

HUMAN IMPACTS

by the numbers

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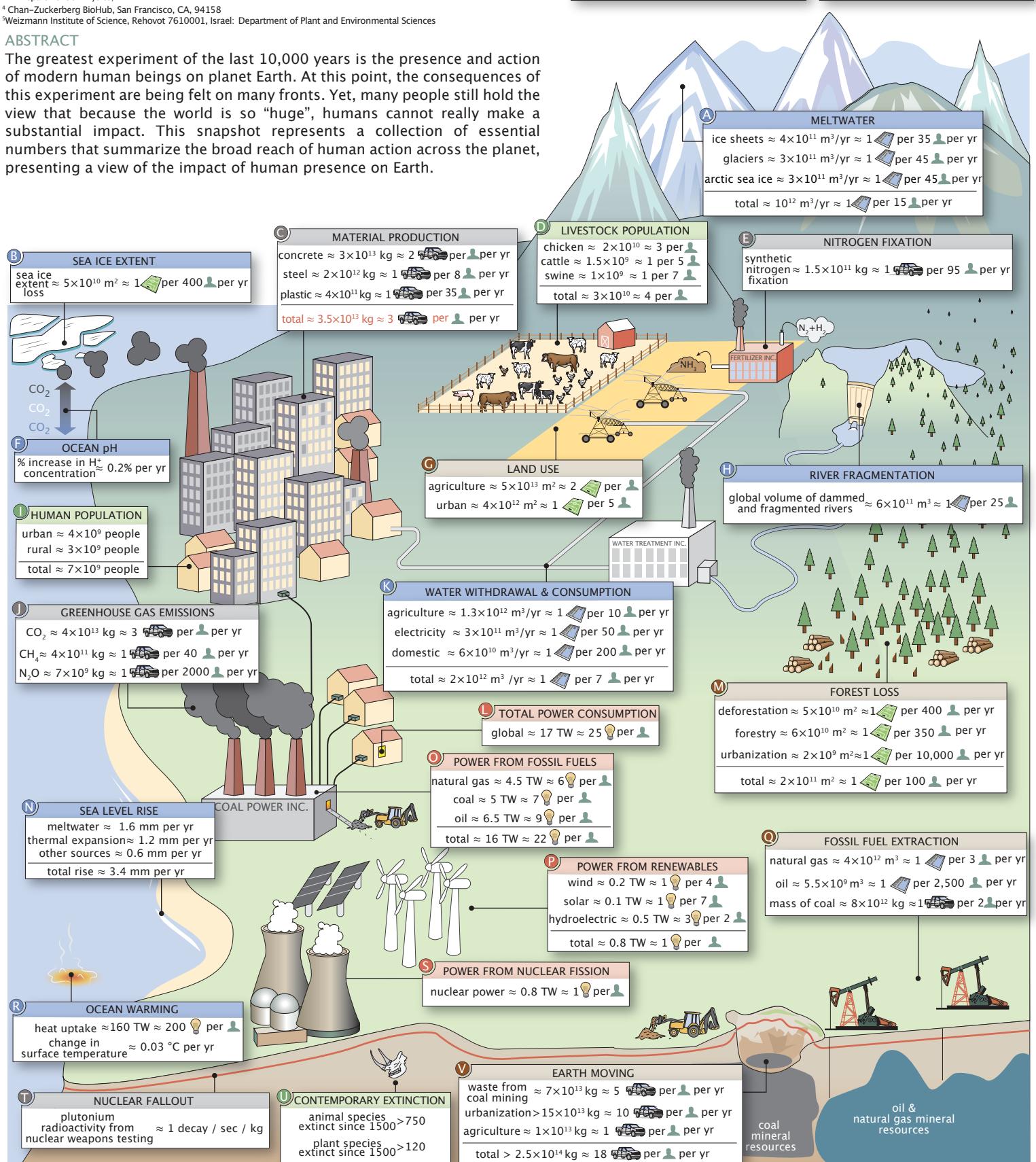
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