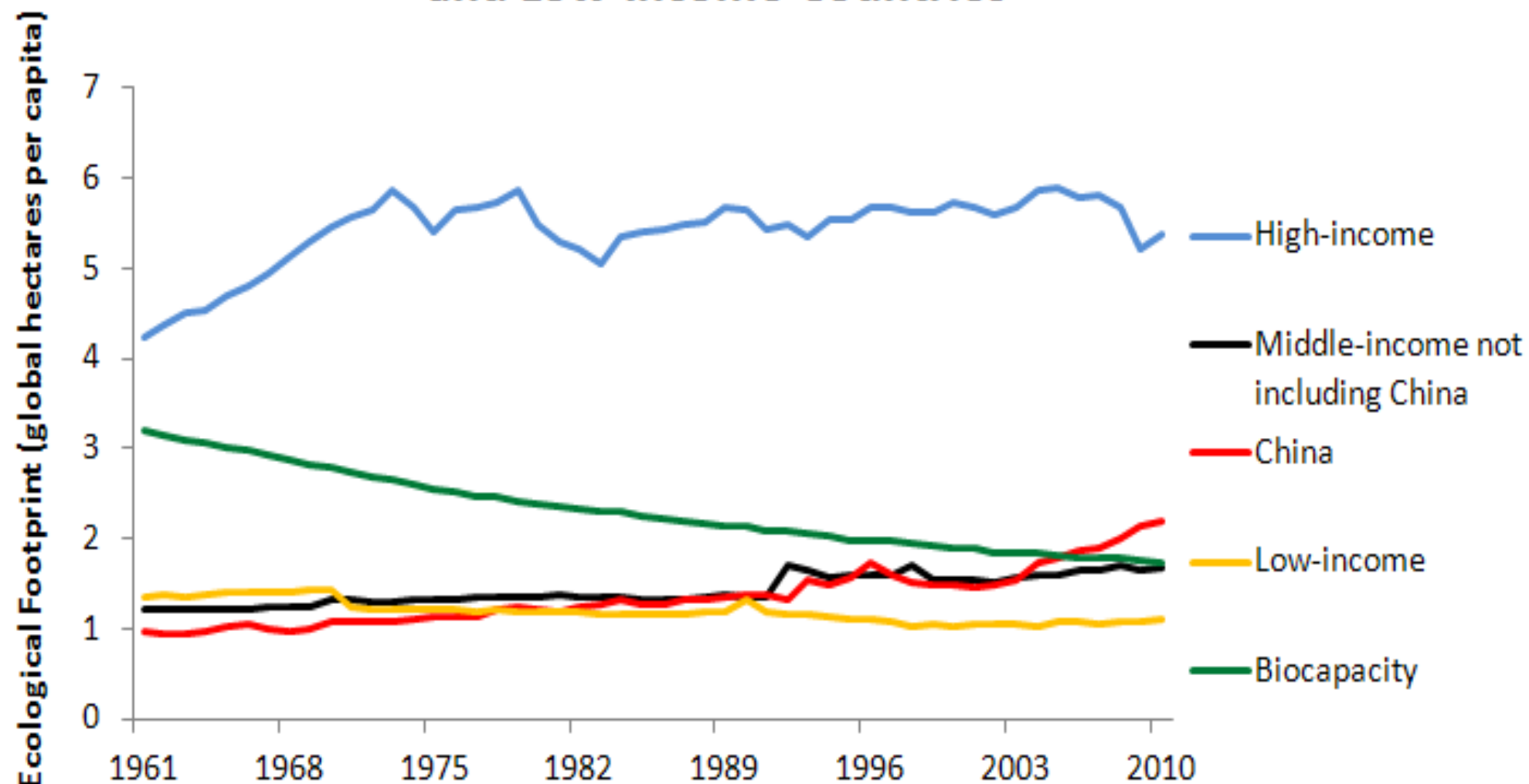
cf. <https://www.footprintnetwork.org/resources/footprint-scenario-tool/>



