

HUMAN IMPACTS

by the numbers

Griffin Chure¹, Avi Flamholz², Nicholas S. Sarai³, Tine Valencic¹,
Mason Kamb, Yinon Bar-On⁴, Ron Milo⁴, Rob Phillips^{2,5,*}

California Institute of Technology, Pasadena, CA, USA, 91125

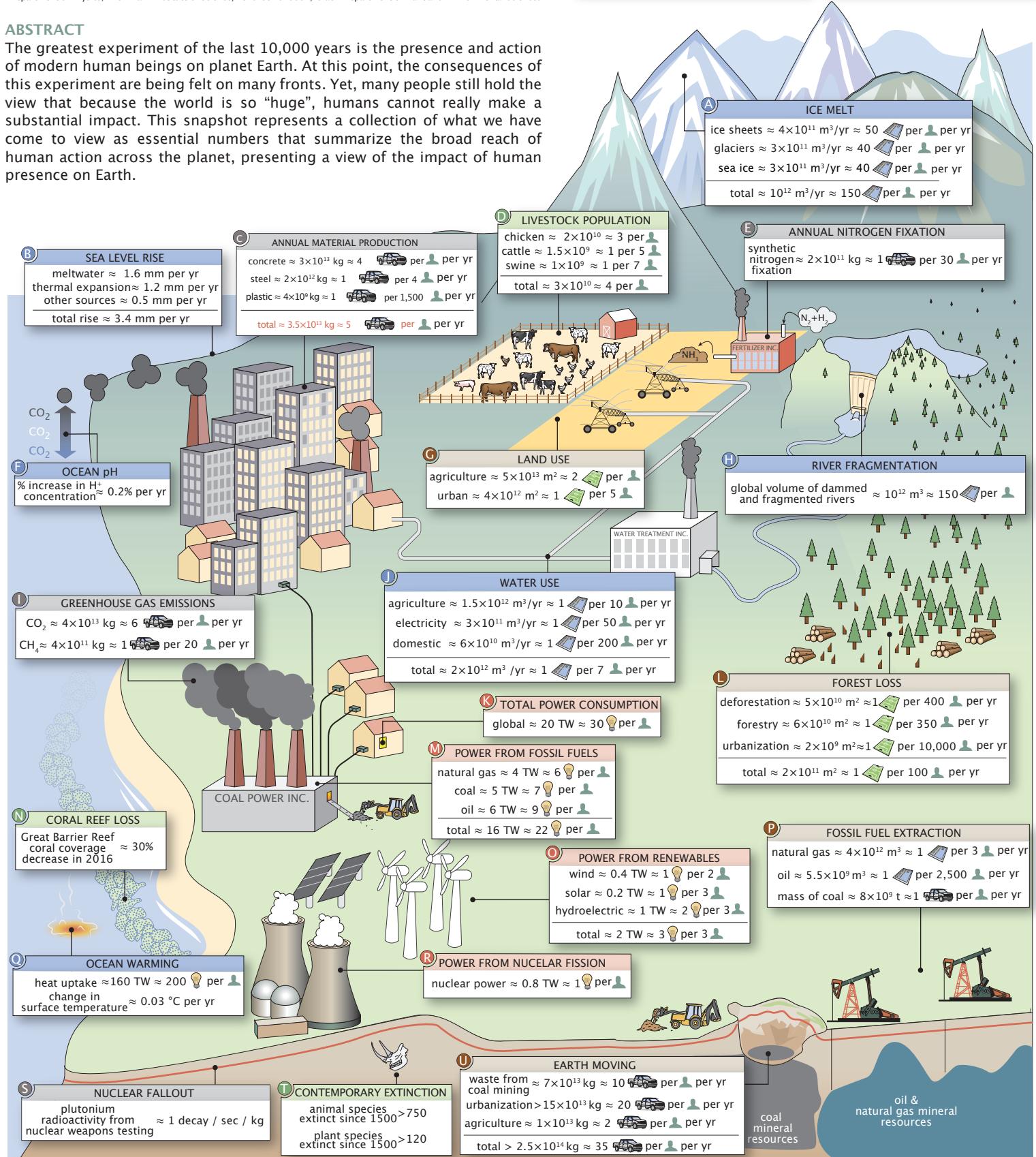
¹Department of Applied Physics; ²Division of Biology and Biological Engineering; ³Division of Chemistry and Chemical Engineering;

