HUMAN IMPACTS
by the numbers

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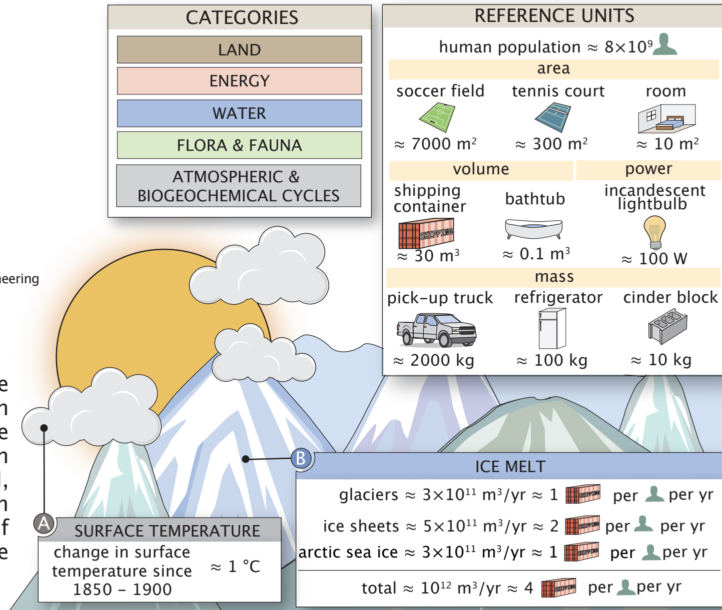
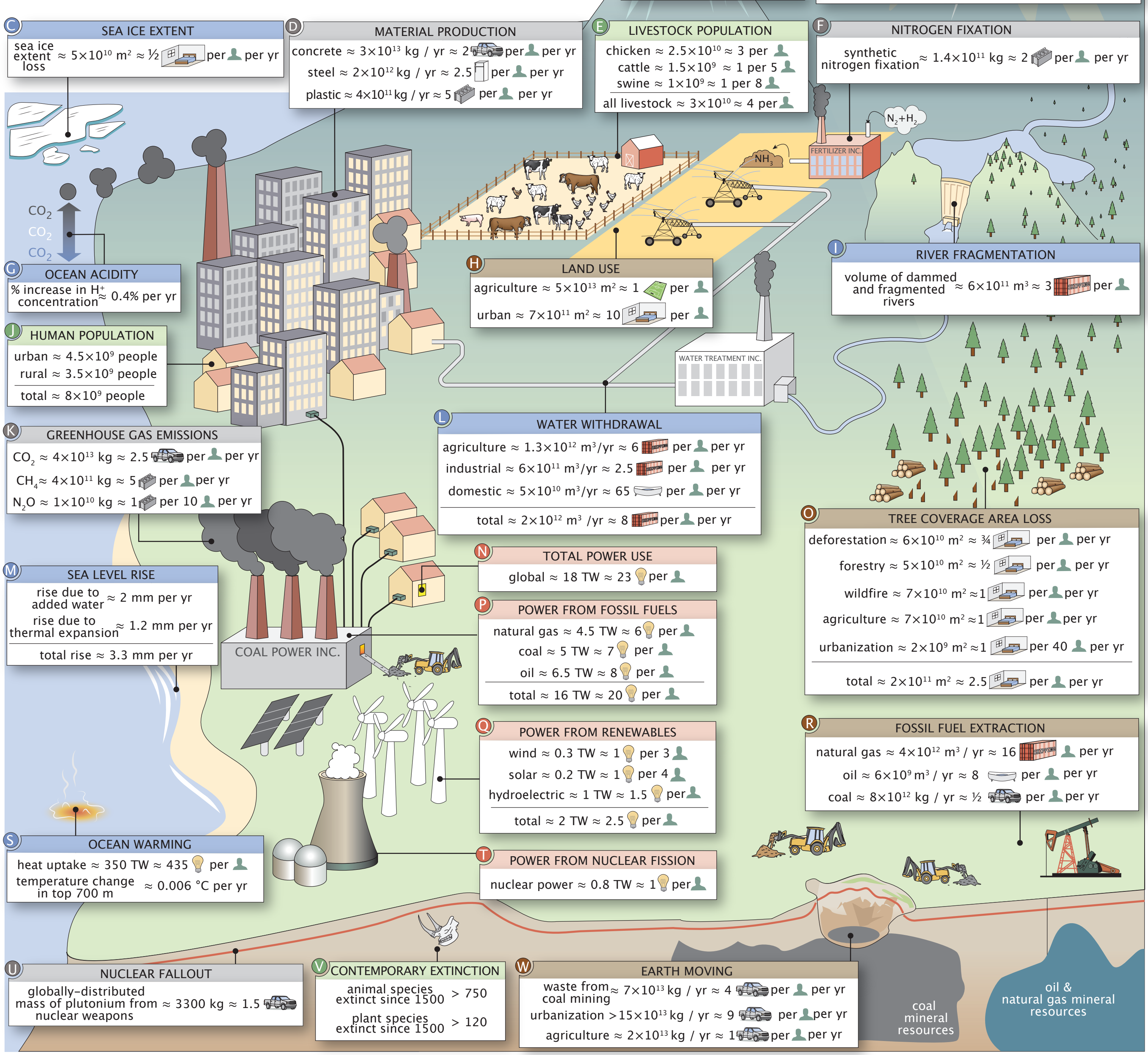
ABSTRACT