World Ecological Footprint by Land Type



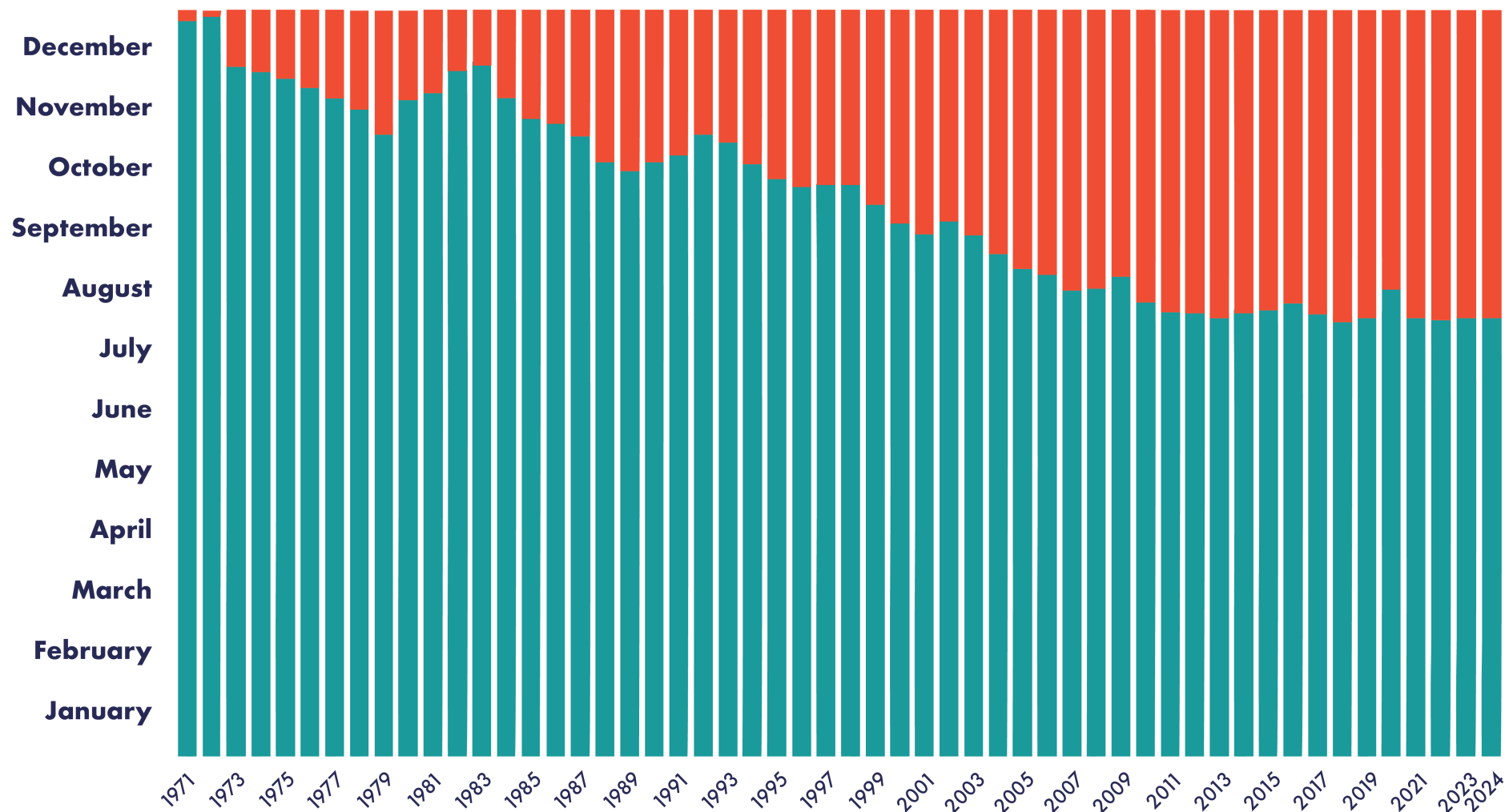
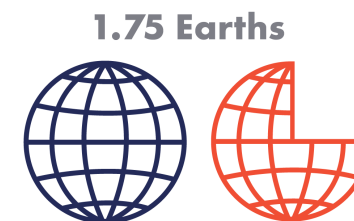
Ecological Footprint Per Capita in High-, Middle- and Low-Income Countries





EarthOvershoot Day

1971 - 2024



Global earth overshoot day

2024 was August 1st

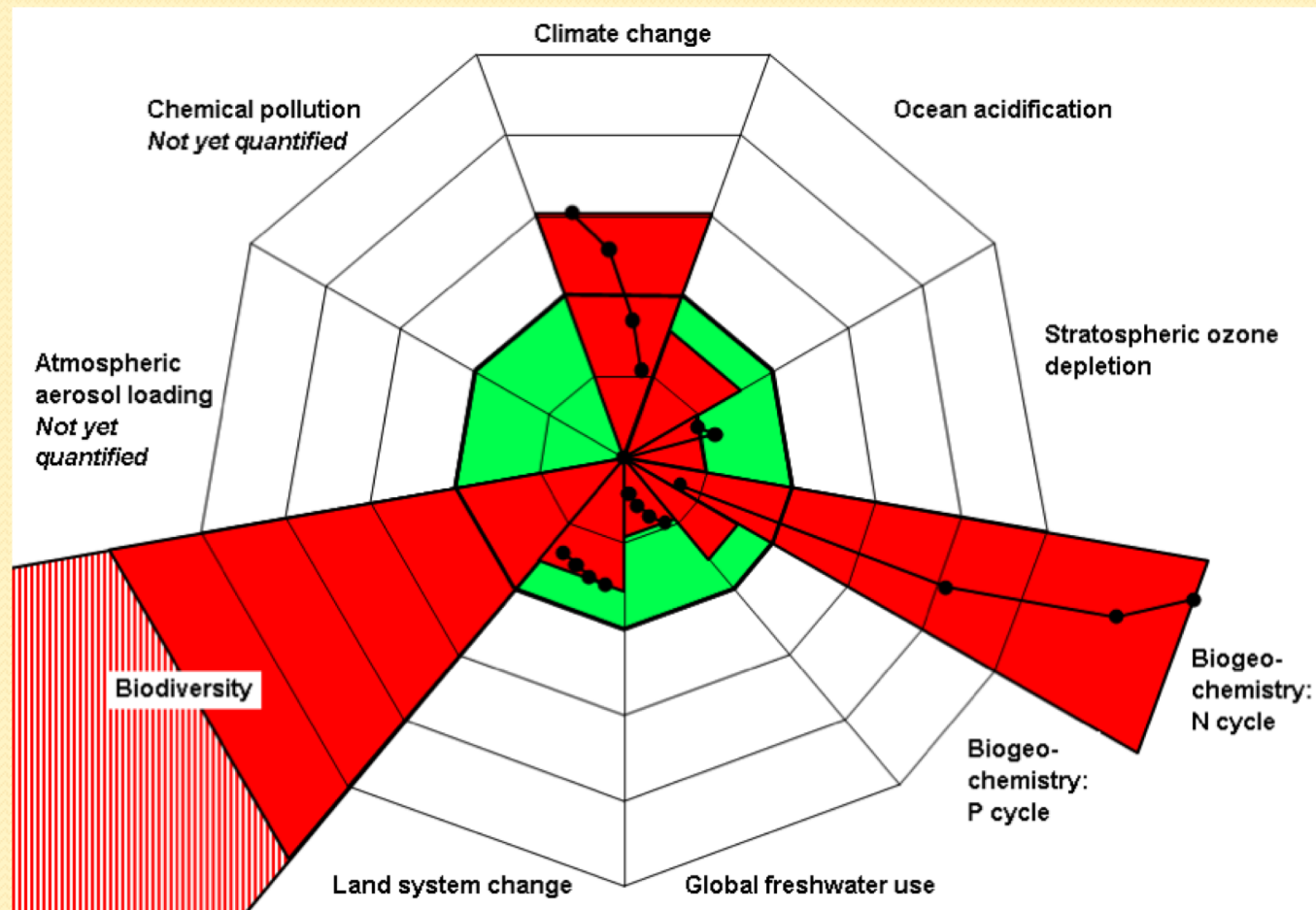
in Uzbekistan August 25, in Sweden April 10

Global ecological overshoot became a reality in the early 1970s and is driven by these key factors: how much we consume, how efficiently products are made and used, how many people are living on our planet, and how much nature's ecosystems are able to produce.