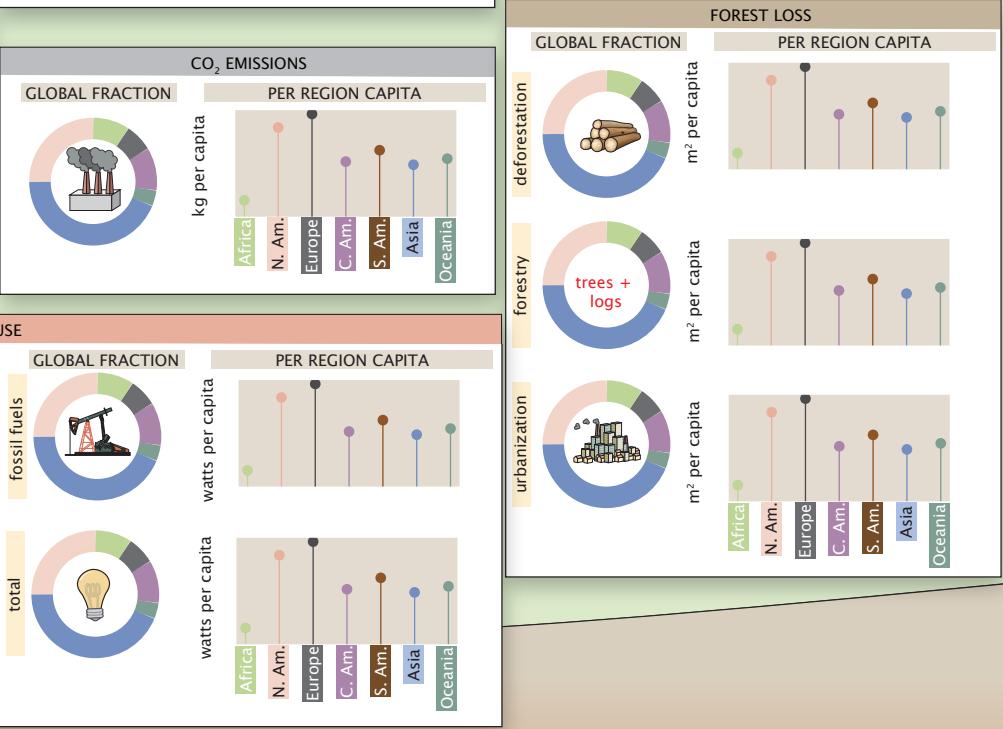
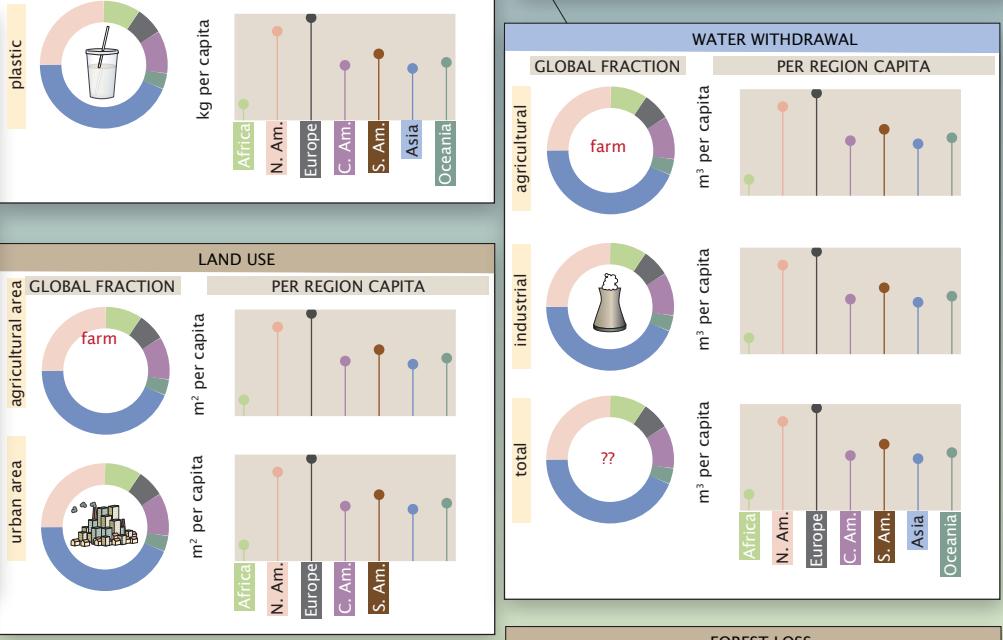
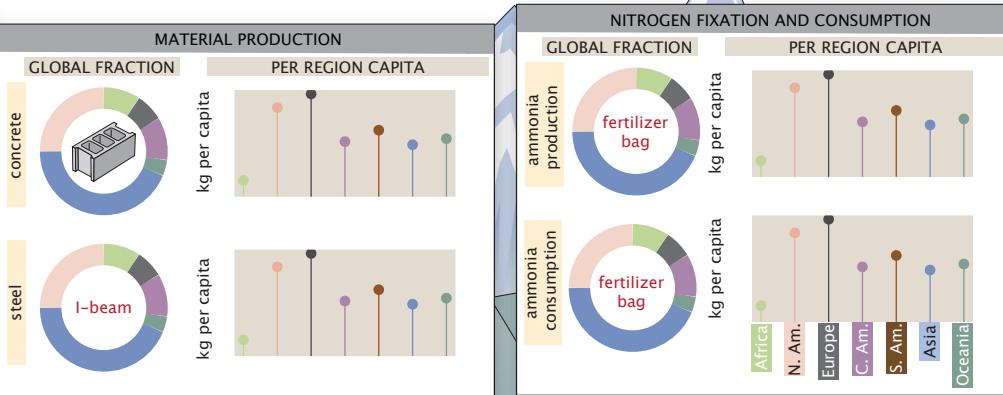
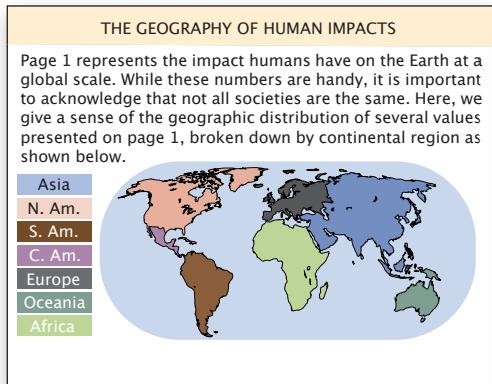
ABSTRACT

