Agenda for this week

The grand picture (Sustainability @ "Anthropocene")

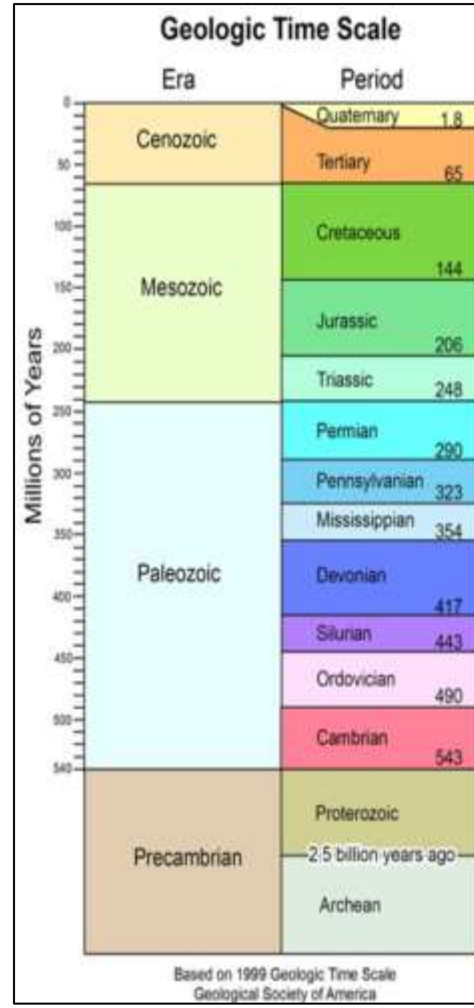
- Human habitat and resources.

- Sustainability of Human Activity & Life on Earth,
  Limit to growth, Club of Rome,
  Socio-economic/ecological network.

- Finite resources: arable land and water for food production, materials for fabrication & construction, fuels for machinery & transportation,
  Human eco-footprint, choices, and dilemmas,

- Energy utilization and environment,
  Energy consumption and human development
  External costs of energy use,
  Planetary climate, greenhouse effect.

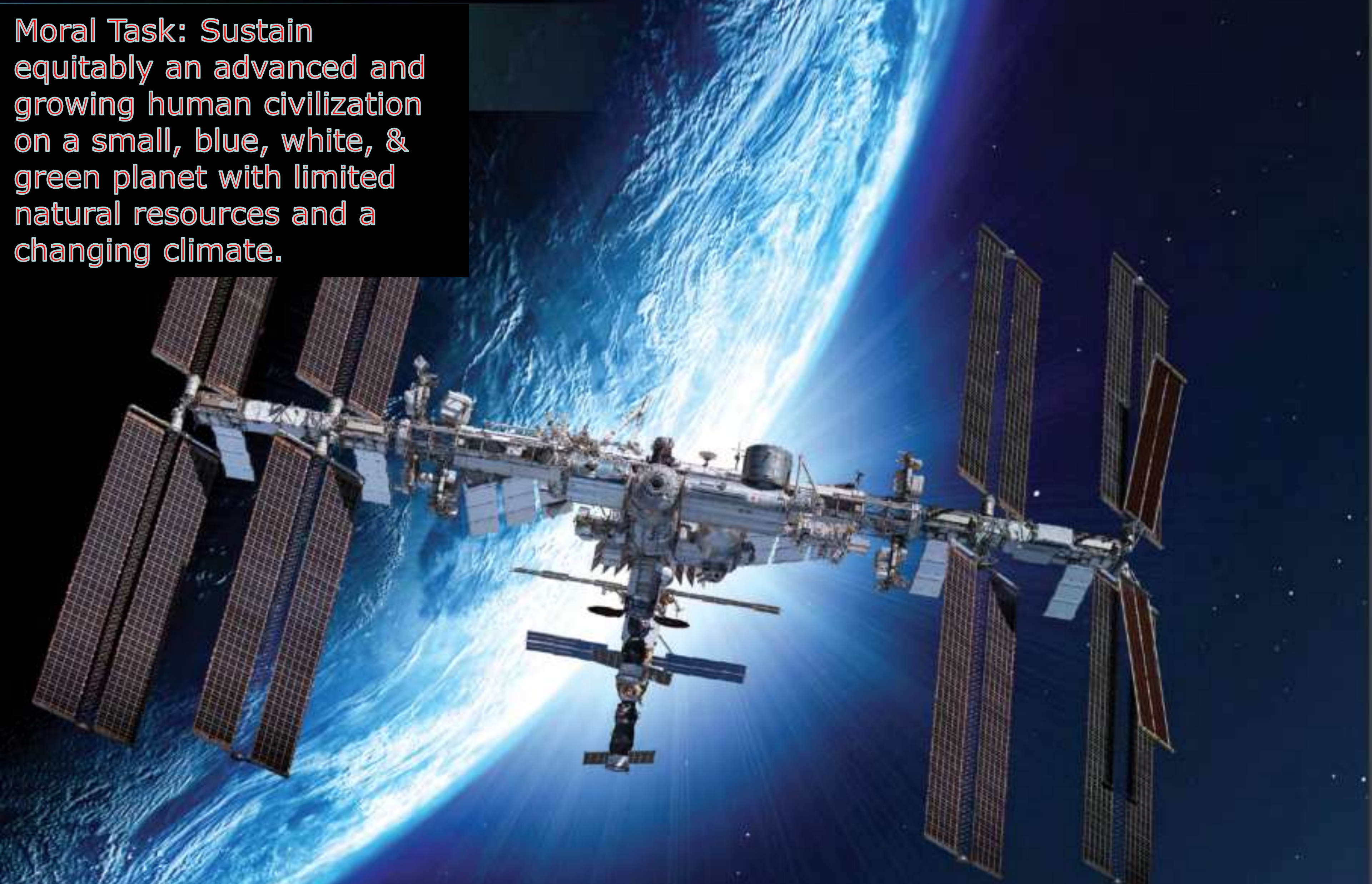
- Stated (aspirational) and actual public policies, mitigation vs. adaptation to environmental & resource challenges.



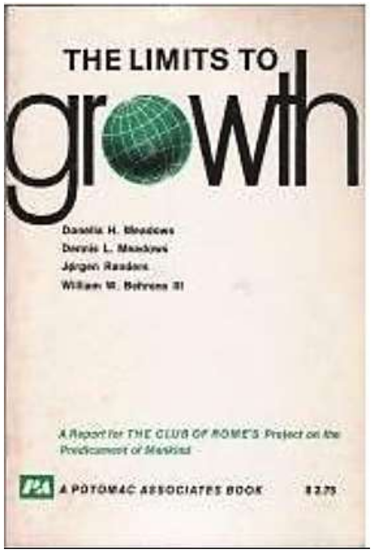
Earth Rise

Existential Theme of Our Time

Moral Task: Sustain equitably an advanced and growing human civilization on a small, blue, white, & green planet with limited natural resources and a changing climate.



Club of Rome (MIT-Sims) Predictions



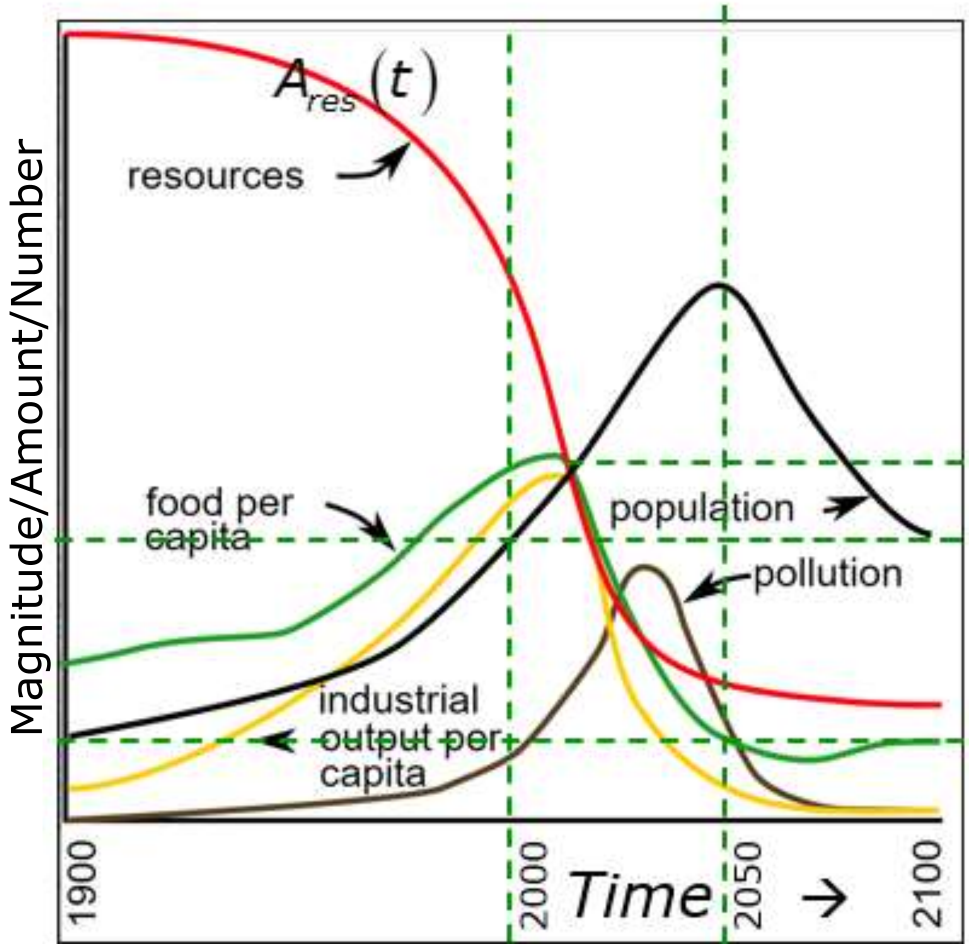
1972

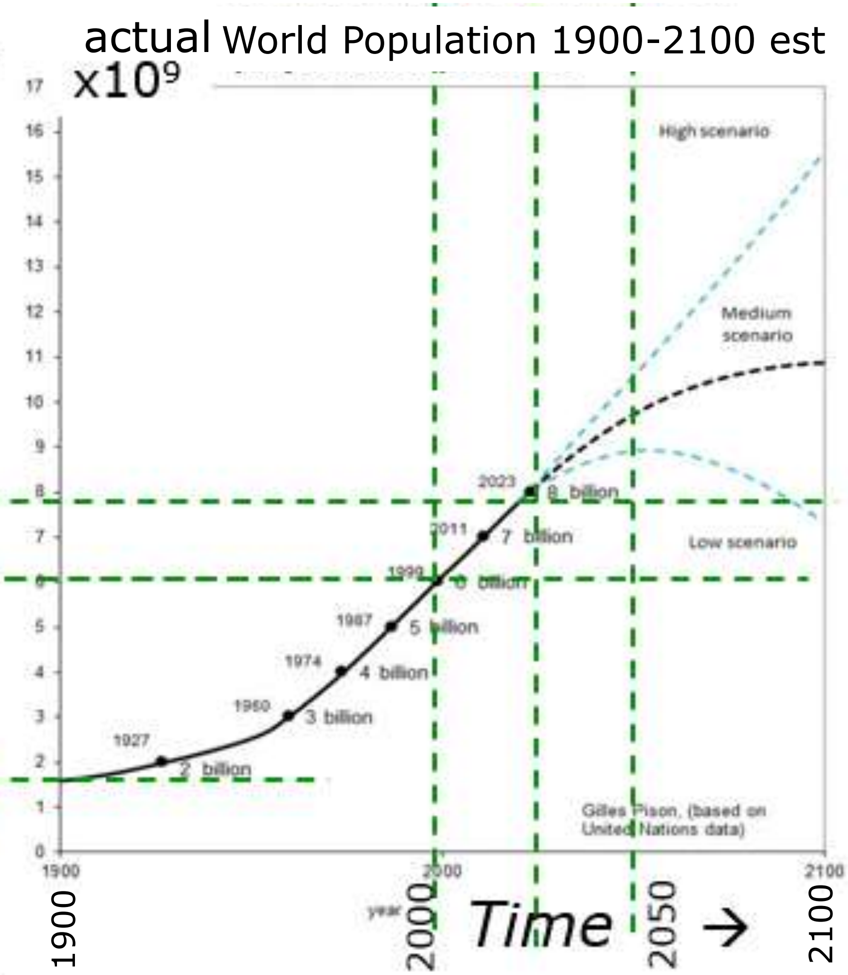
At the behest of the *Club of Rome*, a team of MIT scientists set out to code a computer simulation model of interconnected global developments and various alternative scenarios, i.e., set of model assumptions. Variations were made with respect to available resources, agricultural productivity, birth rates, and environmental protection measures. projecting from the basic understanding in the 1970s, the limit of sustainability of the model world was predicted to be reached around 2030, a "tipping point," unless certain counter-measures were put in place.