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.

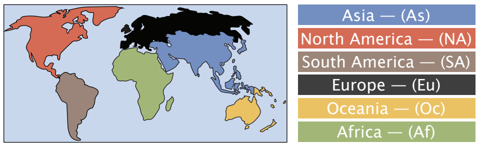




Human Impacts by the Numbers — Impacts By Region

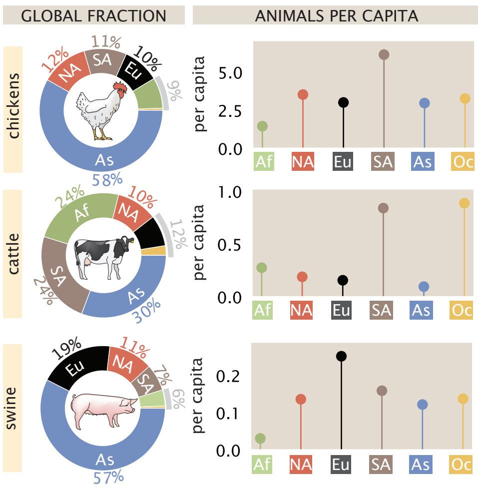
THE GEOGRAPHY OF HUMAN IMPACTS

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 disproportionate to 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.



THE LIVESTOCK POPULATION

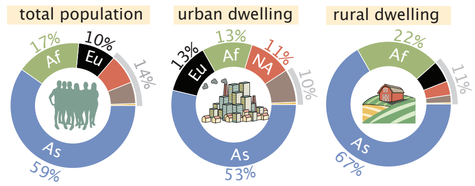
The global population of terrestrial livestock is around 30 billion individuals, much of which are chickens. Asia houses most of this population, though South America and Europe harbor more animals on a per-capita basis.



Sources: Food and Agricultural Organization of the United Nations

THE HUMAN POPULATION

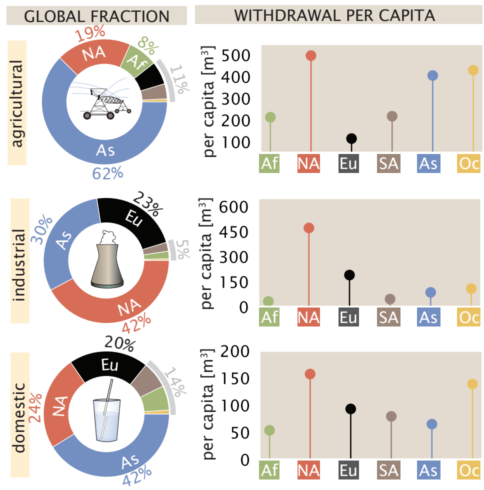
There are ≈ 8 billion humans on the planet, with approximately 50% living in 'urban' environments. The majority of the worlds population (as well as the majority of both urban and rural dwellers) live in Asia.