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 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 = ≈ 2000 kg	



Human Impacts by the Numbers — Impacts by Region



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

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

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 human action, 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 ≈ 30% of Earth's terrestrial surface. [Read more about this number.](#)

THE ANTHROPOMASS NUMBER

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

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 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 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

$$Ex = \frac{\text{number of known animal extinctions}}{\text{number of expected natural animal extinctions}} = \frac{\text{extinct bird}}{\text{extinct bird + still extant bird}} > 10$$

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, more than 760 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 alteration of the environment. 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 ≈ 1.5×10¹² kg, despite having a population of only ≈ 1.5 billion (Huld: 92006). [Read more about this number.](#)

THE DEFORESTATION NUMBER

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

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, Huld: 96098) and forestry (Huld: 38352), whereas expansion of urban areas accounts for < 1% of the total annual forest loss (Huld: 19429). Wildfires account for ≈ 20% or ≈ 5×10¹⁰ m² annually (Huld: XXXXX). [This paragraph will be rewritten after the vignette is finalized.](#)

THE NIAGARA NUMBER

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

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 ≈ 4×10⁹ 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 (≈ 7×10⁸ m³/day, Huld: 77411), domestic/municipal use (≈ 10⁹ 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 ½ the daily discharge of the Amazon river.

THE RIVER NUMBER

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

Hydroelectric power generation captures the potential energy stored in water found at elevation, for example snowmelt cascading 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 (≈ 6×10¹¹ m³, Huld: 55718) as is under direct human control, such as through dams and reservoirs or through man-made channels (≈ 6×10¹¹ m³, Huld: 61661). Of the global free-flowing river volume, approximately 50% of the volume is contained within the Amazon river alone.

