HUMAN IMPACTS
by the numbers

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ABSTRACT

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

REFERENCE UNITS

human population ≈ 8×10^9

area
soccer field ≈ 6000 m^2
tennis court ≈ 200 m^2
room ≈ 10 m^2

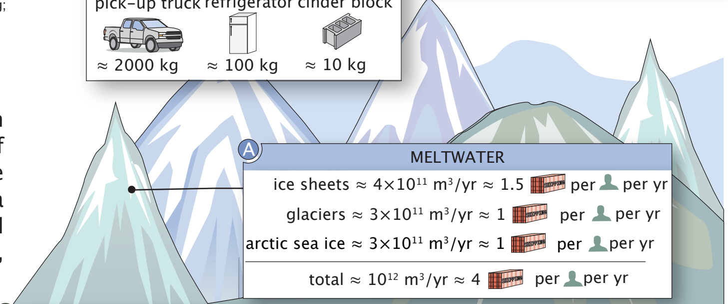
volume
shipping container ≈ 30 m^3
bathtub ≈ 0.1 m^3

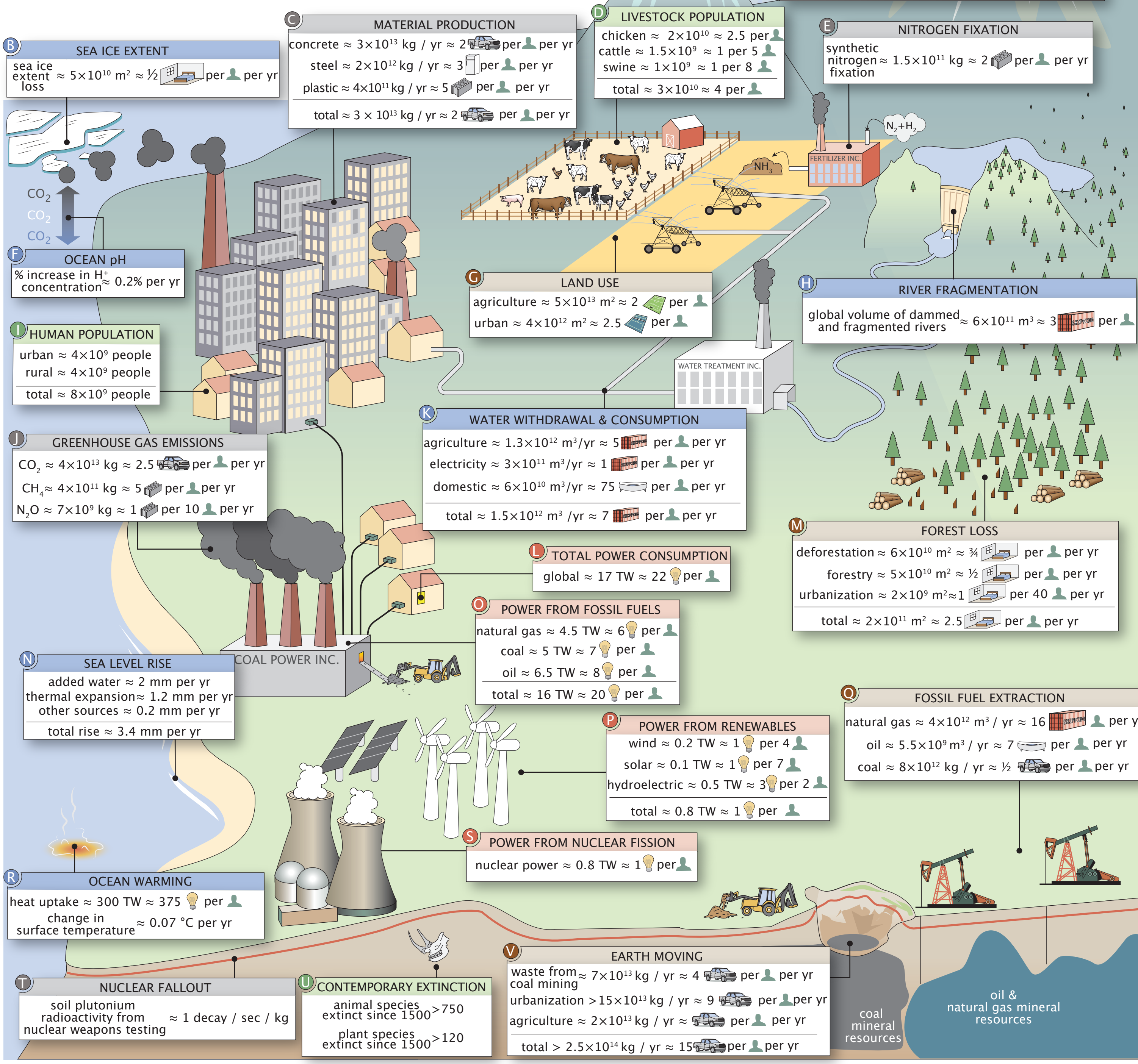
power
lightbulb ≈ 100 W

mass
pick-up truck ≈ 2000 kg
refrigerator ≈ 100 kg
cinder block ≈ 10 kg

HUMAN IMPACT CATEGORIES

LAND
ENERGY
FLORA & FAUNA
WATER
