

HUMAN IMPACTS

by the numbers

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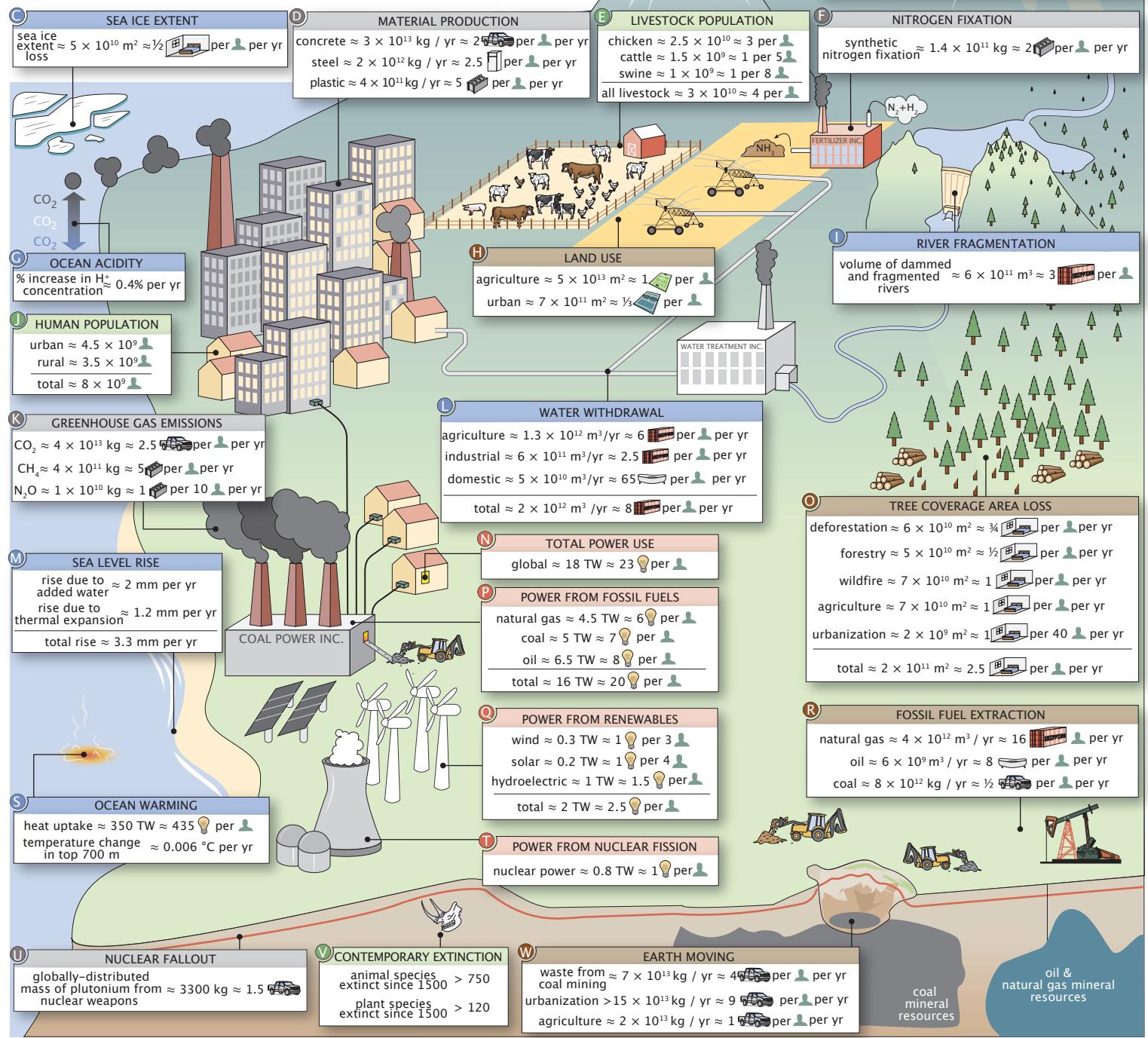
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ABSTRACT

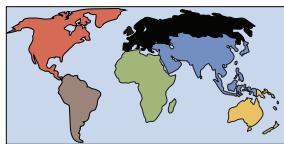
A candidate for the greatest experiment of the last 10,000 years is the presence and action of modern human beings on planet Earth, the often complex results of which are now being felt on various fronts. While there has been a deluge of careful studies exploring each facet of these “human impacts” on Earth, they are often highly focused and necessarily technical, rarely displaying their integration with other human impacts as a whole. In this snapshot, we present a diverse (yet necessarily incomplete) array of quantities that summarize the broad reach of human action across the planet.



Human Impacts by the Numbers — Impacts By Region

THE GEOGRAPHY OF HUMAN IMPACTS

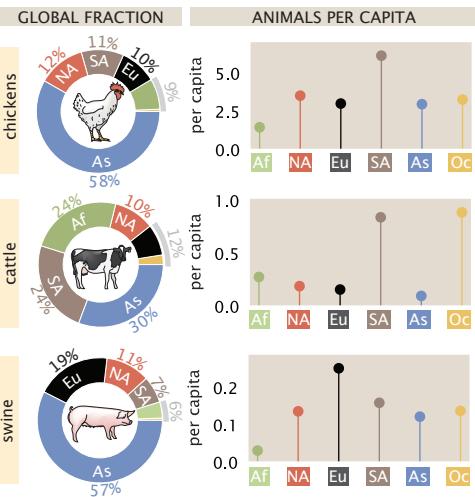
Page 1 represents the impact humans have on the Earth at a global scale. While these numbers are handy, it is important to acknowledge that they vary from country-to-country and continent-to-continent. Furthermore, the consequences of these anthropogenic impacts are also unequally distributed, meaning some regions experience effects disproportionately to their contribution. Here, we give a sense of the geographic distribution of several values presented on page 1, broken down by continental region as shown below.



- Asia — (As)
- North America — (NA)
- South America — (SA)
- Europe — (Eu)
- Oceania — (Oc)
- Africa — (Af)

THE LIVESTOCK POPULATION

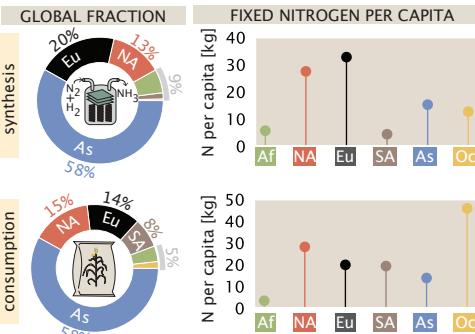
The global population of terrestrial livestock is around 30 billion individuals, most of which are chickens. Asia houses most of the global livestock population, though South America and Europe harbor more animals on a per-capita basis.



Sources: Food and Agricultural Organization of the United Nations

NITROGENOUS FERTILIZER USE & PRODUCTION

Modern agriculture requires nitrogen in amounts beyond what is produced naturally. Asia synthesizes and consumes a large majority of fixed nitrogen. However, Europe and North America dominate per capita synthesis whereas Oceania consumes more fertilizer per capita than any other region.



