"Machines are Hungry Too"

The Biosphere as a Model for the Technosphere in the Anthropocene

A science essay by Reinhold Leinfelder[1]

Anthropocene Working Group (IUGS) and Freie Universität Berlin

Production and consumption in nature

All organisms produce and consume. This requires basic building blocks and energy. In the plant kingdom, organic materials are produced with the help of solar energy from recycled building blocks in the soil ("nutrients") as well as carbon dioxide (Fig. 1). Animals consume existing organic material, be it plant or animal, living or dead, in order to gain energy from it and thus to grow and produce offspring themselves. Dead materials that are not consumed further are decomposed by microbes, fungi and atmospheric processes, and made available as nutrients for new bio-production. Additional products can be dwellings, nests or even smaller storage facilities. All feats of strength, such as flight, loco-motion, food crushing or nest building, are also based on the available energy of their own bodies. Optimisations exist in many ways, through social structures, symbioses for mutual benefit, but also through parasites that feed and spread from other organisms.

[1] English version of the blog essay: Leinfelder, R. (2020)„Auch Maschinen haben Hunger" – Die Biosphäre als Modell für die Technosphäre im Anthropozän.- Der Anthropozäniker – Unswelt statt Umwelt, Scilogs (Spektrum-Publishers), https://scilogs.spektrum.de/der-anthropozaeniker/auch-maschinen-haben-hunger/
This english version is deposited at http://reinhold-leinfelder.de/pdfs/machines_hungry.pdf (Jan. 2021)

Author: Prof. Dr. Reinhold Leinfelder, Department of Geosciences, Freie Universität Berlin,
e-mail reinhold.leinfelder@fu-berlin.de