⁴ Department of Physics; ⁵Weizmann Institute of Science, Rehovot 7610001, Israel; Department of Plant and Environmental Sciences

REFERENCE UNITS	HUMAN IMPACT CATEGORIES
per capita (global) = 1 person	LAND
human population = ≈ 7 × 10 ⁹	ENERGY
area of soccer pitch = ≈ 3000 m ²	FLORA & FAUNA
volume of olympic pool = ≈ 2000 m ³	WATER
power of an incandescent light bulb = ≈ 100 W	ATMOSPHERIC & BIOGEOCHEMICAL CYCLES
mass of a pick-up truck = ≈ 1000 kg	

ABSTRACT

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



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

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

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 humanity, urban centers occupy between 750 thousand and a few million km² (Huld: 39341, 87575). In contrast, approximately 50 million km² (Huld: 29582) of land on Earth is used either to grow crops or rear livestock. Together, urban and agricultural lands make up $\approx 30\%$ of Earth's terrestrial surface. [Read more about this number.](#)

THE ANTHROPOMASS NUMBER

$$An = \frac{\text{total anthropomass}}{\text{total biomass}} = \frac{\text{humans + concrete + asphalt + plastic}}{\text{trees + animals + plants}} \approx 1$$

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 (Huld: XXXXX). 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 10⁵ 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

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

The Extinction Number reflects the fact that over the past 500 years, far more animal species have gone extinct than would be expected due to natural processes. Since 1500, at least 762 species of animals have been determined to be extinct (Huld: 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 interference in the environment¹. 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

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

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, Huld: 94934), they represent a small proportion of the total livestock biomass. This biomass is dominated by cattle which collectively weigh in at $\approx 1.5 \times 10^{12}$ kg, despite having a population of only ≈ 1.5 billion (Huld: 92006). [Read more about this number.](#)

THE DEFORESTATION NUMBER

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

TO BE WRITTEN

THE NIAGARA NUMBER

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

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 (volumetric flow rate). Agriculture once again defines this aspect of the human interaction with the Earth system as it uses $\approx 4 \times 10^9$ m³ (Huld: 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 ($\approx 7 \times 10^8$ m³/day, Huld: 77411), domestic/municipal use ($\approx 10^8$ m³/day, Huld: 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 $\frac{1}{3}$ the daily discharge of the Amazon river.

THE RIVER NUMBER

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

Hydroelectric power generation captures the potential energy stored in water found at elevation, for example snowmelt cascading down from mountains towards the ocean. Capturing this energy, however, requires damming the river and interrupting its flow. **The River Number** quantifies the scale of human interference in river flow by relating the volume of fragmented river systems (such as dammed rivers) to that of free-flowing rivers. Globally, approximately an equal volume of water is free flowing ($\approx 6 \times 10^{11}$ m³, Huld: 61661) as is under direct human control, such as through dams and reservoirs or through man-made channels (\approx XXXXX, Huld: XXXXX). Of the global free-flowing river volume, approximately 50% of the volume is contained within the Amazon river system alone, illustrating the ecological significance of the world's largest river (by volumetric flow).

THE EROSION NUMBER

$$Em = \frac{\text{annual mass of earth moved by humans}}{\text{annual mass of earth moved by rivers}} = \frac{\text{excavator digging}}{\text{rivers}} \approx 8$$

TO BE WRITTEN

THE NITROGEN NUMBER

$$N_2 = \frac{\text{mass of N}_2 \text{ fixed synthetically}}{\text{mass of N}_2 \text{ fixed biologically}} = \frac{\text{NH}_3 \text{ from industry}}{\text{NH}_3 \text{ from plants}} \approx 1$$

TO BE WRITTEN

THE CO₂ NUMBER

$$CO_2 = \frac{\text{annual mass of anthropogenic CO}_2}{\text{annual mass of volcanic CO}_2} = \frac{\text{factories + cars}}{\text{volcanoes}} \approx 1.5$$

TO BE WRITTEN

THE CH₄ NUMBER

$$Me = \frac{\text{annual mass of anthropogenic CH}_4}{\text{annual mass of natural CH}_4} = \frac{\text{cow + factory}}{\text{wetland}} \approx 1$$

While CO₂ receives the most attention in discussions around human emissions of greenhouse gas, humans have also begun emitting large amounts of CH₄ (methane), a highly potent greenhouse gas. **The CH₄ Number** sizes up the scale of humanity's methane emissions compared to the scale of all natural sources of methane. Anthropogenic emissions, such as emissions from fossil fuel mining and from ruminant livestock, comes in around ≈ 4 billion kg a year. This is comparable to the mass of methane released from natural sources, such as wetlands, although there remains much uncertainty in the precise value. Thus, methane emissions of human origin roughly match the natural emissions of the entire biosphere, further indicating that humans have become a dominant factor in sculpting the chemistry of the atmosphere.