THE EARTH MOVER NUMBER

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

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 (Huld: XXXXX). Rivers, by comparison, transport ≈ 12 billion tonnes a year when corrected for the increased river sediment load via human action³. This remarkable anthropogenic action rapidly increases erosion rates, leading to increased topsoil loss and turnover, ultimately perturbing natural biogeochemical cycles.

THE NITROGEN NUMBER

$$N_2 = \frac{\text{mass of } N_2 \text{ fixed via the Haber-Bosch Process}}{\text{mass of } N_2 \text{ fixed biologically}} \approx \frac{\text{NH}_3 \text{ tank}}{\text{NH}_3 \text{ plant}} \approx 1$$

Though molecular nitrogen (N₂) makes up nearly 80% of our atmosphere, it must be converted into a more reactive form like ammonia (NH₃) 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 billion⁴. The Nitrogen Number reveals that humans synthesize as much reactive nitrogen industrially (≈ 1.5×10¹¹ kg per year, Huld: 91803) as is synthesized by nitrogen-fixing microbes in terrestrial ecosystems (≈ 1×10¹¹ kg per year, Huld: 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

$$CO_2 = \frac{\text{annual mass of anthropogenic CO}_2}{\text{annual mass of volcanic CO}_2} \approx \frac{\text{factory smokestack}}{\text{volcanic eruption}} \approx 100$$

The CO₂ Number compares annual amount of human-caused CO₂ emissions to the dominant natural source of CO₂ emissions, volcanism. There are many climate-related consequences of increasing CO₂ emissions. Beyond accelerating climate change, ≈30% of CO₂ released into the atmosphere is absorbed by the oceans, making them appreciably more acidic over time. In recent years, human activities including burning fossil fuels and making concrete have led to the release of ≈ 4×10¹³ kg of CO₂ into the atmosphere each year. Whether through seeps or eruptions, volcanism releases a total of ≈ 10¹¹ kg of CO₂ per year. Thus, the CO₂ number is ≈100, representing the magnitude by which humans outpace nature as a source of CO₂ emissions.

THE CH₄ NUMBER

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

While CO₂ is the most often discussed greenhouse gas, human activities also entail substantial emissions of methane (CH₄), which even more potent greenhouse gas than CO₂. The CH₄ 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 CH₄ 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

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

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 (20×10¹² 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](https://github.com/rpgroup-pboc/human_impacts) and https://github.com/rpgroup-pboc/human_impacts. A subset of the numbers presented here are investigated in more depth and presented as a collection of vignettes accessible via https://rpgroup.caltech.edu/hi_vignettes (URL subject to change).