Global biocapacity is 1.6 gha per person (in 2017). To support human activities today we use just over 1.6 Earths per year. To keep up with our level of demand by 2030 we would need the capacity of two Earths. This puts the well-being of many of the planet's residents at risk.

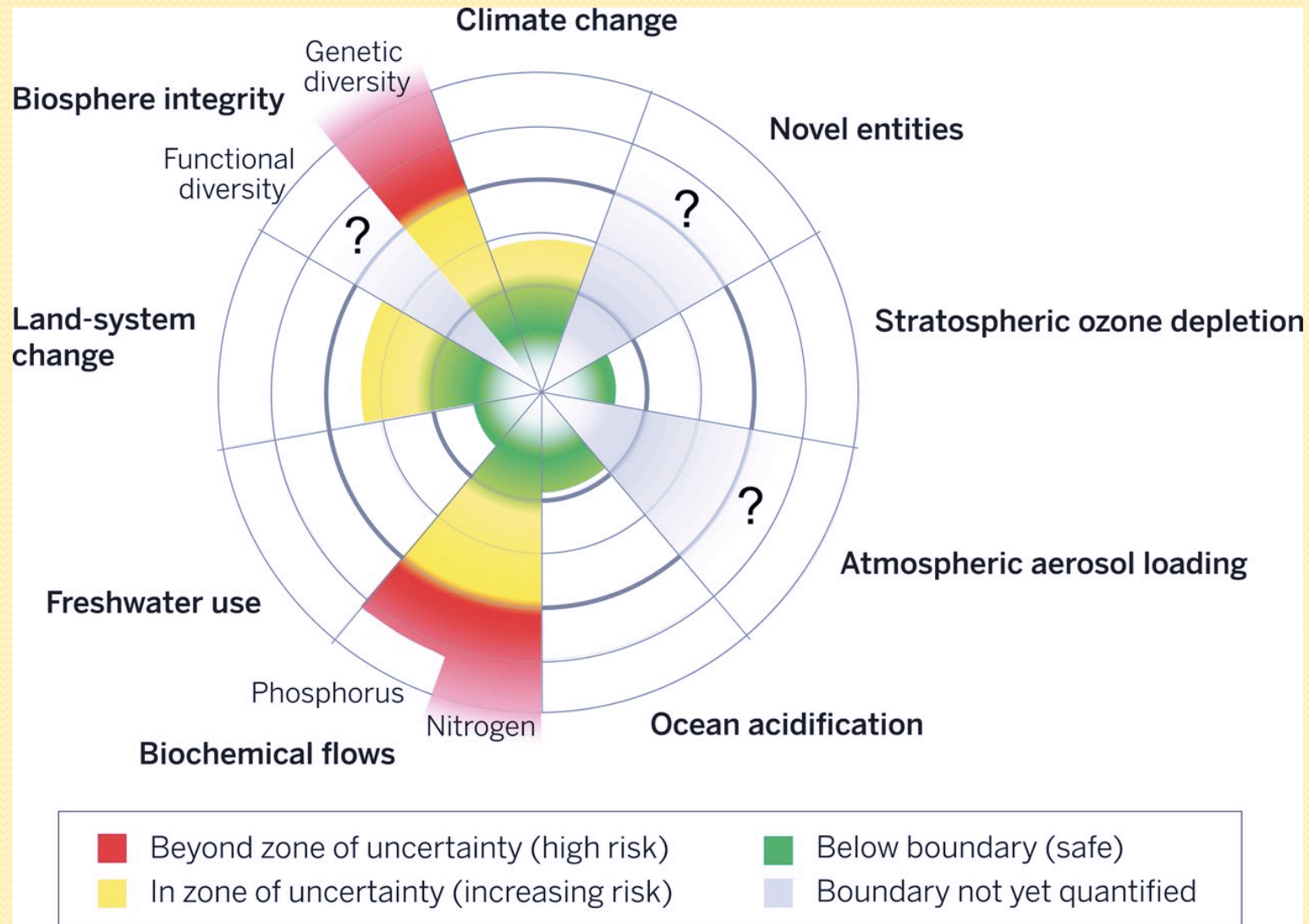
The Planetary Boundary Concept

Planetary Boundaries 1: A stable operating space for humanity, NATURE Vol 461. 24 September 2009.



The Planetary Boundary Concept

Planetary Boundaries 2: Steffen et al 2015.