ATMOSPHERIC & BIOGEOCHEMICAL CYCLES

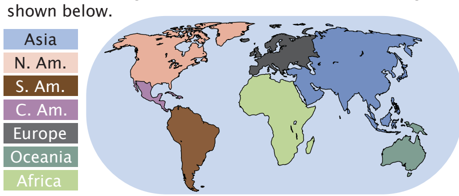




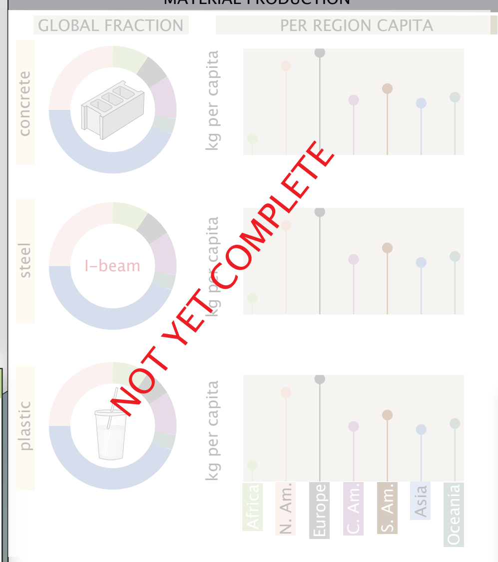
Human Impacts by the Numbers — Impacts by Region

THE GEOGRAPHY OF HUMAN IMPACTS

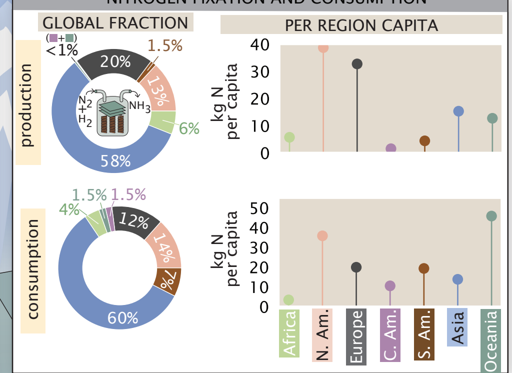
Page 1 represents the impact humans have on the Earth at a global scale. While these numbers are handy, it is important to acknowledge that not all societies are the same. Here, we give a sense of the geographic distribution of several values presented on page 1, broken down by continental region as shown below.