ANNUAL ICE MELT		HUMAN POPULATION		POWER FROM RENEWABLES	
glaciers $\approx 3 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 32459	fraction of population that is urban $\approx 55\%$	Huid: 93995	wind $\approx 0.2 \text{ TW}$	Huid: 30518
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 $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	total population $\approx 7.6 \times 10^9 \text{ people}$	Huid: 85255	solar $\approx 0.1 \text{ TW}$	Huid: 99885
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 . 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 $\approx 3 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 89520	hydroelectric $\approx 0.5 \text{ TW}$	Huid: 99885	total $\approx 0.8 \text{ TW}$	Huid: XXXXX
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 $\approx 1 \times 10^{12} \text{ m}^3 / \text{yr}$	Huid: 89075	GREENHOUSE GAS EMISSIONS		FOSSIL FUEL EXTRACTION	
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.		anthropogenic CO ₂ $\approx 4.2 \times 10^{13} \text{ kg / yr}$	Huid: 47200; 98043	natural gas volume $\approx 4 \times 10^{12} \text{ m}^3$	Huid: 11468
B ANNUAL SEA ICE EXTENT LOSS		Data Source(s): Friedlingstein et al. 2019, DOI: 10.5194/essd-11-1783-2019. Original data sources relevant to this study compiled in Friedlingstein et al.: 1) Gilfillan et al. https://energyapp.state.edu/CDIAC/2 Average of two bookkeeping models: Houghton and Nassikas 2017 DOI: 10.1002/2016GB005546; Hansis et al. 2015 DOI: 10.1029/2015GB005546; 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 $\approx 18.8 \text{ Gt / yr}$ in 2018 (Huid: 98043); most of the remainder is taken up by the land sink and ocean sink.	oil volume $\approx 5.5 \times 10^9 \text{ m}^3$	Huid: 66789	
arctic sea ice extent loss $\approx 5 \times 10^{10} \text{ m}^2 / \text{yr}$	Huid: 66277	anthropogenic CH ₄ $\approx 4 \times 10^{11} \text{ kg / yr}$	Huid: 96837; 56405; 30729	coal mass $\approx 8 \times 10^9 \text{ t}$	Huid: 78435
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/N5K02F82 . [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.		anthropogenic CH ₄ $\approx 4 \times 10^{11} \text{ kg / yr}$	Huid: 96837; 56405; 30729	OCEAN WARMING	
steel production $\approx 3 \times 10^{13} \text{ kg / yr}$	Huid: 25488	Data Source(s): Table 2 of Saunois, et al. 2020. DOI: 10.5194/essd-12-1561-2020. Notes: Value corresponds to CH ₄ emissions from anthropogenic sources in the calendar year 2017. Represents emissions from agriculture and waste, fossil fuels, and biomass and biofuel burning. Value is not simply the sum of these sources but is based on a full anthropogenic inventory of emissions. Natural emissions amount to $\approx 0.3 \text{ Gt / yr}$ in 2017. CH ₄ 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.	power deposition $\approx 160 \text{ TW}$	Huid: 59201	
steel production $\approx 2 \times 10^{12} \text{ kg / yr}$	Huid: 51453	anthropogenic N ₂ O $\approx 7 \times 10^{10} \text{ kg / yr}$	Huid: 44575; 68619	ocean surface warming $\approx 0.03^\circ \text{C}$	Huid: 87228
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 corresponds to the USGS 2019 value.		Data Source(s): Table 1 of Tian, H., et al. (2020). DOI: 10.1038/s41586-020-2780-0. Notes: Value corresponds to annualized N ₂ O emissions from anthropogenic sources in the years 2007–2016.	POWER FROM NUCLEAR FISSION		
concrete production $\approx 3 \times 10^{13} \text{ kg / yr}$	Huid: 25488	K WATER WITHDRAWAL & CONSUMPTION (DESCRIPTION TO BE UPDATED)		nuclear power $\approx 0.8 \text{ TW}$	Huid: XXXXX
steel production $\approx 2 \times 10^{12} \text{ kg / yr}$	Huid: 51453	agriculture $\approx 1.5 \times 10^{12} \text{ m}^3 / \text{yr}$	Huid: 43593	NUCLEAR FALLOUT	
Data Source(s): 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.		power generation $\approx 3 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 78784	²³⁹⁺²⁴⁰ Pu activity in soil $\approx 1 \text{ Bq/kg}$	Huid: 38748; 91171
plastic production $\approx 4 \times 10^{11} \text{ kg / yr}$	Huid: 97241	domestic $\approx 6 \times 10^{10} \text{ m}^3 / \text{yr}$	Huid: 69424	CONTemporary EXTINCTION	
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.		total $\approx 2 \times 10^{12} \text{ m}^3 / \text{yr}$	Huid: 27342	animal species > 750	Huid: 44641
