The human-made mass – “Would you like a little more?”

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Illustration: Henning Wagenbreth, UdK Berlin (used with permission)

At the end of last year, on the occasion of the publication of an exciting new study, several reports went through the press such as "Human-made stuff now outweighs all life on Earth" (Scientific American), "Human-made materials now weigh more than the Earth's entire biomass" (The Guardian) or "Human-made mass exceeds biomass for the first time in 2020" (Bayerischer Rundfunk). In fact, the new study published in the renowned scientific journal Nature on 9.12.2020 was also titled "Global human-made mass exceeds all living biomass" (Elhacham et al. 2020).

In the meantime, I have been asked several times whether the Anthropocene Working Group (AWG) (and thus also I) has not already come up with completely different, orders of magnitude higher values for the mass of the "technosphere" at the end of 2016 and how this new study fits in. Such questions, as well as the metabolism metaphor often used in my recent Scilogs blogposts to compare the biosphere and the technosphere, but also the creation of some new number-based graphs for lectures, current talks and a paper in preparation, are what I take as an opportunity to compare the different approaches in more detail in this post.

1. Human-made mass *sensu* Elhaham et al. (2020)

The "human made mass" by Elhacham et al. (2020) lists only materials that are currently in use. The main units are concrete (consisting of cement and concrete aggregate, i.e. gravel and sand), other aggregates (mainly gravel, sand), bricks, asphalt, metals and “rest” (Fig. 1). The “rest” (which in the calculation, however, only accounts for around 2% of the total mass) includes in particular glass, plastics and industrial wood (using roundwood mass as a measure of wood products).

Only what is currently in use was counted, i.e. no plastic waste, industrial waste, demolished houses, discarded appliances, etc. So, unlike other technomaterial approaches, only "inanimate", "visible" materials currently in use were considered. Wood products are included as the only product of the biosphere because of their dead character, but livestock and living crops are not. In an appendix, further calculations are alternatively taken into account, for example by including farm animals in human-modified mass on an experimental basis, but this is rather negligible due to the small share of vertebrates in the total biomass.

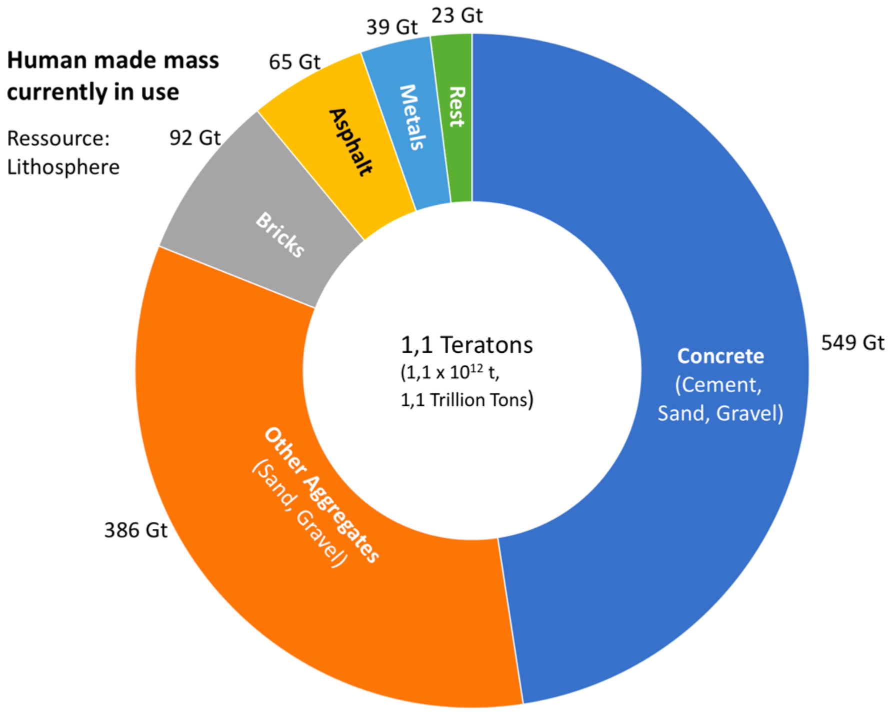


Fig. 1: Human-made mass currently in use, data from Elhacham etal. (2020). From Leinfelder (2021, submitted).