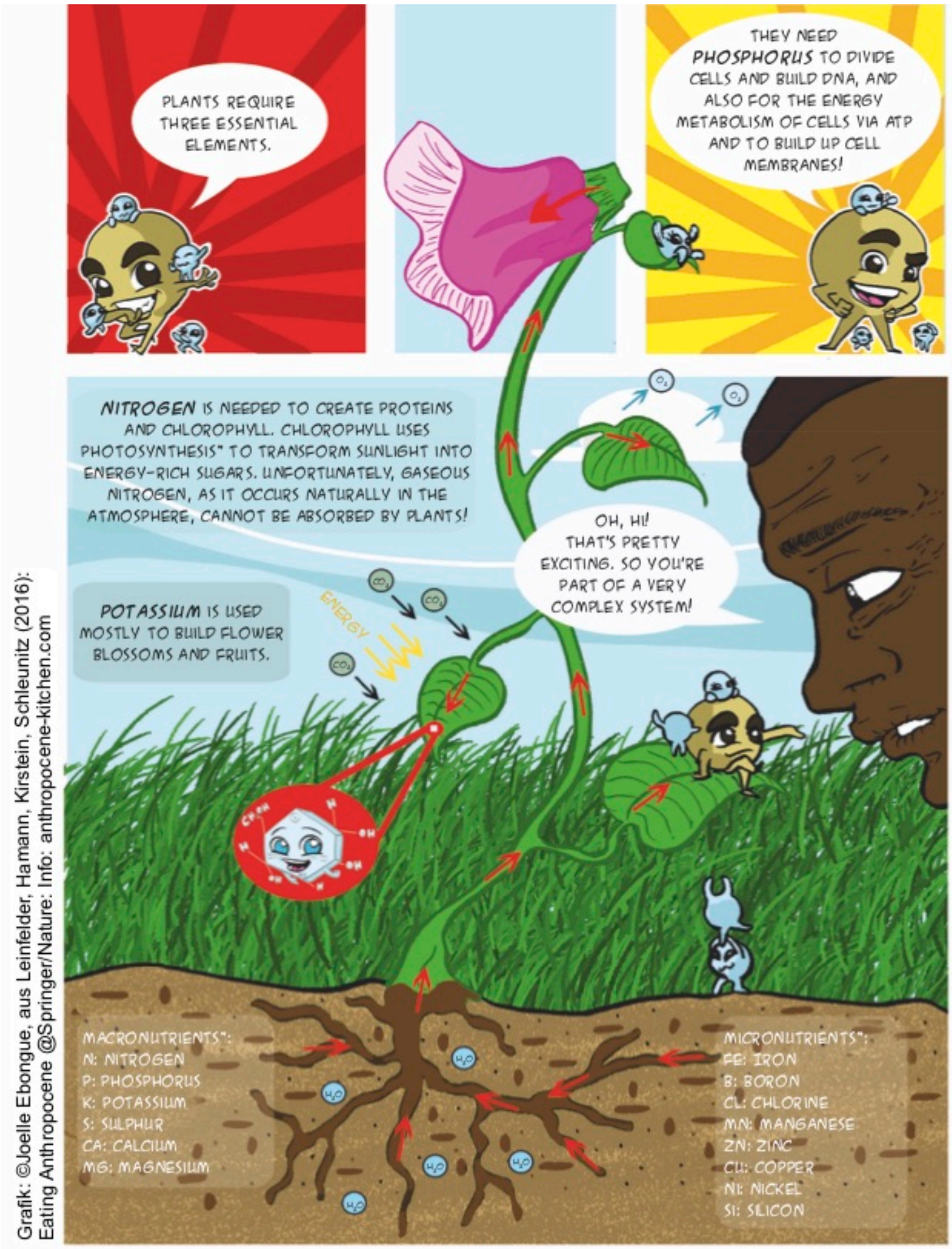


Fig. 1: Plant growth is based on sunlight, CO2 and nutrients. Infographic by Joelle Ebongue, from Leinfelder et al. 2016

Once upon a time

Through cultural evolution, humans have increasingly moved away from this biological pattern of production and consumption. Tools (Fig. 2a) and fire minimised our own energy expenditure in the Palaeolithic, farm animals, first for transport, later also for food, allowed us to become sedentary in the Neolithic, as well as, together with the development of clothing, our expansion into cooler regions, where we depended on supplies from the high productivity of cultivated nature during the summer in winter (Fig. 2b).

*Fig. 2a, b: Top (a): The first tools are invented – here we go hunting in the Palaeolithic.
Bottom (b): The Neolithic has arrived: we settle down, farm and raise livestock, and get through the winter with supplies. Graphic Sylvain Mazas, from Leinfelder et al. 2016*[2].

Let's go industrialise!

This was followed by water power, the steam engine and diesel engines, which made industrial evolution possible (Fig. 3, cf. Fig. 5). Work could thus increasingly be delegated to machines. They weaved, drilled, dredged, transported, cemented for us and increasingly also allowed us to practise industrial agriculture.

[2] See also this Scilogs article:
https://scilogs.spektrum.de/der-anthropozaeniker/rohstoffmanagement-im-anthropozaen-das-beispiel-der-phosphate/