LIVESTOCK POPULATION		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 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.	plant species > 120	Huid: 86866	
chicken $\approx 2 \times 10^{10}$	Huid: 94934	L TOTAL POWER CONSUMPTION		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 ($>$).	
cattle $\approx 2 \times 10^9$	Huid: 92006	global power consumption $\approx 17 \text{ TW}$	Huid: 31373	V EARTH MOVING	
swine $\approx 1 \times 10^9$	Huid: 21368	Data Source(s): bp Statistical Review of World Energy, 2020. Notes: represents the sum total energy consumed from oil, natural gas, coal, and nuclear energy and electricity generated from hydroelectric and renewables	coal mining waste/overburden $\approx 6.5 \times 10^{13} \text{ kg / yr}$	Huid: 72899	
total $\approx 3 \times 10^{10}$	Huid: 15765	M FOREST LOSS		urbanization $> 1.4 \times 10^{14} \text{ kg / yr}$	Huid: 59640
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.		commodity-driven $\approx 5 \times 10^{10} \text{ m}^2 / \text{yr}$	Huid: 96098	Data Source(s): Table 1 of Cooper et al. 2018. DOI: doi.org/gwfhd. 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.	
OCEAN pH		forestry $\approx 6 \times 10^{10} \text{ m}^2 / \text{yr}$	Huid: 38352	agriculture $\approx 1.2 \times 10^{13} \text{ kg / yr}$	Huid: XXXXX
change in [H ⁺] $\approx 0.2 \% / \text{yr}$	Huid: 19394	urbanization $\approx 2 \times 10^{10} \text{ m}^2 / \text{yr}$	Huid: 19429	Data Source(s): Table 1 and Figure 3 of Curtis et al. 2018 DOI:10.1126/science.aau3445. Hansen et al. 2013 DOI:10.1126/science.1244693. Global Forest Watch, 2020. Notes: Commodity-driven deforestation is defined as "long-term, permanent, conversion of forest and 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."	
LAND USE		total $\approx 2 \times 10^{11} \text{ m}^2 / \text{yr}$	Huid: 78576	Data Source(s): Table 2 of Wang and Van Oost 2019. DOI: 10.1177/0959683618816499. Notes: Cumulative sediment mass loss over history of human agriculture due to accelerated erosion is estimated to be $\approx 30,000 \text{ Gt}$. Recent years have an estimated erosion rate of $\approx 12 \text{ Gt / year}$. 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.	
agriculture $\approx 5 \times 10^{13} \text{ m}^2 / \text{yr}$	Huid: 29582	N SEA LEVEL RISE		ACKNOWLEDGMENTS	
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.		meltwater rise $\approx 1.6 \text{ mm / yr}$	Huid: 97108	This work was supported by the Resnick Institute for Sustainability at the California Institute of Technology. Add financial support information. No specific order, thank the following: Joel Cohen, Alon Shepon, Eric Galbraith, Sean Carroll, Justin Bois, Shyam Saladi, AP150c course, Wati Taylor, Dan Fisher, Gidon Eshel, Greg Huber, Michelle Dan, Brad Marston, Hamza Raniwala, Yue Qin for providing data on water consumption, Suzy Beeler, Soichi Hirokawa, Manuel Razo-Mejia and all members of the Phillips lab at Caltech.	
urban $\approx 7 \times 10^{11} \text{ m}^2 / \text{yr}$	Huid: 41339; 39341	thermal expansion $\approx 1.2 \text{ mm / yr}$	Huid: 97688		
Data Source(s): Florczyk et al. 2019 (http://data.europa.eu/89/3473144-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 $\approx 6.5 \times 10^{11} \text{ m}^2$ and $\approx 7.5 \times 10^{11} \text{ m}^2$ from Florczyk et al. 2019 and Liu et al. 2018, respectively.		total annual sea-level rise $\approx 3.4 \text{ mm / yr}$	Huid: 81373		
RIVER FRAGMENTATION		Data Source(s): Table 1 of Frederikse et al. 2020. DOI: 10.1088/1748-0221/ab5f47. 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. "Other sources" accounts for sea level change from changes in the terrestrial water shed as well as for other factors not explicitly specified. Total sea level rise of $\approx 3.4 \text{ mm / yr}$ comes directly from measurement while values for meltwater, thermal expansion, and terrestrial water shed storage come from modeling.	POWER FROM FOSSIL FUELS		
fragmented river volume $\approx 6 \times 10^{11} \text{ m}^3$	Huid: 61661, 15550	natural gas $\approx 4.5 \text{ TW}$	Huid: 49947		
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 $0.1 \text{ m}^3 / \text{sec}$. The ratio of global river volume in disrupted rivers / free-flowing rivers ≈ 0.9 .		oil $\approx 6.5 \text{ TW}$	Huid: 42121		
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	coal $\approx 5 \text{ TW}$	Huid: 10400		