THE SOLAR NUMBER

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

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 (Huld: 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.

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 <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: XXXXXX and https://github.com/rpgroup-pboc/human_impacts. A subset of the numbers presented here are investigated in more depth and presented as a collection of vignettes accessible via https://rpgroup.caltech.edu/hv_vignettes (URL subject to change).

A ICE MELT

glaciers $\approx 3 \times 10^{11} \text{ m}^3$ [HuID: 32459](#)
Data Source(s): Intergovernmental Panel on Climate Change (IPCC) 2019 Special Report "The Ocean and Cryosphere in a Changing Climate." Table 2.A.1 on pp. 199–202. **Notes:** Value corresponds to the trend of annual mass loss from major glaciated regions (2006–2015). Volume loss was calculated from mass loss.

ice sheets $\approx 4 \times 10^{11} \text{ m}^3$ [HuID: 44746; 88530](#)

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

arctic sea ice $\approx 3 \times 10^{11} \text{ m}^3$ [HuID: 89520](#)

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

total $\approx 1 \times 10^{12} \text{ m}^3$ [HuID: 89075](#)

Data Source(s): Sum of glacial, ice sheet, and sea ice melt rate.

Notes: Antarctic sea ice loss is not included due to data sparsity. The periods of analysis are not the same, therefore this rate represents an approximation rather than an exact calculation.

B ANNUAL SEA LEVEL RISE

meltwater rise $\approx 1.6 \text{ mm}$ [HuID: 97108](#)

thermal expansion $\approx 1.2 \text{ mm}$ [HuID: 97688](#)

total annual sea-level rise $\approx 3 \text{ mm}$ [HuID: 81373](#)

Data Source(s): Table 1 of Frederikse et al. 2020. DOI: 10.1063/5.00689. **Notes:** Values correspond to the average global sea level rise of the years 1993 – 2018. Meltwater is defined as the global annual sea level rise due to melt of glaciers, the Greenland ice sheet, and the Antarctic ice sheet.

C ANNUAL MATERIAL PRODUCTION

concrete production $\approx 3 \times 10^8 \text{ t}$ [HuID: 25488](#)

steel production $\approx 2 \times 10^8 \text{ t}$ [HuID: 51453](#)

Data Source(s): USGS 2020, Mineral commodities. DOI: 10.3133/mcs2020; Monteiro et al. 2017, DOI: 10.1318/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 corresponds to the USGS 2019 value.

plastic production $\approx 4 \times 10^8 \text{ t}$ [HuID: 97241](#)

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

total \approx [HuID: XXXX](#)

Data Source(s): Notes:

D LIVESTOCK POPULATION

chicken $\approx 2 \times 10^{10}$ [HuID: 94934](#)

cattle $\approx 2 \times 10^9$ [HuID: 92006](#)

swine $\approx 1 \times 10^9$ [HuID: 21368](#)

total $\approx 3 \times 10^{10}$ [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 $\approx 2 \times 10^8 \text{ t}$ [HuID: 60580; 30310; 78152](#)

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

F OCEAN pH

yearly change in $[\text{H}^+]$ $\approx 2\%$ [HuID: 19394](#)

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

G LAND USE

agriculture $\approx 5 \times 10^{13} \text{ m}^2$ [HuID: 29582](#)
Data Source(s): Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT). **Notes:** "Agriculture" land is defined as all land that is under agricultural management including pastures, meadows, permanent crops, temporary crops, land under fallow, and land under agricultural structures. Reported value corresponds to 2017 measurements by FAO.