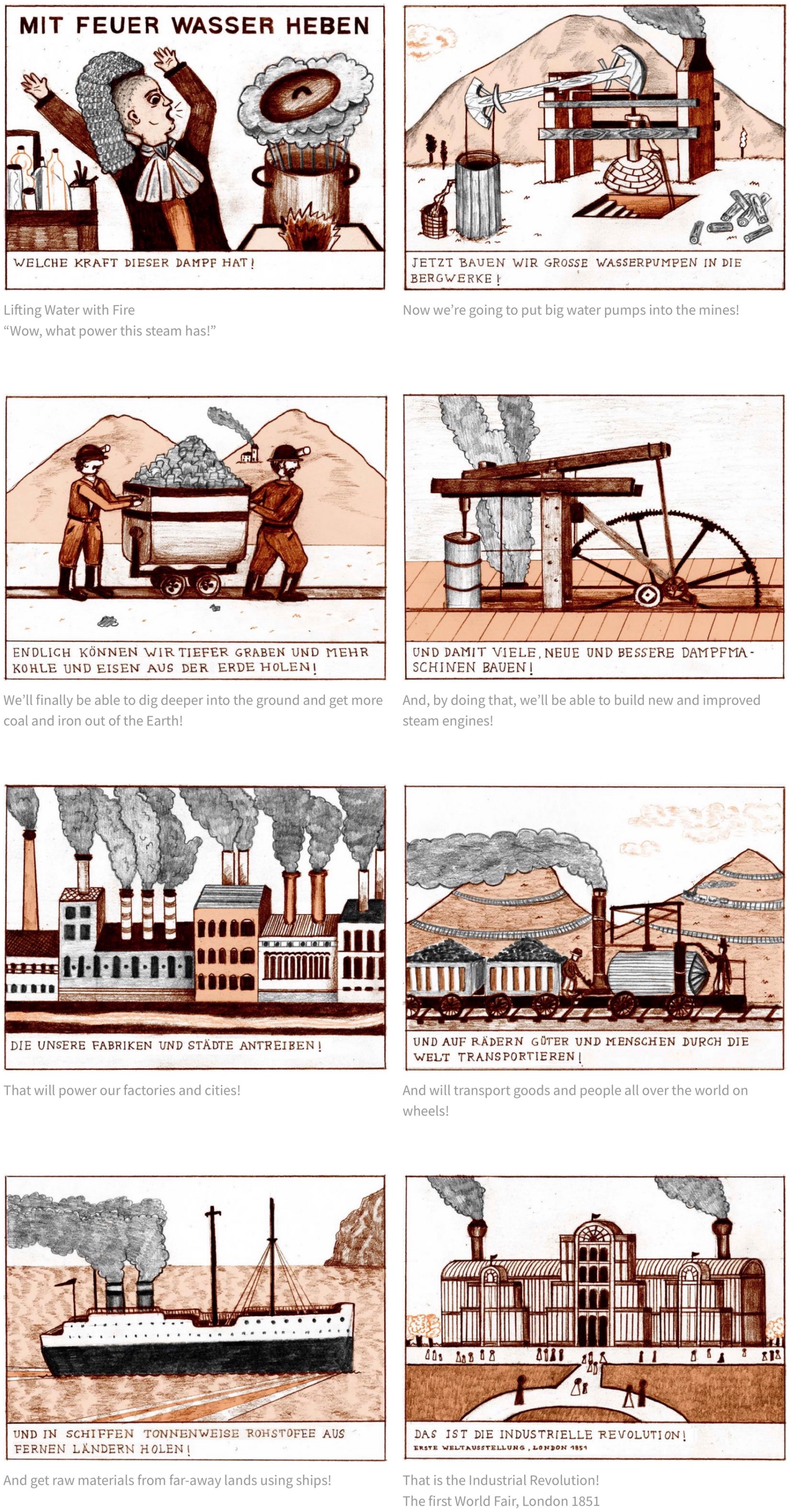


Fig. 3: With the invention and optimisation of the steam engine by James Watt, industrialisation really took off. Comic strip from Hamann et al. 2014, graphic: Marina Portas Chassignet.[3]

[3] *For version with English subtitles see* http://www.environmentandsociety.org/exhibitions/anthropocene/milestones-anthropocene

All this not only allowed an immense growth of our population, but also required not only renewable but also non-renewable resources such as ores, sand, lime, phosphates (Fig. 4), etc..