Source: Food and Agricultural Organization (FAO) of the United Nations.

Notes: Values account for reactive nitrogen production/consumption in context of fertilizer only and does not account for plastics, explosives, or other uses.

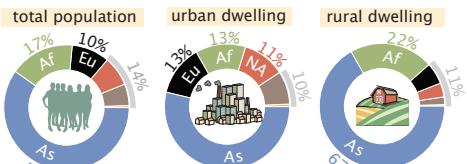
From heating water, to powering lights, to moving our vehicles, nearly every facet of modern human life requires the consumption of power, culminating in nearly 20 TW of power use in recent years. Asia consumes over half of the power derived from combustion of fossil fuels, with Europe and North America each consuming around 20% of the global total. Asia also produces the plurality of power from renewable technologies, such as hydroelectric, wind, and solar, however, North America, South America, and Europe each produce more on a per capita basis. Nuclear energy, however, is primarily produced in Europe, with North America and Asia coming in second and third place, respectively. On a per-capita basis, North America consumes or produces more energy than all other regions considered here, yielding a total power consumption of nearly 10,000 W per person.

Sources: Energy Information Administration of the United States (2017)

Notes: "Renewables" includes hydroelectric, biofuels, biomass (wood), geothermal, wind, and solar. "Fossil fuels" includes coal, oil, and natural gas.

THE HUMAN POPULATION

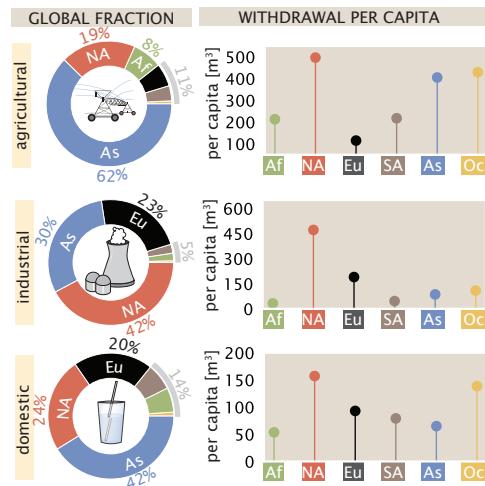
There are ≈ 8 billion humans on the planet, with approximately 50% living in 'urban' environments. The majority of the world's population (as well as the majority of both urban and rural dwellers) live in Asia.



Sources: Food and Agricultural Organization of the United Nations — World Population Notes: Urban/rural designation has no set definition and follows the conventions set by each reporting country.

WATER WITHDRAWAL

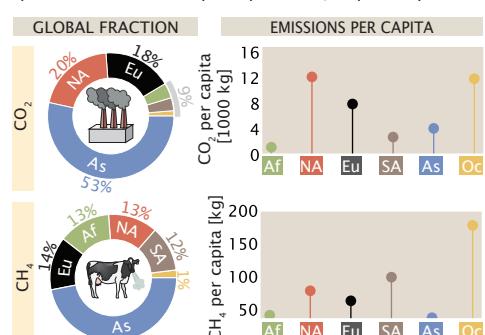
While Asia withdraws the most water for agricultural and municipal needs, North America withdraws the plurality of water for industrial purposes. North America also withdraws more water per capita than any other region.



Source: AQUASTAT Main Database, Food and Agriculture Organization of the United Nations. Notes: Values are reported directly from member countries and represent average of 2013–2017 period. Per capita values are computed given population of reporting countries.

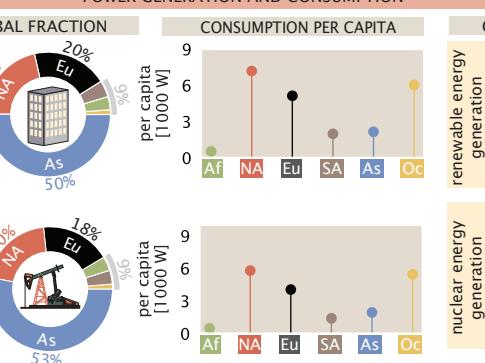
GREENHOUSE GAS EMISSIONS

CO_2 and CH_4 are two potent greenhouse gases which are routinely emitted by anthropogenic processes such as burning fuel and rearing livestock. While Asia emits roughly half of all CO_2 and CH_4 , North America and Oceania produce the most on a per capita basis, respectively.



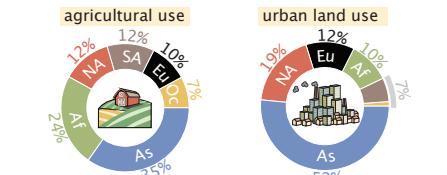
Sources: CO_2 data collated by Friedlingstein, P. et al. (2019). doi: 10.5194/esd-11–1783–2019. See Panel J on Pg. 4 for complete list of sources. CH_4 data from Saunois et al. 2020 doi: 10.5194/esd-12–1561–2020 Notes: Values report decadal averages in kg CO_2 or CH_4 per year over time period 2008–2017.

POWER GENERATION AND CONSUMPTION



LAND USE

Though humans are nearly evenly split between urban and rural environments, agricultural land is the far more common use of land area. Together, Asia and Africa contain more than half of global agricultural land. Asia alone accommodates more than half of the global urban land area.



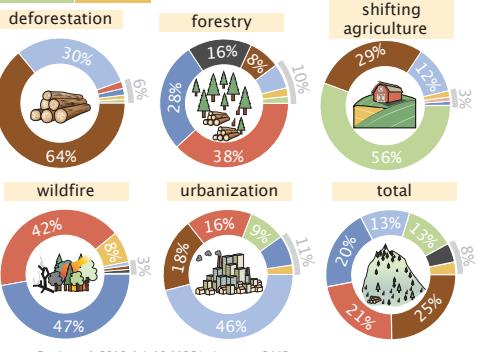
Sources: Food and Agricultural Organization (FAO) of the United Nations — Land Use [agricultural area]; Florczyk et al. 2019 — GHS Urban Centre Database 2015 [urban land area]. Notes: Urban is defined as any inhabited area with ≥ 2500 residents, as defined by the USDA.

TREE COVERAGE AREA LOSS

Most drivers of tree coverage area loss are comparable in their effect at a global scale. However, there are drastic regional differences in the relative magnitudes.

REGION DEFINITION

Central & South America	Russia, China, & South Asia
North America	Southeast Asia
Africa	Oceania
	Europe (- Russia)

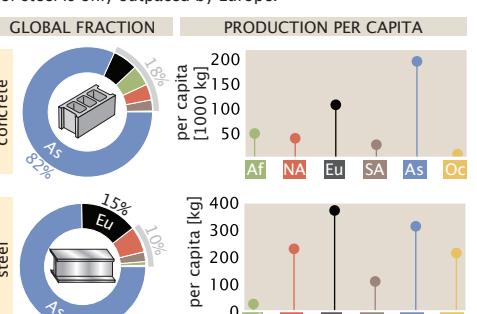


Source: Curtis et al. 2018 doi: 10.1126/science.aau3445.