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

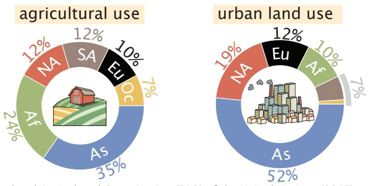
While Asia withdraws the most water for agricultural and municipal needs, North America withdraws the plurality of water for industrial purposes. North America also withdraws more water per capita than any other region.



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.

LAND USE

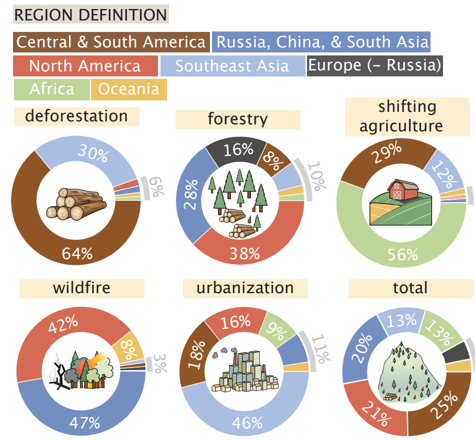
Though humans are nearly evenly split between urban and rural environments, agricultural land is the far more common use of land area. Together, Asia and Africa contain more than half of global agricultural land. Asia alone accomodates more than half of the global urban land area.



Sources: Food and Agricultural Organization (FAO) of the United Nations (2015) — 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

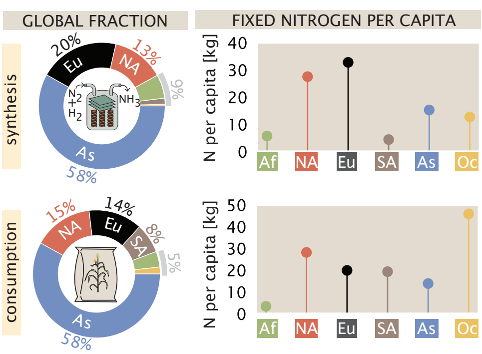
Most drivers of tree coverage area loss are comparable in their effect at a global scale. However, there are drastic regional differences in the relative magnitudes.



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.

NITROGENOUS FERTILIZER USE & PRODUCTION

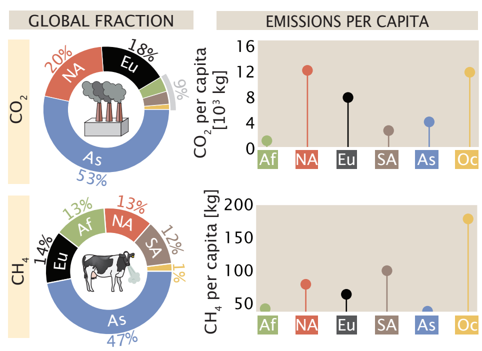
Modern agriculture requires nitrogen in amounts beyond what is produced naturally. Asia synthesizes and consumes a large majority of fixed nitrogen. However, Europe and Oceania synthesize and consume the most fixed nitrogen on a per capita basis, respectively.



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.

GREENHOUSE GAS EMISSIONS

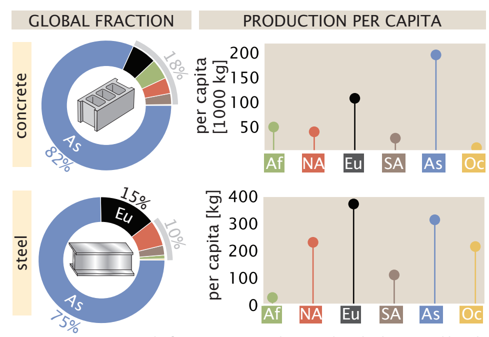
CO_2 and CH_4 are two potent greenhouse gases which are routinely emitted by anthropogenic processes. While Asia emits roughly half of all CO_2 and CH_4, North America and Oceania produce the most on a per capita basis, respectively.