2. Global biomass *sensu* Elhacham et al. (2020)

The biomass figures come from an equally remarkable study by the same working group (Bar-On et al. 2018). However, in contrast to the 2018 paper, which calculated the biomass based on the carbon content (so-called energetic biomass), they were converted into dry biomass for their current paper. For this purpose, c-biomass values were multiplied by a conversion factor of 2.25. For further comparison, wet biomass was also used in part, for which a further conversion factor dry/wet of 1 to 2 was used (for calculation see Elhacham et al. 2020). A further change in the figures to the original paper (Bar-On et al 2018), is based on a critique by Flemming & Wuertz (2019), most of whose justification has been conceded (Bar-On & Milo 2019). Fig. 2 shows the carbon-based biomass figures from Bar-On et al. (2018) in this corrected form.

Thus, according to the Elhacham Group's calculation, the "human made mass" will exceed the dry biomass of the entire biosphere in 2020. However, based on carbon-based biomass figures, the biomass weight of all life today would be less than half of the technical mass in use, and based on wet weight it would be twice as much (cf. Fig. 4d).

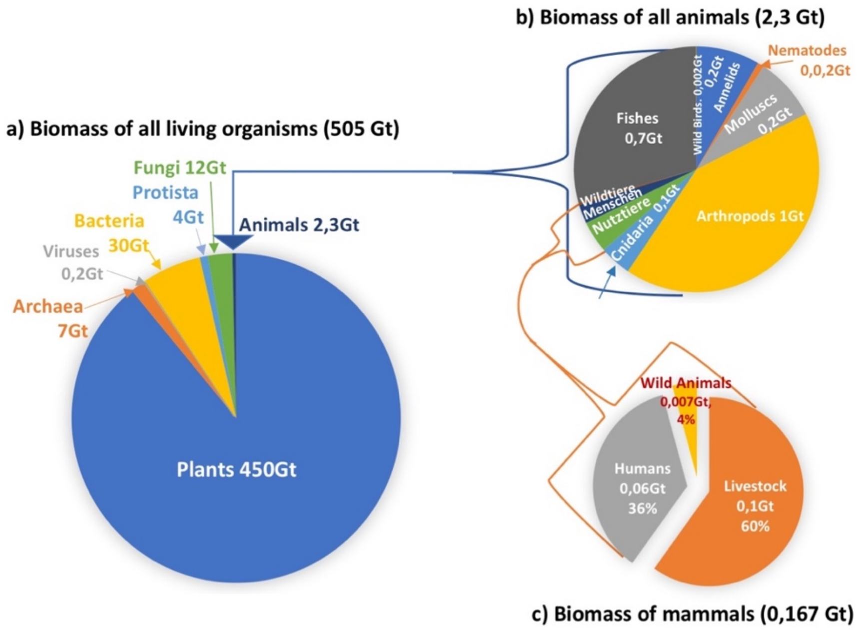


Fig. 2: Carbon-based global biomass and its breakdown by organism group. Data according to Bar-On et al. (2018), a) corrected according to Bar-On & Milo (2019), from Leinfelder (2021, submitted).