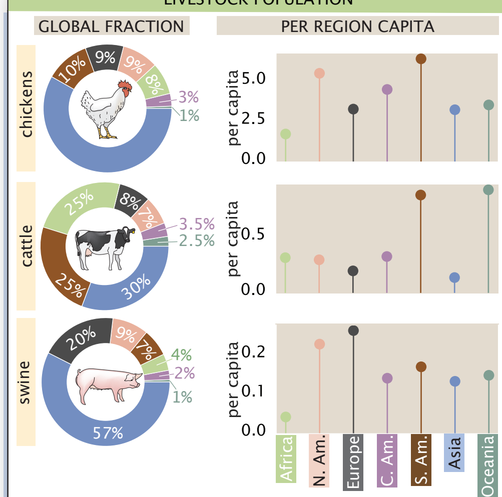
MATERIAL PRODUCTION



NITROGEN FIXATION AND CONSUMPTION

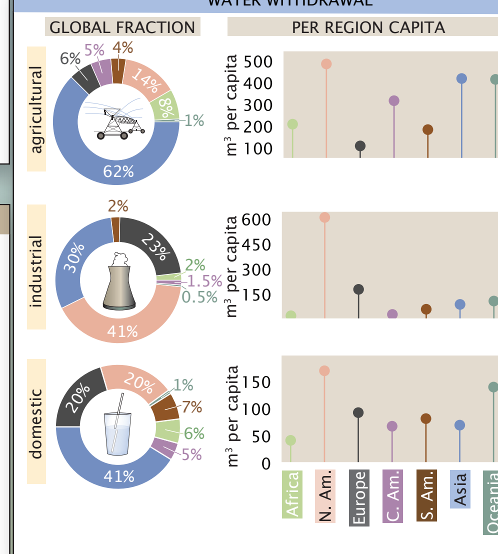


LIVESTOCK POPULATION

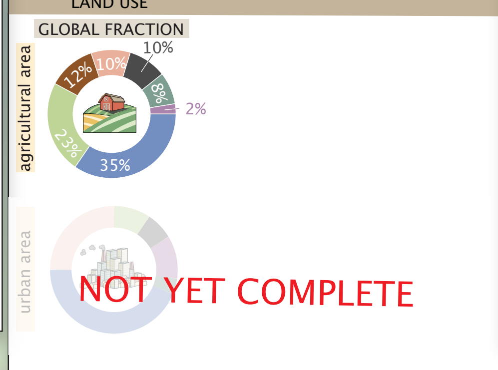


Sources: Food and Agricultural Organization of the United Nations – Livestock (2018). [Livestock populations]. Food and Agricultural Organization of the United States – World Population [region populations]

WATER WITHDRAWAL

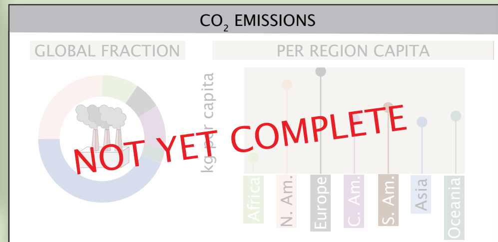


LAND USE

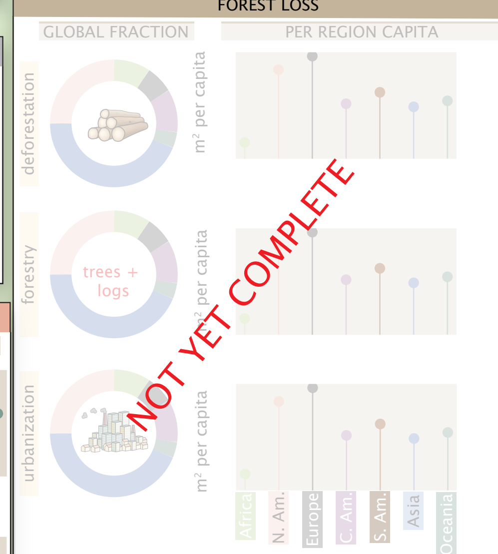


RIVER FRAGMENTATION

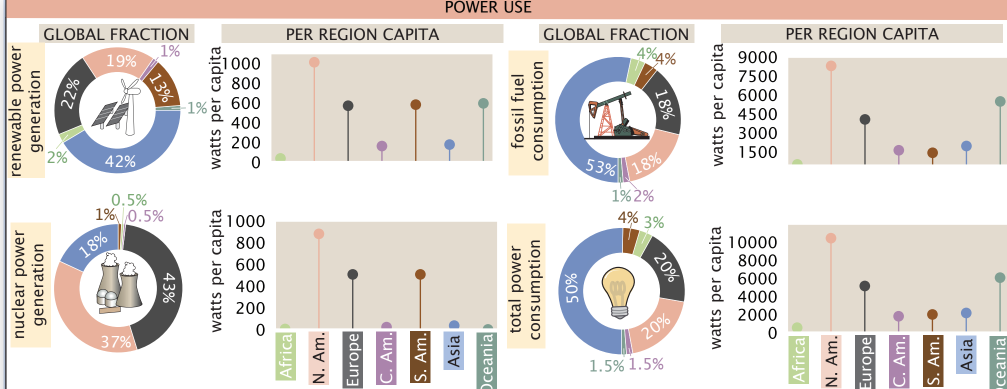
CO_2 EMISSIONS



FOREST LOSS



POWER USE



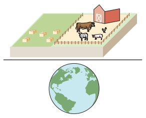
Sources: Energy Information Administration of the United States (2017) [power use/generation]
Food and Agricultural Organization of the United States – World Population [region populations]
Notes: "Renewables" includes hydroelectric, biofuels, biomass (wood), geothermal, wind, and solar. "Fossil fuels" includes coal, oil, and natural gas.