Notes: Regions are as reported in Curtis et al. 2018. "Deforestation" here denotes permanent removal of tree cover for commodity production. "Shifting agriculture" here denotes forest/shrub land converted to agriculture and later abandoned. All values correspond to breakdown of cumulative tree cover area loss from 2001 – 2015.

MATERIAL PRODUCTION

Humans excavate and transform an enormous amount of material from the Earth's crust. Two of these materials, concrete and steel, are produced primarily in Asia on both a global and per capita basis. Asia's per capita production of steel is only outpaced by Europe.



Sources: USGS Statistics and Information 2020. Steel Statistical Yearbook 2019 World Steel Association. Food and Agricultural Organization (FAO) of the United Nations — Annual Population. Notes: Reported values for cement and steel production corresponds to 2017 and 2018 values, respectively. Mass of concrete was calculated using a rule-of-thumb that 1 kg of cement yields 7 kg of concrete (Monteiro et al. 2017. doi: 0.138/nmat4930).

Human Impacts by the Numbers — The Dimensionless Ratios

Much of our understanding of the scales of things is comparative. When we measure lengths, we do so relative to some intuitive distance that provides context. Our aim here is to present some "yardstick" to measure those numbers presented on pages 1 and 2 in a ratiometric form that compares the magnitude of a given human impact to a natural scale for that same quantity. For example, in considering the use of land by humans, a natural dimensionless way to characterize that number is by comparing it to the total land area of our planet, a comparison that yields what we call the "Terra number."

Similarly, when we consider the entirety of human-made materials, it is natural to compare this mass to the total biomass on our planet. Here we present twelve key human impacts in this dimensionless form. These numbers describe the solid earth, the atmosphere, the oceans, and human energy use, and we hope that our readers will be emboldened to consider their own favorite examples in a similar dimensionless format. Where appropriate, we reference key values using a Human Impacts Database number (HuID) accessible via humanimpacts.org

THE TERRA NUMBER

$$Te = \frac{\text{land area used by humans}}{\text{total land area of Earth}} = \frac{\text{area with buildings and crops}}{\text{entire Earth}} \approx 0.3$$

The Terra Number reflects the fact that, while we have been constrained to the small fraction of Earth's surface that is land, we have transformed the terrestrial surface to support our dwellings and, much more importantly, our agriculture. Despite being icons of human activity, urban centers occupy between 6.5 and $7.5 \times 10^7 \text{ km}^2$ (HuID: 41339, 39341), a total less than 1% of the terrestrial surface. In contrast, approximately 50 million km^2 (HuID: 29582) of land on Earth is used either to grow crops or raise livestock. Together, urban and agricultural lands make up $\approx 30\%$ of Earth's terrestrial surface.

THE BARNYARD NUMBER

$$By = \frac{\text{mass of terrestrial livestock}}{\text{mass of terrestrial wild animals}} \approx \frac{\text{cows, chickens, pigs}}{\text{elephants, foxes, pelicans}} \approx 30$$

The Barnyard Number focuses another lens onto the massive agricultural transformation of the planet by comparing the total biomass of terrestrial livestock (e.g. cows, chickens, and pigs) to that of terrestrial wild animals (e.g. elephants, foxes, and pelicans) [3]. Agricultural intensification of the 20th century has resulted in livestock outweighing all wild terrestrial animals by a factor of ≈ 30 . While poultry make up the vast majority of terrestrial livestock (≈ 25 billion individuals, HuID: 94934), they represent a small proportion of livestock biomass. Despite a smaller population of ≈ 1.5 billion (HuID: 92006), cattle dominate livestock biomass with a total weight of $\approx 1.5 \times 10^{12} \text{ kg}$.

THE RIVER NUMBER

$$Rv = \frac{\text{river volume controlled by humans}}{\text{free-flowing river volume}} \approx \frac{\text{dammed rivers}}{\text{natural rivers}} \approx 1$$

Humans have harnessed water from rivers for irrigation, flood control, and generation of hydroelectric power. Harnessing this water, however, requires damming the river – thus interrupting its flow and altering the riverine ecosystem. The River Number quantifies the scale of human interference in river flow by relating the volume of river systems under human control (primarily due to damming) to that of free-flowing rivers. Globally, approximately equal volumes of river water are free flowing ($\approx 6 \times 10^{11} \text{ m}^3$, [6] HuID: 55718) as are under direct human control, such as through dams and reservoirs or man-made channels ($\approx 6 \times 10^{11} \text{ m}^3$, HuID: 61661). Approximately 50% of global free-flowing river volume is within the Amazon river alone.

THE CO₂ NUMBER

$$CO_2 = \frac{\text{annual mass of anthropogenic CO}_2}{\text{annual mass of naturally removed CO}_2} \approx \frac{\text{fossil fuel CO}_2}{\text{plant O}_2} \approx 2$$

The CO₂ Number compares the annual amount of human-caused CO₂ emissions to the mass of CO₂ naturally removed from the atmosphere each year. There are many climate-related consequences of increasing CO₂ emissions. Beyond accelerating climate change, $\approx 25\%$ of CO₂ released into the atmosphere is absorbed by the oceans, making them appreciably more acidic over time. In recent years, human activities, including burning fossil fuels and making concrete, have led to the release of $\approx 4 \times 10^{13} \text{ kg}$ of CO₂ (HuID: 54608, 24789) into the atmosphere each year. While many natural processes like volcanoes and wildfires release CO₂, they are generally accompanied by corresponding sinks that remove even more CO₂, like plant photosynthesis. Once all natural processes have been accounted for, a net natural sink of $\approx 2 \times 10^{13} \text{ kg}$ of CO₂ per year remains (HuID: 52670). Thus, the CO₂ number quantifies the extent to which human emissions outpace the natural removal of CO₂.

THE ANTHROPOMASS NUMBER

$$An = \frac{\text{total anthropomass}}{\text{total biomass}} = \frac{\text{humans + buildings + infrastructure}}{\text{plants + animals}} \approx 1$$

The Anthropomass Number takes stock of our material production by comparing the total quantity of human-made materials to the entirety of the biomass on planet Earth. Around 2020, total human made materials added up to the same mass as the total biomass dry weight ($\approx 1.1 \text{ Tt}$ [1]). Concretes and aggregates (such as gravel) dominate the anthropomass, with bricks and asphalt coming in a distant second. Despite their ubiquity, plastics and metals constitute less than 10% of total anthropomass. Altogether, the total amounts to a dizzying $\approx 10^5 \text{ kg}$ of human made mass, or about 20 African bush elephants, per person on the planet.