By then, the prediction went, the population had grown exponentially to a size that led to significant depletion of major resources like water, food, essential materials, and energy.

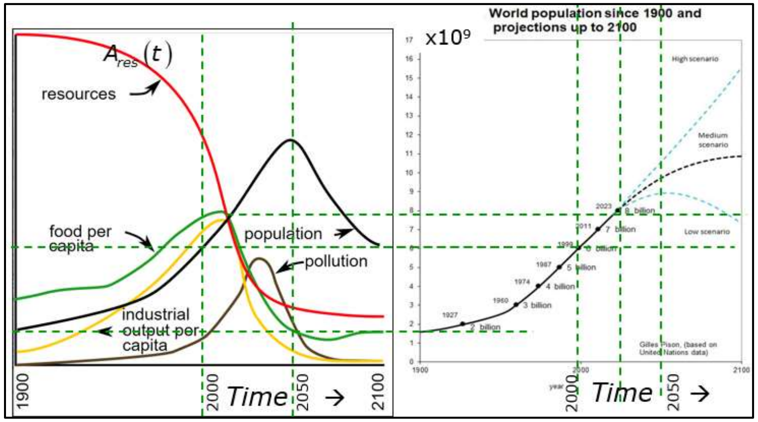
Enormous consequences were envisioned, including wide-spread poverty, famines, and diseases leading to mass migrations around the world. Fortunately, several of them turned out to be exaggerated.

Extrapolating MIT Prognostic Simulations





Examples for Resource Depletion



Assumed consumption rate

$$\frac{dA_{res}(t)}{dt} = -\lambda = const$$

$$\rightarrow A_{res}(t) = A_{res}(0) - \lambda t$$

Resource decreases linearly in time

Consumption rate @ constant fraction

$$\frac{dA_{res}(t)}{A_{res}(t)\,dt} = -\lambda = const; \quad \rightarrow A_{res}(t) = A_{res}(0)\,e^{-\lambda \cdot t}$$

Resource decreases exponentially in time

Consumption rate proportional to population

$$N_{pop}(t) \propto e^{+\nu \cdot t} \quad \textit{Simplest example} \quad \frac{dA_{res}(t)}{dt} = -\lambda \cdot N_{pop}; \quad \lambda > 0$$

$$A_{res}(t) = A_{res}(0) \cdot \exp\left\{-(\lambda/\nu) \cdot \left[e^{\nu \cdot t} - 1\right]\right\}$$

$$\approx A_{res}(0) \cdot \exp\left\{-\lambda \cdot \left[t + (1/2)\nu \cdot t^2 + \cdots\right]\right\}$$

Resource decreases in time much faster than exponentially

To Avoid Collapse → Main Task: Achieve Sustainability

Brundtland Commission of the United Nations (1987):

"sustainable … is development that meets the needs of the present without compromising the ability of future generations to meet their own needs…."

Human moral responsibility: Limit depletion of resources, detrimental/ destructive impact on Earth's ecosystems. Specifically eliminate anthropogenic causes of environmental changes (habitat pollution, climate), and reduce utilization of non-renewable resources.

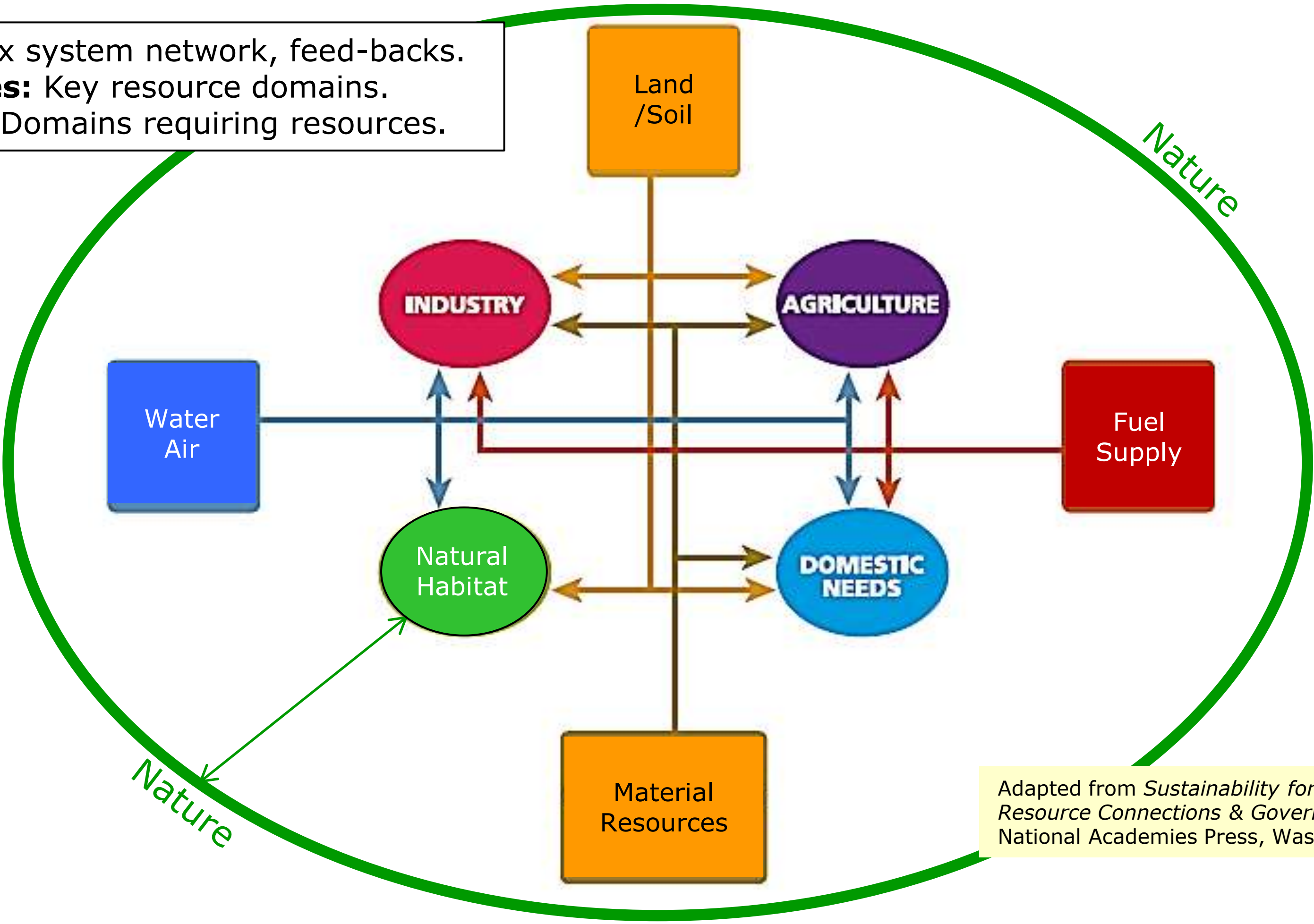
→ This mandates limits on the use, or devaluation, of energy and on the emission of associated byproducts, waste and pollution.

But: Prerequisite for all life and, especially, human civilization is access to, and use of, natural resources and energy (≈ ability to initiate processes changing objects and/or their relations) is a

→ Complex task with many dilemmas → needs holistic system approach !

Interacting Socio-Economical Network

Complex system network, feed-backs.
Squares: Key resource domains.
Ovals: Domains requiring resources.



Adapted from *Sustainability for the Nation: Resource Connections & Governance Linkages*, National Academies Press, Washington, D.C., 2013

Interlinked socio-ecological system needs long-term, systems sensitive, adaptive, collaborative management. **Example**: Sustainably managing water resources

Example: Network Management

Interlinked socio-ecological system needs long-term, systems sensitive, adaptive, collaborative management.

Example: Sustainable management of water resources considers

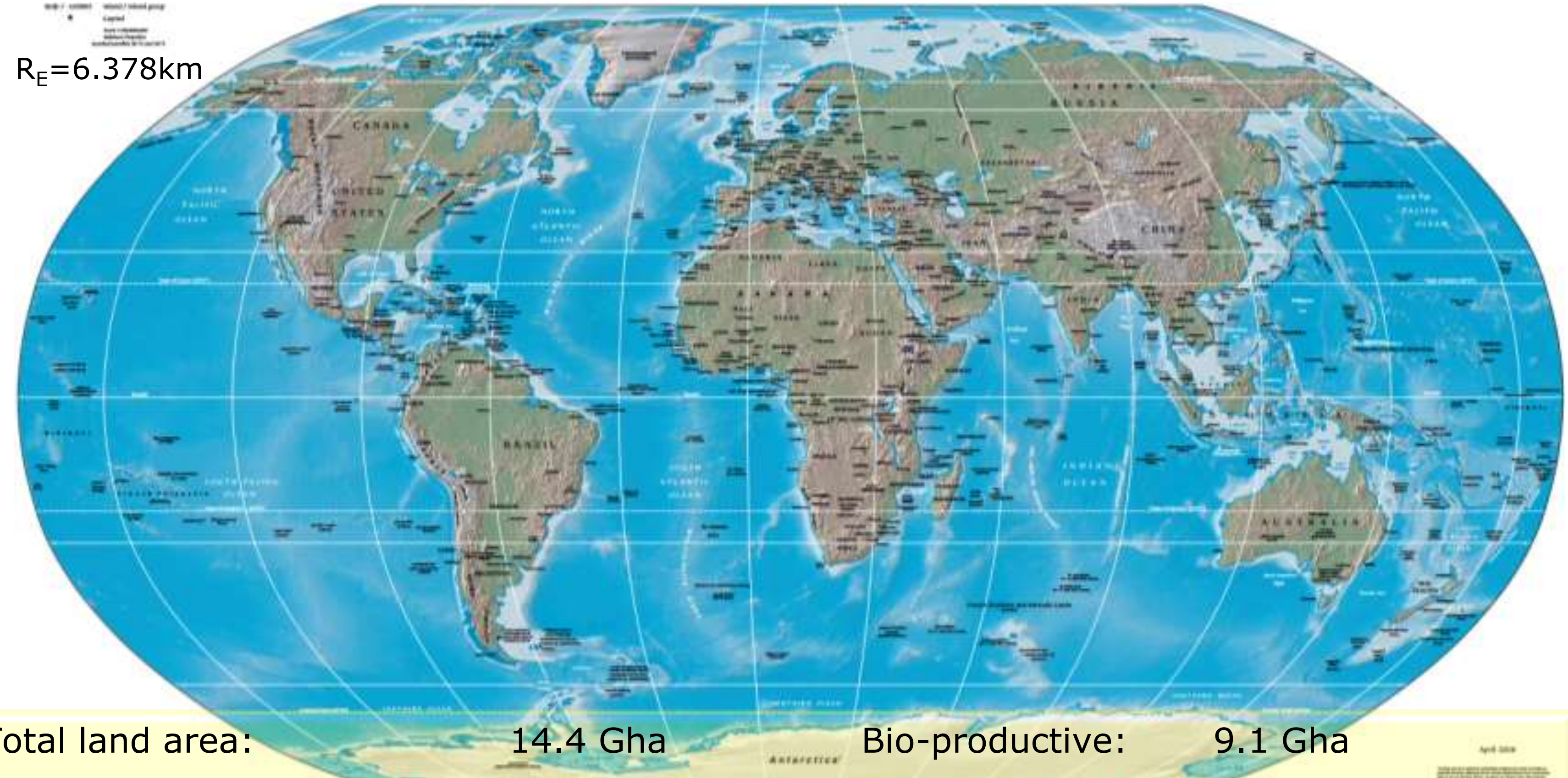
- water quantity/quality,
- connection to air quality (acid rain),
- use (food vs. bio-energy), hydro-energy vs. irrigation, wetlands,
- effect on land, urban development, drinking water, wastewater,
- electricity from hydropower ←→ fisheries, recreation,
- impacts on human health,
- cultural impact.