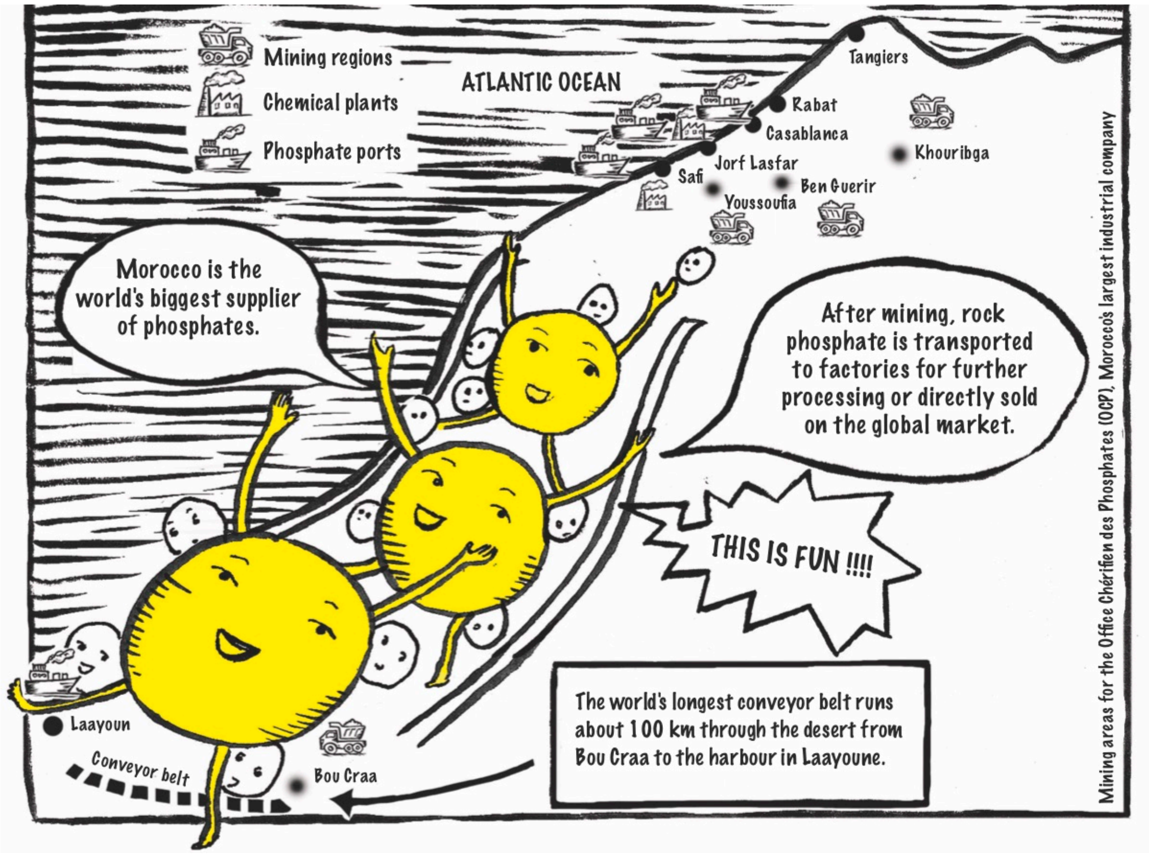


Fig. 4: Example of phosphate as a resource: Our industrialised agriculture has so far been enormously dependent on the phosphate deposits of this earth. These are very finite. By far the largest deposits are found in the Western Sahara annexed by Morocco: Zineb Benjelloun, from Leinfelder et al. 2016.[4]

The necessary energy for this also came from non-renewable fossil fuels. The production and operation of technical devices and machines thus consumes enormous resources and energy (Williams et al. 2016). Expressed as a metaphor: washing machines, cars and computers work for us, but only if we "feed" them (Fig. 5, 6).

Welcome to the Anthropocene - and now?

However, with the help of technologies, humans have also significantly and permanently changed the face of the planet and have thus become the most important global factor influencing the climate and many other environmental parameters. This

[4] *See also this SciLogs article:*
https://scilogs.spektrum.de/der-anthropozaeniker/rohstoffmanagement-im-anthropozaen-das-beispiel-der-phosphate/

has accelerated vehemently since the middle of the 20th century – we have arrived in the Anthropocene[5]. Humanity has converted around 30 trillion tonnes of earth resources into new materials, goods or technical infrastructures (Zalasiewicz et al. 2017)[6]. For every person alive today, there are about 4000 tonnes of technomaterials (Figs. 5, 6, 7). So far, these have only been subject to minimal recycling; the majority of this newly created technical habitat becomes waste (and thus often geosignatures of the Anthropocene that can be passed on, the technofossils[7]).