Sources: Collated by: Friedlingstein, P. et al (2019). doi: 10.5194/essd-11-1783-2019. See Panel J on Pg. 4 for complete list of sources. Notes: Values report decadal averages in kg CO2 or CH4 per year over time period 2008-2017.

MATERIAL PRODUCTION

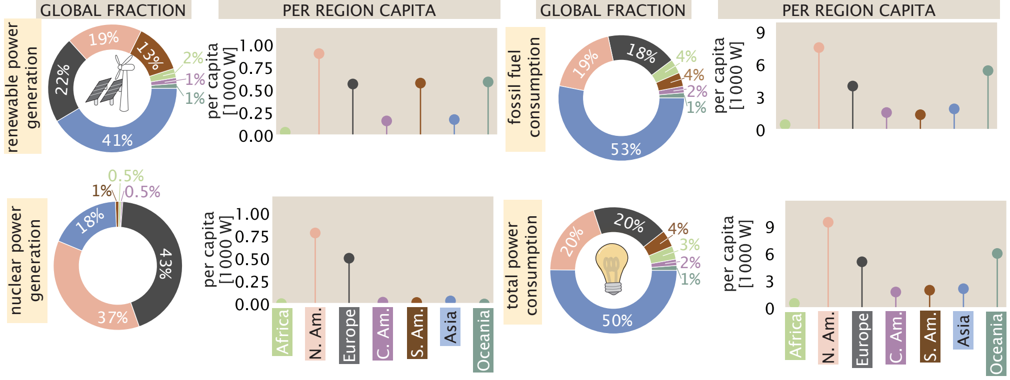
Humans excavate and transform an enormous amount of material from the Earth's crust. Two of these materials, concrete and plastic, are produced primarily in Asia on both a global and per capita basis. Asia's per capita production of steel is only outpaced by Europe.



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).

POWR GENERATION AND CONSUMPTION

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, At 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.



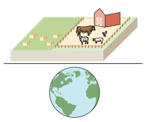
Source: Energy Information Administration of the United States (2017)
Notes: "Renewables" includes hydroelectric, biofuels, biomass (wood), geothermal, wind, and solar. "Fossil fuels" includes coal, oil, and natural gas.

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 some 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

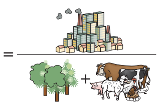
$$Te = \frac{\text{land area used by humans}}{\text{total land area of Earth}} \approx 0.3$$



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 × 10^7 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 ≈ 30% of Earth's terrestrial surface.

THE ANTHROPOMASS NUMBER

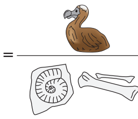
$$An = \frac{\text{total anthropomass}}{\text{total biomass}} \approx 1$$



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 (≈1.1 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 ≈10^5 kg of human made mass, or about 20 African bush elephants, per person on the planet.

THE EXTINCTION NUMBER

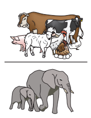
$$Ex = \frac{\text{number of known animal extinctions}}{\text{number of expected natural animal extinctions}} > 10$$



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 BARNYARD NUMBER

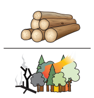
$$By = \frac{\text{mass of terrestrial livestock}}{\text{mass of terrestrial wild animals}} \approx 30$$



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 ≈ 1.5 × 10^{12} kg.

THE DEFORESTATION NUMBER

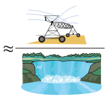
$$Df = \frac{\text{annual forest loss from human action}}{\text{annual forest loss from wildfire}} \approx 2$$



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 (≈ 6 × 10^{10} m^2, HuID: 96098), forestry (≈ 5 × 10^{10} m^2, HuID: 38352), and shifting forest land to agriculture(≈ 7.5 × 10^{10} m^2, HuID: 24388). Expansion of urban areas accounts for < 1% of the total annual forest loss (HuID: 19429). In total, ≈ 15 × 10^{10} m^2 of forest is lost annually due to intentional human action, whereas wildfires (both naturally sparked and those caused by humans) account for ≈ 7 × 10^{10} m^2 annually (HuID: 92221).