⇨ Present governments ill prepared (fractionation of agency tasks, competition for funds,.., **politics**), Poor Results.

Example: Great Lakes as (US+Canada) fresh-water resource, urban development, industry,+…., Hydro-dams on large rivers (Colorado,..)

Westcoast water trading, Ca ←→ OR, WA? Industrial agriculture.

Finite Earth: Gross Biological Potential



R_E=6.378km

Total land area:	14.4 Gha	Bio-productive:	9.1 Gha
		Cropland	1.5
		Pasture	3.5
		Forest	3.8 (3.04.10^{12} trees)*
		Built-up	0.3
Ocean & inland waters:	36.6 Gha	Bio-productive:	2.3 Gha
		Fisheries	2.3

1ha=100 ares=10,000 m^2=2.471 acres)   ***Nature, 2022***

After: M. Wackernagel, C. Monfreda, Encyclop. Energy V. 2, (Elsevier, 2004)

Where We Are (As Globally Evolving Civilization)

- Global mean (on average): Now in late phase of a 300-year major socio-irreversible economic transition.

  Agrarian mode of subsistence → Industrial mode, "1st machine age."

  Land based socio-ecological regime → fossil-fuel based economy.

- Global North-South gradient:

  Countries in the global North are at different stage in transition than countries in the global South. North is more advanced, but global correlations and influences exist.

- Ongoing transition: Industrial/fossil-fuel based → Second machine age, digital revolution/AI. → Sustainable, equitable regime (**?**)

  Managing ongoing transition needs understanding interconnections and feedback, rooted in historic evolution.

  Task: non-chaotic/non-violent transition (population pressures).

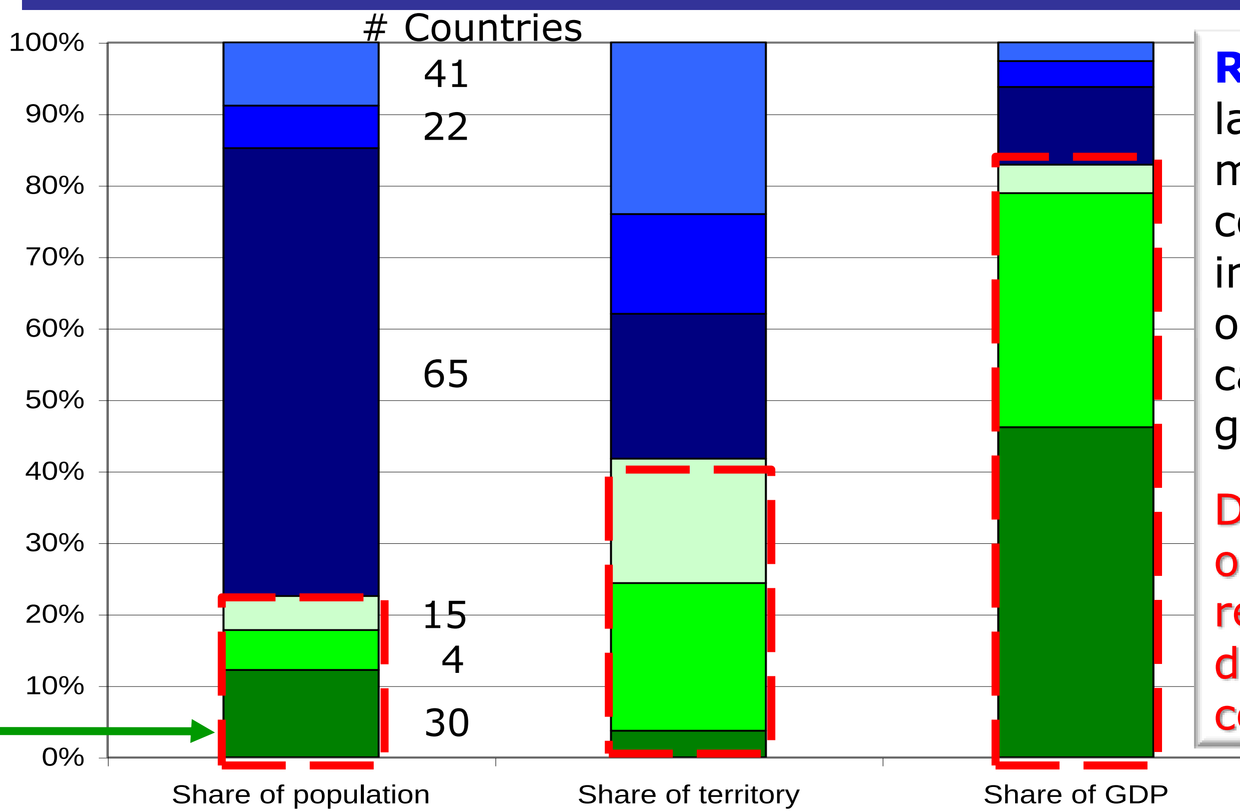
Transition to equitable sustainable regime ...?

Def: **Socio-ecological regime** (mode of organization, subsistence, and/or production) =complex system, social organization exploiting accessible ecological (natural) systems (land/soil, water, material resources, wild/domesticated animals,...)

After: M. Fischer-Kowalski, Institute of Social Ecology, IFF Vienna, Klagenfurt University, Austria (2008)

Utilization of Global Resources (2008)

Industrial low population density, Old World: Former Soviet Union, Scandinavian countries
Industrial low population density, New World: North America, Australia, New Zealand
Industrial high population density (> 50/km²), Europe, Japan, South Korea
Developing high population density (> 50/km²), Old World: Arid countries in Africa, Asia
Developing low population density, New World: South America
Developing high population density, India, China, Central America, African countries.



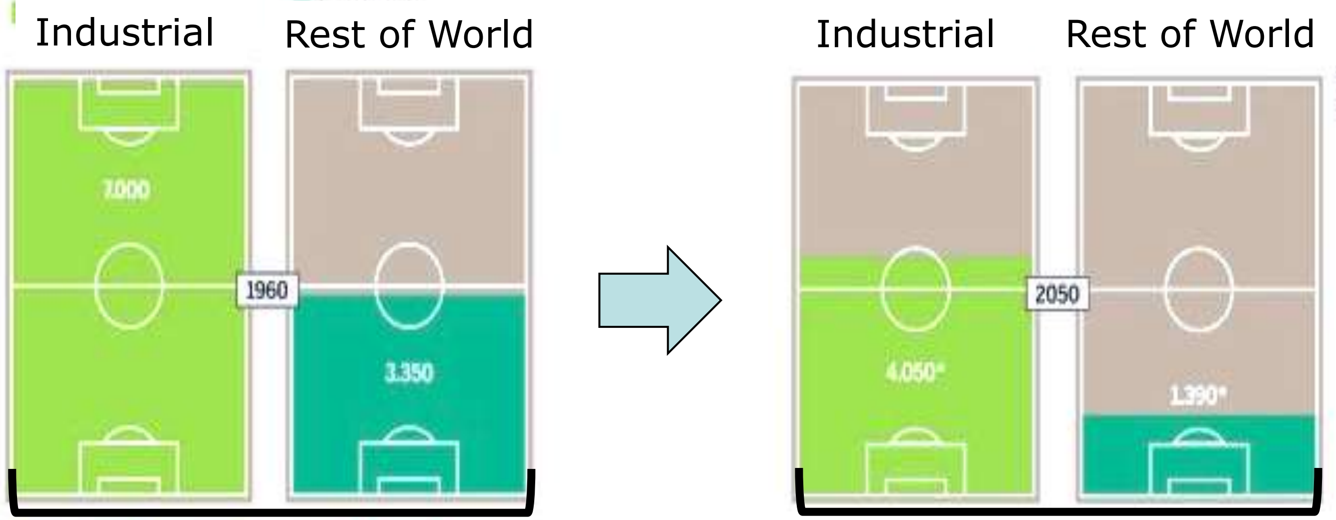
Resources: Arable land, water, energy, materials (wood, construction minerals, industrial minerals, ores,..). **Energy** fuel categories: solid, liquid, gaseous. →

Disparate distribution of essential global resources → destabilizing global consequences.