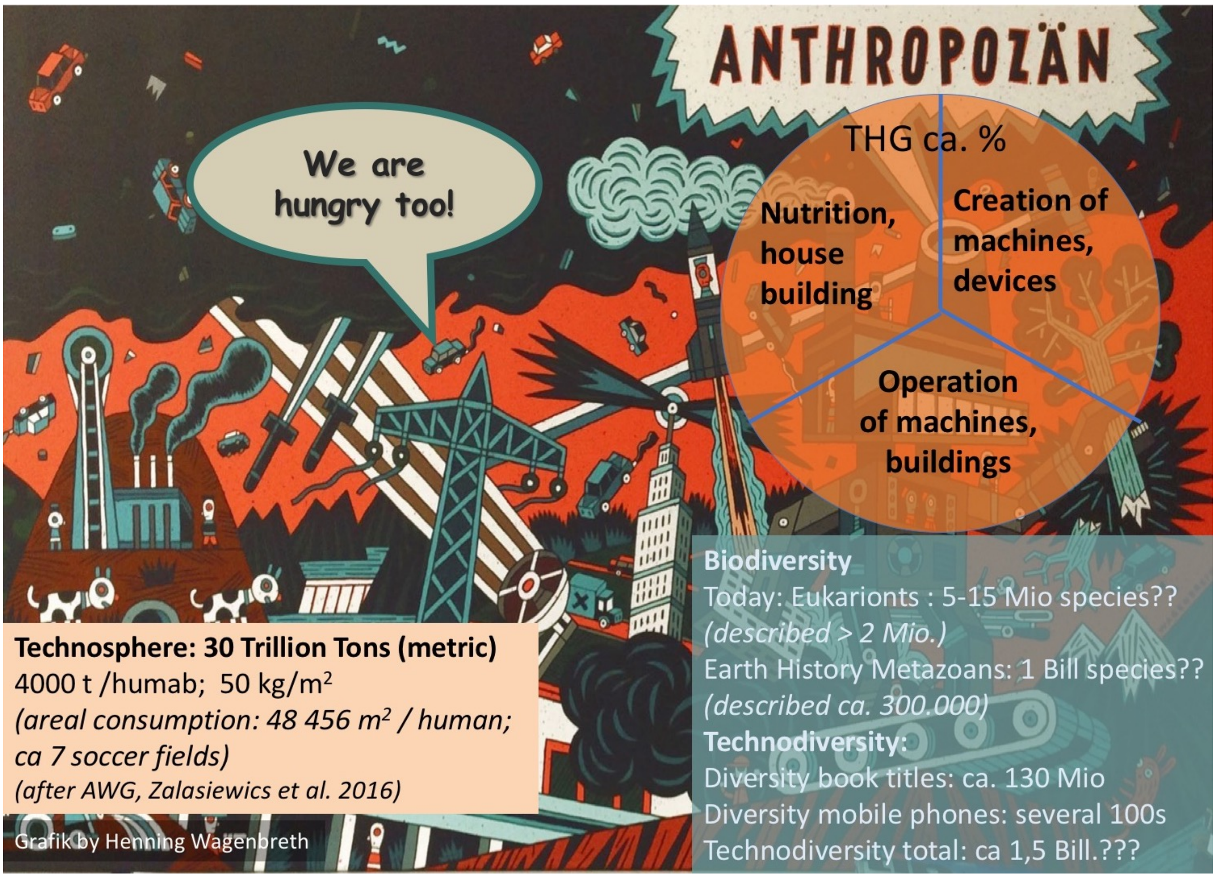


Fig. 5: Extent of the human-made technosphere, the approximate share of GHG emissions for resource extraction, production and operation of technical products, and a rough diversity comparison between technosphere and biosphere. Technosphere figures from Zalasiewicz et al. 2017, GHG figures from various sources. Graphic: Henning Wagenbreth (from cover of Hamann et al. 2014; overlaying text added).

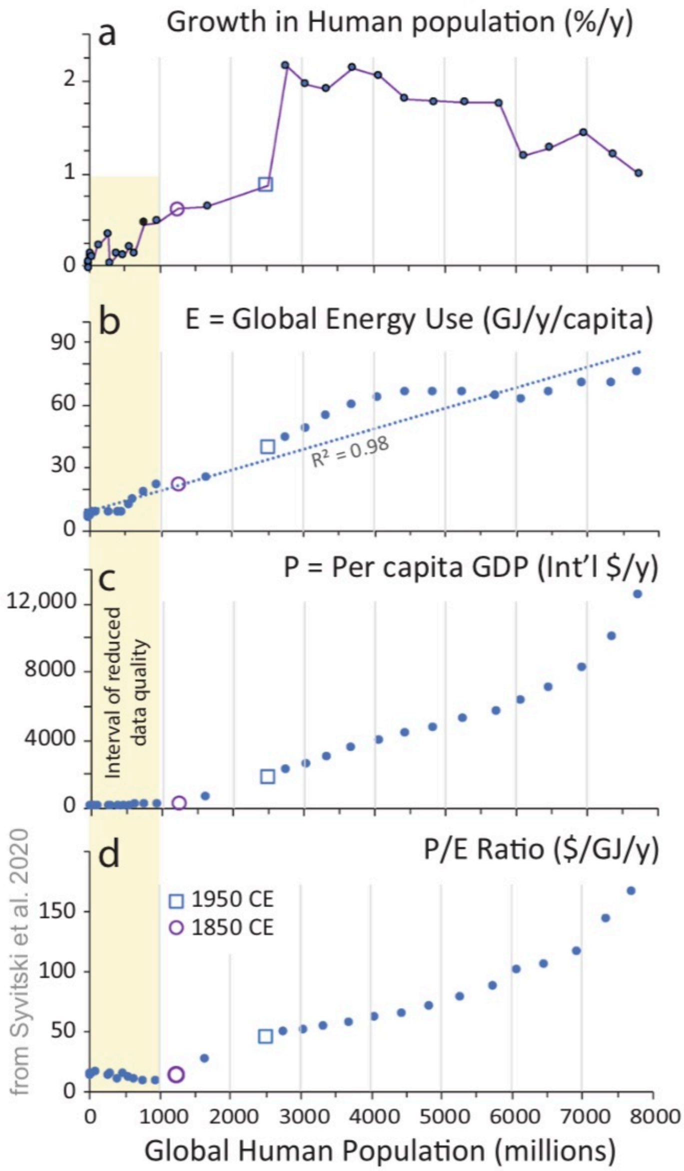
The energy required to build up the technosphere, which has so far mainly come from fossil fuels, adds up to ~22 zetajoules (22×1021J) from 1950 to the present, while from the beginning of the post-glacial period 10,700 years ago until 1950 only ~14.6 ZJ were consumed in total (incl. muscle power) (Fig. 7) (Syvitski et al. 2020).