THE NIAGARA NUMBER

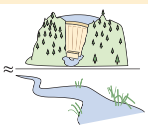
$$Ni = \frac{\text{daily water volume used by humans}}{\text{Niagara Falls daily discharge volume}} \approx 30$$



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 ≈ 1.5 × 10^{12} 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 × 10^{11} m^3 / yr (HuID: 27142). Finally, domestic use (such as drinking water and sanitation) withdraws ≈ 6 × 10^{10} m^3 / 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 ⅓ the yearly discharge of the Amazon river [5].

THE RIVER NUMBER

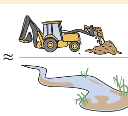
$$Rv = \frac{\text{river volume controlled by humans}}{\text{free-flowing river volume}} \approx 1$$



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 (≈ 6 × 10^{11} m^3, [6] HuID: 55718) as are under direct human control, such as through dams and reservoirs or man-made channels (≈ 6 × 10^{11} m^3, HuID: 61661). Approximately 50% of global free-flowing river volume is within the Amazon river alone.

THE EARTH MOVER NUMBER

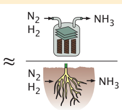
$$Em = \frac{\text{annual mass of earth moved by humans}}{\text{annual mass of earth moved by rivers}} > 15$$



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 × 10^{14} kg of earth a year (HuID: 72899, 59640, 19415, 41496). Rivers, by comparison, transport ≈ 1.3 × 10^{13} 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 NITROGEN NUMBER

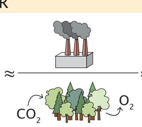
$$N_2 = \frac{\text{mass of } N_2 \text{ fixed via the Haber-Bosch Process}}{\text{mass of } N_2 \text{ fixed biologically}} \approx 1$$



Though molecular nitrogen (N_2) makes up nearly 80% of our atmosphere, it must be converted into a more reactive form like ammonia (NH_3), 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 NH_3 from N_2 was critical for supporting the agricultural needs of a growing human population and for supplying NH_3 for chemical and explosive synthesis. The Nitrogen Number reveals that humans synthesize as much reactive nitrogen industrially (≈ 1.4 × 10^{11} kg per year, HuID: 61614, 60580) as is synthesized by nitrogen-fixing microbes in terrestrial ecosystems (≈ 1 × 10^{11} kg per year, HuID: 15205). Beyond influencing the environmental balance of reactive nitrogen, modern synthesis technologies require a sizable amount of energy contributing significantly to global CO_2 emissions.

THE CO_2 NUMBER

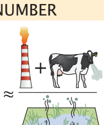
$$CO_2 = \frac{\text{annual mass of anthropogenic } CO_2}{\text{annual mass of naturally removed } CO_2} \approx 2$$



The CO_2 Number compares the annual amount of human-caused CO_2 emissions to the mass of CO_2 naturally removed from the atmosphere each year. There are many climate-related consequences of increasing CO_2 emissions. Beyond accelerating climate change, ≈ 25% of CO_2 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 ≈ 4 × 10^{13} kg of CO_2 (HuID: 54608, 24789) into the atmosphere each year. While many natural processes like volcanoes and wildfires release CO_2, they are generally accompanied by corresponding sinks that remove even more CO_2, like plant photosynthesis. Once all natural processes have been accounted for, a net natural sink of ≈ 2 × 10^{13} kg of CO_2 per year remains (HuID: 52670). Thus, the CO_2 number quantifies the extent to which human emissions outpace the natural removal of CO_2.