After: Fischer-Kowalski & Weisz, ISEE, (2008),

Resource Allocation: Arable Land

Arable land mass increases but continues to disappear per capita



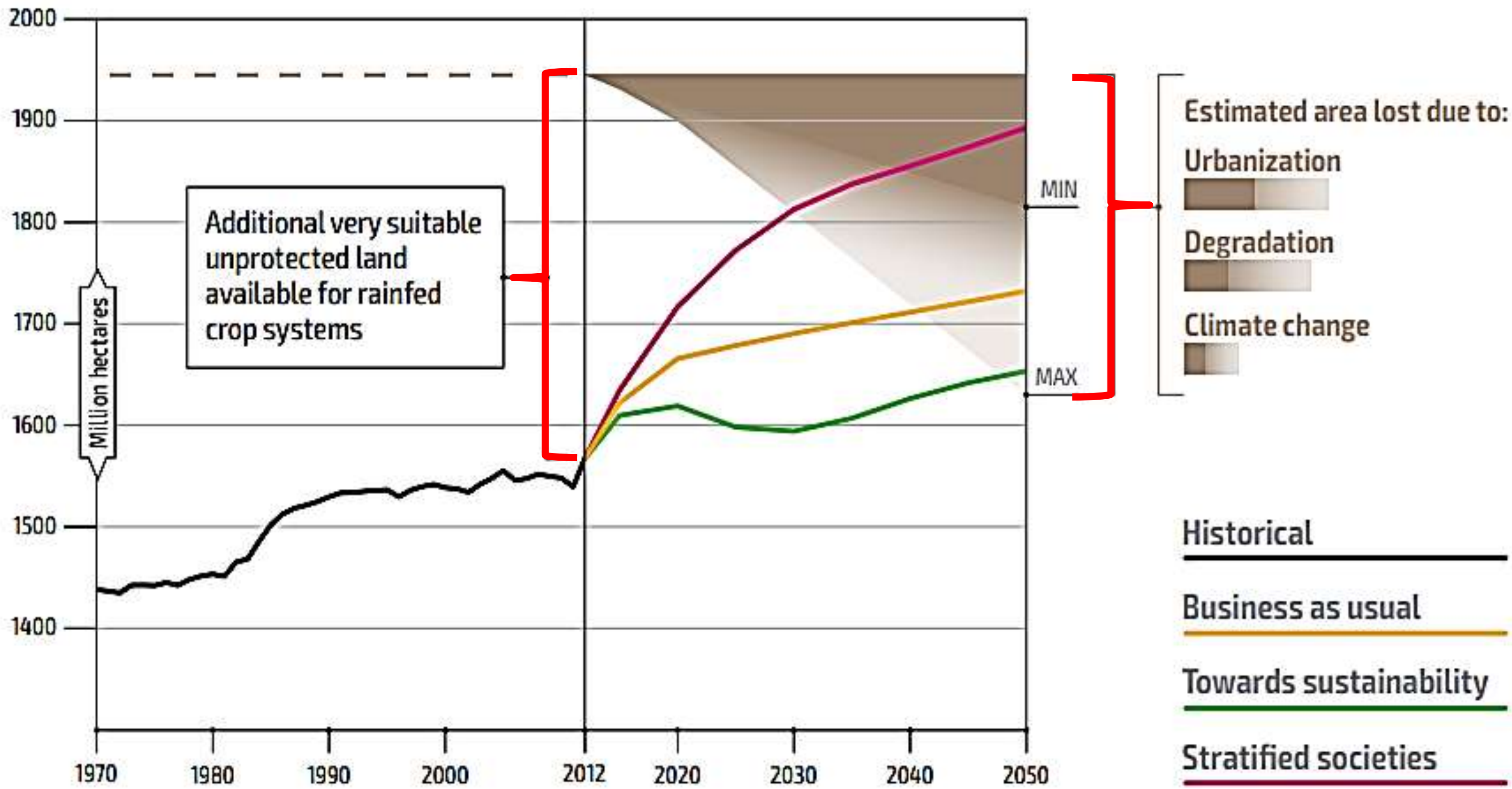
1960: 7000 m²/cap (industrial) Extrapolating →2050: 4050 m²/cap (ind.)
3350 m²/cap for rest 1390 m²/cap for rest

Inequity between industrial and developing world:

Sustainable at expected populations: ≤ 2000 m²/cap on average.

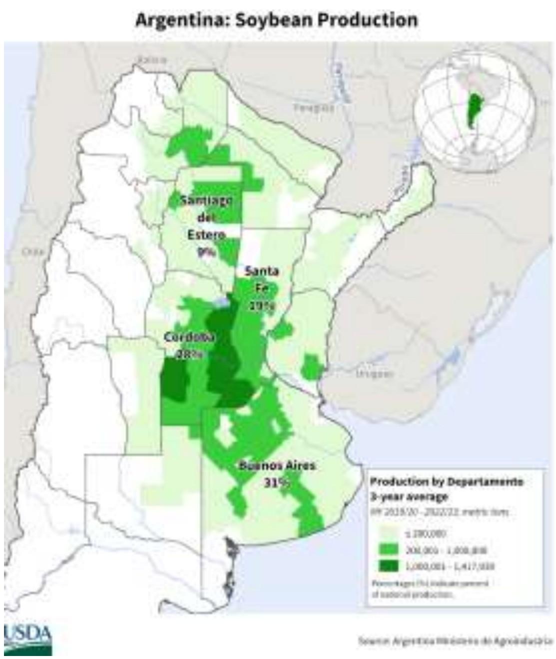
Q: Is this sufficient? Must count on industrial agriculture „Efficiency" gains via, fertilizer, pesticides, gen-mod. But: decreasing soil quality, run-off pollution,...

Arable Land Requirements/Loss



Human Ecological "Footprint" on Land

Arable land mass increases (polar shift, reduced permafrost, deforestation) but disappears per capita



2024: 52Mt "Soy for the world" (1988)→ (2024)
4Mha → 18Mha

Inequity: industrial (rich) vs. developing (poor)

Rich countries rent arable for growing food, feed for livestock, bio-fuel,…

World: 33% arable land for lifestock feed.
Example: EU livestock feed uses arable land = size of England.
Example Saudi U.S. rental: Arizona alfalfa farms

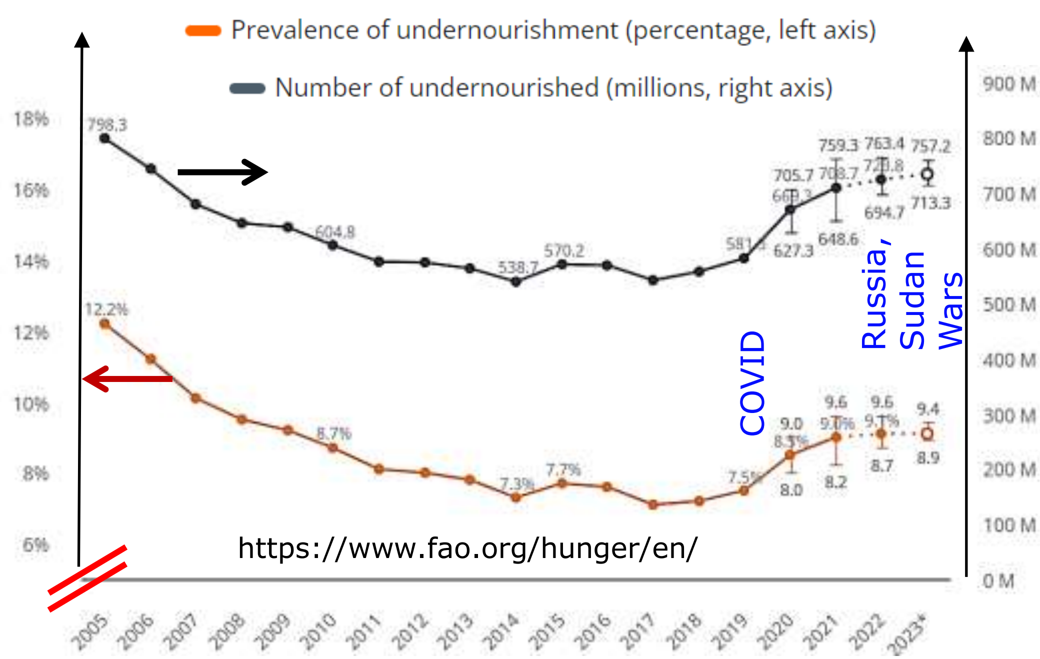
Reduction in SA (Argentina) forest and grass land
Much of it for soy production (new immigrants).
Massive deforestation: Rainforest in Brazil,....
in SE Asia (Indonesia,..) for oil, bio-fuels.

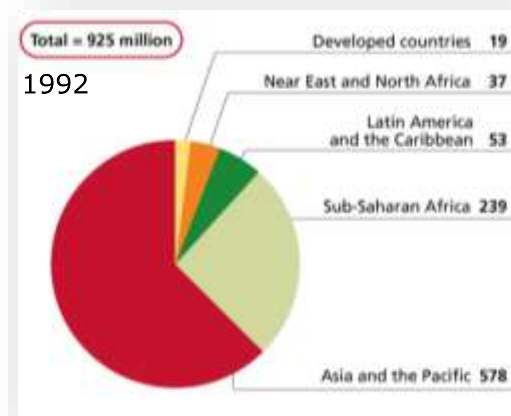
New: Rental of arid lands S-America for mining of Li etc. utilizing scarce water resources.

World Hunger (Dilemma: Bio-Energy Generation)

UN Food and Agriculture Organization (FAO) measures 'under-nutrition': relatively unchanged around 2015, hunger jumped in 2020 and continued to rise in 2021, to 9.8% of the world population.
Since 2018/22 increased number of under nourished people due to:

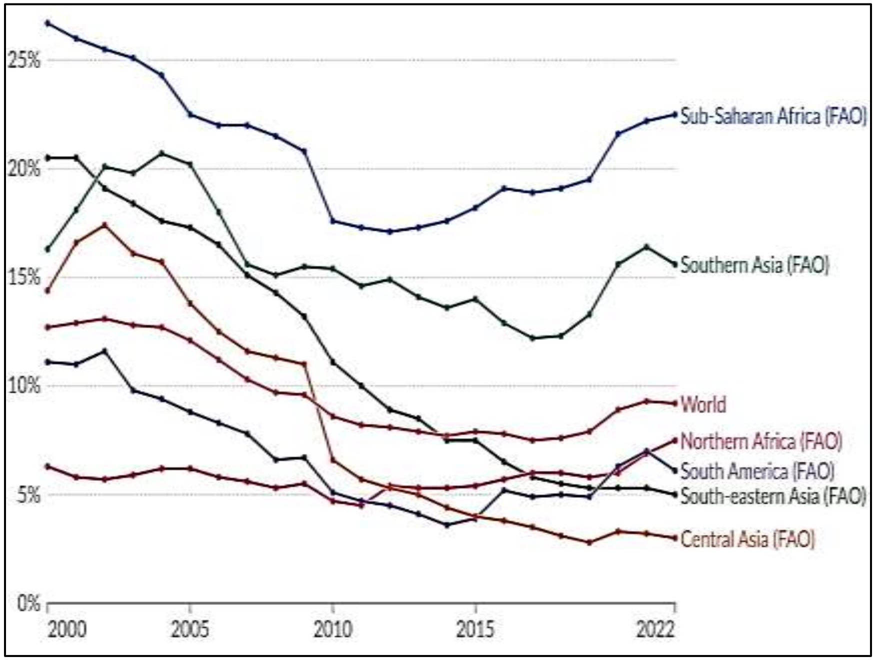
1) Mega droughts on various continents (Africa, NA, Europe, Australia)
2) Covid epidemic, disruption of trade
3) Worldwide economic crisis/wars
4) Russia's war on Ukraine, Sudan internal war
5) Renting arable land for animal feed and biofuels