THE DEFORESTATION NUMBER

$$Df = \frac{\text{annual forest loss from human action}}{\text{annual forest loss from wildfire}} \approx \frac{\text{loggers + fires}}{\text{wildfires}} \approx 2$$

The Deforestation Number reflects that humans intentionally deforest and disrupt forested land at twice times the rate of wildfires, some of which are also caused by humans. This human-caused forest loss is due to commodity-driven deforestation ($\approx 6 \times 10^{10} \text{ m}^2$, HuID: 96098), forestry ($\approx 5 \times 10^{10} \text{ m}^2$, HuID: 38352), and shifting forest land to agriculture/ $\approx 7.5 \times 10^{10} \text{ m}^2$, HuID: 24388). Expansion of urban areas accounts for $< 1\%$ of the total annual forest loss (HuID: 19429). In total, $\approx 15 \times 10^{10} \text{ m}^2$ of forest is lost annually due to intentional human action, whereas wildfires (both naturally sparked and those caused by humans) account for $\approx 7 \times 10^{10} \text{ m}^2$ annually (HuID: 9221).

THE EARTH MOVER NUMBER

$$Em = \frac{\text{annual mass of earth moved by humans}}{\text{annual mass of earth moved by rivers}} \approx \frac{\text{bulldozers + rivers}}{\text{rivers}} > 15$$

Humans are formidable rivals of the natural processes that generate and move sediment. This is illustrated by The Earth Mover Number, which reveals that humans move approximately 15 times more earth than is moved by global river systems. Through construction, mining, and agriculture, humans move more than $2.5 \times 10^{14} \text{ kg}$ of earth a year (HuID: 72899, 59640, 19415, 41496). Rivers, by comparison, transport $\approx 1.3 \times 10^{13} \text{ kg}$ a year when corrected for the increased river sediment load via human action [7]. This remarkable anthropogenic action rapidly increases erosion rates, leading to increased topsoil loss and turnover, ultimately perturbing natural biogeochemical cycles.

THE METHANE NUMBER

$$Me = \frac{\text{annual mass of anthropogenic CH}_4}{\text{annual mass of natural CH}_4} \approx \frac{\text{fossil fuel + ruminants}}{\text{plants + soil}} \approx 1$$

While CO₂ is the most often discussed greenhouse gas, human activities also release substantial amounts of methane (CH₄), an even more potent greenhouse gas than CO₂. The CH₄ Number compares human methane emissions to all natural sources of methane. Anthropogenic emissions, resulting from fossil fuel extraction, ruminant livestock (mostly cows), rice cultivation, and other sources total $\approx 3 - 4 \times 10^9 \text{ kg}$ per year (HuID: 96837). Natural emissions of CH₄, stemming mostly from wetlands and other anaerobic environments, produce a comparable amount ($2 - 4 \times 10^9 \text{ kg}$ per year) to anthropogenic emissions (HuID: 56405). There is substantial uncertainty regarding the magnitude of both natural and anthropogenic methane emissions, on the order of up to $1 \times 10^9 \text{ kg}/\text{year}$ in the anthropogenic case and $2 \times 10^9 \text{ kg}/\text{year}$ in the natural case, due to difficulties in accounting for different sources and some discrepancies between bottom-up accounting and atmospheric modeling approaches.

THE EXTINCTION NUMBER

$$Ex = \frac{\text{number of known animal extinctions}}{\text{number of expected natural animal extinctions}} = \frac{\text{dinosaurs}}{\text{dinosaurs + modern species}} > 10$$

Over the past 500 years, far more animal species have gone extinct than would be expected due to natural processes. Since 1500, at least 760 animal species have gone extinct (HuID: 44641). Recent estimates of ancient rates of animal extinction predict that tenfold fewer (≈ 50) species would have gone extinct over the same period in the absence of humans [2]. It's important to emphasize that these data are incomplete and reflect only a fraction of species that have been assessed for conservation status. The Extinction Number therefore represents a lower bound on the degree of modern species loss, with the true value likely being much higher.

THE NIAGARA NUMBER

$$Ni = \frac{\text{daily water volume used by humans}}{\text{Niagara Falls daily discharge volume}} \approx \frac{\text{household usage}}{\text{natural waterfall}} \approx 30$$

The Niagara Number captures the magnitude of human water usage relative to the scale of Niagara Falls, the largest waterfall in North America by discharge volume. Agriculture defines this aspect of the human interaction with the Earth system as it uses $\approx 1.5 \times 10^{12} \text{ m}^3$ (HuID: 43593) of water annually, accounting for the majority of human water usage. Water used for industrial purposes, including cooling thermoelectric plants amounts to $5.9 \times 10^{11} \text{ m}^3/\text{yr}$ (HuID: 27142). Finally, domestic use (such as drinking water and sanitation) withdrawals $\approx 6 \times 10^{10} \text{ m}^3/\text{yr}$ (HuID: 69424). In total, human water annual water withdrawal is ≈ 30 times the volume that flows over the Niagara Falls in a year [4] and is comparable to $\approx 1/3$ the yearly discharge of the Amazon river [5].

THE NITROGEN NUMBER

$$N_2 = \frac{\text{mass of N}_2 \text{ fixed via the Haber-Bosch Process}}{\text{mass of N}_2 \text{ fixed biologically}} \approx \frac{\text{industrial NH}_3}{\text{natural NH}_3} \approx 1$$

Though molecular nitrogen (N₂) makes up nearly 80% of our atmosphere, it must be converted into a more reactive form like ammonia (NH₃), a primary ingredient in fertilizer, in order for most plants to utilize it. The 1910 development of the Haber-Bosch process for industrial synthesis of NH₃ from N₂ was critical for supporting the agricultural needs of a growing human population and for supplying NH₃ for chemical and explosive synthesis. The Nitrogen Number reveals that humans synthesize as much reactive nitrogen industrially ($\approx 1.4 \times 10^{11} \text{ kg}/\text{year}$, HuID: 61614, 60580) as is synthesized by nitrogen-fixing microbes in terrestrial ecosystems ($\approx 1 \times 10^{11} \text{ kg}/\text{year}$, HuID: 15205). Beyond influencing the environmental balance of reactive nitrogen, modern synthesis technologies require a sizable amount of energy contributing significantly to global CO₂ emissions.

THE SOLAR NUMBER

$$Su = \frac{\text{annual human power usage}}{\text{annual incident solar power}} \approx \frac{\text{household power}}{\text{sunlight}} \approx 0.0001$$

While humans derive biological energy from food, we derive mechanical and electrical power from various fuel sources like coal, oil, natural gas, and fissile nuclear material. Current global human power usage amounts to an enormous 18 terawatts, a number which has been increasing steadily over the last 200 years. The Solar Number puts the 18 TW power consumption of human activities (HuID: 31373, 85317) in relief by comparing it to the power incident on our planet from the sun, which represents a power source roughly 10,000 times greater than our current demands. Of course, it is unlikely that we could ever harness 100% of solar energy incident on our planet, but capturing even 1% of this energy would be sufficient to produce 100 times more power than we currently use.