SIZING UP THE ANTHROPOCENE

Much of our understanding of the scales of things is comparative. When we measure lengths, we do so relative to some standard length that helps us develop intuition for whatever situation we might be thinking about. With the many examples of human impacts presented on Page 1, our aim here is to present some measure of each of those numbers 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 available on our planet, a comparison that yields what we will christen the Terra number. Similarly, when we consider the entirety of human-made materials, a dimensionless version of that mass that provides a sense of perspective is to compare it to the total biomass on our planet. Here we present twelve key human impacts in this kind of dimensionless form that range across the earth, the atmosphere, the oceans and our energy use, with the hope that our readers will be emboldened to consider their own favorite examples in a similar dimensionless format.

THE TERRA NUMBER

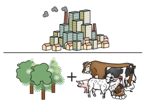
$$Te = \frac{\text{land area used by humans}}{\text{total land area of Earth}} = \approx 0.3$$



The Terra Number reflects the fact that, while we have been constrained to the 30% 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 action, urban centers occupy between 750 thousand and a few million km^2 (HuID: 39341, 87575). In contrast, approximately 50 million km^2 (HuID: 29582) of land on Earth is used either to grow crops or rear livestock. Together, urban and agricultural lands make up ≈ 30% of Earth's terrestrial surface. Read more about this number.

THE ANTHROPOMASS NUMBER

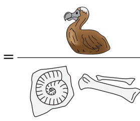
$$An = \frac{\text{total anthropomass}}{\text{total biomass}} = \approx 1$$



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. Surprisingly, already in 2007, human-made materials added up to more mass than that of the entire biosphere itself (HuID: XXXXX to be added). Concretes and aggregates dominate the anthropomass, with bricks and asphalt coming in a distant second. Though around us everywhere, plastics and metal constitute a tiny fraction of the total anthropomass. The total anthropomass budget amounts to a dizzying 10^5 kg of human made mass per person on planet earth, with a volume per person that corresponds to roughly the entirety of one lane of an Olympic-sized swimming pool.

THE EXTINCTION NUMBER

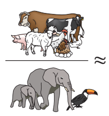
$$Ex = \frac{\text{number of known animal extinctions}}{\text{number of expected natural animal extinctions}} = > 10$$



The Extinction Number reflects the fact that over the past 500 years, far more animal species have gone extinct than than would be expected due to natural processes. Since 1500, more than 760 species of animals have been determined to be 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 human alteration of the environment[1]. It's important to emphasize that these data are incomplete and reflect only a fraction of nature that has 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

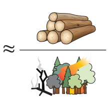
$$By = \frac{\text{mass of terrestrial livestock}}{\text{mass of terrestrial wild animals}} \approx \approx 30$$



The Barnyard Number focuses another lens onto this massive transformation of the planet by comparing the total biomass of terrestrial livestock (e.g. cows, chickens, and pigs) to that of wild terrestrial wild animals (e.g. elephants, foxes, and pelicans)[2]. As a result of agricultural intensification throughout the 20th century, livestock now outweigh 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 the total livestock biomass. This biomass is dominated by cattle which collectively weigh in at ≈ 1.5×10^{12} kg, despite having a population of only ≈ 1.5 billion (HuID: 92006). Read more about this number.

THE DEFORESTATION NUMBER

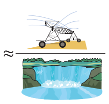
$$Df = \frac{\text{annual forest loss from human action}}{\text{annual forest loss from wildfire}} \approx \approx 3$$



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

THE NIAGARA NUMBER

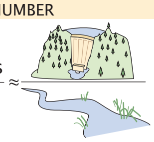
$$Ni = \frac{\text{daily water volume used by humans}}{\text{Niagara Falls daily discharge volume}} \approx \approx 30$$



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 (volumetric flow rate). Agriculture once again defines this aspect of the human interaction with the Earth system as it uses ≈ 4×10^9 m^3 (HuID: 43593) of water per day, accounting for the majority of human water usage. Combining agricultural use with the water volume used for hydroelectric power generation (≈ 7×10^8 m^3/day, HuID: 77411), domestic/municipal use (≈ 10^8 m^3/day, HuID: 69424), and all other uses yields a total daily volume of water ≈ 30 times that which flows over Niagara Falls daily. This is a volume comparable to ⅓ the daily discharge of the Amazon river.