What would it cost to more fully develop poor regions? Investment, energy

Quest for Hunger Mitigation

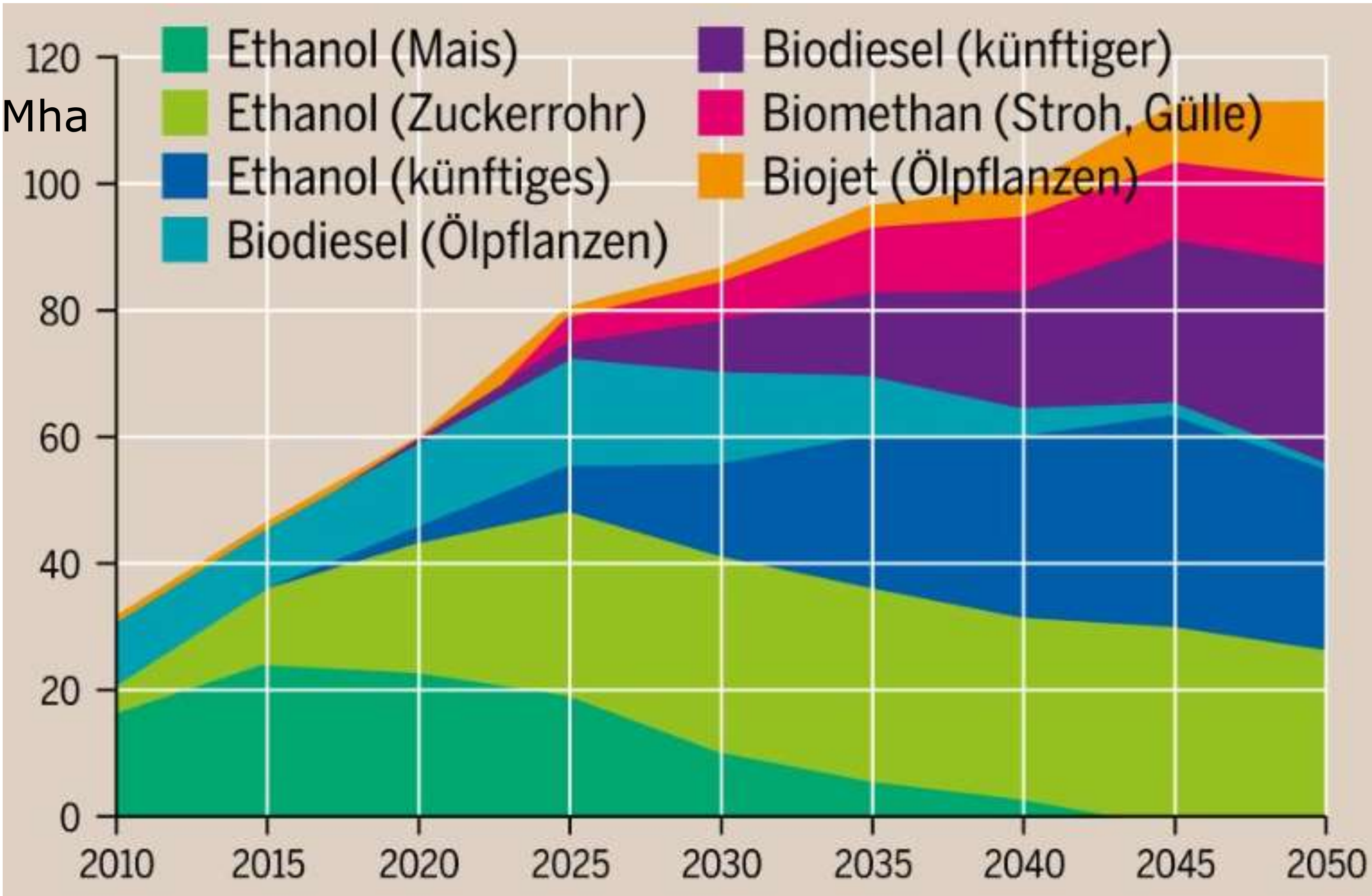


Protect rural lifestyle/liveliness

Reconcile demand with ecologically sustainable production of healthy, affordable food. → Difficult, dilemmas.

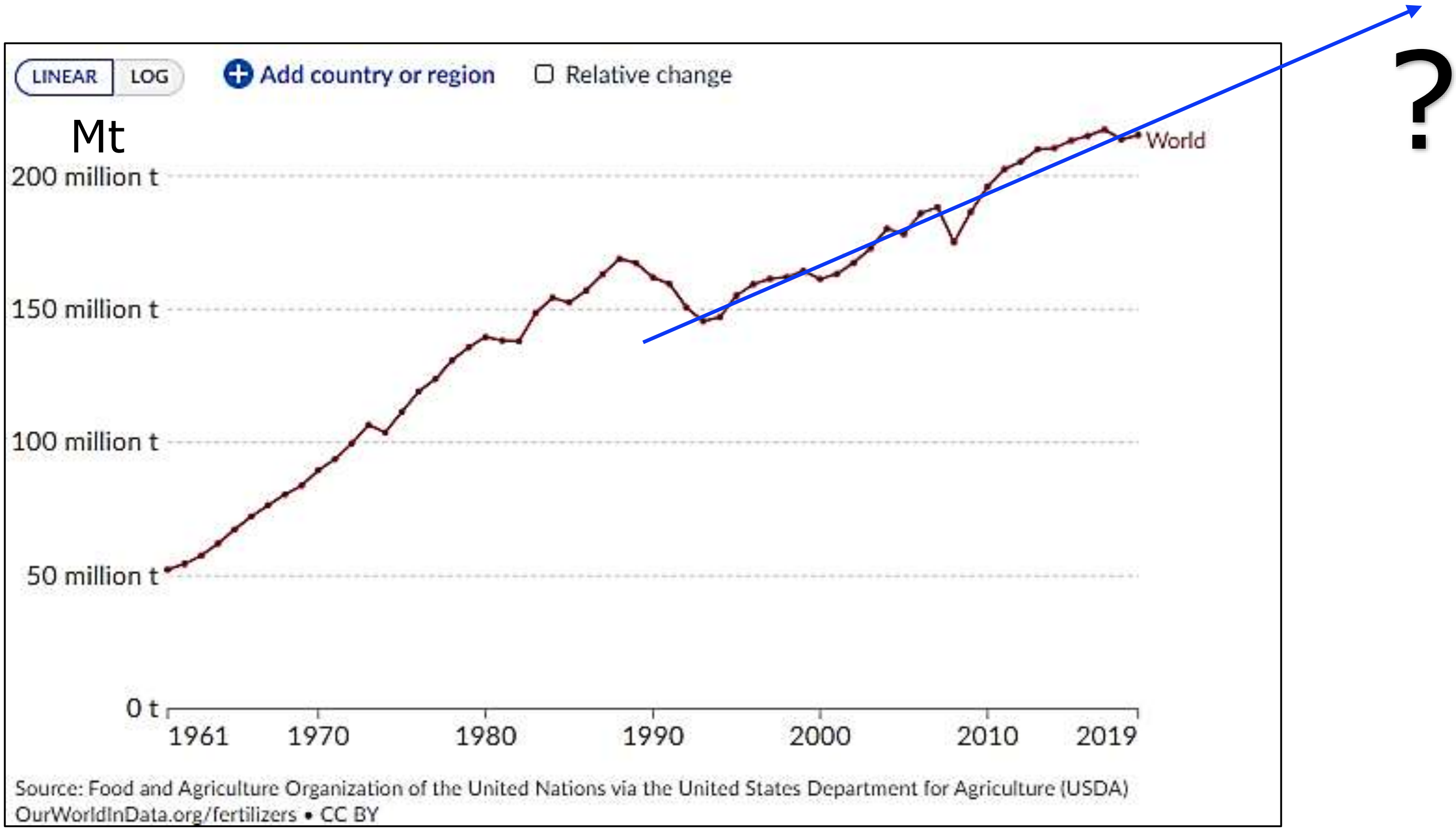
- Reduce food waste in rich countries
  Improve equitable food distribution
  Invest in safe distribution systems
  Refocus use of crops on nutrition
- Increase arable land
  Reduce pasture/range land
  Clear forestland/deforest
  Drain wetlands
- Increase crop yield per area
  Research new ag. methods
  Increase autom./industr. agriculture
  Increase chemical fertilization
  Merge individual farms
- Expand/refocus diet and food base
  Consume less meat/animal products
  Consume more local ag. products
  Research innovative food sources
  (sea weed, insects,…)

Disputable Future Choices (Fuel vs. Food)



Use of arable land (Mha) projected in some policies promoting biofuels. Competes with food, livestock feed (fodder). Scalability problem for biofuels

Chemical Fertilizer Consumption/Year

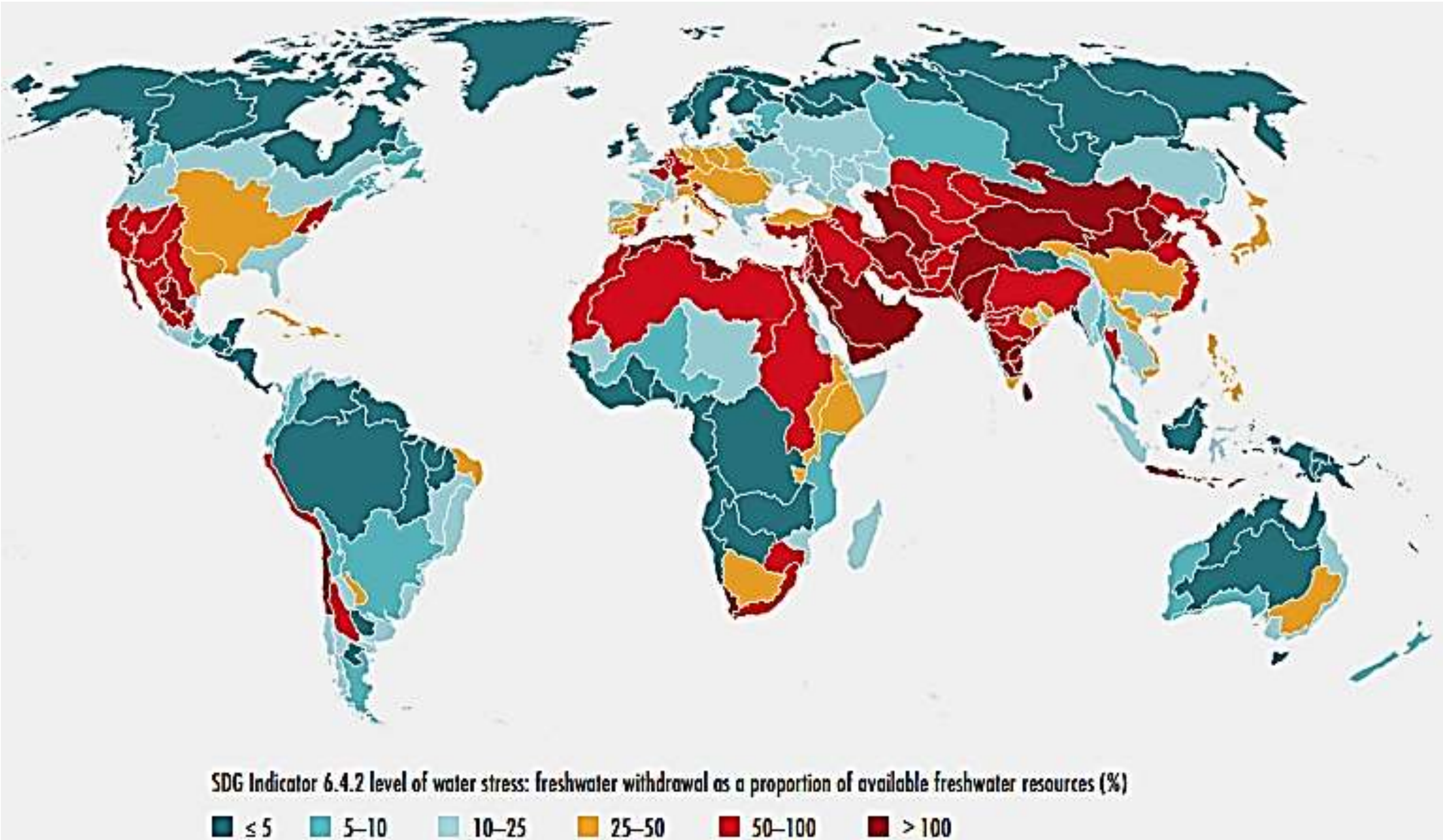


https://ourworldindata.org/fertilizers

Global agricultural yields keep increasing slowly but require increased use of synthetic fertilizers. Running out of (nitric) fertilizer, phosphate, etc. supplies.