[1] Elhacham, et al. 2020, in press. [2] Ceballos et al. 2015 doi:10.1126/sciadv.1400253. [3] Bar-On, Y.M. et al. 2018. doi:10.1073/pnas.1711842115 [4] National Water Information System, 2020, U.S.G.S. [5] Transboundary River Basin Overview – Amazon, 2015, AQUASTAT. [6] Grill et al. doi: 10.1038/s41586-019-1111-9. [7] Syvitski et al. 2005, doi:10.1126/science.1109454. [8] Smil 1999. doi: 10.1038/22672

Human Impacts by the Numbers — Supporting Information

About: Here, we present citations and notes corresponding to each quantity assessed here. Each value presented on page 1 is assigned a Human Impacts Database identifier (**HuID**), accessible via humanimpacts.org. 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: XXXXXX and https://github.com/rpgroup-pboc/human_impacts

SURFACE TEMPERATURE	
Surface temperature change relative to 1850–1900 $\approx 1 - 2^\circ\text{C}$	HuID: 79598, 76539, 12147
Data Source(s): HadCRUT.4.6 (Morice et al., 2012, DOI: 10.1029/2011JD017187), GISTEMP v4 (GISTEMP Team, 2020: GISS Surface Temperature Analysis (GISTEMP), version 4. NASA Goddard Institute for Space Studies. Dataset accessed 2020-12-10 at https://data.giss.nasa.gov/gistemp/ & Lenssen et al., 2019, DOI: 10.1029/2018JD029522) and NOAAGlobalTemp v5 (Zhang et al., 2019, DOI: 10.1029/2019EO128229) datasets.	
Notes: The global mean surface temperature captures near-surface air temperature over the planet's land and ocean surface. The value reported represents the spread of the three estimates. Temperature changes from all three datasets are expressed relative to the 1850–1900 average temperature from the HadCRUT.4.6 dataset. Since data for the period 1850–1880 are missing in GISTEMP v4 and NOAAGlobalTemp v5, data are centered by setting the 1880–1900 mean of all datasets to the HadCRUT.4.6 mean over the same period.	
ANNUAL ICE MELT	
glaciers = $(3.0 \pm 1.2) \times 10^{11} \text{ m}^3 / \text{yr}$	HuID: 32459
Data Source(s): Intergovernmental Panel on Climate Change (IPCC) 2019 Special Report on the Ocean and Cryosphere in a Changing Climate. Table 2.A.1 on pp. 199–202. Notes: Value corresponds to the trend of annual glacial ice mass loss from major glaciated regions (2006–2015) based on aggregation of observation methods (original data source: Zemp et al. 2019, DOI: 10.1038/s41586-019-1071-0) with satellite gravimetric observations (original data source: Wouters et al. 2019, DOI: 10.3389/feart.2019.00096). Water volume loss was calculated from ice mass loss assuming a standard pure ice density of 920 kg / m^3 . Uncertainty represents a 95% confidence interval calculated from standard error propagation of the 95% confidence intervals reported in the original sources assuming them to be independent.	
ice sheets = $(4.7 \pm 0.4) \times 10^{11} \text{ m}^3 / \text{yr}$	HuID: 95798, 93137
Data Source(s): D. N. Wiese et al. 2019 JPL GRACE and GRACE-FO Mascon Ocean, Ice, and Hydrology Equivalent HDR Water Height RL06M CRI Filtered Version 2.0, Ver. 2.0, PO.DAAC, CA, USA. Dataset accessed [2020–Aug–10]. DOI: 10.5067/TEM-SC-3MJ62	
Notes: Value corresponds to the trends of combined annual ice mass loss from the Greenland and Antarctic Ice Sheets (2002–2020) measured by satellite gravimetry. Water volume loss was calculated from ice mass loss assuming a standard pure ice density of 920 kg / m^3 . Uncertainty represents one standard deviation and considers only propagation of monthly uncertainties in measurement.	
Arctic sea ice = $(3.0 \pm 1.0) \times 10^{11} \text{ m}^3 / \text{yr}$	HuID: 89520
Data Source(s): PIOMAS Arctic Sea Ice Volume Reanalysis, Figure 1 of webpage as of October 31, 2020. Original method source: Schweiger et al. 2011, DOI:10.1029/2011JC007084	
Notes: Value reported corresponds to the trend of annual volume loss from Arctic sea ice (1979–2020). The uncertainty in the trend represents the range in trends calculated from three ice volume determination methods.	
SEA ICE EXTENT	
extent loss at yearly maximum cover (September) $\approx 8.4 \times 10^{10} \text{ m}^2 / \text{yr}$	HuID: 33993
extent loss at yearly minimum cover (March) $\approx 4.0 \times 10^{10} \text{ m}^2 / \text{yr}$	HuID: 87741
average annual extent loss = $5.5 \pm 0.2 \times 10^{10} \text{ m}^2 / \text{yr}$	HuID: 70818
Data Source(s): Comiso et al. 2017, DOI:10.1002/2017JC012768. Fetterer et al. 2017, updated daily. Sea Ice Index, Version 3, Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center, DOI:10.7265/NSK072F8, [Accessed 2020–Oct–19]. Notes: Sea ice extent refers to the area of the sea with > 15% ice coverage. Annual value corresponds to the linear trend of annually averaged Arctic sea ice extent from 1979–2015 (Comiso et al 2017) calculated from four different methods. This is in good agreement with the linear trend of annual extent loss calculated by averaging over every month in a given year ($5.5 \times 10^{10} \text{ m}^2 / \text{yr}$ HuID: 66277). The minimum cover extent loss corresponds to the linear trend of Arctic sea ice extent in September from 1979–2020 and the maximum cover extent loss corresponds to the linear trend of sea ice extent in March from 1979–2020. The Antarctic sea ice extent trend is not shown because a significant long-term trend over the satellite observation period is not observed and short-term trends are not yet attributable.	
MATERIAL PRODUCTION	
concrete production = $(2 - 3) \times 10^{13} \text{ kg / yr}$	HuID: 25488, 81346, 16995
Data Source(s): United States Geological Survey (USGS), Mineral Commodity Summaries 2020, pp. 42–43, DOI:10.3133/mcs2020. Miller et al. 2016, Table 1, DOI:10.1088/1748-9326/11/7/074029. Monteiro et al. 2017, DOI:10.1038/nmat4930. Krausmann et al. 2017, DOI:10.1073/pnas.1613773114 Notes: Concrete is formed when aggregate material is bonded together by hydrated cement. The USGS reports the mass of cement produced in 2019 as $4.1 \times 10^{12} \text{ kg}$ in 2019. As most cement is used to form concrete, cement production can be used to estimate concrete mass using a multiplicative conversion factor of 7 (Monteiro et al.). Miller et al. report that the cement, aggregate and water used in concrete in 2012 sum to $2.3 \times 10^{13} \text{ kg}$. Krausmann et al. report an estimated value from 2010 based on a material input, stocks, and outputs model. The value is net annual addition to concrete stocks plus annual waste and recycling to estimate gross production of concrete.	
steel production = $(1.4 - 1.9) \times 10^{12} \text{ kg / yr}$	HuID: 51453, 44894, 85981
Data Source(s): United States Geological Survey (USGS), Mineral Commodity Summaries 2020, pp. 82–83, DOI:10.3133/mcs2020. World Steel Association, World Steel in Figures 2020, p. 6. Krausmann et al. 2017, DOI:10.1073/pnas.1613773114 Notes: CCrude steel includes stainless steels, carbon steels, and other alloys. The USGS reports the mass of crude steel produced in 2019 as 1900 megatonnes (Mt). The World Steel Association reports a production value of 1869 Mt in 2019. Krausmann et al. report an estimated value from 2010 based on a material input, stocks, and outputs model. The value is net annual addition to steel stocks plus annual waste and recycling to estimate gross production of steel.	
plastic production $\approx 4 \times 10^{11} \text{ kg / yr}$	HuID: 97241, 25437
Data Source(s): Geyer et al. 2017, Table S1, DOI:10.1126/sciadv.1700782.; Krausmann et al. 2017, DOI:10.1073/pnas.1613773114. Notes: Value represents the approximate sum total global production of plastic fibers and plastic resin during the calendar year of 2015. Notably, comprehensive data about global plastic production is sorely lacking. Geyer et al. draw data from various industry groups to estimate total production of different polymers and additives. Some of the underlying data is not publicly available, and data from financially-interested parties is inherently suspect. Krausmann et al. report an estimated value from 2010 based on a material input, stocks, and outputs model. The value is net annual addition to stocks plus annual waste and end-of-life recycling to estimate gross production of plastics.	

