ALL NUMBERS PROVISIONAL -- AUTHOR LIST SUBJECT TO CHANGE -- PLEASE DO NOT DISTRIBUTE

HUMAN IMPACTS by the numbers

Griffin Chure[1], Avi Flamholz[2], Nicholas S. Sarai[3], Tine Valencic[1], Mason Kamb, Yinon Bar-On[4], Ron Milo[4], Rob Phillips[2,5,*]

California Institute of Technology, Pasadena, CA, USA, 91125:
[1]Department of Applied Physics; [2]Division of Biology and Biological Engineering; [3]Division of Chemsitry and Chemical Enigineering; [5] Department of Physics
[4]Weizmann Institute of Science, Rehovot 7610001, Israel:
Department of Plant and Environmental Sciences

ABSTRACT

The greatest experiment of the last 10,000 years is the presence and action of modern human beings on planet Earth. At this point, the consequences of this experiment are being felt on many fronts. Yet, many people still hold the view that because the world is so "huge", humans cannot really make a substantial impact. This snapshot represents a collection of what we have come to view as essential numbers that summarize the broad reach of human action across the planet, presenting a view of the impact of human presence on Earth.

REFERENCE UNITS

per capita (global) = 1×

human population = ≈ 7×10^9

area of soccer pitch = ≈ 3000 m²

volume of olympic pool = ≈ 2000 m³

power of an LED lightbulb = ≈ 10 W

mass of a pick-up truck = ≈ 1 t

HUMAN IMPACT CATEGORIES

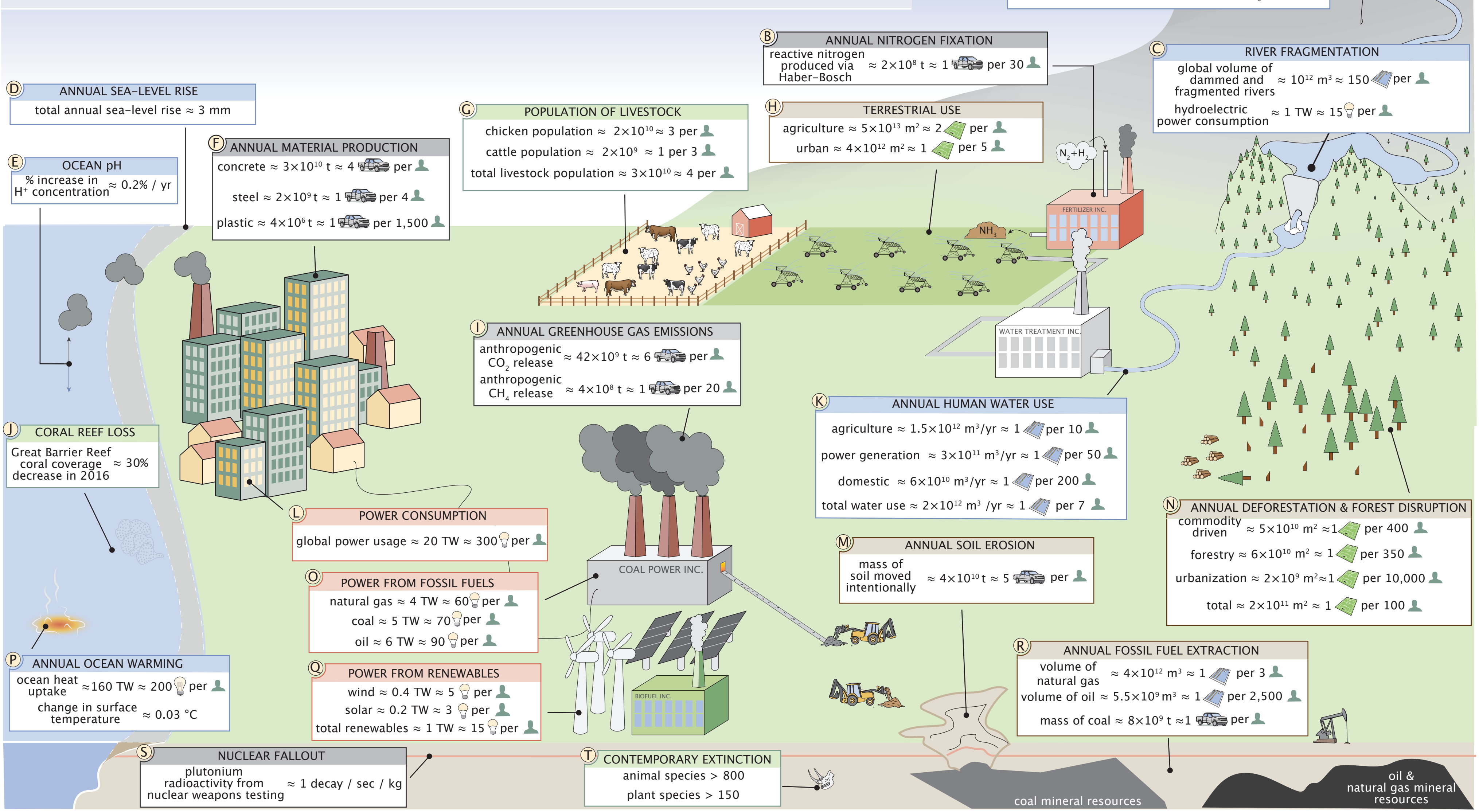
LAND

ENERGY

FLORA & FAUNA

WATER

ATMOSPHERIC & BIOGEOCHEMICAL CYCLES



(A) ANNUAL ICEMELT

glacial melt volume ≈ 3×10^{11} m³/yr ≈ 40 per

ice-sheet melt volume ≈ 4×10^{11} m³/yr ≈ 60 per

total melt volume ≈ 10^{12} m³/yr ≈ 150 per

(B) ANNUAL NITROGEN FIXATION

reactive nitrogen produced via Haber-Bosch ≈ 2×10^8 t ≈ 1 per 30

(C) RIVER FRAGMENTATION

global volume of dammed and fragmented rivers ≈ 10^{12} m³ ≈ 150 per

hydroelectric power consumption ≈ 1 TW ≈ 15 per

(D) ANNUAL SEA-LEVEL RISE

total annual sea-level rise ≈ 3 mm

(E) OCEAN pH

% increase in H^+ concentration ≈ 0.2% / yr

(F) ANNUAL MATERIAL PRODUCTION