3. Lithosphere materials anthropogenically altered by mining and civil engineering *sensu* Cooper et al. (2018)

Quite different figures of "human made mass" emerge under extended but consistent assumptions, as published by another working group, including members of the AWG in 2018 (Cooper et al. 2018). They consider the following basic categories:

1. Summed mass of technomaterials produced and used over the period 1950-2015;
2. Mass of additional materials moved for raw material extraction, such as overlying cap rock to be removed over a large area in opencast mining and waste rock that cannot be used any further when extracting the resources. This was taken into account for the following minerals: bauxite, arsenic, asbestos, barytes, bentonite/fullers earth, bromine, cadmium, chromium ores, diamond, diatomite, feldspar, fluorspar, graphite, gypsum, iodine, kaolin, lithium minerals, magnesite, manganese ore, mercury, mica, phosphate rock, rare earth minerals, salt, sillimanite minerals, talc, tantalum and niobium minerals, titanium minerals, zirconium minerals, beryl, borates, nephelene syenite, potash, perlite, strontium minerals, vermiculite, wollastonite, natural sodium carbonate, and mine production of antimony, bismuth, cobalt, copper, gold, lead, molybdenum, nickel, platinum group metals, silver, tin, tungsten, uranium, vanadium and zinc, as well as coal (see below).
3. Inclusion of the materials to be removed during civil engineering, e.g. for tunnels, underground tubes, underground car parks, basements, foundations, etc.
4. Mass of fossil energy sources (coal only) required for the extraction, transport, production and operation of the technical products, excluding gaseous and liquid energy sources, i.e. excluding oil and gas, see section 5 below).

In particular, the addition of the mining weight of unused materials to ores/minerals and coal extraction is very significant. Fig. 3 shows an extreme case: gold mining today. Since gold nuggets lying around freely or easily washed out of water bodies have long since been fully collected, 4-12 tonnes (average approx. 12 tonnes) of rock must be mined today to extract four grammes of gold, i.e. the average amount of gold in a wedding ring, from which 1-4 tonnes (average approx. 2.5 tonnes) of gold-bearing ore can be selected, which can then be further crushed and mixed with toxic chemicals such as cyanides or mercury, as well as huge amounts of water, to enable the extraction of a total of 4 grammes of gold (Cooper et al. 2018).