LIVESTOCK POPULATION	
chicken standing population $\approx 2.5 \times 10^{10}$	HuID: 94934
cattle standing population $\approx 1.5 \times 10^9$	HuID: 92006
swine standing population $\approx 1 \times 10^9$	HuID: 21368
all livestock standing population $\approx 3 \times 10^{10}$	HuID: 15765
Data Source(s): Food and Agriculture Organization (FAO) of the United Nations Statistical Database (2020) — Live Animals. Notes: Counts correspond to the estimated standing populations in 2018. Values are reported directly by countries, yet the FAO uses non-governmental statistical sources to address uncertainty and missing (non-reported) data. Reported values are therefore approximations.	
NITROGEN FIXATION	
annual mass of fixed nitrogen $\approx 1.5 \times 10^{11} \text{ kg N / yr}$	HuID: 60580, 61614
Data Source(s): United States Geological Survey (USGS), Mineral Commodity Summaries 2020, pp. 116–117, DOI:10.3133/mcs2020. International Fertilizer Association (IFA) Statistical Database (2020) — Ammonia Production & Trade Tables by Region. Smith et al. 2020, DOI: 10.1039/c9ee02873k. Notes: Ammonia (NH_3) produced globally is compiled by the USGS and IFA from major factories that report output. The USGS estimates the approximate mass of nitrogen in ammonia produced in 2018 as $1.50 \times 10^{11} \text{ kg N}$ and the International Fertilizer Association reports a production value of $1.50 \times 10^{11} \text{ kg N}$ in 2019. Nearly all of this mass is produced by the Haber-Bosch process (> 96%, Smith et al. 2020). In the United States most of this mass is used for fertilizer, with the remainder being used to synthesize nitrogen-containing chemicals including explosives, plastics, and pharmaceuticals ($\approx 88\%$, USGS Mineral Commodity Summaries 2020).	
OCEAN ACIDITY	
surface ocean $[\text{H}^+]$ ≈ 0.2 parts per billion	HuID: 90472
annual change in $[\text{H}^+]$ $= 0.36 \pm 0.03 \%$	HuID: 19394
Data Source(s): Figures 1–2 of European Environment Agency report CLIM 043 (2020). Original data source of the report is "Global Mean Sea Water pH" from Copernicus Marine Environment Monitoring Service. Notes: Reported value is calculated from the global average annual change in pH over years 1985–2018. The average oceanic pH was ≈ 8.057 in 2018 and decreases annually by ≈ 0.002 units, giving a change in $[\text{H}^+]$ of roughly $10^{-8.056} - 10^{-8.057} \approx 4 \times 10^{-11} \text{ mol/L}$ or about 4% of the global average. $[\text{H}^+]$ is calculated as $10^{-\text{pH}} \approx 10^{-8} \text{ mol/L}$ or 0.2 parts per billion (ppb) which is calculated by noting that $[\text{H}_2\text{O}] \approx 55 \text{ mol / L}$. Uncertainty for annual change is the standard error of the mean.	
LAND USE	
agricultural $\approx 5 \times 10^{13} \text{ m}^2$	HuID: 29582
Data Source(s): Food and Agriculture Organization (FAO) of the United Nations Statistical Database (2020) — Land Use. Notes: Agricultural land is defined as all land that is under agricultural management including pastures, meadows, permanent crops, temporary crops, land under fallow, and land under agricultural structures (such as barns). Reported value corresponds to 2017 estimates by FAO.	
urban $\approx (6 - 8) \times 10^{11} \text{ m}^2$	HuID: 41339, 39341
Data Source(s): Florczyk et al. 2019 (https://tinyurl.com/yxxgxtll) and Table 3 of Liu et al. 2018 DOI: 10.1016/j.rse.2018.02.055. 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 and has a minimum population density of 300 people per km ² . Reported value gives the range of recent measurements of $\approx 6.5 \times 10^{11} \text{ m}^2$ (2015) and $\approx (7.5 \pm 1.5) \times 10^{11} \text{ m}^2$ (2010) from Florczyk et al. 2019 and Liu et al. 2018, respectively.	
RIVER FRAGMENTATION	
global fragmented river volume $\approx 6 \times 10^{11} \text{ m}^3$	HuID: 61661
Data Source(s): Grill et al. 2019 DOI: 10.1038/s41586-019-1111-9. Notes: Value corresponds to the water volume contained in rivers that fall below the connectivity threshold required to classify them as free-flowing. Value considers only global rivers with upstream catchment areas greater than 10 km ² or discharge volumes greater than 0.1 m ³ per second. The ratio of global river volume in disrupted rivers to free-flowing rivers is approximately 0.9. The exact value depends on the cutoff used to define a "free-flowing" river. We direct the reader to the source for thorough detail.	
HUMAN POPULATION	
urban-dwelling fraction of population $\approx 55\%$	HuID: 93995
total population $\approx 7.6 \times 10^9$	HuID: 85255
Data Source(s): Food and Agricultural Organization (FAO) of the United Nations Report on Annual Population, 2019. Notes: Value for total population in 2018 comes from a combination of direct population reports from country governments as well as inferences of underreported or missing data. The definition of "urban" differs between countries and the data does not distinguish between urban and suburban populations despite substantive differences between these land uses (Jones and Kammen 2013, doi: 10.1021/es403464). As explained by the United Nations population division, "When the definition used in the latest census was not the same as in previous censuses, the data were adjusted whenever possible so as to maintain consistency." Rural population is computed from this fraction along with the total human population, implying that the total population is composed only of "urban" and "rural" communities.	
GREENHOUSE GAS EMISSIONS	
anthropogenic CO ₂ = $(4.25 \pm 0.33) \times 10^{13} \text{ kg CO}_2 / \text{yr}$	HuID: 24789, 54608, 98043
Data Source(s): Table 6 of 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: 10.1002/2014GB004997) Slugokenky and Tans, NOAA/GML https://www.esrl.noaa.gov/gmd/ccgg/trends/ . Notes: Value corresponds to total CO ₂ emissions from fossil fuel combustion, industry (predominantly cement production), and land-use change during calendar year 2018. Changes to land can lead to CO ₂ emissions indirectly. When forests are harvested, for example, CO ₂ that would otherwise be removed by photosynthesis remains in the atmosphere. In 2018, $1.88 \times 10^{12} \text{ kg CO}_2 / \text{yr}$ accumulated in the atmosphere, reflecting the balance of emissions and CO ₂ uptake by plants and oceans. Uncertainty corresponds to one standard deviation.	