concrete ≈ 3×10^{10} t ≈ 4 per

steel ≈ 2×10^9 t ≈ 1 per 4

plastic ≈ 4×10^6 t ≈ 1 per 1,500

(G) POPULATION OF LIVESTOCK

chicken population ≈ 2×10^{10} ≈ 3 per

cattle population ≈ 2×10^9 ≈ 1 per 3

total livestock population ≈ 3×10^{10} ≈ 4 per

(H) TERRESTRIAL USE

agriculture ≈ 5×10^{13} m² ≈ 2 per

urban ≈ 4×10^{12} m² ≈ 1 per 5

(I) ANNUAL GREENHOUSE GAS EMISSIONS

anthropogenic CO_2 release ≈ 42×10^9 t ≈ 6 per

anthropogenic CH_4 release ≈ 4×10^8 t ≈ 1 per 20

(J) CORAL REEF LOSS

Great Barrier Reef coral coverage decrease in 2016 ≈ 30%

(K) ANNUAL HUMAN WATER USE

agriculture ≈ 1.5×10^{12} m³/yr ≈ 1 per 10

power generation ≈ 3×10^{11} m³/yr ≈ 1 per 50

domestic ≈ 6×10^{10} m³/yr ≈ 1 per 200

total water use ≈ 2×10^{12} m³ /yr ≈ 1 per 7

(L) POWER CONSUMPTION

global power usage ≈ 20 TW ≈ 300 per

(M) ANNUAL SOIL EROSION

mass of soil moved intentionally ≈ 4×10^{10} t ≈ 5 per

(N) ANNUAL DEFORESTATION & FOREST DISRUPTION

commodity driven ≈ 5×10^{10} m² ≈ 1 per 400

forestry ≈ 6×10^{10} m² ≈ 1 per 350

urbanization ≈ 2×10^9 m² ≈ 1 per 10,000

total ≈ 2×10^{11} m² ≈ 1 per 100

(O) POWER FROM FOSSIL FUELS

natural gas ≈ 4 TW ≈ 60 per

coal ≈ 5 TW ≈ 70 per

oil ≈ 6 TW ≈ 90 per

(P) ANNUAL OCEAN WARMING

ocean heat uptake ≈ 160 TW ≈ 200 per

change in surface temperature ≈ 0.03 °C

(Q) POWER FROM RENEWABLES

wind ≈ 0.4 TW ≈ 5 per

solar ≈ 0.2 TW ≈ 3 per

total renewables ≈ 1 TW ≈ 15 per

(R) ANNUAL FOSSIL FUEL EXTRACTION

volume of natural gas ≈ 4×10^{12} m³ ≈ 1 per 3

volume of oil ≈ 5.5×10^9 m³ ≈ 1 per 2,500

mass of coal ≈ 8×10^9 t ≈ 1 per

(S) NUCLEAR FALLOUT

plutonium radioactivity from nuclear weapons testing ≈ 1 decay / sec / kg

(T) CONTEMPORARY EXTINCTION

animal species > 800

plant species > 150

Human Impacts by the Numbers

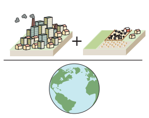
SIZING UP THE ANTHROPOCENE

A brief, introductory paragraph which sets the stage for why we expand ont he first page of this snapshot to consider dimensionless ratios. the rest of this pagaraph is nonsense

Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat. Ut wisi enim ad minim veniam, quis nostrud exerci tation ullamcorper suscipit lobortis nisl ut aliquip ex ea commodo consequat. Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat . Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat. Ut wisi enim ad minim veniam, quis nostrud exerci tation ullamcorper suscipit lobortis nisl ut aliquip ex ea commodo consequat. Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, v Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sediam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat. Ut wisi enim ad minim veniam, quis nostrud exerci tation ullamcorper suscipit lobortis nisl ut aliquip ex ea commodo consequat. Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat . Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat. Ut wisi enim ad minim veniam, quis nostrud exerci tation ullamcorper suscipit lobortis nisl ut aliquip ex ea commodo consequat. Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat el illum dolore eu feugiat .

THE TERRA NUMBER

$$Te = \frac{\text{urban and rural land area}}{\text{Earth's terrestrial land area}} =$$

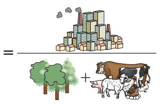


≈ 0.3

The **Terra Number** reflects the fact that, while we have been constrained to the 30% of Earth's surface that is terrestrial, we have transformed the habitable area of the terrestrial land to support our dwellings and, more importantly, our agriculture. Approximately 50 million km^2 (HuID: 29582) of land on Earth is used either to grow crops or rear livestock. Despite being icons of humanity, urban centers occupy only a few million km^2 (HuID: 87575). Together, agricultural and urban land makes up ≈ 30% of Earth's terrestrial area.

THE ANTHROPOMASS NUMBER

$$An = \frac{\text{total anthropomass}}{\text{total biomass}} =$$



≈ 1

The **Anthropomass Number** reflects the fact that humans have synthesized a mass of materials that is comparable to entire mass of Earth's biosphere. The sum total mass of all concretes, plastics, metals, and other aggregated materials (collectively termed the 'anthropomass') has now surpassed the planet's biomass. As of 2019, the planetary anthropomass was ≈ 1.1× 10^{12} tonnes (HuID: XXXXX), equiavelent to a recent estimation of the total mass of all living organisms[1]. Including discarded (waste) anthropomass increases the total anthropomass to > 1.6× 10^{12} tonnes.

THE EXTINCTION NUMBER

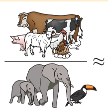
$$Ex = \frac{\text{contemporary extinction rate}}{\text{background extinction rate}} =$$

$> 10^3$

A visit to any natural history museum will reveal that much about Earth's history can be learned by examining the geological and fossil record. The **Extinction Number** reflects the fact that over the past 500 years, the extinction rate of the surveyed plant and animal species is larger than the pre-historic background extinciton rate by at least a factor of 10^3 (HuID: XXXXX). While the data is incomplete, recent work[2] has estimated that the modern extinction rate of plants and animals is ≈ 1000 extinctions per million-species-years (E/MSY) whereas the fossil record exhibits a background rate of ≈ 1 E/MSY.

THE BARNYARD NUMBER

$$By = \frac{\text{mass of terrestrial livestock}}{\text{mass of terrestrial wild animals}} \approx$$

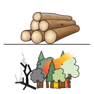


≈ 30

Human land use as reflected in the Terra number illustrates the lengths to which we have turned to keep food on our tables. Much of that land is used to feed the animals that feed us. The Barnyard number takes a by the numbers, rather than by the mass, approach to understanding the total quantity of animals in our farms and on our pastures. **The Barnyard Number** reveals that our domesticated animals outnumber us by a factor of 4. By numbers, it is our poultry with several tens of billions of chickens (HuID:) handily outnumbering humans. For our cows, the number is more like one cow on planet Earth for every three humans, though their land use footprint is monstrously larger than that of all other domesticated farm animals.

THE DEFORESTATION NUMBER

$$Df = \frac{\text{human-caused forest area loss}}{\text{forest area loss due to wildfire}} \approx$$

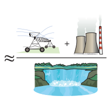


≈ 3

The **Deforestation Number** reflects that through direct action, humans deforest and disrupt forested land at three times the rate of natural forest loss. The bulk of this forest loss is due to commodity-driven deforestation (such as logging, HUID: 96098) and forestry (HuID: 38352), where as expansion of urban areas accounts for < 1% of the total annual forest loss (HuID: 19429). Wildfires account for ≈ 20% or ≈ 5×10^{10} m^2 annually (HuID: 92221).