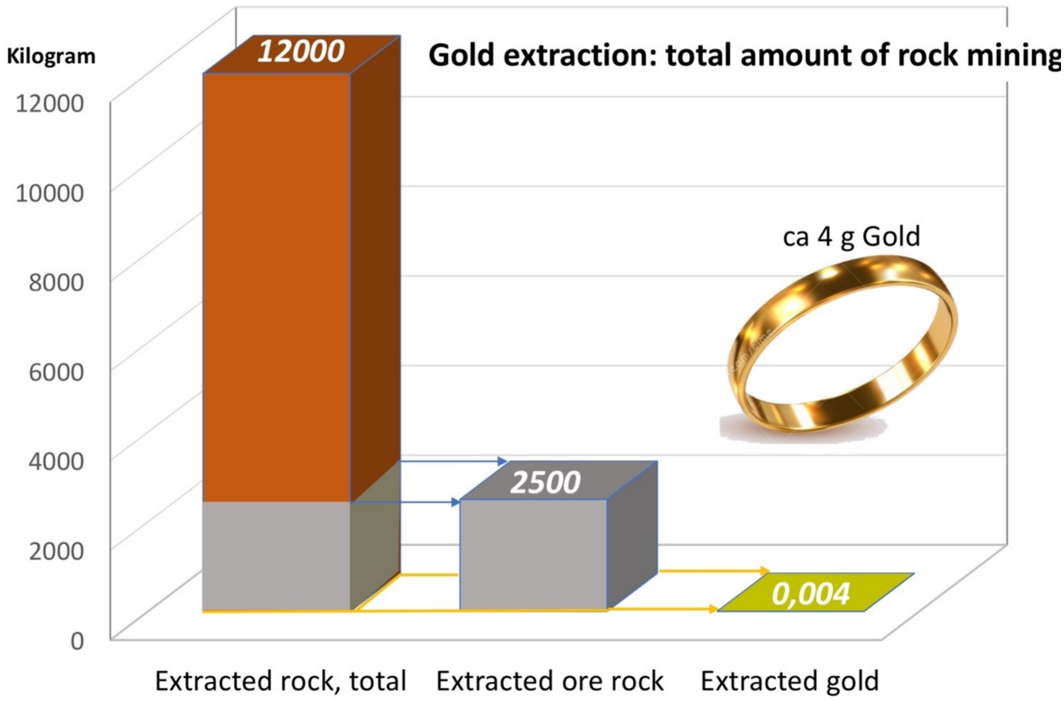
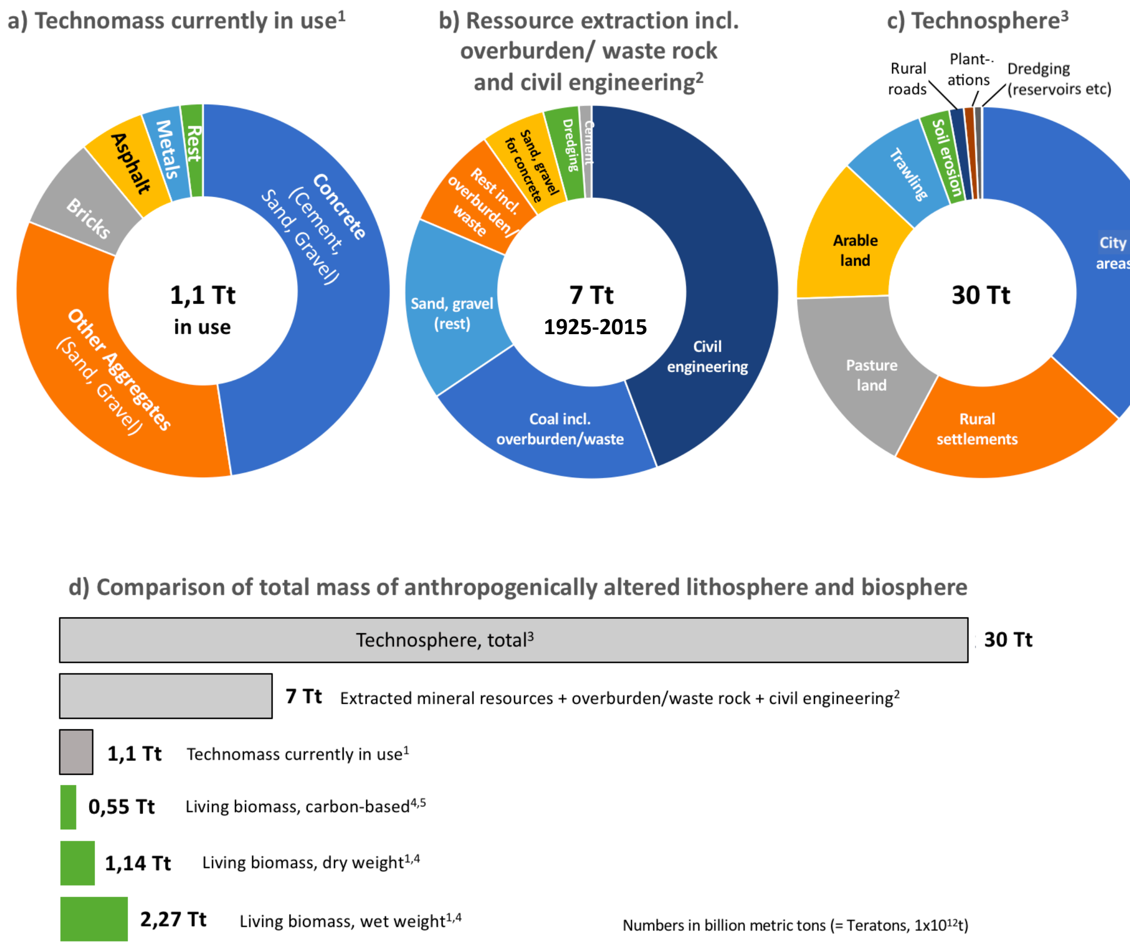


Fig. 3. ratios of total mining, gold-bearing ore rock and recovered gold. Data from Cooper et al. 2018, see also text.