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		total $\approx 16 \text{ TW}$	Huid: XXXXX		
arctic sea ice $\approx 3 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 89520	D HUMAN POPULATION			
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.		fraction of population that is urban $\approx 55\%$	Huid: 93995		
total $\approx 1 \times 10^{12} \text{ m}^3 / \text{yr}$	Huid: 89075	total population $\approx 7.6 \times 10^9 \text{ people}$	Huid: 85255		
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		hydroelectric $\approx 0.5 \text{ TW}$	Huid: 99885		
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	P POWER FROM RENEWABLES			
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		wind $\approx 0.2 \text{ TW}$	Huid: 30518		
arctic sea ice $\approx 3 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 89520	solar $\approx 0.1 \text{ TW}$	Huid: 99885		
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.		hydroelectric $\approx 0.5 \text{ TW}$	Huid: 99885		
total $\approx 1 \times 10^{12} \text{ m}^3 / \text{yr}$	Huid: 89075	Q FOSSIL FUEL EXTRACTION			
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		natural gas volume $\approx 4 \times 10^{12} \text{ m}^3$	Huid: 11468		
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	oil volume $\approx 5.5 \times 10^9 \text{ m}^3$	Huid: 66789		
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		coal mass $\approx 8 \times 10^9 \text{ t}$	Huid: 78435		
arctic sea ice $\approx 3 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 89520	R OCEAN WARMING			
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		power deposition $\approx 160 \text{ TW}$	Huid: 59201		
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	ocean surface warming $\approx 0.03^\circ \text{C}$	Huid: 87228		
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		S POWER FROM NUCLEAR FISSION			
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	natural gas $\approx 0.8 \text{ TW}$	Huid: XXXXX		
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		T NUCLEAR FALLOUT			
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	²³⁹⁺²⁴⁰ Pu activity in soil $\approx 1 \text{ Bq/kg}$	Huid: 38748; 91171		
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		U CONTEMPORARY EXTINCTION			
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	animal species > 750	Huid: 44641		
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		plant species > 120	Huid: 86866		
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	V EARTH MOVING			
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		coal mining waste/overburden $\approx 6.5 \times 10^{13} \text{ kg / yr}$	Huid: 72899		
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	urbanization $> 1.4 \times 10^{14} \text{ kg / yr}$	Huid: 59640		
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		>Data Source(s): Table 1 of Cooper et al. 2018. DOI: doi.org/gwfhd. 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.			
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	agriculture $\approx 1.2 \times 10^{13} \text{ kg / yr}$	Huid: XXXXX		
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		Data Source(s): Table 2 of Wang and Van Oost 2019. DOI: 10.1177/0959683618816499. Notes: Cumulative sediment mass loss over history of human agriculture due to accelerated erosion is estimated to be $\approx 30,000 \text{ Gt}$. Recent years have an estimated erosion rate of $\approx 12 \text{ Gt / year}$. 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.			
ice sheets $\approx 4 \times 10^{11} \text{ m}^3 / \text{yr}$	Huid: 95798; 93137	ACKNOWLEDGMENTS			
Data Source(s): D. N. Wiese et al. 2019 https://doi.org/10.5067/TEMS-3C3MJ62 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.		This work was supported by the Resnick Institute for Sustainability at the California Institute of Technology. Add financial support information. No specific order, thank the following: Joel Cohen, Alon Shepon, Eric Galbraith, Sean Carroll, Justin Bois, Shyam Saladi, AP150c course, Wati Taylor, Dan Fisher, Gidon Eshel, Greg Huber, Michelle Dan, Brad Marston, Hamza Raniwala, Yue Qin for providing data on water consumption, Suzy Beeler, Soichi Hirokawa, Manuel Razo-Mejia and all members of the Phillips lab at Caltech.			