**How can we
improve things?**

**There are many ways to an
increased resource efficiency!**

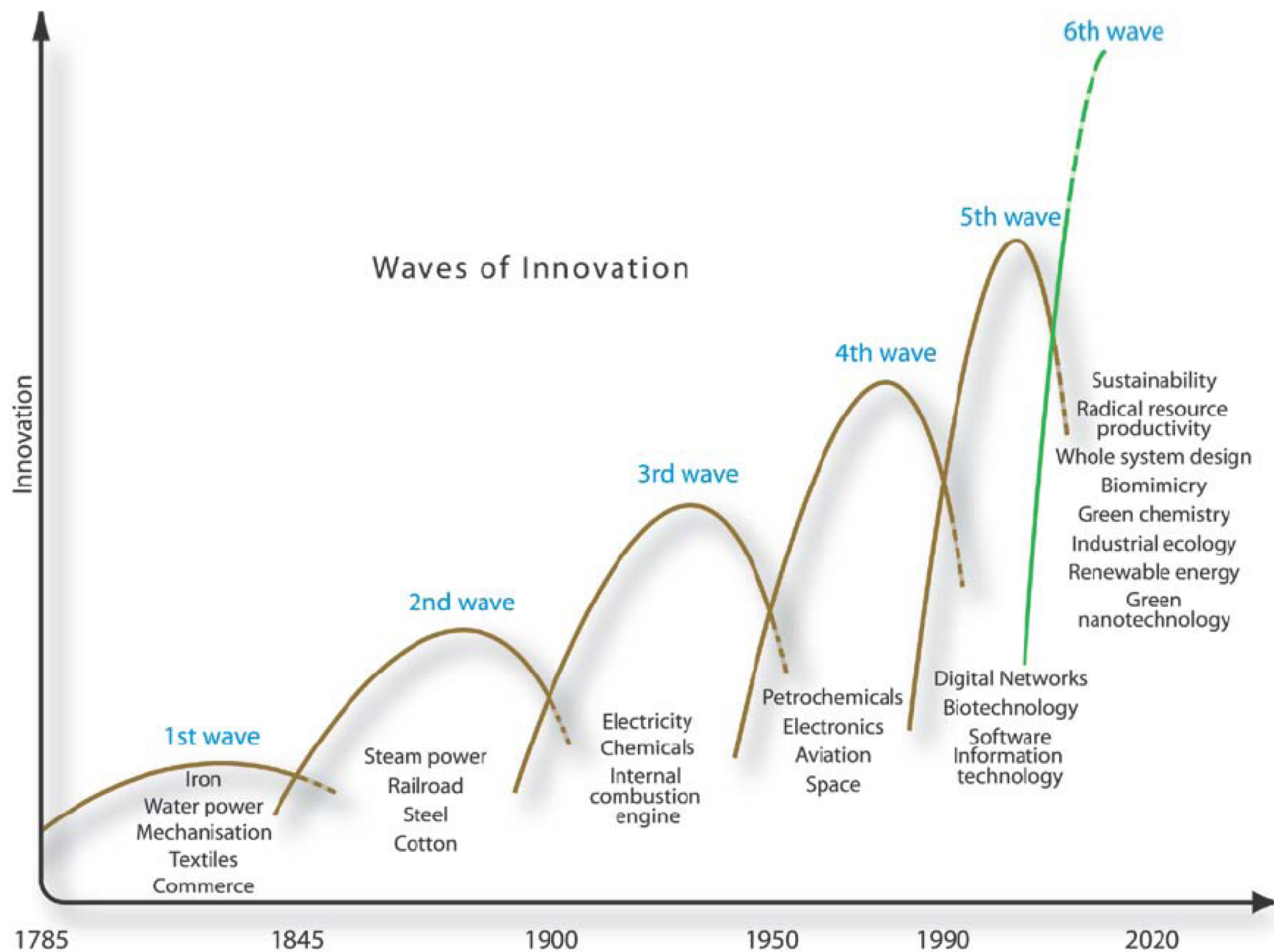


Figure 4 *Waves of Innovation*

Source: Courtesy of The Natural Edge Project¹⁹

3R

Reduce-Reuse-Recycle

3R

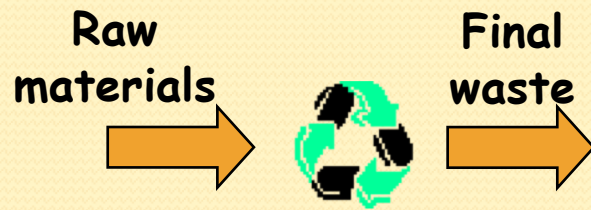
Reduce-Reuse-Recycle

4R

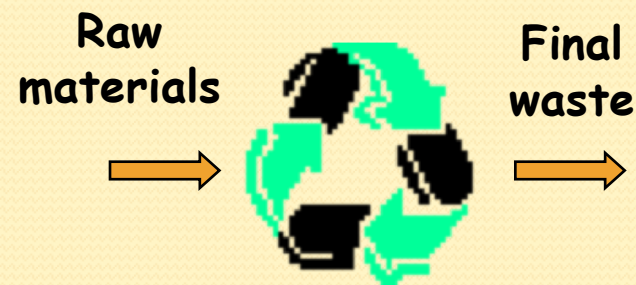
**Reduce-Reuse-Recycle-
Recover**

The Future Circular Economy

Resource Management can be improved!



Schematic situation today
Relatively high raw material use
Relatively low recycle rate



Schematic future situation
Relatively lower raw material use
Relatively higher recycle rate