Cooper et al. (2018) summed all these materials (categories 1-4) over a period of 1950-2015, roughly the duration of the Anthropocene to date. This resulted in a human-altered lithosphere mass of 7 teratonnes over this period (Fig. 4a, *i.e.* about seven times the mass currently in use, as calculated by Elhacham et al. (2020) (Fig. 4d). In their appendix, Elhacham et al. (2020) briefly refer to this paper and conclude that, taking into account the additional overburden, the weight of the human made masses would have already exceeded that of the biosphere in 1975 (cf. Cooper et al. 2018; Colin Waters, oral communication).



Data based on [1]Elhacham et al. (2020), [2]Cooper et al. (2018), [3]Zalasiewicz et al. (2017), [4]Bar-On et al. (2018), [5]Bar-On & Milo (2019)

Fig. 4: The very different estimates of anthropogenic technomass are based on very different approaches (cf. text). Figures in teratonnes (trillions of tonnes). a) Technomass currently in use (incl. roundwood, otherwise abiogenic materials), without taking into account the additional substances moved by mining, extraction, separation and construction measures (anthropogenic mass or human-made mass *sensu* Elhacham et al. 2020). b) Estimation of the lithosphere mass moved by mineral extraction and infrastructure measures since 1950 (anthropogenic sediment flux through mineral extraction and civil engineering, *sensu* Cooper et al. 2018);
c) Estimation of the mass shares of all anthropogenic changes in inanimate and animate nature (physical technosphere *sensu* Zalasiewicz et al. 2017); d) Mass comparison of the anthropogenically altered lithosphere and biosphere. Especially the biosphere masses differ by a factor of 4, depending on whether carbon-based, dry or wet biomass is specified (cf. text). From Leinfelder (2021,submitted).

4. Total technosphere weight *sensu* Zalasiewicz et al. (2017)[1]

In this work, which also received much media attention, members of the AWG attempted to estimate the total weight of all natural materials changed by humans through cultural techniques over the entire period of human history. In addition to the materials already

[1] Note: This study appeared online first already at the end of 2016, so that it is often cited under 2016 publication date – including in Anthropocene blog posts that were posted at “Der Anthropozäniker” directly on occasion of its first publication. The printed version then appeared in early 2017, which according to the publisher is also the formal publication date, which is why it is now listed as Zalasiewicz et al. (2017).

mentioned above, the authors also include the transformation of natural sediments through trawling, agricultural soil modification (including ploughing, planting and harvesting machinery and the addition of fertiliser) and the generation of anthropogenic sediments (such as reservoir sediments through water regulation).

Since this also represents anthropogenically modified matter, livestock, crops and "plantation forests" planted by humans were also taken into account, whereby only forests account for a detectable proportion of the total biomass due to their high trunk biomass. The total non-decomposable proportion of discarded materials ("technical waste") was also included in the calculations[2]. The aim was to assess the quantifiable and geologically documentable extent of anthropogenic intervention in the Earth system and, if necessary, to use it to define the Anthropocene.

Naturally, due to the different approaches, the quantitative calculation methods are also different.