[5] https://scilogs.spektrum.de/der-anthropozaeniker/das-anthropozaen-unbequeme-fakten-fuer-ein-menschengesteuertes-erdsystem/

[6] https://scilogs.spektrum.de/der-anthropozaeniker/30-billionen-tonnen-technik/

[7] https://scilogs.spektrum.de/der-anthropozaeniker/erdgeschichte-veraendert/

Fig.6: Temporal course of a) growth rate of global population, b) energy consumption per capita and year, c) productivity per capita and year, d) ratio of productivity and energy consumption per capita and year. Circle marker 1850 CE, square marker: 1950 CE: While energy consumption increases continuously on average, the percentage rate of population growth has been falling since the 1970s. Productivity growth has also been rising faster than energy consumption growth for a long time, due to increasing efficiency. From Syvitski et al. 2020, Fig. 2



Human nutrition has been a classic area of culture since the Neolithic at the latest. Today, it not only encompasses a wide variety of production and distribution methods, but also focuses on - sometimes contradictory - values (including good living, justice, health, animal welfare, ecological sustainability), traditions ("Grandma's apple pie recipe is the best"), but also openness to the unknown, such as the diversity of international cuisine. Especially when it comes to food, ecological and social sustainability is closely linked to cultural sustainability.

Table 1 Average values of key human and environmental drivers for each studied time interval.

Geological Unit	Greenlandian Age	Northgrippian Age	Meghalayan Age	Pre-industrial Interval (informal)	Industrial interval (informal)	Anthropocene (proposed Epoch)
Time Interval (y before 2020 CE)	11,720–8256	8256–4270	4270–70	350–170	170–70	70–present
Interval span (y)	3464	3986	4200	180	100	70
Global climate change (°C)	~ +0.5	~ 0.0	~ −0.5	~ 0.0	~ +0.2	~ +0.9
Sea Level Rise (mm/y)	15	3.6	0.3	0.15	0.75	2.4
Population growth rate (%/y)	0.01	0.03	0.2	0.4	0.8	1.6
Primary energy source	Wood & human muscle	Wood & increasingly animal muscle	Wood, muscle, coal in cities	Wood, muscle, whale oil, coal, streams	Coal, oil, hydroelectric	Coal, oil, gas, nuclear, renewables
Per capita energy consumption (GJ/y)	6.2	7.1	8.3	18.4	27.2	61
Total interval energy (ZJ/y)	0.12	0.34	14.2	2.9	4.9	22
Generalized human narrative	Primitive Agrarian Societies	Organized Agrarian Societies	Advanced Agrarian Societies	Empires, Nations, City States	Nations & Empires	UN
GDP (Int'l $/Capita/y)	96	109	144	170	679	5400

Human and environmental drivers across the IUGS/ICS-approved Holocene ages, along with values for two informal intervals occurring in the last 280 years of the ~11,700-y Holocene history, and the proposed Anthropocene Epoch starting in this paper at 1950 CE. All values shown are interval averages.

aus Syvitski et al. 2020

Table 2 Selection of key global environmental parameter values spanning the Holocene-Anthropocene transition.

Environmental Parameter	1900 CE	1950 CE	2000 CE	2015 CE
Human Population (millions)	1643	2499	6076	7349
No. of megacities (>10 M)	0	2	39	45
Human Energy Consumption (EJ/y)	41	100	377	514
Fossil Fuel Consumption (TWh)	5973	20,139	94,462	132,891
CO_2 emissions (Gt/y)	2	5.8	25	35
Atmospheric CO_2 (ppm)	296	311	369	404
Atmospheric N_2O (ppb)	280	289	316	328.5
Atmospheric CH_4 (ppb)	890	1162	1774	1835
Sea level (mm)	−152	−87	0.0	49
Land-Ocean Temperature Index	−0.19	−0.08	0.39	0.83
GDP (billions 1990 Intl $/y)	1116	4656	38,267	73,902
Number of motor vehicles (M)	0.01	8	450	1200
Number of 15 m+ Dams (thousands)	1.6	7	47	50
Global Freshwater use (km^3)	671	1230	3790	4000
Global Shrimp Farming (Mt/y)	0	0.01	1.0	3.5
Plastic Production (Mt/y)	0	2	213	381
Cement Production (Mt/y)	5	130	1600	4180
Ammonia (NH_3) production (Mt/y)	0	2	126	175
Aluminum Production (Mt/y)	0	2	24	58
Copper Production (Mt/y)	0.5	2.4	13	19
Mineral Species (thousands)	5.3	8.3	85	170
Iron & Steel Production (Mt/y)	35	134	573	1160
Sulfur Production (Mt/y)	1	11	59	69
Salt Production (Mt/y)	12	48	195	271
Gypsum Production (Mt/y)	1	23	108	260
Helium Production (kt/y)	0.0	0.4	20	26

Global environmental parameter values for 1900 CE, 1950 CE, 2000 CE and 2015 CE. Almost all parameters see their largest increases after 1950 CE, with many parameters at or near zero near 1900 CE. Data references are listed within the Supplementary Online Material.

from Syvitski et al. 2020

Fig. 7a,b: Examples of the magnitudes of important global environmental parameters a) since the beginning of the Holocene (with the Greenlandian, Northgrippian and Meghalayan subunits[8]) and the Anthropocene to date (top), and b) at the transition from the Holocene to the Anthropocene (bottom). From Syvitski et al. 2020 (Tab. 1 and 2).