THE RIVER NUMBER

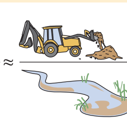
$$Rv = \frac{\text{river volume controlled by humans}}{\text{free-flowing river volume}} \approx \approx 1$$



Hydroelectric power generation captures the potential energy stored in water found at elevation, for example snowmelt cascading from alpine glaciers towards the ocean. Capturing this energy, 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 an equal volume of river water is free flowing (≈ 6×10^{11} m^3, HuID: 55718) as is under direct human control, such as through dams and reservoirs or through man-made channels (≈ 6×10^{11} m^3, HuID: 61661). Of the global free-flowing river volume, approximately 50% of the volume is contained within the Amazon river alone.

THE EARTH MOVER NUMBER

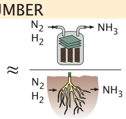
$$Em = \frac{\text{annual mass of earth moved by humans}}{\text{annual mass of earth moved by rivers}} \approx > 15$$



Humans are becoming formidable rivals to the natural processes by which sediment is generated and moved. 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 250 billion tonnes of sediment a year (HuID: XXXXX). Rivers, by comparison, transport ≈ 12 billion tonnes a year when corrected for the increased river sediment load via human action[3]. This remarkable anthropogenic action rapidly increases erosion rates, leading to increased topsoil loss and turnover, ultimately perturbing natural biogeochemical cycles.

THE NITROGEN NUMBER

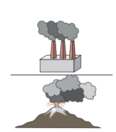
$$N_2 = \frac{\text{mass of } N_2 \text{ fixed via the Haber-Bosch Process}}{\text{mass of } N_2 \text{ fixed biologically}} \approx \approx 1$$



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) in order for most plants to synthesize biomass. Deemed the "detonator of the population explosion," the development of the Haber-Bosch process for industrial synthesis of ammonia from molecular nitrogen was critical for supporting a global population above ≈ 3 billion[4]. The Nitrogen Number reveals that humans synthesize as much reactive nitrogen industrially (≈ 1.5×10^{11} kg per year, HuID: 91803) as is synthesized by nitrogen-fixing microbes in terrestrial ecosystems (≈ 1×10^{11} kg per year, HuID: 15205). Beyond influencing the balance of reactive nitrogen in the environment, the Haber-Bosch process uses a sizable amount of energy and significantly contributes to global CO2 emissions.

THE CO2 NUMBER

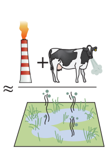
$$CO_2 = \frac{\text{annual mass of anthropogenic } CO_2}{\text{annual mass of volcanic } CO_2} \approx \approx 100$$



The CO_2 Number compares annual amount of human-caused CO_2 emissions to the dominant natural source of CO_2 emissions, volcanism. There are many climate-related consequences of increasing CO_2 emissions. Beyond accelerating climate change, ≈30% 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 into the atmosphere each year. Whether through seeps or eruptions, volcanism releases a total of ≈ 10^{11} kg of CO2 per year. Thus, the CO_2 number is ≈100, representing the magnitude by which humans outpace nature as a source of CO_2 emissions.

THE CH_4 NUMBER

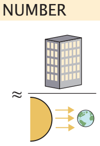
$$Me = \frac{\text{annual mass of anthropogenic } CH_4}{\text{annual mass of natural } CH_4} \approx \approx 1$$



While CO_2 is the most often discussed greenhouse gas, human activities also entail substantial emissions of methane (CH_4), which even more potent greenhouse gas than CO_2. The CH_4 Number compares humanity's methane emissions to all natural sources of methane. Anthropogenic emissions from factories and ruminant livestock (mostly cows) total ≈ 4 billion kg per year, comparable to natural emissions of CH_4 from wetlands, though there is substantial uncertainty regarding the magnitude of natural methane emissions. Thus, human methane emissions roughly equal emissions from all natural sources, indicating that we are approaching nature in our impact on atmospheric methane chemistry.