- For the estimation of techomass currently in use, Elhacham et al. (2020) use the production figures of their six basic categories from around 1925 onwards and estimate the materials still in use in a kind of socio-economic lifecycle analysis (in particular using Krausmann et al. 2017). A number of buildings, in particular those built before 1925 but still in use, fell under the table.
- In addition to production data, Cooper et al. (2018) use in particular data on mining operations as compiled by national geological services.
- Zalasiewicz et al. (2017) attempted to estimate both the areal extent and mean thicknesses (geologically "thicknesses") of human-altered and resedimented materials based on archaeological, historical and urban studies, as well as compilations of land use changes. Altered means both "moved and redeposited" and the estimation of a mean thickness of debris from theoretically levelled and resedimented cities. In the case of very old cities, for example of Roman origin, a thick building relic subsoil is already present, but hardly any of these cities are distinguished by today's mighty elevated buildings. In contrast, US-American cities, for example, are young, i.e. have hardly any urban materials in the subsoil, but are characterised by high-rise buildings today. Average resedimentation thicknesses - for cities on average approx. 200 cm, for rural settlements approx. 100 cm, for farmland approx. 15 cm, etc. - were assigned to their areal extent (urban regions approx. 3.7 million km2) as well as average material densities - based on investigations of building rubble dumps, for example (approx. 1.5 g/cm2) - in order to calculate the weight (for more information, see here[3] and here[4] in this blog).

Overall, this proxy approach yields a total weight of the technosphere of about 30 trillion tonnes (Fig. 4c), i.e. thirty times the weight of its human made mass calculated by Elhacham et al.(2020) under other assumptions (Fig. 4d). Despite their small area share of about 2.5% of the land surface, the mass of cities takes up almost 40% of the technosphere mass, namely 11.1 Tt. Zalasiewicz et al. (2017) point out that the 30 trillion tonnes of natural matter moved and otherwise altered by humans only indicates the order of magnitude of human interventions; they are chosen rather conservatively, but could nevertheless easily be only 25 trillion, but perhaps also 40 trillion tonnes, especially since only such areal fractions of the subsurface of anthromes that are strongly influenced by

[2] For definition, from Zalasiewicz et al. 2017 "..... defined here as the summed material output of the contemporary human enterprise. It includes active urban, agricultural and marine components, used to sustain energy and material flow for current human life, and a growing residue layer, currently only in small part recycled back into the active component."

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

[4] https://scilogs.spektrum.de/der-anthropozaeniker/ach-du-dickes-b-wieviel-wiegt-berlin/

humans were taken into account, but not human made particles occurring interspersed in natural sediments (such as plastic particles in ocean sediments) that only occur as isolated components.

5. Not to forget - the energy required

In two previous scilog posts (here[5] and here[6]) I have already discussed another recent work of the Anthropocene Working Group, on the gigantic energy consumption of humankind from the end of the last ice age until today (Syvitski et al. 2020). We tried to compile the amount of anthropogenic energy use. The energy use of the early Holocene hunting and incipient agricultural societies through human muscle power and wood burning can be estimated at 6.2 gigajoules per capita and year. In the middle Holocene, the muscle power of pack animals was added, agricultural societies slowly developed further, and energy consumption increased to 7.1 GJ per capita per year. In the late Holocene, peat was also used, and later coal, whale oil, hydropower and petroleum. Agricultural societies continued to develop, and later city states, nations and imperial empires were founded. Energy consumption rose to an average of 8.3 GJ, in the pre-industrial period (ca 1670 - 1850) to 18.4, during industrialisation (1850-1950) to 27.2 GJ per capita per year. Since the proposed beginning of the Anthropocene around 1950, natural gas, nuclear energy and, to a still small extent, other renewable energies have been added, and energy consumption has risen to 61 GJ per capita per year. In total, humanity consumed 14.6 zettajoules of energy during the Holocene, including almost 8 zettajoules from 1670 -1950 alone, i.e. in 280 years. Since 1950, the postulated beginning of the Anthropocene, humanity has consumed an unimaginable 22 zettajoules of energy - in the last 70 years almost 1.5 times of what humanity had consumed during the previous 12,000 years (Fig. 5). Productivity per capita has even increased in recent times (Syvitski et al. 2020).