[8] See https://scilogs.spektrum.de/der-anthropozaeniker/meghalayan-oder-anthropozaen/

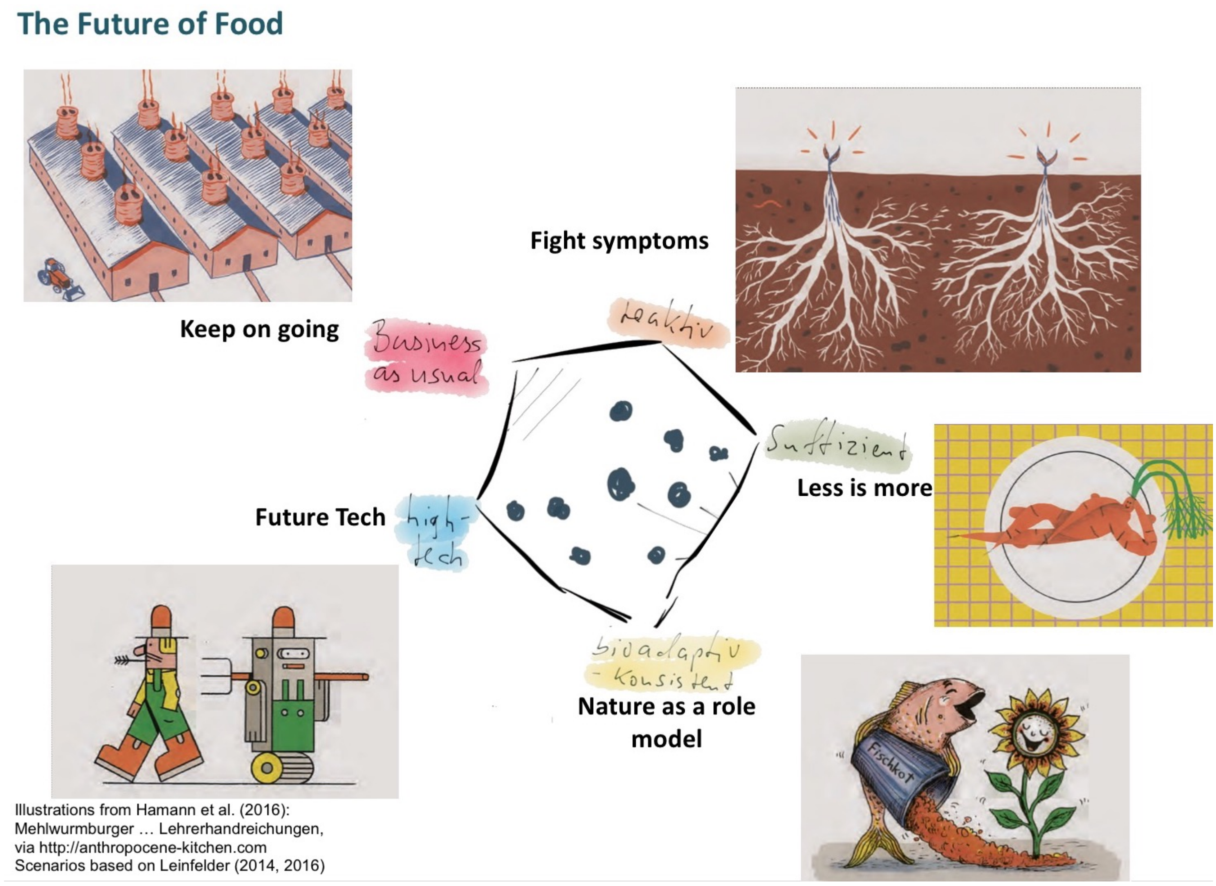


Fig. 8: Possible "futures" of nutrition. 1) Business as usual should not be an option. Possible options could be 2) reactive measures (legislation, reduction of food loss, adapted new breeds), 3) focus on sufficiency (local, seasonal food, possibly vegetarian, vegan), 4) bioadaptive path, with nature as a model (circular economy such as aquaponics, resource-saving insect breeding as food, etc.) and 5) high-tech path (GPS-controlled, nature-compatible agriculture, farm-scraping, Beyond Meet products, lab meat). Mixed portolios can be composed from 1-4. Based on Leinfelder 2014, 2018. Graphics from Hamann et al. 2016.

This awareness could be used and expanded with the help of narratives and further cultural practices[9] to enable cultural shifts in perspective[10] (for example, insects as food, artificial meat, old varieties) (Fig. 8) and, in particular, to allow the insight to grow that the biosphere is an excellent model for dealing with the technosphere in the future.