Human Impacts by the Numbers — Supporting Information

K

GREENHOUSE GAS EMISSIONS (CONTINUED)

anthropogenic CH₄ = (3.4 – 3.9) × 10¹¹ kg CH₄ / yr [HuD: 96837, 30725](#)
Data Source(s): Table 3 of Saunois, et al. 2020. DOI: 10.5194/essd-12-1561-2020. **Notes:** Value corresponds to 2008–2017 decadal average mass of CH₄ emissions from anthropogenic sources. Includes emissions from agriculture and landfill, fossil fuels, and burning of biomass and biofuels, but other inventories of anthropogenic methane emissions are also considered. Reported range represents the minimum and maximum estimated emissions from a combination of “bottom-up” and “top-down” models.

anthropogenic N₂O = 1.1 (+0.6, – 0.5) × 10¹⁰ kg N₂O / yr [HuD: 44575](#)

Data Source(s): Table 1 of Tian, H., et al. 2020. DOI: 10.1038/s41586-020-2780-0. **Notes:** Value corresponds to annualized N₂O emissions from anthropogenic sources in the years 2007–2016. The value reported in the source is 7.3 (4.2, 11.4) Tg N / year. This is converted to mass of N₂O using the fact that N ≈ 14/22 of the mass of N₂O. Reported value is mean with the uncertainty bounds (+,–) representing the maximum and minimum values observed in the 2007–2016 time period.

L

WATER WITHDRAWAL

agricultural withdrawal = 1.3 × 10¹² m³ / yr [HuD: 84545, 43593, 95345](#)
 industrial withdrawal = 5.9 × 10¹¹ m³ / yr [HuD: 27142](#)
 domestic withdrawal = 5.4 × 10¹⁰ m³ / yr [HuD: 69424](#)
 total withdrawal = (1.7 – 2.2) × 10¹² m³ / yr [HuD: 27342, 68004](#)

Data Source(s): Figure 1 of Qin et al. 2019. DOI: 10.1038/s41893-019-0294-2. AQUASTAT Main Database, Food and Agriculture Organization of the United Nations **Notes:** Agricultural and total withdrawal include one value from Qin et al. (who reports “consumption”) and one value from the AQUASTAT database. Industrial water withdrawal is from AQUASTAT and domestic withdrawal value is from Qin et al. Values in AQUASTAT are self-reported by countries and have missing values from some countries, probably accounting for a few percent underreporting. All values represent withdrawals. For agricultural and domestic, water withdrawal is assumed to be the same as water consumption as reported in Qin et al.

M

SEA LEVEL RISE

added water = 1.97 (+0.36, –0.34) mm / yr [HuD: 97108](#)
 thermal expansion = 1.19 (+0.25, –0.24) mm / yr [HuD: 97688](#)
 total observed sea-level rise = 3.35 (+0.47, –0.24) mm / yr [HuD: 81373](#)

Data Source(s): Table 1 of Frederikse et al. 2020. DOI: 10.1038/s41586-020-2591-3. **Notes:** Values correspond to the average global sea level rise of the years 1993 – 2018. “Added water” (barystatic) change includes effects from meltwater from glaciers and ice sheets, added mass from sea-ice discharge, and changes in the amount of terrestrial water storage. Thermal expansion accounts for the volume change of water with increasing temperature. Values for “added water” and “thermal expansion” come from direct observations of ocean temperature and gravimetry/altimetry, respectively. Total sea level rise is the observed value using a combination of measurement methods. “Other sources” reported on page 1 accounts for observed residual sea level rise not attributed to a source in the model. Values in brackets correspond to the upper and lower bounds of the 90% confidence interval.

N

TOTAL POWER USE

global power use = 17 – 18 TW [HuD: 31373, 85317](#)
Data Source(s): bp Statistical Review of World Energy, 2020; U.S. Energy Information Administration, 2020. **Notes:** Value represents the sum of total primary energy consumed from oil, natural gas, coal, and nuclear energy and electricity generated by hydroelectric and other renewables. Value is calculated using annual primary energy consumption as reported in data sources assuming uniform use throughout a year, yielding ≈ 17 – 18 TW.

O

TREE COVERAGE AREA LOSS

commodity-driven deforestation = (5.7 ± 1.1) × 10¹⁰ m² / yr [HuD: 96098](#)
 forestry = (5.4 ± 0.8) × 10¹⁰ m² / yr [HuD: 38352](#)
 urbanization = (2 ± 1) × 10⁹ m² / yr [HuD: 19429](#)
 shifting agriculture = (7.5 ± 0.9) × 10¹⁰ m² / yr [HuD: 24388](#)
 wildfire = (7.2 ± 1.3) × 10¹⁰ m² / yr [HuD: 92221](#)

Data Source(s): Table 1 of Curtis et al. 2018 DOI:10.1126/science.aaq3445. Hansen et al. 2013 DOI:10.1126/science.1244693. Global Forest Watch, 2020. Reported values in source correspond to total loss from 2001 – 2015. Values given are averages over this 15 year window. **Notes:** Commodity-driven deforestation is “long-term, permanent, conversion of forest and shrubland to a non-forest land use such as agriculture, mining, or energy infrastructure.” Forestry is defined as large-scale operations occurring within managed forests and tree plantations with evidence of forest regrowth in subsequent years. Urbanization converts forest and shrubland for the expansion and intensification of existing urban centers. Disruption due to “shifting agriculture” is defined as “small- to medium-scale forest and shrubland conversion for agriculture that is later abandoned and followed by subsequent forest regrowth”. Disruption due to wildfire is “large-scale forest loss resulting from the burning of forest vegetation with no visible human conversion or agricultural activity afterward”. Uncertainty corresponds to the 95% confidence interval. Uncertainty is approximate for “urbanization” as the source reports an ambiguous error of “± <1%”.