6. Conclusions

All calculation methods have their justification and advantages and complement each other (Figs. 4, 5):

- It is impressive to see that the "inanimate" materials and products we have created and are currently building and using weigh as much as the entire living biosphere.
- When listing up production data hardly any thought is normally given to the amount of mining work which is necessary for that and to the immense masses of lithosphere materials that have to be moved to extract what we actually want to use.
- Even less is known about how much of the Earth's surface we are changing altogether to do this, thereby also creating new anthropogenic sediment layers - those of the physical technosphere.
- The energy figures underline the extreme amount of energy we now use to extract all these materials, process them and then use them as technical products.

[5] https://scilogs.spektrum.de/der-anthropozaeniker/die-menschheit-verbrauchte-seit-1950-mehr-energie-als-in-fast-12-000-jahren-zuvor/
[6] https://scilogs.spektrum.de/der-anthropozaeniker/auch-maschinen-haben-hunger/

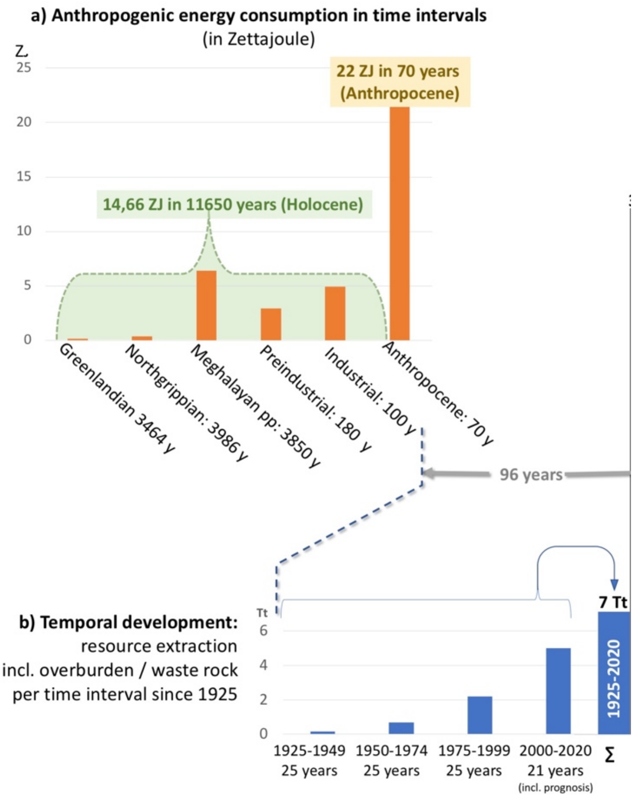


Fig. 5: Energy input and degradation dynamics.

a) Anthropogenic energy consumption since the last ice age (see text), based on data from Syvitski et al. (2020). The duration of the stratigraphic subunits of the Holocene up to 1950 is given, and the informal time units pre-industrial and industrial, during which energy consumption increased rapidly, especially due to the onset of industrialisation and the use of coal, are also separated. Nevertheless, during the Anthropocene that followed, 1.5 times more energy was consumed in 70 years than during the almost 12,000-year Holocene epoch. Data in zettajoules (1 ZJ = 1x10^{21} joules).

b) Temporal increase in the extraction of mineral resources from the lithosphere (incl. overburden, waste rock and other mineral waste). For comparison, the total technosphere mass is shown as well (see Fig. 4 and text). From Leinfelder (2021, submitted).

Or more simply, and expressed in analogy with the biosphere:

- The ratio of matter obtained to materials actually used could be called the feed conversion ratio of the technology. For comparison: in predatory fish such as salmon, the feed-to-meat ratio is up to 5:1, in cattle usually above 6:1, in insects about 1-2 :1.
- The total technosphere shows what proportion of the natural lithosphere and pedosphere has been converted to an anthropogenic sphere, the technosphere, and how extensive this process is. This can be compared with anthropogenic land use in the biosphere.
- From all this, we then created our cultural-technical helpers, such as machines, vehicles, computers, appliances which now make our lives so much easier. However, we have long since stopped using our own muscle power or the muscle power of farm animals to generate the energy needed to extract raw materials, to construct buildings, machines and devices, and to operate them; instead, we get it - in the form of fossil, finite fuels - from the lithosphere as well.