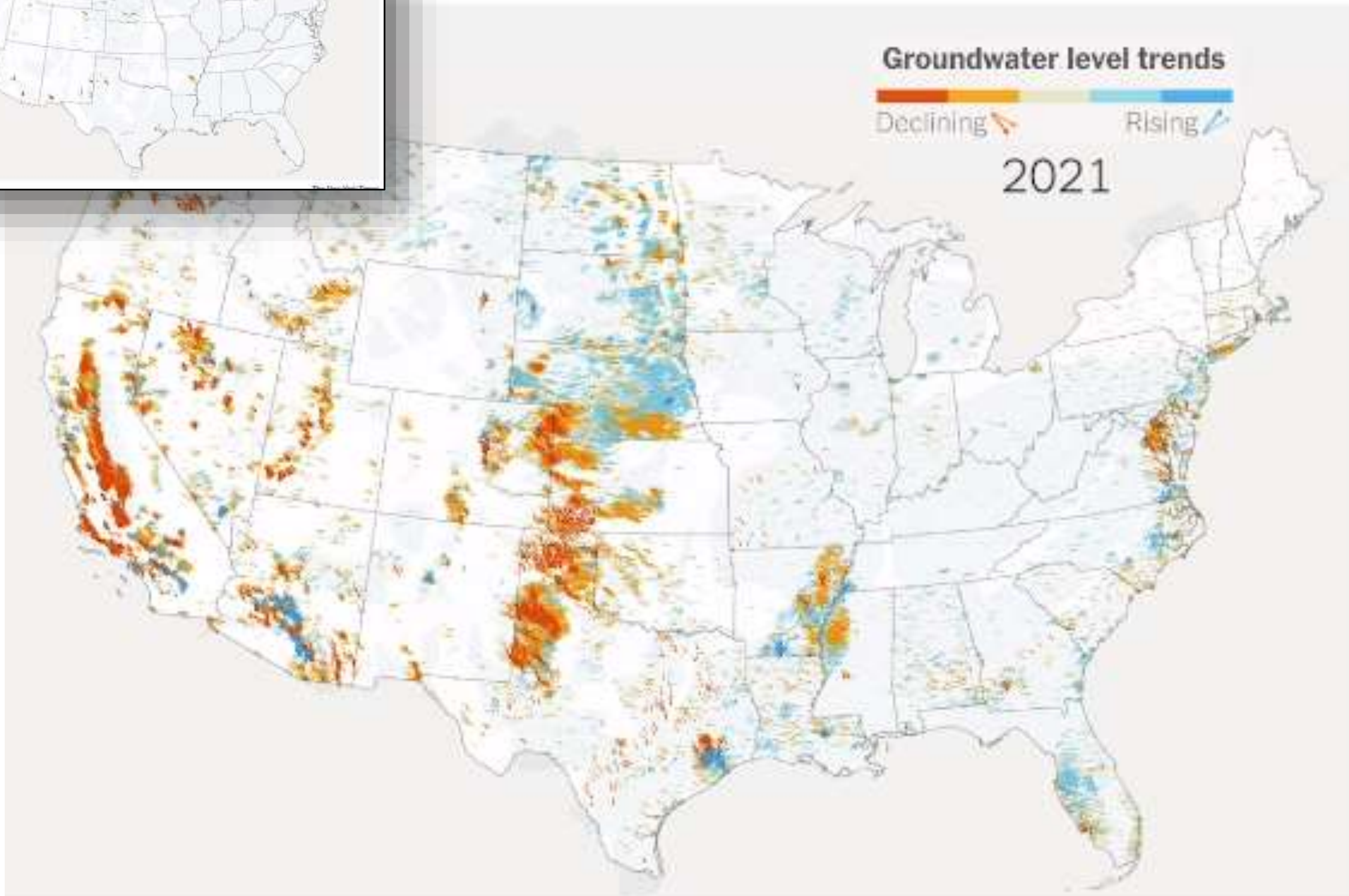
Negative side effects for soil, marine life

Depleting Natural Resources: Stressed Aquifers



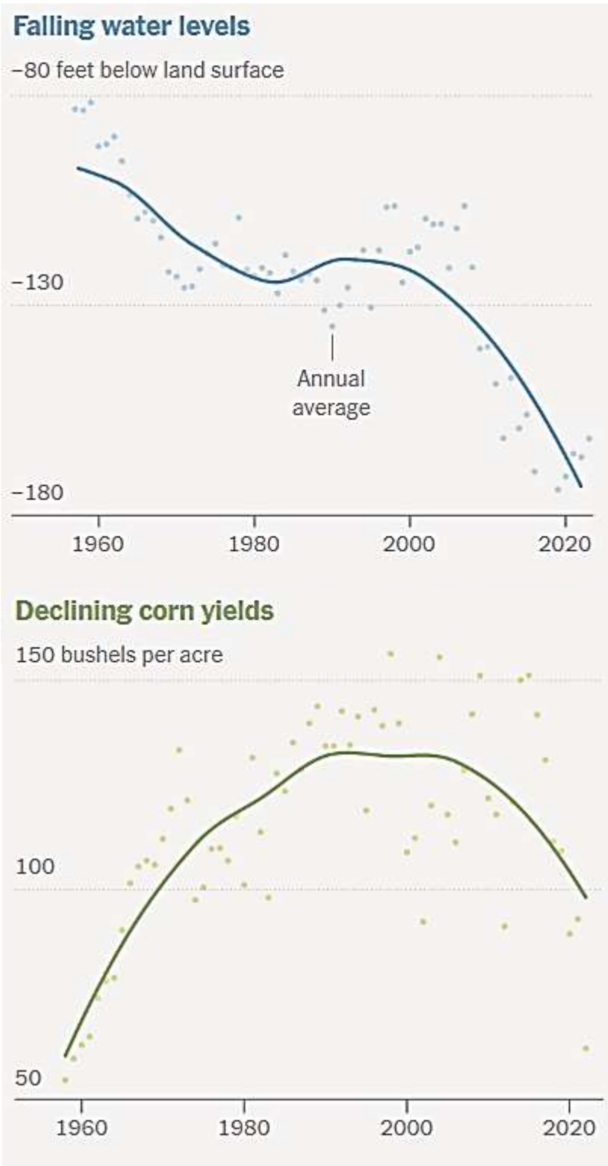
Ratio (%) between total freshwater withdrawn by all major sectors (agricultural, industrial and municipal) and total renewable freshwater resources, after considering environmental flow requirements.

Example: Drained U.S. Groundwater



The New York Times

Consequences of Falling Aquifer Levels

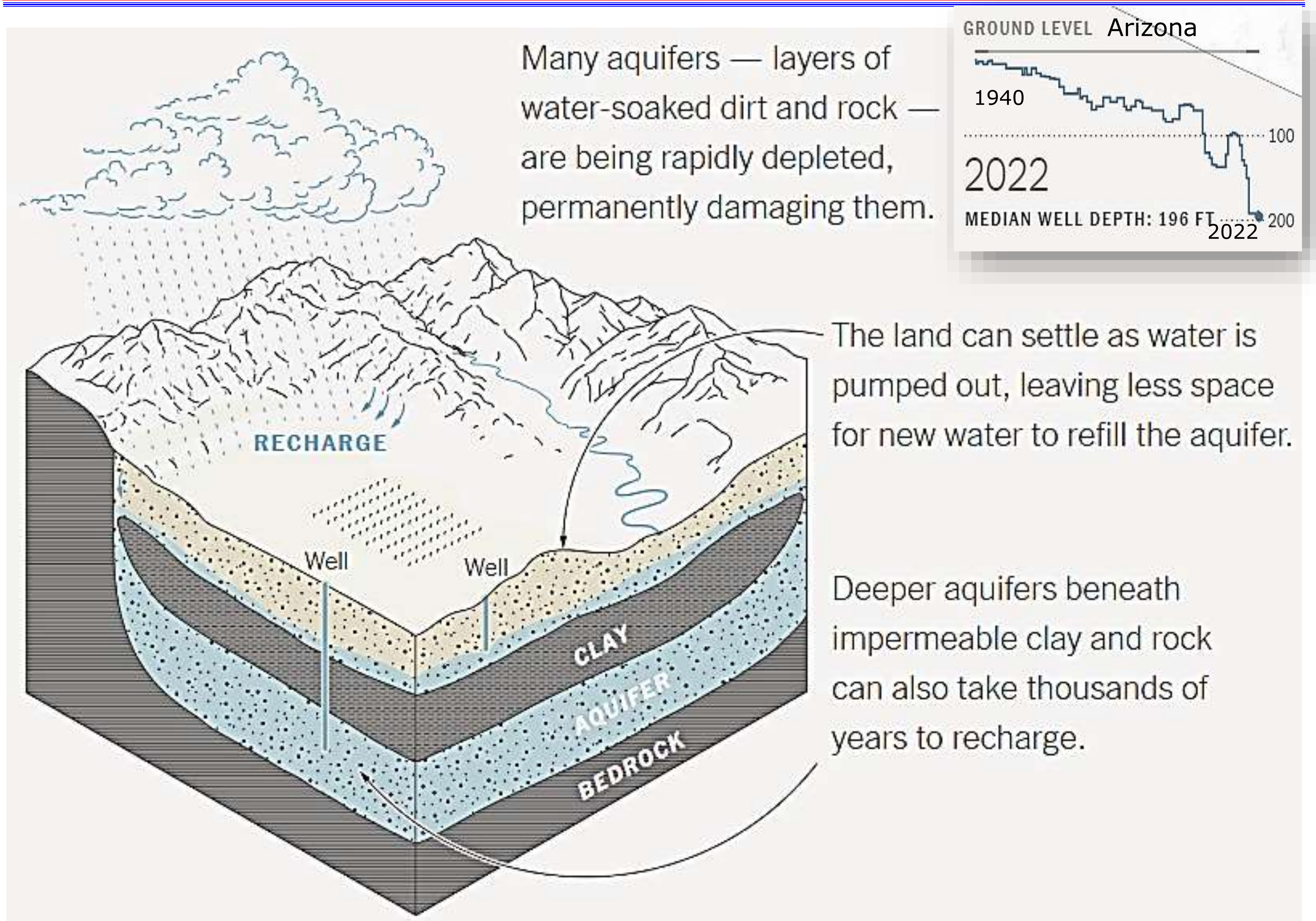


Center-pivot irrigation. Farming is a major groundwater user.