**The production itself is a very
important part – it may be
improved tremendously by**

Cleaner Production, CP

**Cleaner Production is good
not only for the environment
but also for the economy!**

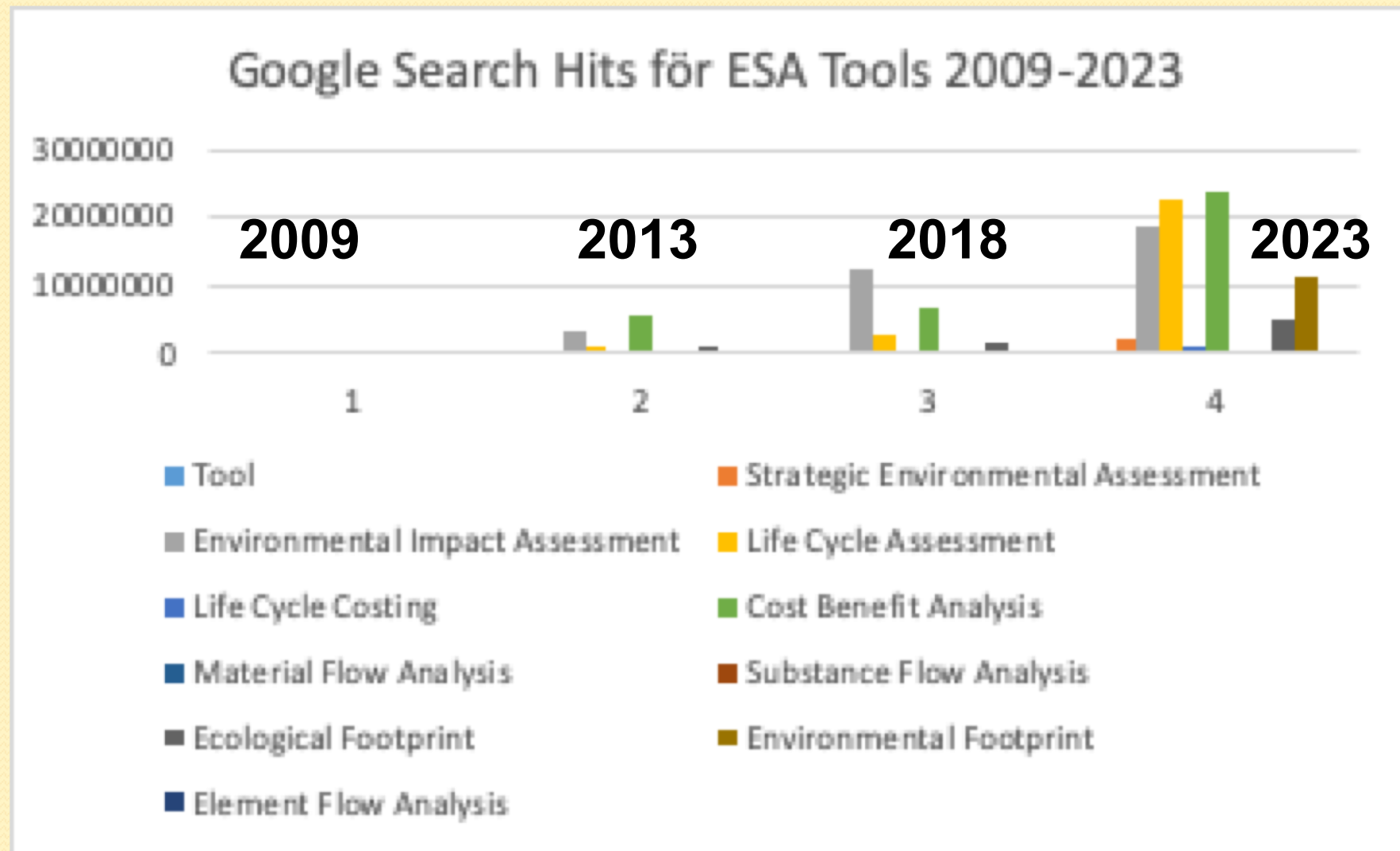
Of course!

**You make products efficiently,
not pollutants - inefficiently**



Quantification of resource flows

Quantification of Resource Flows – Google Hits for 2009, 2013, 2018 and 2023



Ecological Rucksack

Today, less than 5 % on average of the material resources taken from nature ends up in products. The rest becomes waste on the way. Some 30 tons of nature is used to create one ton of car – without counting water consumption - and for many industrial goods the ratio is similar.

Information and Communication Technology [ICT]: the costs for one message on Internet is equal to that of producing four aluminum cans for soft drinks.

Wuppertal Institute – Material Intensity factors of materials and energy sources
<https://www.gdrc.org/sustdev/concepts/27-rucksacks.html>