THE METHANE NUMBER

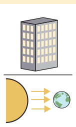
$$Me = \frac{\text{annual mass of anthropogenic } CH_4}{\text{annual mass of natural } CH_4} \approx 1$$



While CO_2 is the most often discussed greenhouse gas, human activities also release substantial amounts of methane (CH_4), an even more potent greenhouse gas than CO_2. The CH_4 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 ≈ 3 – 4 × 10^9 kg per year (HuID: 96837). Natural emissions of CH4, stemming mostly from wetlands and other anaerobic environments, produce a comparable amount (2 – 4 × 10^9 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 × 10^9 kg/year in the anthropogenic case and 2 × 10^9 kg/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 SOLAR NUMBER

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



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. Etach 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: XXXXXXX and https://github.com/rpgroup-pboc/human_impacts

A SURFACE TEMPERATURE

Surface temperature change relative to 1850-1900 ≈ 1 - 2° 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.

B ANNUAL ICE MELT

glaciers = $(3.0 \pm 1.2) \times 10^{11}$ m³ / 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 glacierized 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 / m³. 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 = $(4.7 \pm 0.4) \times 10^{11}$ m³ / 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 / m³. Uncertainty represents one standard deviation and considers only propagation of monthly uncertainties in measurement.

Arctic sea ice = $(3.0 \pm 1.0) \times 10^{11}$ m³ / 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.

C SEA ICE EXTENT

extent loss at yearly maximum cover (September) ≈ 8.4×10^{10} m² / yr HuID: 33993

extent loss at yearly minimum cover (March) ≈ 4.0×10^{10} m² / yr HuID: 87741

average annual extent loss = $5.5 \pm 0.2 \times 10^{10}$ m² / 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, [Sea_Ice_Index_Monthly_Data_with_Statistics_G02135_v3.0.xlsx], Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center, DOI:10.7265/N5K072F8, [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 x 1010 m2 / 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.

D MATERIAL PRODUCTION

concrete production = $(2 - 3) \times 10^{13}$ kg / yr HuID: 25488, 81346

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. Notes: Concrete is formed when aggregate material is bonded together by hydrated cement. The USGS reports the mass of cement produced in 2019 as 4.1×10^{12} 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 2.3×10^{13} kg.

steel production = 1.9×10^{12} kg / yr HuID: 51453, 44894

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. Notes: Crude 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.

plastic production ≈ 4×10^{11} kg / yr HuID: 97241

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. Krausmann et al. report an error of ± 15%, equal to three standard deviations from the mean value obtained in 103 runs of their model.

E LIVESTOCK POPULATION

chicken standing population ≈ 2.5×10^{10} HuID: 94934

cattle standing population ≈ 1.5×10^{9} HuID: 92006

swine standing population ≈ 1×10^{9} HuID: 21368

all livestock standing population ≈ 3×10^{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.

F NITROGEN FIXATION

annual mass of fixed nitrogen ≈ 1.4×10^{11} kg / 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 (2019) — 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 reports the approximate mass of nitrogen in ammonia produced in 2018 as 1.44×10^{11} kg and the International Fertilizer Association reports a production value of 1.46×10^{11} kg in 2018. Both sources compile 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 (≈ 88%, USGS Mineral Commodity Summaries 2020).

G OCEAN ACIDITY

surface ocean [H+] ≈ 0.2 parts per billion HuID: 90472

annual change in [H+] = 0.36 ± 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 [H+] of roughly $10^{-8.056} - 10^{-8.057}$ ≈ 4×10^{-11} mol/L or about 4% of the global average. [H+] is calculated as $10^{-pH} \approx 10^{-8}$ mol/L or 0.2 parts per billion (ppb) which is calculated by noting that [H_2O] ≈ 55 mol / L. Uncertainty for annual change is the standard error of the mean.

H LAND USE

agricultural ≈ 5×10^{13} m² 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 ≈ $(6 - 8) \times 10^{11}$ m² HuID: 41339, 39341

Data Source(s): Florczyk et al. 2019 (https://tinyurl.com/yyxxgtll) 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 km². Reported value gives the range of recent measurements of ≈ 6.5×10^{11} m² (2015) and ≈$(7.5 \pm 1.5) \times 10^{11}$ m² (2010) from Florczyk et al. 2019 and Liu et al. 2018, respectively.