THE NIAGARA NUMBER

$$Ni = \frac{\text{daily human water use}}{\text{Niagara Falls drainage rate}} \approx$$

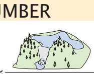


≈ 10

The **Niagara Number** caputures the magnitude of human water usage relative to Niagara Falls, the largest waterfall in North America by flow rate. Agriculture once again defines this aspect of the human interaction with the Earth system, comprising ≈ 5×10^9 m^3/day, accounting for the majority of human water usage. Combining agricultural use with the water volume used for power generation (≈10^9 m^3/day, HuID: 78784), domestic/municipal use (≈10^8 m^3/day, HuID: 69424), and all other uses yields a total daily volume of water 10 times that which flows over Niagara Falls daily. This is a volume comparable to the daily drainage of the Amazon river.

THE RIVER NUMBER

$$Rv = \frac{\text{fragmented river volume}}{\text{free-flowing river volume}} \approx$$



amazon

≈ 1

The potential energy in rivers' elevation gradients has long been an appealing source of power for growing energy needs of civilization. The **River Number** demonstrates the human pursuit of this renewable energy source by relating the volume of fragmented river systems (such as dammed rivers) to that of wild, free-flowing rivers. Globally, approximately an equal volume of water is free flowing (≈ 6×10^{11} m^3, HuID: 61661) as is under direct human control, such as through dams and reservoirs or through man-made channels (≈ XXXXX , HuID: XXXXX). Of the global free-flowing river volume, approximately 50% of the volume is contained within the Amazon river system alone, illustrating its ecological, economic, and hydrological importance.

THE EROSION NUMBER

$$Er = \frac{\text{soil mass moved by humans}}{\text{soil mass moved by rivers}} \approx$$

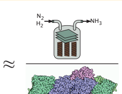
muddy river

≈ 8

Humans are becoming formidable rivals to natural geomorphological processes. This is illustrated by the **Erosion Number** which reveals humans move approximately 8 times more soil than is natively moved by global river systems. Through construction, mining, and other processes outside of agriculture, humans move ≈ 40 billion tonnes of soil a year (HuID: 59841). RIvers, by comparison, transport ≈ 5 billion tonnes a year (HuID: 60397) when corrected for the increased river sediment load via human action. This remarkable anthropogenic action rapidly increases erosion rates, leading to increased topsoil loss and turnover, ultimately perturbing natural biogeochemical cycles.

THE NITROGEN NUMBER

$$N_2 = \frac{N_2 \text{ fixation through Haber-Bosch process}}{N_2 \text{ fixation through biological processes}} \approx$$

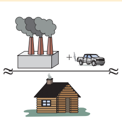


≈ 1

Deemed the "detonator of the population explosion"[4], the development of Haber-Bosch process for synthesis of ammonia from molecular nitrogen was critical for supporting a global population above ≈ 2 billion. The **Nitrogen Number** reveals that humans synthesize an amount of reactive nitrogen that is comparable to biosynthesis through nitrogen fixing microbes in the soil, albeit at a much lower efficiency. XXX

THE CO_2 NUMBER

$$CO_2 = \frac{\text{atmospheric } CO_2 \text{ now}}{\text{pre-industrial } CO_2} \approx$$

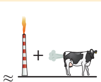


≈ 1.5

No molecular signature is more indicative of the human experince than the tremendous increase in atmospheric CO_2 following the industrial revolution of the early 19th century and the rapid acceleration of CO_2 release from the 1970's through today. The **CO_2 Number** compares the mass of anthropogenic CO_2 present int the atmosphere today compared to the level before the industrial revolution. This ratio is ≈ 1.5, revealing that humans have drastically increased the atmospheric CO_2. Beyond atmospheric deposition, the ocean absorbs ≈ 30% of the atmospheric CO_2 leading to an increase in the overal ocean acidity, posing widespread ecological dangers to the marine system which rely on the carbonate buffering system of the ocean.

THE METHANE NUMBER

$$Me = \frac{\text{volume of anthropogenic } CH_4}{\text{volume of biological } CH_4} \approx$$



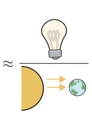
wetlands

$$\approx \frac{400 \text{ Mt / yr}}{300 \text{ Mt / yr}} \approx 1.3$$

Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat. Ut wisi enim ad minim veniam, quis nostrud exerci tation ullamcorper suscipit lobortis nisl ut aliquip ex ea commodo consequat. Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat nulla facilisis at vero eros et accumsan et iusto odio dignissim qui blandit praesent luptatum zzril delenit augue duis dolore te feugait nulla facilisi.
Lorem ipsum dolor sit amet, cons ectetuer adipiscing

THE SOLAR NUMBER

$$Su = \frac{\text{annual human power usage}}{\text{annual incident solar power}} \approx$$



≈ 0.0001

It could be argued that human impacts derive from two main sources: our need to eat and our need for power. Human power usage is enormous and demand for it has been increasing at a steady pace as the entire human population seeks to raise their standard of living. The **Solar Number** puts the 20 TW power consumption of human activities (HuID: 94934) in relief by comparing it to the incident power that arrives on our planet from the sun. As can be seen, despite our enormous power consumption, it still pales in comparison with the incident power coming from the nuclear reactions taking place within the sun.