Life Cycle Assessments, LCA

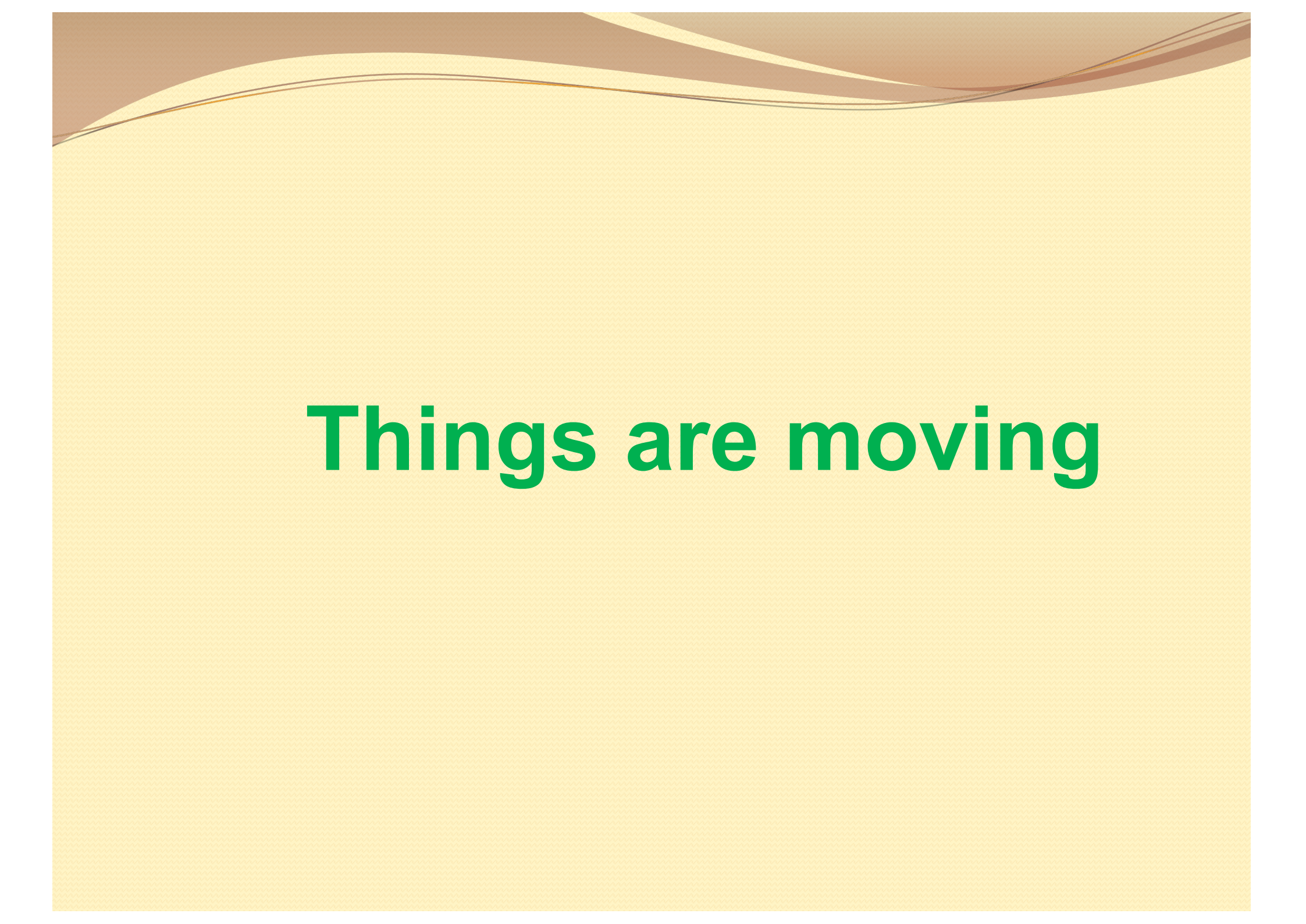
Material intensities

Material intensities can be used for calculating LCA for many products.

Ecological Rucksack for the cradle to the point of sale, the amount of material used which is not in the product itself can be calculated from LCA.

MIPS for cradle to cradle Material Input [in kg] Pro unit Service (per unit value or utility) obtained.

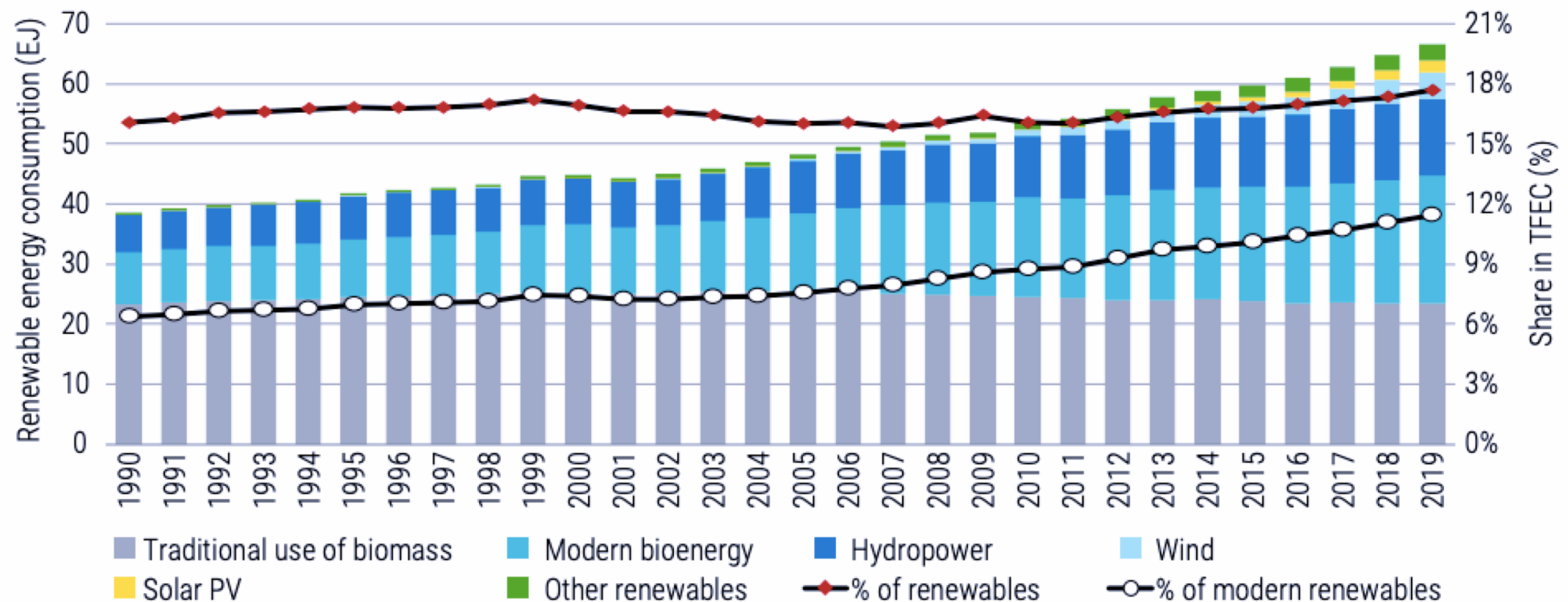
Material intensities and LCA for many products are available in databases. Total Material Flows, TMF output and input, are available for many countries.

The background of the slide features a light beige or cream-colored field with a fine, repeating halftone dot pattern. At the top, there are several overlapping, wavy, horizontal bands in shades of tan and light brown, creating a sense of depth and movement. The text "Things are moving" is centered in a bold, green, sans-serif font.