I RIVER FRAGMENTATION

global fragmented river volume ≈ 6×10^{11} m³ 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 km² or discharge volumes greater than 0.1 m³ 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.

J HUMAN POPULATION

urban-dwelling fraction of population ≈ 55% HuID: 93995

total population ≈ 7.6×10^{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. 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.

K GREENHOUSE GAS EMISSIONS

anthropogenic CO_2 = $(4.25 \pm 0.33) \times 10^{13}$ kg CO_2 / 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) Dlugokencky and Tans, NOAA/GMLhttps://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, 1.88×10^{12} kg CO_2 / yr accumulated in the atmosphere, reflecting the balance of emissions and CO_2 uptake by plants and oceans. Uncertainty corresponds to one standard deviation.

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K GREENHOUSE GAS EMISSIONS (CONTINUED)

anthropogenic CH_4 = (3.4 - 3.9) × 10^{11} kg CH_4 / yr HuID: 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 CH_4 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 N_2O = 1.1 (+0.6, - 0.5) × 10^{10} kg N_2O / yr HuID: 44575

Data Source(s): Table 1 of Tian, H., et al. 2020. DOI: 10.1038/s41586-020-2780-0. Notes: Value corresponds to annualized N_2O 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 N_2O using the fact that N ≈ 14/22 of the mass of N_2O. 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 × 10^{12} m³ / yr HuID: 84545, 43593, 95345
industrial withdrawal = 5.9 × 10^{11} m³ / yr HuID: 27142
domestic withdrawal = 5.4 × 10^{10} m³ / yr HuID: 69424
total withdrawal = (1.7 - 2.2) × 10^{12} m³ / yr HuID: 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 HuID: 97108
thermal expansion = 1.19 (+0.25, -0.24) mm / yr HuID: 97688
total observed sea-level rise = 3.35 (+0.47, -0.24) mm / yr HuID: 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 HuID: 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) × 10^{10} m² / yr HuID: 96098
forestry = (5.4 ± 0.8) × 10^{10} m² / yr HuID: 38352
urbanization = (2 ± 1) × 10^9 m² / yr HuID: 19429
shifting agriculture = (7.5 ± 0.9) × 10^{10} m² / yr HuID: 24388
wildfire = (7.2 ± 1.3) × 10^{10} m² / yr HuID: 92221

Data Source(s): Table 1 of Curtis et al. 2018 DOI:10.1126/science.aau3445. 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 HuID: 49947, 86175
oil = 6.0 - 6.5 TW HuID: 4121, 39756
coal = 5.0 - 5.5 TW HuID: 10400, 60490
total = 15.1 - 16.5 TW HuID: 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 spe- cific 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.

Q POWER FROM RENEWABLE RESOURCES

wind = 0.32-0.38 TW HuID: 30581, 85919
solar = 0.12 - 0.20 TW HuID: 99885, 58303
hydroelectric = 1.2 TW HuID: 15765, 50558
total renewable power = 1.9 TW HuID: 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) × 10^{12} m³ / yr HuID: 11468, 20532
volume of oil = (5.5 ± 5.8) × 10^9 m³ / yr HuID: 66789, 97719
mass of coal = (7.8 - 8.1) × 10^{12} kg / yr HuID: 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 HuID: 94108
upper ocean (0 - 700 m) warming ≈ (5.9 ± 0.4) × 10^{-3} ° C / yr HuID: 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 HuID: 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 ^{239}Pu and ^{240}Pu from weapons testing ≈ 1.4 × 10^{11} kg / yr HuID: 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 ^{239}Pu and ^{240}Pu 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 HuID: 44641
plant species extinct since 1500 > 120 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 ≈ 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 × 10^{13} kg / yr HuID: 72899
earth moved from urbanization > 1.4 × 10^{14} kg / yr HuID: 59640

Data Source(s): Supplementary table 1 of Cooper et al. 2018. DOI: doi.org/gfwfhd. 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 × 10^{13} kg / yr HuID: 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.

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