THE SOLAR NUMBER

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



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 20 terawatts (20×10^{12} W), a number which has been increasing steadily over the last 200 years. The Solar Number puts the 20 TW power consumption of human activities (HuID: 94934) 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.Barnosky et al. (2011). DOI:10.1038/nature09678 2. Bar-On, Y.M. et al. (2018). DOI:10.1073/pnas.1711842115 3. Syvitski & Kettner (2011). DOI: 10.1098/rsta.2010.0329 4.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 https://human-impacts.herokuapp.com. When possible, primary data sources have been collated and stored as files in comma-separated-value (csv) format on the GitHub repository associated with this snapshot, accessible via DOI: XXXXXXX and https://github.com/rpgroup-pboc/human_impacts

A ANNUAL ICE MELT

glaciers = $(2.8 \pm 1.1) \times 10^{11}$ m^3 / yr — HuID: 32459

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

ice sheets = $(4.3 \pm 0.4) \times 10^{11}$ m^3 / yr — HuID: 95798; 93137

Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMSC-3MJ62 Notes: Value corresponds to the trends of combined annual mass loss from the Greenland and Antarctic Ice Sheets (2002-2020). Volume loss was calculated from mass loss.

arctic sea ice $\approx (3 \pm 1) \times 10^{11}$ m^3 / yr — HuID: 89520

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

total $\approx (10.0 \pm 1.5) \times 10^{12}$ m^3 / yr — HuID: 89075

Data Source(s): Sum of glacial, ice sheet, and sea ice melt rate. Notes: Uncertainty is propagated assuming uncorrelated, normally-distributed errors of individual measurements and is calculated as $\pm 10^{11}\,\mathrm{m^3 \cdot yr^{-1}} \times (1^2 + 0.4^2 + 1.1^2)^{1/2}$.

B ANNUAL SEA ICE EXTENT LOSS

arctic sea ice extent loss $\approx 5\times10^{10}$ m^2 / yr — HuID: 66277

Data Source(s): Fetterer, F., K. Knowles, W. N. Meier, M. Savoie, and A. K. Windnagel. 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: https://doi.org/10.7265/N5K072F8. [Accessed 2020-Oct-19]. Notes: Value corresponds to the average annual loss of Arctic sea ice extent from 1979-2019. Sea ice extent refers to the area of the sea with > 15% ice coverage. 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.

C ANNUAL MATERIAL PRODUCTION

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

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

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

plastic production $\approx 4\times10^{11}$ kg / yr — HuID: 97241

Data Source(s): Table S1 of Geyer et al. 2017. DOI:10.1126/sciadv.1700782. Notes: Value represents the sum total global production of plastic fibers and plastic resin during calendar year 2015.

D LIVESTOCK POPULATION

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

cattle $\approx 2\times10^{9}$ — HuID: 92006

swine $\approx 1\times10^{9}$ — HuID: 21368

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

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

E ANNUAL NITROGEN FIXATION

fixed mass of nitrogen = 1.4×10^{11} kg / yr — HuID: 60580; 78152

Data Source(s): USGS Mineral Commodity Summaries 2020, DOI:10.3133/mcs2020. International Fertilizer Association 2020. Notes: The approximate mass of nitrogen in salient ammonia (NH3) produced globally in 2018 is reported by the USGS as $\approx$ 144 Mt and by the International Fertilizer association as $\approx$ 146 Mt. Approximately 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).

F OCEAN pH

change in [H$^+$] $\approx$ 0.2% / yr — HuID: 19394

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

G LAND USE

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

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

urban $\approx$ [7×10^{11} m^2 / yr — HuID: 41339; 39341

Data Source(s): Florczyk et al. 2019 (http://data.europa.eu/89h/53473144-b88c-44bc-b4a3-4583ed1f547e) and 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. Reported value is average of recent measurements of $\approx 6.5\times10^{11}$ m^2 and $\approx 7.5\times10^{11}$ m^2 from Florczyk et al. 2019 and Liu et al. 2018, respectively.

H RIVER FRAGMENTATION

fragmented river volume $\approx 6\times10^{11}$ m^3 — HuID: 61661, 15550

Data Source(s):Grill et al. 2019 DOI: 10.1038/s41586-019-1111-9. Notes: Values correspond to the sum of river volume contained in rivers that fall below the connectivity threshold required to classify them as free-flowing. Disruption factors include fragmentation, flow regulation, sediment trapping, water consumption, ...

... and infrastructure development. 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 / free-flowing rivers $\approx$ 0.9. The ratio of global ocean-connected river volume in disrupted rivers / free-flowing rivers $\approx$ 1.2.