Things are moving

Renewable Energy in the world

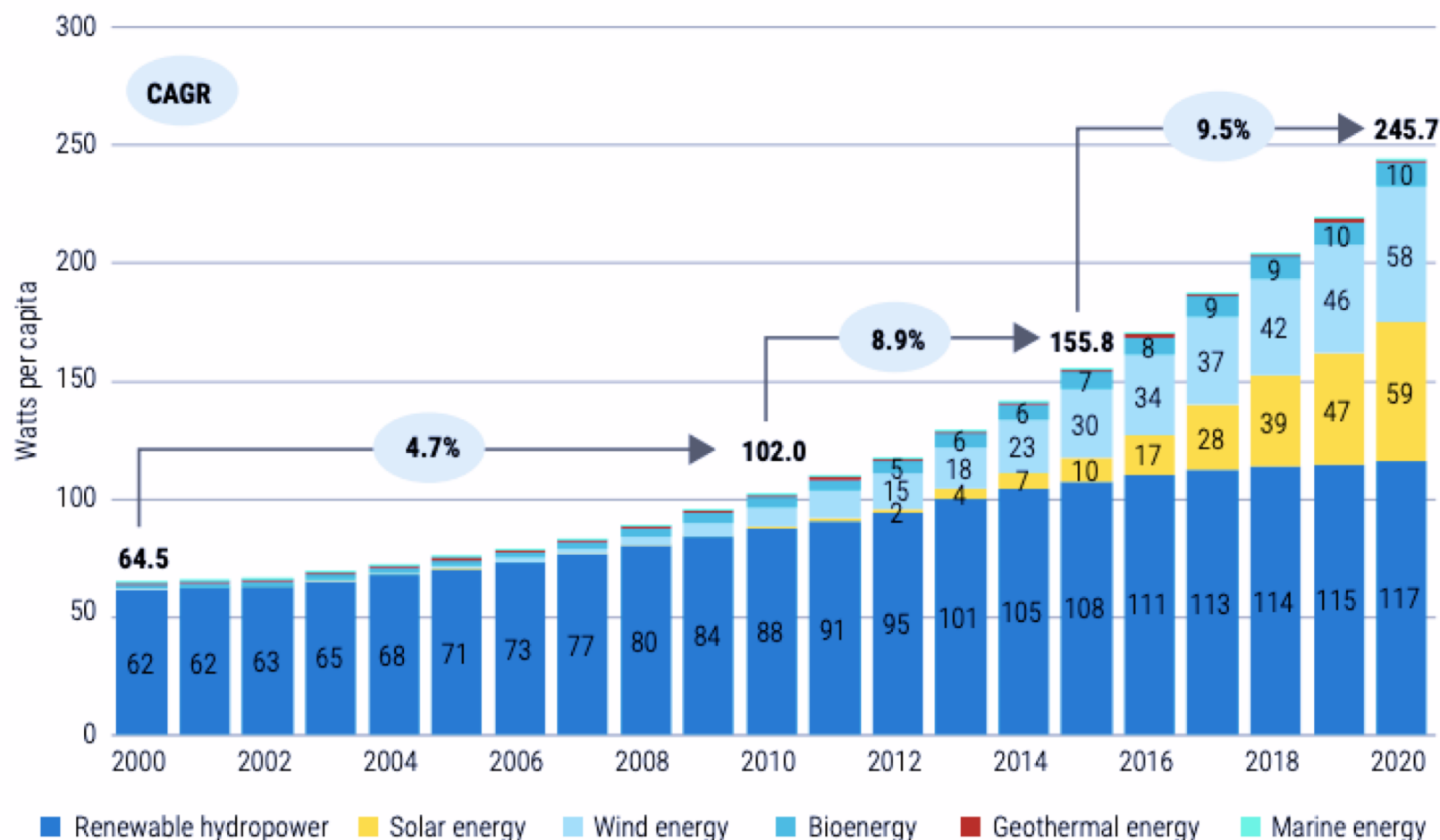
FIGURE ES.5 • Renewable energy consumption by technology and share in total energy consumption, 1990-2019



Source: IEA 2021a and UNSD 2021.

Installation Rate of Renewable Energy in Developing Countries

Figure 3.3 • Renewable installed capacity per capita in developing countries (2000–20) and compound annual growth rate for selected periods



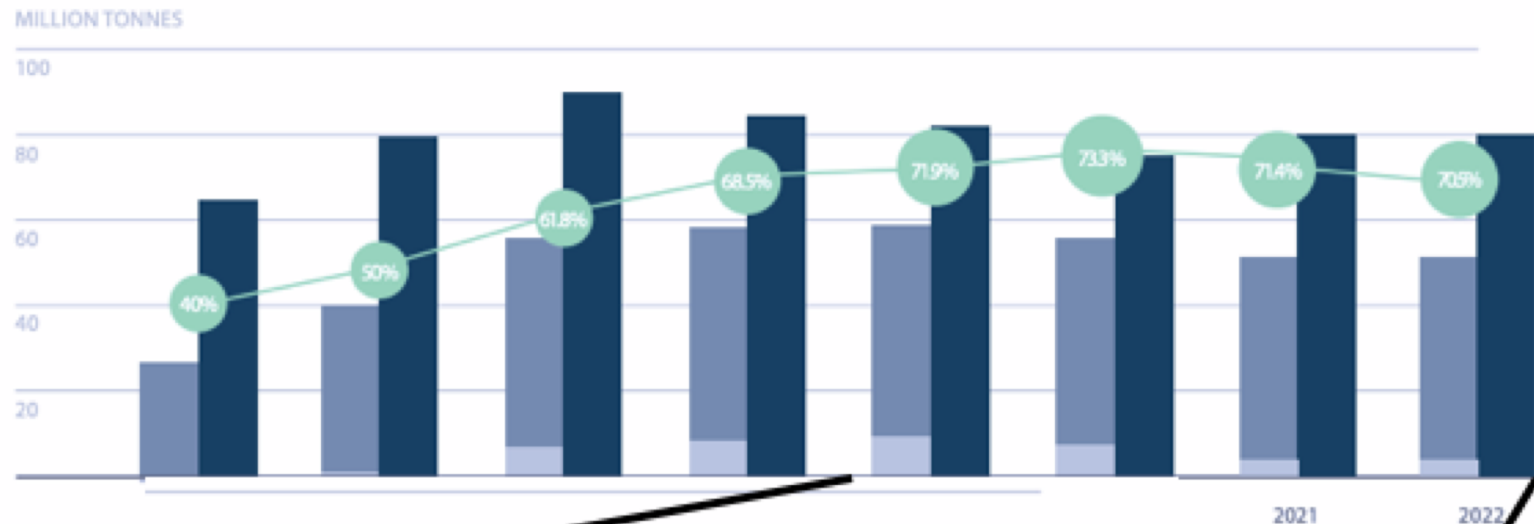
Source: International Renewable Energy Agency (IRENA, 2021b)