P

POWER FROM FOSSIL FUELS

natural gas = 4.2 – 4.8 TW [HuD: 49947, 86175](#)
 oil = 6.0 – 6.5 TW [HuD: 4121, 39756](#)
 coal = 5.0 – 5.5 TW [HuD: 10400, 60490](#)
 total = 15.1 – 16.5 TW [HuD: 29470, 29109](#)

Data Source(s): bp Statistical Review of World Energy, 2020. U.S. Energy Information Administration, 2020. **Notes:** Values are self-reported by countries. values from bp Statistical Review correspond to 2019 whereas values from the EIA correspond to 2018 estimates. Reported values of TW are computed from primary energy units assuming uniform use throughout the year. 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 subbituminous 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.

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Q

POWER FROM RENEWABLE RESOURCES

wind = 0.32–0.38 TW [HuD: 30581, 85919](#)
 solar = 0.12 – 0.20 TW [HuD: 99885, 58303](#)
 hydroelectric = 1.2 TW [HuD: 15765, 50558](#)
 total renewable power = 1.9 TW [HuD: 75741, 20246](#)

Data Source(s): bp Statistical Review of World Energy, 2020. U.S. Energy Information Administration, 2020. **Notes:** Reported values correspond to estimates for the 2017 calendar year. Renewable resources are defined as wind, geothermal, solar, biomass and waste. Hydroelectric, while presented here, is not defined as a renewable in the bp dataset. All values are reported as input-equivalent energy, meaning the input energy that would have been required if the power was produced by fossil fuels. BP reports that fossil fuel efficiency used to make this conversion was about 40% in 2017.

R

FOSSIL FUEL EXTRACTION

volume of natural gas = (3.9 – 4.0) × 10¹² m³ / yr [HuD: 11468, 20532](#)
 volume of oil = (5.5 ± 5.8) × 10⁹ m³ / yr [HuD: 66789, 97719](#)
 mass of coal = (7.8 – 8.1) × 10¹² kg / yr [HuD: 78435, 48928](#)

Data Source(s): bp Statistical Review of World Energy, 2020. U.S. Energy Information Administration, 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 solid commercial fuels such as bituminous coal, anthracite, lignite, subbituminous coal, and other solid fuels. All values from bp Statistical Review correspond to 2019 whereas values from the EIA correspond to 2018 estimates.

S

OCEAN WARMING

heat uptake by ocean ≈ 346 ± 51 TW [HuD: 94108](#)
 upper ocean (0 – 700 m) warming ≈ (5.9 ± 0.4) × 10⁻³ °C / yr [HuD: 51068](#)

Data Source(s): Table S1 of Cheng et al. 2017, doi: 10.1126/sciadv.1601545. **Notes:** Values reported are averages over the time period 1992–2015. Uncertainties correspond to the 95% confidence intervals. Temperature change is considered in the upper 700 m because sea surface temperatures have high decadal variability and are a poor indicator of ocean warming; see Roemmich et al. 2015, doi: 10.1038/NCLIMATE2513.

T

POWER FROM NUCLEAR FISSION

nuclear power = 0.75–0.87 TW [HuD: 48387](#)

Data Source(s): bp Statistical Review of World Energy, 2020. U.S. Energy Information Administration, 2020. **Notes:** Values are self-reported by countries and correspond to estimates for 2017 calendar year. Values are reported as ‘input-equivalent’ energy, meaning the energy needed to produce a given amount of power if the input were a fossil fuel. This is calculated by multiplying the given power by a conversion factor representing the efficiency of power production by fossil fuels. In 2017, this factor was about 40%.

U

NUCLEAR FALLOUT

anthropogenic ²³⁹Pu and ²⁴⁰Pu from weapons testing ≈ 1.4 × 10¹¹ kg / yr [HuD: 42526](#)

Data Source(s): Table 1 in Hancock et al. 2014 doi: 10.1144/SP395.15. Fallout in activity from UNSCEAR 2000 Report on Sources and Effects of Ionizing Radiation Report to the UN General Assembly – Volume 1. **Notes:** The approximate mass of Plutonium isotopes ²³⁹Pu and ²⁴⁰Pu released into the atmosphere from the ≈ 500 above-ground nuclear weapons tests conducted between 1945 and 1980. Naturally occurring ²³⁹Pu and ²⁴⁰Pu is rare meaning that nearly all contemporary labile plutonium comes from human action.(Taylor 2001,doi: 10.1016/S1569-4860(01)80003-6) The sum total mass of radionuclides released is ≈ 3300 kg with a combined radioactive fallout of ≈11 PBq. These values do not represent the globally distributed mass (excluding close-in fallout at some testing sites) and do not account for non-weapons sources.

V

CONTEMPORARY EXTINCTION

animal species extinct since 1500 > 750 [HuD: 44641](#)

plant species extinct since 1500 > 120 [HuD: 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 ≈ 520 years. Of the predicted ≈ 8 million animal species, the IUCN databases catalogues only ≈ 900,000 with only ≈ 75,000 being assigned a conservation status. Representation of plants and fungi is even more sparse with only ≈ 40,000 and ≈ 285 being assigned a conservation status, respectively. The number of extinct animal species is undoubtedly higher than these reported values, as signified by an inequality symbol (>).

W

EARTH MOVING

waste and overburden from coal mining ≈ 6.5 × 10¹³ kg / yr [HuD: 72899](#)

earth moved from urbanization > 1.4 × 10¹⁴ kg / yr [HuD: 59640](#)

Data Source(s): Supplementary table 1 of Cooper et al. 2018. DOI: doi.org/gfwfh. **Notes:** Coal mining waste and overburden mass is calculated given commodity-level stripping ratios (mass of overburden/waste per mass of coal resource mined) and reported values of global coal production by type. Urbanization mass is presented as a lower bound estimate of the mass of earth moved from global construction projects. This comes from a conservative estimate that the ratio of the mass of earth moved per mass of cement/concrete used in construction globally is 2:1. This value is highly context dependent and we encourage the reader to read the source material for a more thorough description of this estimation.

erosion from agricultural land > 1.2 – 2.4 × 10¹³ kg / yr [HuD: 19415, 41496](#)

Data Source(s): Pg. 377 of Wang and Van Oost 2019, DOI: 10.1177/0959683618816499. Pg. 21996 of Borrelli et al. 2020 DOI: 10.1073/pnas.2001403117. **Notes:** Cumulative sediment mass loss over history of human agriculture due to accelerated erosion is estimated to be ≈ 30,000 Gt. Recent years have an estimated erosion rate ranging from 12 Pg / yr (Wang and Van Oost) to ≈ 24 Pg / yr (Borrelli et al.). Values come from computational models conditioned on time-resolved measurements of sediment deposition in catchment basins.