C LAND USE (continued)

urban $\approx 4 \times 10^{12} \text{ m}^2$ [HuID: 87575](#)

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

R RIVER FRAGMENTATION

fragmented river volume $\approx 10^{12} \text{ m}^3$ [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 (or only rivers connected to the ocean) that fall below the connectivity threshold required to classify them as free-flowing. Disruption factors indexed in this dataset are fragmentation, flow regulation, sediment trapping, water consumption, and infrastructure development. This analysis is based on a dataset of global rivers whose upstream catchment areas are greater than 10 km^2 or whose discharge is greater than 0.1 m^3 per second. This dataset thus contains a global river network of 35.9 million kilometers. The ratio of global river volume in disrupted rivers / free-flowing rivers ≈ 0.9 . The ratio of global ocean-connected river volume in disrupted rivers / free-flowing rivers ≈ 1.2 .

I GREENHOUSE GAS EMISSIONS

anthropogenic CO₂ $\approx 42 \times 10^9 \text{ t}$ [HuID: 47200; 98043](#)

Data Source(s): Friedlingstein et al. 2019, DOI: 10.5194/esd-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 CO₂ emissions from fossil fuel combustion, industrial emissions (predominantly cement production), and land-use change during calendar year 2018. CO₂ was added to the atmosphere at a rate of $\approx 18 \text{ Gt} / \text{yr}$ in 2018 (HuID: 98043); most of the remainder is taken up by the land sink and ocean sink.

anthropogenic CH₄ $\approx 4 \times 10^9 \text{ t}$ [HuID: 96837; 56405; 30725](#)

Data Source(s): Table 2 of Saunois, et al. 2020. DOI: 10.5194/esd-12-1561-2020. **Notes:** Value corresponds to CH₄ emissions from anthropogenic sources in the calendar year 2017. Represents emissions from agriculture and waste, fossil fuels, and biomass and biofuel burning. Value is not simply the sum of these sources but is based on a full anthropogenic inventory of emissions. Natural emissions amount to $\approx 0.3 \text{ Gt} / \text{yr}$ in 2017. CH₄ was added to the atmosphere at a rate of $\approx 17 \text{ Mt/yr}$ in 2017; most of the remainder is taken up by chemical loss sink and soil sink.

J WATER USE

agriculture $\approx 1.5 \times 10^{12} \text{ m}^3$ [HuID: 43593](#)

power generation $\approx 3 \times 10^{11} \text{ m}^3$ [HuID: 78784](#)

domestic $\approx 6 \times 10^{10} \text{ m}^3$ [HuID: 69424](#)

total $\approx 2 \times 10^{12} \text{ m}^3$ [HuID: 27342](#)

Data Source(s): Figure 1 of Qin et al. 2019, DOI: 10.1038/s41993-019-0294-2. **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 maintenance of municipal water supply. "Total" water use includes the above categories as well as other uses of water in reservoir management including flood control and other unannotated uses. All values pertain to estimates for 2016.

K ANNUAL GLOBAL POWER CONSUMPTION

global power consumption $\approx 20 \text{ TW}$ [HuID: 31373](#)

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

L FOREST LOSS

commodity-driven $\approx 5 \times 10^{10} \text{ m}^3$ [HuID: 96098](#)

shifting agriculture $\approx 4 \times 10^{10} \text{ m}^3$ [HuID: 24388](#)

forestry $\approx 6 \times 10^9 \text{ m}^3$ [HuID: 38352](#)

urbanization $\approx 2 \times 10^9 \text{ m}^3$ [HuID: 19429](#)

total $\approx 2 \times 10^{11} \text{ m}^3$ [HuID: 78756](#)

Data Source(s): Table 1 and Figure 3 of Curtis et al. 2018 DOI: 10.1126/science.aaa3445. Hansen et al. 2013 DOI: 10.1126/science.1244693. Global Forest Watch, 2020. **Notes:** Commodity-driven deforestation is defined as long-term, permanent conversion of forest and shrubland to nonforest land use such as agriculture, mining, or energy infrastructure." Forest area loss due to shifting agriculture is defined as "smal-to-medium-scale forest and shrubland conversion for agriculture that is later abandoned and followed by subsequent forest regrowth." Forest area disruption due to forestry is defined as large-scale forestry operations occurring within managed forests and tree plantations with evidence of forest regrowth in subsequent years." Forest land disruption due to urbanization is defined as "forest and shrubland conversion for the expansion and intensification of existing urban centers."