The technical building blocks obtained from nature would have to remain in the system permanently, i.e. they would have to be disassembled and reassembled into new products. The necessary forms of energy for this would be renewable energies, as in the case of the biosphere. There would be no waste in such a system. Biosphere and technosphere would be compatible and humanity, with a new consciousness, new values and new responsibility, would be a significant step further towards the establishment of a functioning Earth system that permanently supports and supplies us (Fig. 9).

[9]See https://scilogs.spektrum.de/der-anthropozaeniker/narrative/
[10] See https://scilogs.spektrum.de/der-anthropozaeniker/haus-zukunft-berlin/

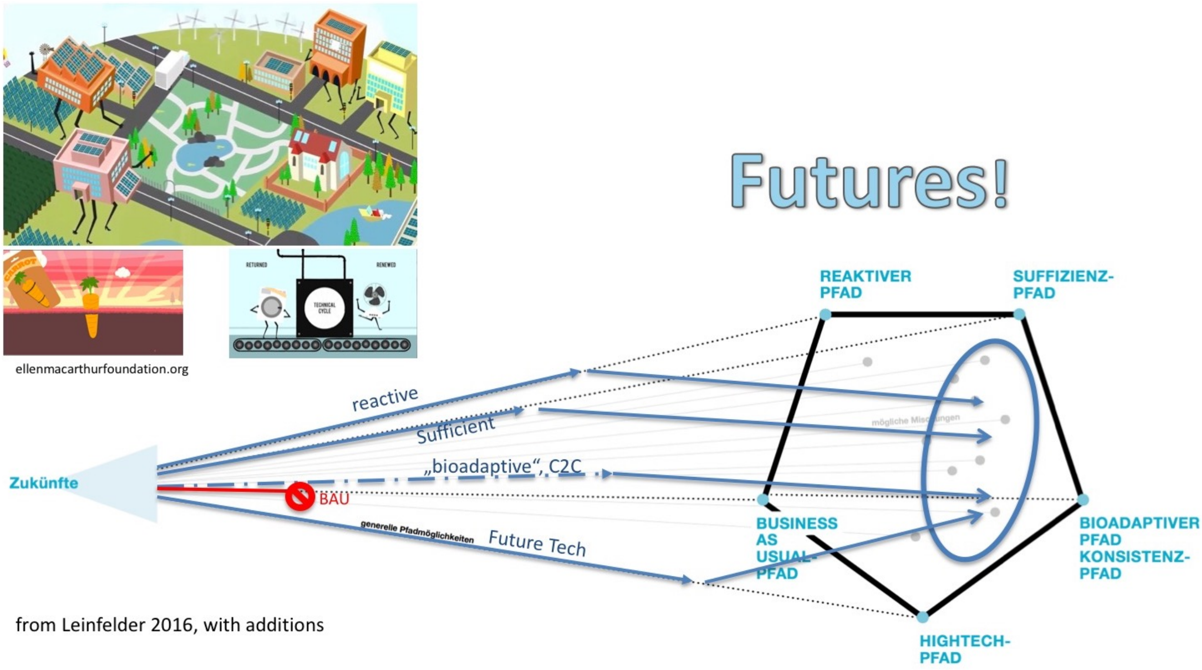


Fig. 9: With the exception of the Business as Usual (BAU) path, which is not compatible with the Earth system, many paths lead to an Anthropocene that is compatible with the Earth system. These can certainly be followed in parallel. The general compass could be a perfect circular economy oriented towards the biosphere (see inset above left), which should, however, also include sufficiency and high-tech aspects, as well as reactive measures (subsidies, further legal regulations, new breeds, etc.). From Leinfelder 2016, supplemented. Inset top left from ellenmacarthurfoundation.org

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Notes

The text of this article is mostly identical with a (German) abstract submitted for the symposium "Learning and Teaching Cultural Sustainability" at the Pädagogische Hochschule Niederösterreich[11]. The illustrations from our own projects were added for this Scilogs version (esp. from Hamann et al. 2014, 2016, Leinfelder 2016, 2018, Leinfelder et al. 2016, Syvitski et al. 2020).

This essay also complements the Scilogs Anthropocene blog post "Addicted to energy"[12], published on 17.10.2020 on the occasion of the release of the new Anthropocene Working Group study (Syvitski et al. 2020).

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[11] See: https://www.ph-noe.ac.at/de/forschung/forschung-und-entwicklung/anthropozaen/symposium.html
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[12] https://scilogs.spektrum.de/der-anthropozaeniker/die-menschheit-verbrauchte-seit-1950-mehr-energie-als-in-fast-12-000-jahren-zuvor/