I HUMAN POPULATION

fraction of population that is urban $\approx$ 55% — HuID: 93995

total population $\approx 7.6\times10^{9}$ people — HuID: 85255

Data Source(s): Food and Agricultural Organization (FAO) of the United Nations Report on Annual Population, 2019. Notes: Value for total population comes from a combination of direct population reports from country governments as well as inferred measurements from underreporting or missing data. Fraction of urban population is determined from what each country reports as "urban" which does not follow a singluar definition. 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 hman population, implying that the totoal population is composed only of "urban" and "rural" communities.

J GREENHOUSE GAS EMISSIONS

anthropogenic $CO_2 = (42.5 \pm 3.3) \times 10^{12}$ kg / yr — HuID: 47200; 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:) Dlugokencky and Tans, NOAA/GML https://www.esrl.noaa.gov/gmd/ccgg/trends/. Notes: Value corresponds to CO_2 emissions from fossil fuel combustion, industrial emissions (predominantly cement production), and land-use change during calendar year 2018. CO_2 was added to the atmosphere at a rate of $\approx$ 18.8 Gt / yr in 2018 (HuID: 98043); most of the remainder is taken up by the land sink and ocean sink. Uncertainty corresponds to one standard deviation.

anthropogenic $CH_4 \approx (3.4 - 4.1) \times 10^{11}$ kg / yr — HuID: 96837; 56405; 30725

Data Source(s): Table 3 of Saunois, et al. 2020. DOI: 10.5194/essd-12-1561-2020. Notes: Value corresponds to CH_4 emissions from anthropogenic sources in the calendar year 2017. Represents emissions from agriculture and waste, fossil fuels, and biomass and biofuel burning. Value is not simply the sum of these sources but is based on a full anthropogenic inventory of emissions. Reported range represents the minimum and maximum estimated emissions from a combination of "bottom-up" and "top-down" models.

anthropogenic $N_2O = 1.1\ (+0.6, -0.5) \times 10^{10}$ kg / yr — HuID: 44575; 68619

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. Reported value is mean with the uncertainty bounds (+,-) representing the maximum and minimum values observed in the 2007-2016 time period.

K WATER WITHDRAWAL & CONSUMPTION (DESCRIPTION TO BE UPDATED)

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

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

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

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

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

L TOTAL POWER CONSUMPTION

global power consumption $\approx$ 17 - 18 TW — HuID: 31373; XXXXX

Data Source(s): bp Statistical Review of World Energy, 2020; U.S. Energy Information Administration, 2020. Notes: Value represents the sum total energy consumed from oil, natural gas, coal, and nuclear energy and electricity generated by hydroelectric and renewables. Value from bp Statistical Review of World Energy (17 TW) is used on pg. 1.

M FOREST LOSS

commodity-driven = $(5.7 \pm 1.1) \times 10^{10}$ m^2 / yr — HuID: 96098

forestry = $(5.4 \pm 0.8) \times 10^{10}$ m^2 / yr — HuID: 38352

urbanization = $(2 \pm 1) \times 10^{9}$ m^2 / yr — HuID: 19429

total = 2.1×10^{11} m^2/ yr — HuID: 78576

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 presented here represent the yearly average over this 15 year window. Notes: Commodity-driven deforestation is defined as "long-term, permanent, conversion of forest and shrubland to a nonforest land use such as agriculture, mining, or energy infrastructure." Forest area disruption due to forestry is defined as large-scale forestry operations occurring within managed forests and tree plantations with evidence of forest regrowth in subsequent years." Forest land disruption due to urbanization is defined as "forest and shrubland conversion for the expansion and intensification of existing urban centers." Value for total forest area loss includes wildfire and shifting agriculture in addition to those presented here. Uncertainty corresponds to the 95% confidence interval.

N 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 annual sea-level rise = 3.35 (+0.47, -0.44) mm / yr — HuID: 81373

Data Source(s): Table 1 of Frederikse et al. 2020. DOI:10/d689. Notes: Values corresponds 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, and changes in the amount of terrestrial water storage. Thermal expansion accounts for the volume change of water with increasing temperature. Values or "added water" and "thermal expansion" come from modeling. Total sea level rise is the observed value using a combination of measurement methods. "Other sources" repoted on page 1 accounts for residual sea level rise not accounted for in the model. Values in brackets correspond to the upper and lower bounds of the 90% confidence interval.