M POWER FROM FOSSIL FUELS

natural gas $\approx 4 \text{ TW}$ [HuID: 49947](#)

oil $\approx 6 \text{ TW}$ [HuID: 42121](#)

coal $\approx 5 \text{ TW}$ [HuID: 10400](#)

total $\approx 16 \text{ TW}$ [HuID: XXXXX](#)

Data Source(s): bp Statistical Review of World Energy, 2020. **Notes:** Values pertain to 2019 estimates only. Oil volume includes crude oil, shale oil, oil sands, condensates, and natural gas liquids separate from specific natural gas mining. Natural gas value excludes gas flared or recycled and includes natural gas produced for gas-to-liquids transformation. Coal value includes 2019 value exclusively for solid commercial...

M POWER FROM FOSSIL FUELS (continued)

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.

N CORAL REEF LOSS

2016 GBR cover loss $\approx 30\%$ [HuID: 90720](#)

Data Source(s): Figures 1A, S1, and S2 of Hughes et al. 2018, DOI: 10.1038/s41586-018-0041-2.

Notes: Value corresponds to measured loss in coral coverage on members of the Great Barrier Reef using field measurements and satellite imaging. Time period considers the total area loss of coral between March and November of 2016. See methods section "Longer Term Mortality" of source publication.

O POWER FROM RENEWABLES

wind $\approx 0.4 \text{ TW}$ [HuID: 30581](#)

solar $\approx 0.2 \text{ TW}$ [HuID: 99885](#)

hydroelectric $\approx 1 \text{ TW}$ [HuID: 99885](#)

total $\approx 2 \text{ TW}$ [HuID: 20246](#)

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

P EARTH MOVING

natural gas volume $\approx 4 \times 10^{12} \text{ m}^3$ [HuID: 11468](#)

oil volume $\approx 5 \times 10^9 \text{ m}^3$ [HuID: 66789](#)

coal mass $\approx 8 \times 10^9 \text{ t}$ [HuID: 78435](#)

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

P OCEAN WARMING

power deposition $\approx 160 \text{ TW}$ [HuID: 59201](#)

ocean surface warming $\approx 0.03^\circ \text{C}$ [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 $\approx 5 \text{ ZJ/yr}$ over the time period of 2005 – 2017. This assumes a constant value for deposition into the ocean surface (0 – 700 m depth) and deep ocean (700 – 2000 m depth) where heat deposition is lower. Ocean surface temperature change is calculated from $\approx 5 \text{ ZJ/yr}$ heat uptake by noting that deposition of $\approx 144 \text{ ZJ/yr}$ raises the temperature of the top 100 m of ocean by $\approx 1^\circ \text{C}$. See the complete report or section 5.2.2.2 of the source material for more information.

R POWER FROM NUCLEAR FISSION

nuclear power $\approx 0.8 \text{ TW}$ [HuID: XXXXX](#)

Data Source(s): bp Statistical Review of World Energy, 2020. **Notes:** Reported values correspond to estimates for the 2019 calendar year.

S NUCLEAR FALLOUT

$^{239+240}\text{Pu}$ activity in soil $\approx 1 \text{ Bq/kg}$ [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 Ciszekwski 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 $\approx 1963 \text{ CE}$ 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 (Ciszekwski and Łokas).

T 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 ≈ 520 years. Of the predicted ≈ 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 ≈ 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 ($>$).

U EARTH MOVING

coal mining waste/overburden $\approx 65 \text{ Gt} / \text{yr}$ [HuID: 72899](#)

urbanization $> 140 \text{ Gt} / \text{yr}$ [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.

U EARTH MOVING (continued)

agriculture $\approx 12 \text{ Gt} / \text{yr}$ [HuID: 59640](#)

Data Source(s): Table 2 Wang and Van Oost 2019. DOI: 10.1177/09596318164949.

Notes: Cumulative sediment mass loss due to accelerated erosion from agriculture is estimated to be $\approx 30,000 \text{ Gt}$. Recent years have an estimated erosion rate of $\approx 12 \text{ Gt} / \text{year}$. Values come from a computational model conditioned on time-resolved measurements sediment deposition in catchment basins. These values agree within a factor of a few of previous, less sophisticated measurements.

ACKNOWLEDGMENTS

This work was supported by the Resnick Institute for Sustainability at the California Institute of Technology. Additional financial support information. No specific order, thank the following: APH150c course, Watt Taylor, Dan Fisher, Gidon Eshel, Greg Huber, Michelle Dan, Brad Marston, Hamza Ranjwal, Yue Qin for providing data on water usage. Suzy Beeler, Soichi Hirokawa, Manuel Razo-Mejia and all members of the Phillips lab at Caltech.