1. Bar-On, Y.M. et al. (2018). DOI:10.1073/pnas.1711842115
2. Rounsevel et al. (2020). DOI:10.1126/science.aba6592
3. XXXXXX
4. Smil (1999). DOI: 10.1038/22672

Human Impacts by the Numbers — Supporting Information

Griffin Chure[1], Avi Flamholz[2], Nicholas Sarai[3], Tine Valencic[1], Yinon Bar-On[4], Ron Milo[4,] and Rob Phillips[2,5,*]

About: Here, we present citations and notes corresponding to each quantity assessed here. Etach value presented on page 1 is assigned a Human Impacts Database identifier (HuID), accessible via https://human-impacts.herokuapp.com. When possible, primary data sources have been collated and stored as files in comma-separated-value (csv) format on the GitHub repository associated with this snapshot, accessible via DOI: XXXXXXX and https://github.com/rpgroup-pboc/human_impacts. A subset of the numbers presented here are investigated in more depth and presented as a collection of vignettes accessible via https://rpgroup.caltech.edu/hi_vignettes (URL subject to change).

Ⓐ ANNUAL ICE MELT

glaciers $\approx 3\times10^{11}$ m^3 HuID: 32459

Data Source(s): Intergovernmental Panel on Climate Change (IPCC) 2019 Special Report "The Ocean and Cryosphere in a Changing Climate." Table 2.A.1 on pp. 199-202 Notes: Value corresponds to the trend of annual mass loss from major glacierized regions (2006-2015). Volume loss was calculated from mass loss.

ice sheets $\approx 4\times10^{11}$ m^3 HuID: 44746; 88530

Data Source(s): NASA JPL Physical Oceanography Distributed Active Archive Center. Notes: Value corresponds to the trend of annual mass loss from the Greenland and Antarctic Ice Sheets (2002-2020). Volume loss was calculated from mass loss.

arcic sea ice $\approx 3\times10^{11}$ m^3 HuID: 89520

Data Source(s): PIOMAS Arctic Sea Ice Volume Reanalysis, original method source: Schweiger et al. 2011 DOI: 10.1029/2011JC007084 Notes: Value reported corresponds to the trend of decadal volume loss from Arctic sea ice (1979-2020) which was converted to annual volume loss.

total $\approx 1\times10^{12}$ m^3 HuID: 89075

Data Source(s): Sum of glacial, ice sheet, and sea ice melt rate. Notes: Antarctic sea ice loss is not included due to data sparsity. The periods of analysis are not the same, therefore this rate represents an approximation rather than an exact calculation.

Ⓑ ANNUAL NITROGEN FIXATION

fixed mass of nitrogen $\approx 2\times10^8$ t **HuID: 60580; 30310; 78152**

Data Source(s): USGS Mineral Commodies Summaries (Fixed Nitrogen), January 2020; Table 2 of "World fertilizer trends and outlook to 2022" Food and Agricultural Organization of the United Nations, 2019, ISBN: 978-92-5-131894-2. Smit et al. 2010, DOI:10.1039/c9ee02873k. Notes: The approximate mass of contained nitrogen in salient ammonia produced globally in 2018 as reported by the USGS is $\approx$ 144 Mt. This value is in moderate agreement with the forecast of $\approx$ 160 Mt of nitrogen-contained ammonia as forecast for 2018 by the FAO. Approximately all of this mass is produced by the Haber-Bosch process (>96%, Smith et al. 2020).

Ⓒ RIVER FRAGMENTATION

fragmented river volume $\approx 10^{12}$ m^3 **HuID: 61661, 15550**

Data Source(s): CSV dataset: DOI: 10.5281/zenodo.3875115, original data source: Grill et al. 2019 DOI: 10.1038/s41586-019-1111-9.Notes: Values correspond to the sum of river volume contained in rivers (or only rivers connected to the ocean) that fall below the connectivity threshold required to classify them as free-flowing. Disruption factors indexed in this dataset are fragmentation, flow regulation, sediment trapping, water consumption, and infrastructure development. This analysis is based on a dataset of global rivers whose upstream catchment areas are greater than 10 km^2 or whose discharge is greater than 0.1 m^3 per second. This dataset thus contains a global river network of 35.9 million kilometers. The ratio of global river volume in disrupted rivers / free-flowing rivers $\approx$ 0.9. The ratio of global ocean-connected river volume in disrupted rivers / free-flowing rivers $\approx$ 1.2.

hydroelectric power $\approx$ 1 TW / yr **HuID: 27945**

Data Source(s): bp Statistical Review of World Energy, 2020. **Notes:** Value corresponds to the reported value of global hydroelectricity consumption for 2019.