The evolution and increasing diversity of the biosphere over billions of years is thus a wonderful example and operating manual of what is possible when all the necessary building blocks remain in a circular system being used again and again, and when the energy needed to reassemble them comes from the sun. Why don't we learn from this wonderful teacher for our further cultural evolution?

It is to be hoped that these numerical examples may contribute a little to a better understanding of the fact that we not only have problems (such as over-fertilisation, water consumption, insect mortality, food or fuel challenge, etc.) with renewable agricultural biosphere resources, but in particular also with non-renewable lithospheric resources, which must not be neglected any further due to the gigantic interventions in nature and the associated emission of greenhouse gases.

Literature cited:

Bar-On, Y.M., Phillips, R., Milo, R. (2018): The biomass distribution on Earth. In: Proc. Nat. Acad. Sci. USA, 115 (25), 6506-6511, http://doi.org/10.1073/pnas.1711842115

Bar-On, Y.M. & Milo, R. (2019): Towards a quantitative view of the global ubiquity of biofilms. Nature Reviews Microbiology, 17, 199- 200, http://doi.org/10.1038/s41579-019-0162-0

Cooper, A.H., Brown, T.J., Price, S.J., Ford, J.R. & Waters, C.N. (2018): Humans are the most significant global geomorphological driving force of the 21st century.-The Anthropocene Review 1-8, http://doi.org/10.1177/2053019618800234

Elhacham, E., Ben-Uri, L, Grozovski, J., Bar-On, Y.M. & Milo, R. (2020): Global human-made mass exceeds all living biomass.- Nature, 588, 442-444, http://doi.org/10.1038/s41586-020-3010-5

Flemming, H.-C. & Wuertz, S. (2019): Bacteria and archaea on Earth and their abundance in biofilms. Nature Reviews Microbiology, 17, 247-260, http://doi.org/10.1038/s41579-019-0158-9

Krausmann, F. et al. (2017): Global socioeconomic material stocks rise 23- fold over the 20th century and require half of annual resource use.- Proc. Nat. Acad. Sci. USA, 114, 1880-1885.

Leinfelder, R. (2021, submitted): "Auch Maschinen haben Hunger" - Biosphäre als Modell für die Technosphäre im Anthropozän (Arbeitstitel).- In: Rauscher, Sippl et al. (eds) "Kulturelle Nachhaltigkeit lernen und lehren", "Pädagogik für Niederösterreich", Innsbruck/Wien (StudienVerlag).

Syvitski, J., Colin N. Waters, John Day, John D. Milliman, Colin Summerhayes, Will Steffen, Jan Zalasiewicz, Alejandro Cearreta, Agnieszka Galuszka, Irka Hajdas, Martin J. Head, Reinhold Leinfelder, John R McNeill, Clement Poirier, Neil Rose, William Shotyk, Michael Wagreich & Mark Williams (2020): Extraordinary human energy consumption and resultant geological impacts beginning around 1950 CE initiated the proposed Anthropocene Epoch. Communications Earth & Environment, http://doi.org/10.1038/s43247-020-00029-y, open access)

Zalasiewicz, J., Williams, M., Waters, C.N., Barnosky, A.D., Palmesino, J., Rönnskog, A.S., Edgeworth, M., Neil, C., Cearreta, A., Crutzen, E., Fairchild, I.J., Grinevald, J., Haff, P., Ivar do Sul, J.A., Jeandel, C., Leinfelder, R., McNeill, J.R., Odada, E., Oreskes, N., Price, S.J., Revkin, A., Steffen, W., Summerhayes, C., Vidas, D., Wing, S., & Wolfe, A.P. (2017 /online first Nov. 28, 2016): Scale and diversity of the physical technosphere: A geological perspective. The Anthropocene Review, 4 (1), 9-22, http://doi.org/10.1177/2053019616677743

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