O POWER FROM FOSSIL FUELS

natural gas = 4.3 - 4.5 TW — HuID: 49947; XXXXX

oil = 6 - 6.5 TW — HuID: 42121; XXXXX

coal = 5 TW — HuID: 10400; XXXXX

total = 15.3 - 16 TW — HuID: XXXXX; XXXXX

Data Source(s): bp Statistical Review of World Energy, 2020. U.S. Energy Information Administration, 2020. Notes: Values are self-reported by countries. Value from bp Statistical Review of World Energy is used on pg. 1. All values from bp Statistical Review correspond to 2019 where as values from the EIA correspond to 2018 estimate. Oil volume includes crude oil, shale oil, oil sands, condensates, and natural gas liquids separate from specific natural gas mining. Natural gas value excludes gas flared or recycled and includes natural gas produced for gas-to-liquids transformation. Coal value includes 2019 value exclusively for solid commercial fuels such as bituminous coal and anthracite, lignite and sub-bituminous coal, and other solid fuels. This includes coal used directly in power production as well as coal used in coal-to-liquids and coal-to-gas transformations.

P POWER FROM RENEWABLES

wind $\approx$ 0.2 TW — HuID: 30581

solar $\approx$ 0.1 TW — HuID: 99885

hydroelectric $\approx$ 0.5 TW — HuID: 99885

total $\approx$ 0.8 TW — HuID: XXXXX

Data Source(s): bp Statistical Review of World Energy, 2020. Notes: Reported values correspond to estimates for the 2019 calendar year. Renewable resources are defined as wind, geothermal, solar, biomass and waste. Hydroelectric, while presented here, is not defined as a renewable in the source material.

Q FOSSIL FUEL EXTRACTION

natural gas volume = $(3.9 - 4.0) \times 10^{12}$ m^3 / yr — HuID: 11468, XXXXX

oil volume = 5.5×10^{9} m^3 / yr — HuID: 66789; XXXXX

coal mass = $(7.8 - 8.1) \times 10^{12}$ kg / yr — HuID: 78435; XXXXX

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 value exclusively for solid commercial fuels such as bituminous coal and anthracite, lignite and sub-bituminous coal, and other solid fuels. All values from bp Statistical Review correspond to 2019 where as values from the EIA correspond to 2018 estimates.

R OCEAN WARMING

average heat uptake = 295 ± 34 TW — HuID: 59201

average surface (0 - 100 m) warming = 0.065 ± 0.007 °C — HuID: 87228

Data Source(s): Intergovernmental Panel on Climate Change (IPCC) 2019 Special Report "The Ocean and Cryosphere in a Changing Climate." Table 5.1 on pp. 458 and footnote 4 on pp. 457. Notes: Value is calculated from the reported annual heat uptake of $\approx 9.33 \pm 1.08$ ZJ/yr over the time period of 2005 - 2017 and was converted to TW assuming uniform energy deposition over the entire year. This assumes a constant value for deposition into the ocean surface (5.31 ± 0.48 ZJ, 0 - 700 m depth) and deep ocean (4.02 ± 0.97 ZJ, 700 - 2000 m depth) where heat deposition is lower. Ocean surface temperature change is calculated from 9.33 ± 1.08 ZJ/yr heat uptake by noting that deposition of $\approx$ 144 ZJ/yr raises the temperature of the top 100 m of ocean by $\approx$ 1° C. Uncertanties correspond to one standard deviation.

S POWER FROM NUCLEAR FISSION

nuclear power $\approx$ 0.80 - 0.83 TW — HuID: XXXX; XXXXX

Data Source(s): bp Statistical Review of World Energy, 2020. U.S. Energy Information Administration, 2020Notes: Values are self-reported by countries. All values from bp Statistical Review correspond to 2019 whereas values from the EIA correspond to 2017 estimates. Value from bp Statistical Review of World Energy is used on pg. 1.

T NUCLEAR FALLOUT

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

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

U CONTEMPORARY EXTINCTION

animal species > 750 — HuID: 44641

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

V EARTH MOVING

coal mining waste/overburden $\approx 6.5\times10^{13}$ kg/ yr — HuID: 72899

urbanization > 1.4×10^{14} kg / yr — HuID: 59640

Data Source(s): 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.

agriculture $\approx (1.2 - 2.3) \times 10^{13}$ kg / yr — HuID: XXXXX; XXXXX

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 $\approx$30,000 Gt. Recent years have an estimated erosion rate ranging from 12 Pg / yr (Wang & Van Oost) to $\approx$ 24 Pg / yr (Borrelli et al.). Values come from a computational models conditioned on time-resolved measurements sediment deposition in catchment basins.