Ⓓ ANNUAL SEA LEVEL RISE

meltwater rise $\approx$ 1.6 mm **HuID: 97108**

thermal expansion $\approx$ 1.2 mm **HuID: 97688**

total annual sea-level rise $\approx$ 3 mm **HuID: 81373**

Data Source(s): Table 1 of Frederikse et al. 2020. DOI:10/d689. Notes: Values corresopnond to the average global sea level rise of the years 1993 - 2018. Meltwater is defined as the global annual sea level rise due to melt of glaciers, the Greenland ice sheet, and the Antarctic ice sheet.

Ⓔ ANNUAL OCEAN pH DECREASE

yearly change in [H$^+$] $\approx$ 2% HuID: 19394

Data Source(s): Figure 2 of European Environment Agency report CLIM 043 (2020). Original data source of report is "Global Mean Sea Water pH" from Copernicus Marine Environment Monitoring Service. Notes: Reported value is calculated from the average annual change in pH over years 1985-2018. Annual change in pH is $\approx$ 0.001 pH units, corresponding to a change in [H$^+$] of $\approx$ 0.2 % / yr.

Ⓕ ANNUAL MATERIAL PRODUCTION

concrete production $\approx 3\times10^8$ t HuID: 25488

steel production $\approx 2\times10^9$ t HuID: 51453

Data Source(s): USGS 2020, Mineral commodities. DOI:10.3133/mcs2020; Monteiro et al. 2017, DOI:10.138/nmat4930 Notes: Concrete production value corresponds to approximate value from multiple sources. USGS 2020 Mineral Commodities Survey reports mass of cement produced in 2019. This is converted to concrete using a multiplicative conversion factor of $\approx$ 7 as described in Monteiro et al. 2017. Steel production correpsonds to the USGS 2019 value.

plastic production $\approx 4\times10^6$ t HuID: 97241

Data Source(s): Table S2 of Geyer et al. 2017. DOI:10.1126/sciadv.1700782. Notes: Value represents the sum total global production of plastic fibers and plastic resin during calendar year 2015.

Ⓖ LIVESTOCK POPULATION

chicken $\approx 2\times10^{10}$ HuID: 94934

cattle $\approx 2\times10^9$ HuID: 92006

swine $\approx 1\times10^9$ HuID: 21368

total $\approx 3\times10^{10}$ HuID: 15765

Data Source(s): Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT). Notes: Counts correspond to the approximate average of the standing populations reported between 2010 - 2018. Values are reported directly by countries, yet the FAO uses non-governmental statistical sources to address uncertainty and missing (non-reported) data.

Ⓗ LAND USE

agriculture $\approx 5\times10^{13}$ m^2 HuID: 29582

Data Source(s): Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT) Notes: "Agriculture" land is defined as all land that is under agricultural management including pastures, meadows, permant crops, temporary crops, land under fallow, and land under agricultural structures. Reported value corresponds to 2017 measurements by FAO.

urban $\approx 4\times10^{12}$ m^2 HuID: 87575

Data Source(s): World Bank and Center for International Earth Science Information Network (CIESIN)/Columbia University. 2013. Notes: Urban land area is determined from satellite imagery. An area is determined to be "urban" if the total population is greater than 5,000. Value correspons to the most recent estimate from 2010.

Ⓘ ANNUAL GREENHOUSE GAS EMISSIONS

anthropogenic $CO_2 \approx 42\times10^9$ t HuID: 47200; 98043

Data Source(s): Friedlingstein et al. 2019, DOI: 10.5194/essd-11-1783-2019. Original data sources relevant to this study compiled in Friedlingstein et al.: 1) Gilfillan et al. https://energy.appstate.edu/CDIAC 2) Average of two bookkeeping models: Houghton and Nassikas 2017 DOI: 10.1002/2016GB005546; Hansis et al. 2015 DOI:) Dlugokencky and Tans, NOAA/GML https://www.esrl.noaa.gov/gmd/ccgg/trends/. Notes: Value corresponds to CO_2 emissions from fossil fuel combustion, industrial emissions (predonimantly cement production), and land-use change during calendar year 2018. CO_2 was added to the atmosphere at a rate of $\approx$ 18.8 Gt / yr in 2018 (HuID: 98043); most of the remainder is taken up by the land sink and ocean sink.

anthropogenic $CH_4 \approx 4\times10^9$ t HuID: 96837; 56405; 30725

Data Source(s): Table 2 of Saunois, et al. 2020. DOI: 10.5194/essd-12-1561-2020. Notes: Value corresponds to CH_4 emissions from anthropogenic sources in the calendar year 2017. Represents emissions from agriculture and waste, fossil fuels, and biomass and biofuel burning. Value is not simply the sum of these sources but is based on a full anthropogenic inventory of emissions. Natural emissions amount to $\approx$ 0.3 Gt / yr in 2017. CH_4 was added to the atmosphere at a rate of $\approx$ 17 Mt/yr in 2017; most of the remainder is taken up by chemical loss sink and soil sink.