Paper and board recycling in Europe

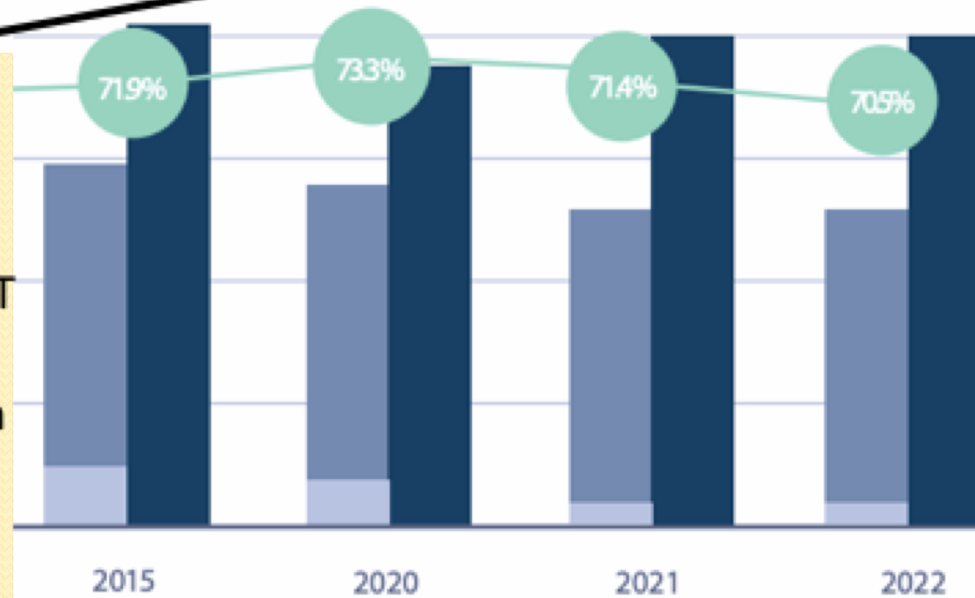
EUROPEAN RECYCLING 1991-2022

Source: Cefi 2022

- Recycling outside Europe
- Recycling inside Europe
- Paper and Board consumption in Europe
- Recycling Rate



Source:
MONITORING REPORT
2022
European Declaration
on Paper Recycling
2021-2030



70,9%

Recycling
Rate 2022

Two initiatives for improved resource use

1. Cradle to Cradle Products Innovation Institute

<https://c2ccertified.org/>

Mission statement: "We are powering the shift to a circular economy by setting the global standard for materials, products and systems that positively impact people and planet".

2. The MacArthur Foundation

<https://www.macfound.org/about/>

The MacArthur Foundation boldly invests in creative solutions to urgent challenges, sparking hope for our future.

Key Messages

- The use of energy and physical matter in the global economy (the physical resource metabolism) has increased tremendously during the last century and is still increasing – this is regarded as ecologically unsustainable
- The climate issue is the single most burning aspect of current development, but several other ecological issues are in critical condition, e.g. water availability and biodiversity loss
- The access to energy and material goods is very unevenly distributed between people in different countries
- Many positive developments in renewable energy supply and mitigation of ecological threats are at hand, but has yet not been able to change the overarching ecological threats – the transition will have to accelerate...

The top of the slide features several overlapping, wavy lines in shades of brown and tan, creating a decorative header effect.

Something to practice

Estimate your footprint

1. Global Footprint Network

How much land area does it take to support your lifestyle? Take this quiz to find out your Ecological Footprint, discover your biggest areas of resource consumption, and learn what you can do to tread more lightly on the earth.

www.footprintcalculator.org.

2. World Wildlife Found, WWF

Worried about your impact on the environment? The way we use the planet's resources makes up our ecological footprint. Measuring yours takes less than 5 minutes and could set you on a life-changing journey...

<https://footprint.wwf.org.uk/#/>

3. Earthday Network

Welcome to the Earthday Network Footprint calculator

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

<https://footprintcalculator.henkel.com/us>

To read

Lecture 2. Flows and Stocks of Resources in the form of Energy and Materials

- IEA (2023) World Energy Outlook 2023 (Executive Summary, pp 22-27), International Energy Agency,
<https://iea.blob.core.windows.net/assets/86ede39e-4436-42d7-ba2a-edf61467e070/WorldEnergyOutlook2023.pdf>
- IBRD (2022) Tracking SDG7: The energy progress report 2023 (Executive Summary, pp 1-4), International Bank for Reconstruction and Development/ The World Bank Washington DC 20433, USA,
<https://www.irena.org/Publications/2023/Jun/Tracking-SDG7-2023>
- Sustainable Use and Management of Natural Resources. Chapter 2 *The planet and its natural resources*. pp 26-45.
- Sustainable Use and Management of Natural Resources. Chapter 11 *Reducing the resource flows by a Factor of 4, 5 or 10*. pp 189-207.

The top of the slide features several overlapping, wavy lines in shades of brown and tan, creating a decorative header.

Thanks for your attention!

bjornfrostell@gmail.com