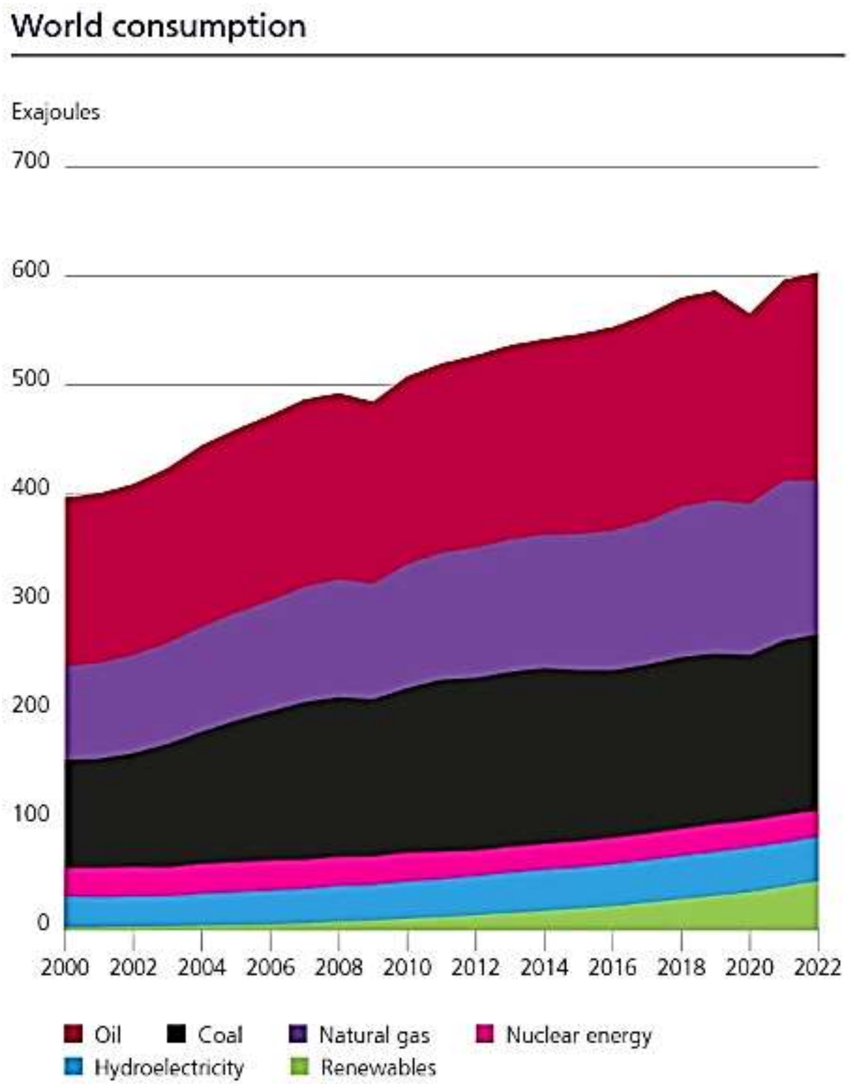
Industrial-type agriculture on the High Plains produces large fractions of global supply in several crops (corn, alfalfa, soy,…).
Feed for stock, bio-fuels, human food

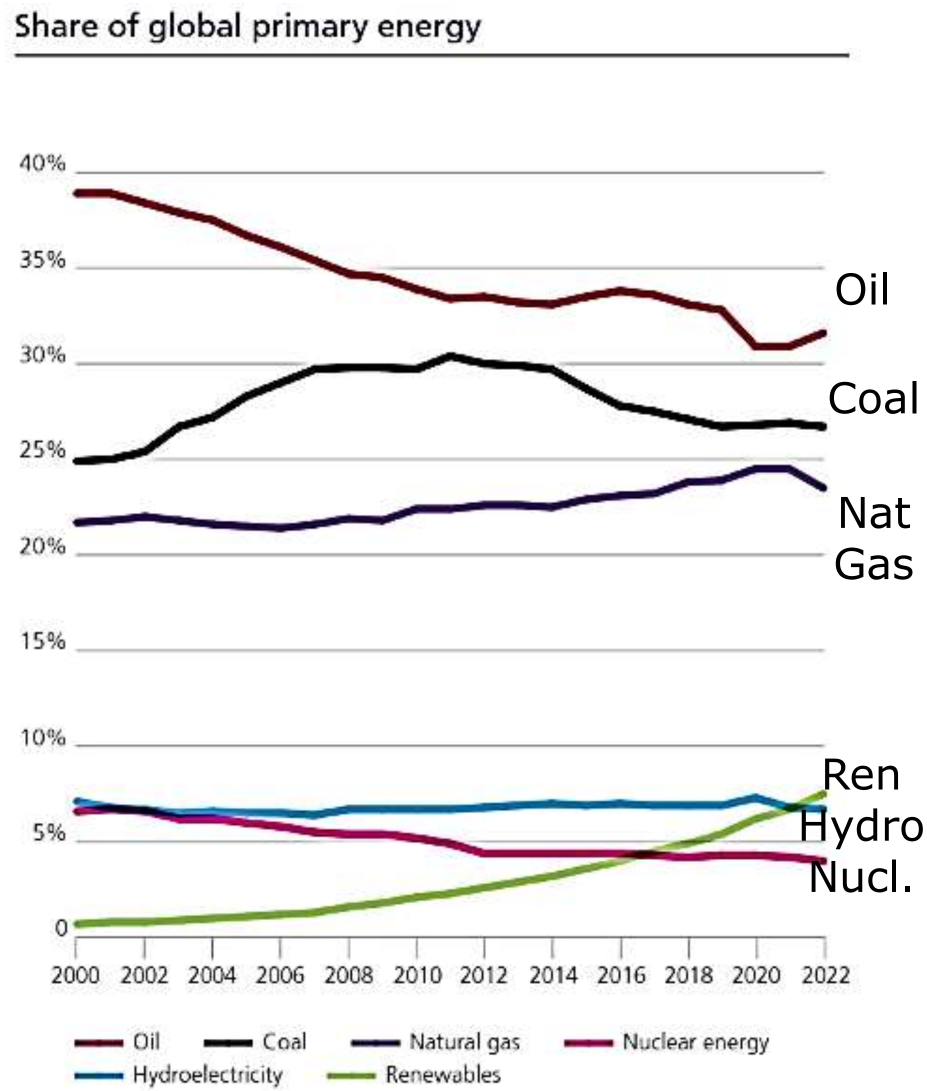
Pivotal irrigation systems hooked up to aquifers. Drained groundwater requires deeper wells, declining yields.

Tapping and Recharging of Aquifers



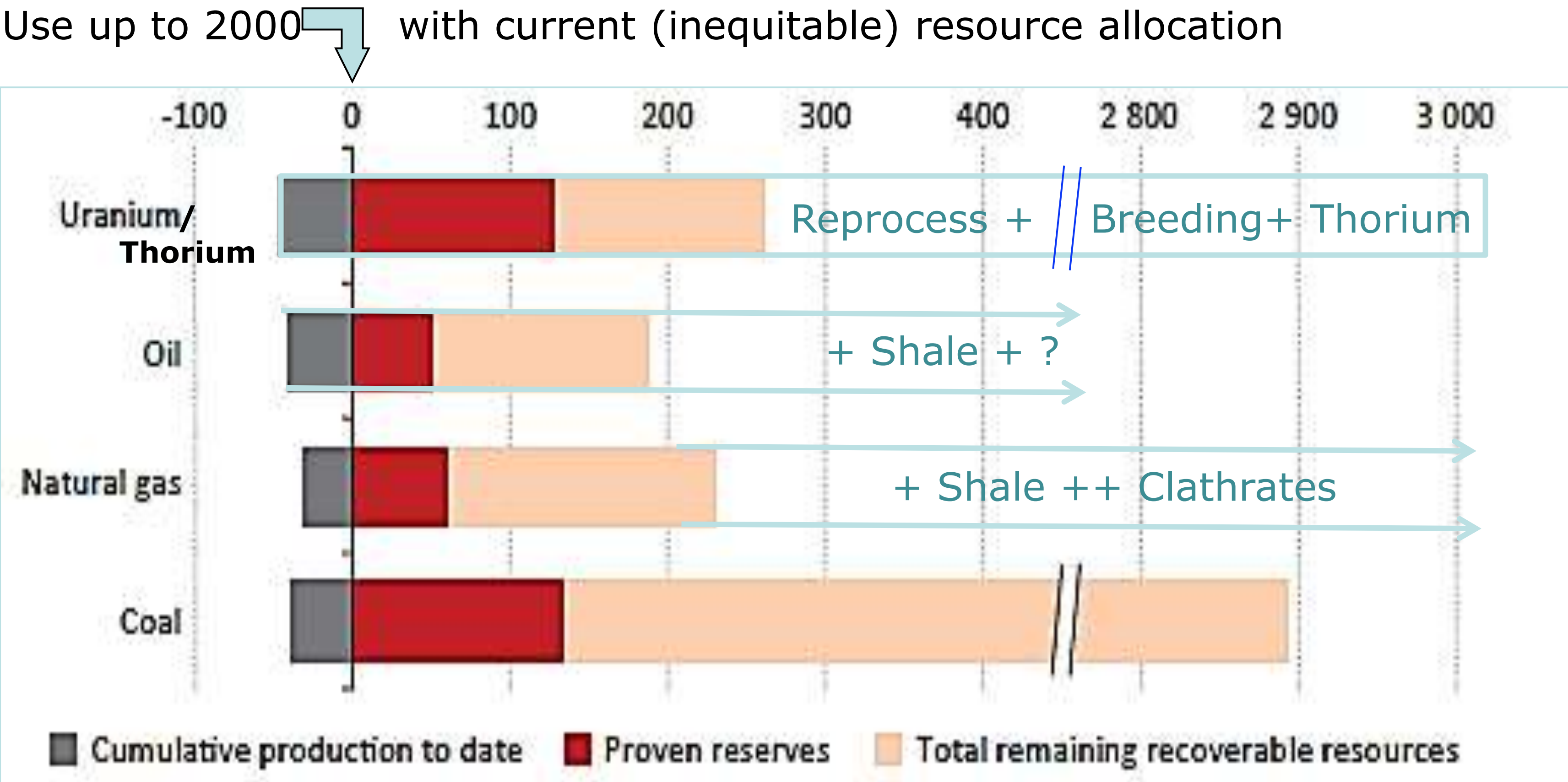
World Energy Consumption per Year





World Primary Energy Resources/Constant Use

Use up to 2000 with current (inequitable) resource allocation

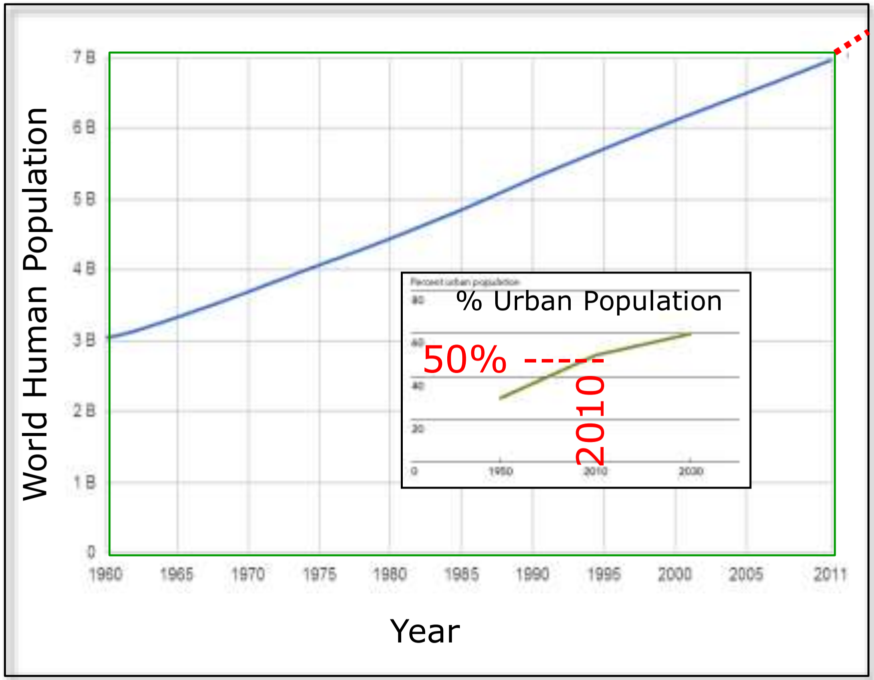


Modified after IEA World Outlook 2014, in light lettering: use reprocessing + U-238 breeding, Th 232 fertile fuel,

unconventional gas (fracking) + clathrates in frozen environments.