Ⓙ CORAL REEF LOSS

2016 GBR cover loss $\approx$ 30% HuID: 90720

Data Source(s): Figures 1A, S1, and S2 of Hughes et al. 2018, DOI:10.1038/s41586-018-0041-2. Notes: Value corresponds to measured loss in coral coverage on members of the Great Barrier Reef using field measuremetns and satellite imaging. Time period considers the total area loss of coral between March and November of 2016. See methods section "Longer Term Mortality" of source publication.

Ⓚ ANNUAL HUMAN WATER USE

agriculture $\approx 1.5\times10^{12}$ m^3 HuID: 43593

power generation $\approx 3\times10^{11}$ m^3 HuID: 78784

domestic $\approx 6\times10^{10}$ m^3 HuID: 69424

total $\approx 2\times10^{12}$ m^3 HuID: 27342

Data Source(s): Figure 1 of Qin et al. 2019. DOI:10.1038/s41893-019-0294-2. Notes: "Agricultural use" is defined as water used for irrigation, maintenance of livestock, and water used in the management of irrigation via damming. "Power generation" is defined as water used for thermal power generation (coal, nuclear, gas, biomass, oil, and other/waste) and hydroelectric generation. "Domestic" is defined as water directly used by humans and water used in the maintencance of municipal water supply. "Total" water use includes the above categories as well as other uses of water in reservoir managment including flood control andd other unannotated uses. All values pertain to estimates for 2016.

Ⓛ ANNUAL GLOBAL POWER CONSUMPTION

global power consumption $\approx$ 20 TW HuID: 31373

Data Source(s): bp Statistical Review of World Energy, 2020. Notes: Reported values correspond to estimates for the 2019 calendar year. Represents the sum total consumed energy from oil, natural gas, coal, nuclear energy, hydroelectric, and renewables.

Ⓜ ANNUAL EROSION

intentionally moved soil mass $\approx$ 40 Gt HuID: 59841

Data Source(s): Table 1 and Figure 4 of Hooke 2000, DOI:10/bdnqv9. K-Tec Earthmovers Inc. March 2018 Newsletter. Grand View Research Construction Industry Analysis, April 2020. Notes: Hooke 2000 estimates $\approx$ 35 Gt of soil moved annually in the latter years of the 20th century. This is in agreement with reported soil volume moved by an industry member (K-Tec) and total revenue of soil movement and construction industry as reported by Grand View Research in April 2020. This value accounts for intentional soil movement only (such as mining and construction) and does not include agricultural soil movement.

Ⓝ ANNUAL DEFORESTATION AND DISRUPTION

commodity-driven $\approx 5\times10^{10}$ m^3 HuID: 96098

shifting agriculture $\approx 4\times10^{10}$ m^3 HuID: 24388

forestry $\approx 6\times10^{10}$ m^3 HuID: 38352

urbanization $\approx 2\times10^9$ m^3 HuID: 19429

total $\approx 2\times10^{11}$ m^3 HuID: 78576

Data Source(s): Table 1 and Figure 3 of Curtis et al. 2018 DOI:10.1126/science.aau3445. Hansen et al. 2013 DOI:10.1126/science.1244693. Global Forest Watch, 2020. Notes: Commodity-driven deforestation is defined as "long-term, permanent, conversion of forest and shurbland toa nonforest land use such as agriculture, mining, or energy infrastructure." Forest area loss due to shifting agriculture is defined as "smal-to-medium-scale forest and shrubland conversion for agriculture that is later abandoned and followed by subsequent forest regrowth." Forest area disruption due to forestry is defined as large-scale forestry operations occurring within managed forests and tree plantations with evidence of forest regrowth in subsequent years." Forest land disruption due to urbanization is defined as "forest and shrubland conversion for the expansion and intensification of existing urban centers."

Ⓞ ANNUAL POWER FROM FOSSIL FUELS

natural gas $\approx$ 4 TW HuID: 49947

oil $\approx$ 6 TW HuID: 42121

coal $\approx$ 5 TW HuID: 10400

Data Source(s): bp Statistical Review of World Energy, 2020. Notes: Values pertain to 2019 estimates only. Oil volume includes crude oil, shale oil, oil sands, condensates, and natural gas liquids separate from specific natural gas mining. Natural gas value excludes gas flared or recycled and includes natural gas produced for gas-to-liquids transformation. Coal value includes 2019 value exclusively for solid commercial fuels such as bituminous coal and anthracite, lignite and sub-bituminous coal, and other solid fuels. This includes coal used directly in power production as well as coal used in coal-to-liquids and coal-to-gas transformations.

Ⓟ ANNUAL OCEAN WARMING

power deposition $\approx$ 160 TW HuID: 59201

ocean surface warming $\approx$ 0.03 °C HuID: 87228

Data Source(s): Intergovernmental Panel on Climate Change (IPCC) 2019 Special Report "The Ocean and Cryosphere in a Changing Climate." Table 5.1 on pp. 458 and footnote 4 on pp. 457. Notes: Value is claculated from the reported annual heat...

...uptake of $\approx$ 5 ZJ/yr over the time period of 2005 - 2017. This assumes a constant value for deposition into the ocean surface (0 - 700 m depth) and deep ocean (700 - 2000 m depth) where heat deposition is lower. Ocean surface temperature change is calculated from $\approx$ 5 ZJ/yr heat uptake by noting that deposition of $\approx$ 144 ZJ/yr raises the temperature of the top 100 m of ocean by $\approx$ 1° C. See the complete report or section 5.2.2.2 of the source material for more information.

Ⓠ ANNUAL POWER FROM RENEWABLES

wind $\approx$ 0.4 TW HuID: 30581

solar $\approx$ 0.2 TW HuID: 99885

biofuels $\approx$ 0.15 TW HuID: 89570

total $\approx$ 1 TW HuID: 20246

Data Source(s): bp Statistical Review of World Energy, 2020. Notes: Reported values correspond to estimates for the 2019 calendar year. Renewable resources are defined as wind, geothermal, solar, biomass and waste, and do not include hydroelectic power generation.

Ⓡ ANNUAL FOSSIL FUEL EXTRACTION

natural gas volume $\approx 4\times10^{12}$ m^3 HuID: 11468

oil volume $\approx 5.5\times10^9$ m^3 HuID: 66789

coal mass $\approx 8\times10^9$ t HuID: 78435

Data Source(s): bp Statistical Review of World Energy, 2020. Notes: Oil volume includes crude oil, shale oil, oil sands, condensates, and natural gas liquids separate from specific natural gas mining. Natural gas value excludes gas flared or recycled and includes natural gas produced for gas-to-liquids transformation. Coal value includes 2019 value exclusively for solid commercial fuels such as bituminous coal and anthracite, lignite and sub-bituminous coal, and other solid fuels. This includes coal used directly in power production as well as coal used in coal-to-liquids and coal-to-gas transformations.

Ⓢ NUCLEAR FALLOUT

$^{239+240}$Pu activity in soil $\approx$ 1 Bq/kg HuID: 38748; 91171

Data Source(s): Figure 4 and Figure 5 in Hancock et al. 2014, DOI:10.1144/SP395.15. Figure 3 (col. 2, rows 3 - 5) of Ciszewski and Łokas, 2019, DOI:10.1515/geochr-2015-0111. Notes: Value corresponds to current-day detectable combined radioactivity of ^{239}Pu and ^{240}Pu present in cores of stratified soil with estimated date of $\approx$ 1963 CE during the peak of atmospheric nuclear weapons testing. Reported is approximate average activity from sediment samples in SE Australia (Hancock et al.) and Polish river basins (Ciszewski and Łokas).

Ⓣ CONTEMPORARY EXTINCTION

animal species > 800 HuID: 44641

plant species > 400 HuID: 86866

Data Source(s): The IUCN Red List of Threatened Species. Version 2020-2. Notes:Values correspond to absolute lower-bound measurements of extinctions caused over the past $\approx$ 500 years. Of the predicted $\approx$ 8 million animal species, The IUCN databases catalogues only $\approx$ 900,000 with only $\approx$ 75,000 being assigned a conservation status. Representation of plants and fungi is even more sparse with only $\approx$40,000 and $\approx$285 being assigned a conservation status, respectively. The number of extinct animal species is undoubetly higher than these reported values, as signified by an inequality symbol (>) of extinct animal species is undoubetly higher than these reported values, as signified by an inequality symbol (>)

Acknowledgements: This work was supported by the Resnick Institute for Sustainibility at the California Institute of Technology. Add financial support information. No specific order, thank the following: APh150c course, Wati Taylor, Dan Fisher, Gidon Eshel, Greg Huber, Michelle Dan, Brad Marston, Hamza Raniwala.