Neglect losses in reprocessing and breeding. Assumed present rate of consumption in future.

Testing the Limits: Human "Ecological Footprint"



Present population: 8.0 *B* (1 Billion = $1\cdot10^9$) ~0.8 *B* food insecure/starving/impoverished

Estimated for 2050 → 9 B (+urbanization → more energy dem.)

Present (2022) eco-footprint of humanity ~ 1.7 Earths → global ecologic overshoot, diffuse unsustainability effect.

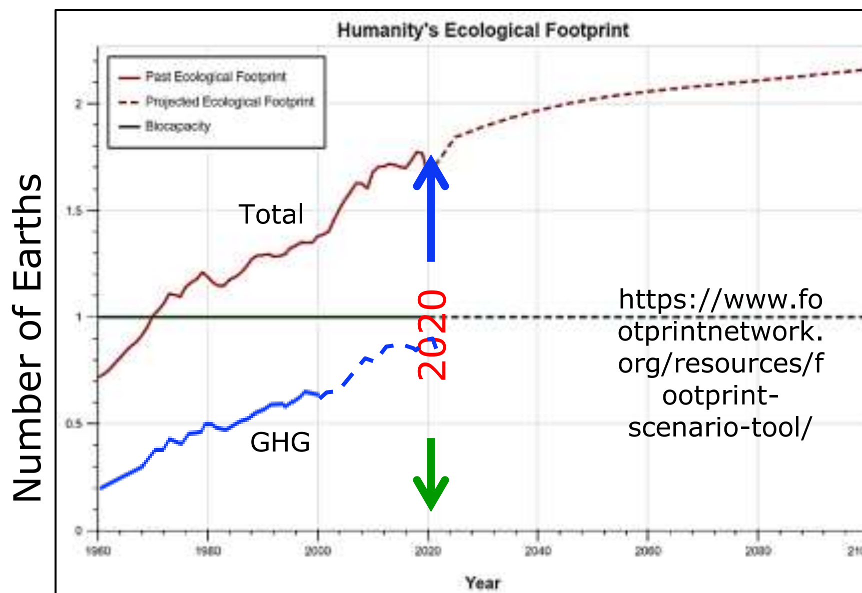
Method to estimate eco-footprint: Sum regenerative capacity (observe+model) of land w/r to maintaining resource, power production, absorbing waste.

Example (1990s): fossil fuel combustion → 6.3 Gt CO_2/a, Ocean absorbs 1.7 Gt CO_2/a

Land absorbs 1.4 Gt CO_2/a

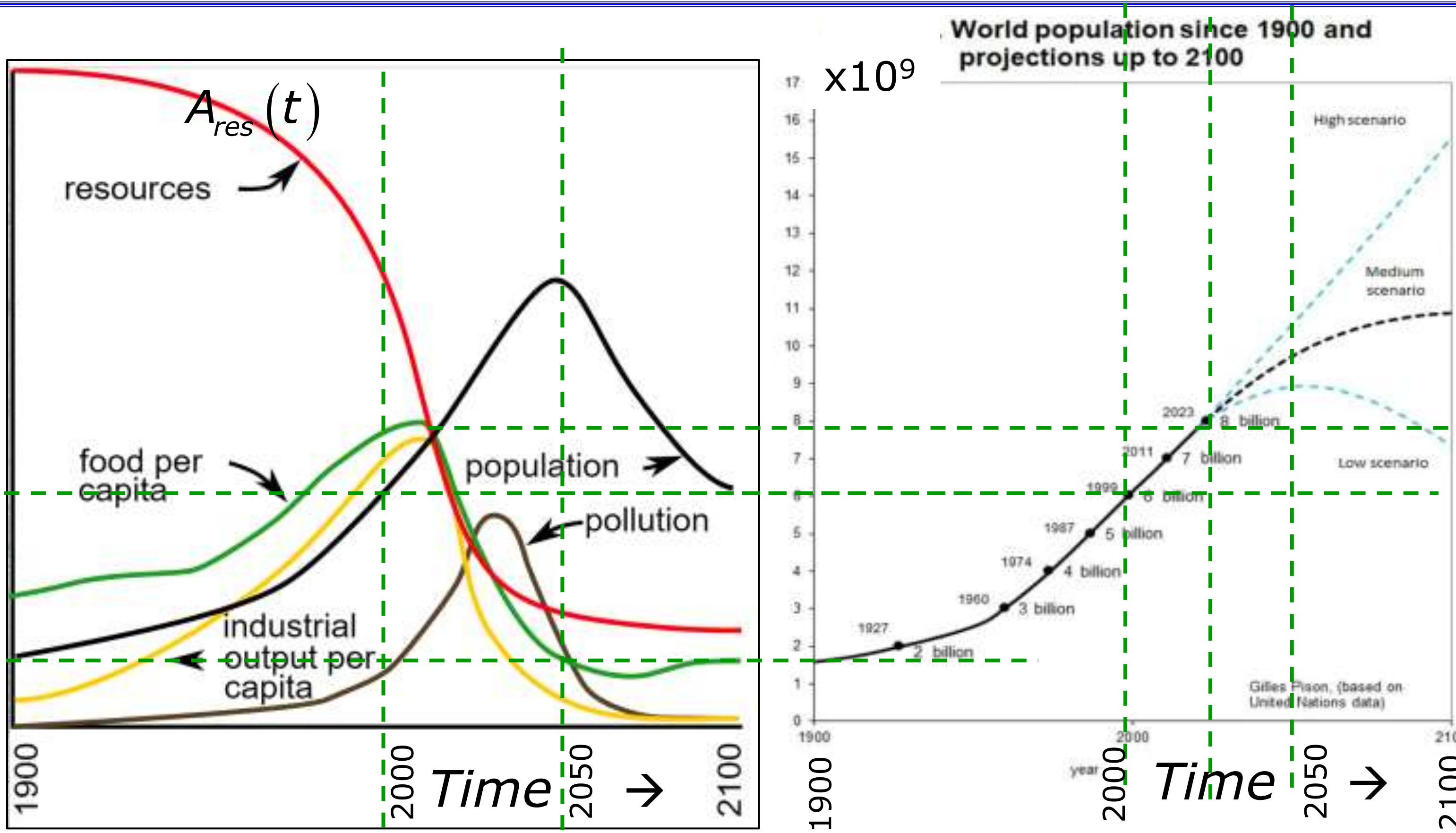
Total absorbed 3.1 Gt CO_2/a

→ 3.2 Gt CO_2/a waste not absorbed but released to atmosphere (= measured).



End of Sustainability 2023a

Extrapolating MIT Simulations



W. Udo Schröder, 2024

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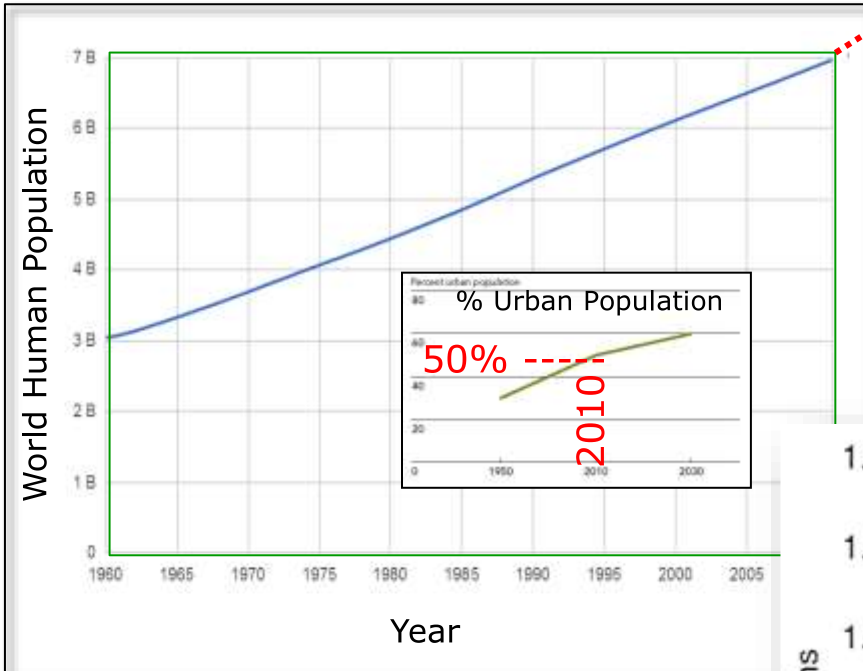
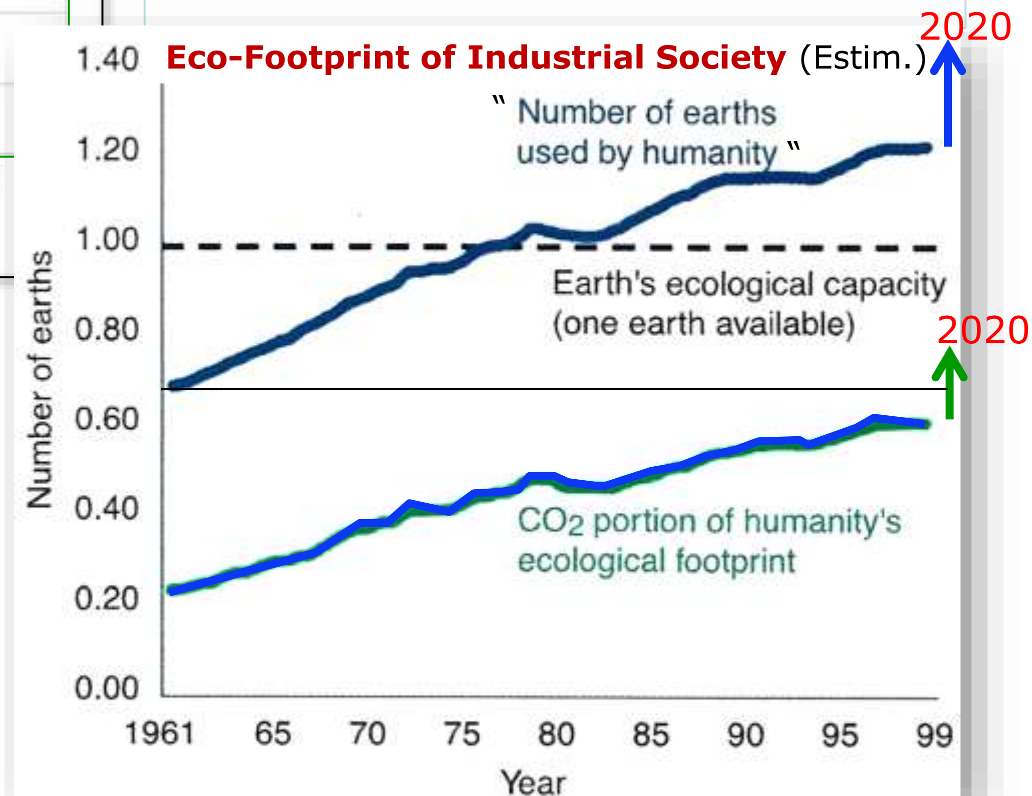


Present population: 7.9 *B* (1 Billion = $1 \cdot 10^9$)
~0.8 *B* food insecure/starving/impoverished

Estimated for 2050 → 9 B (+urbanization → more energy demand)

Present (2020) eco-footprint of humanity ~ 1.5 Earths → global ecologic overshoot, diffuse unsustainability effect (not everywhere immediate impact).



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