

HUMAN IMPACTS by the numbers

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ABSTRACT

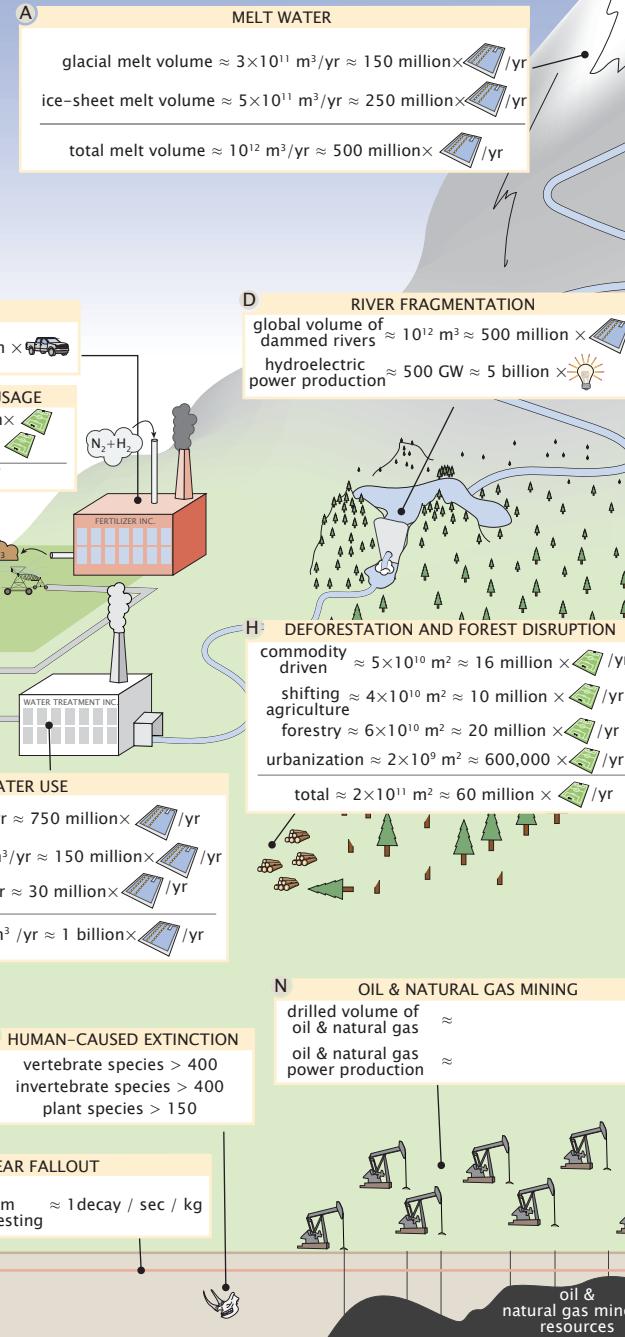
The greatest experiment of the last 10,000 years is the presence and action of modern human beings on planet Earth. At this point, the consequences of this experiment are being felt on many fronts. Yet, many people still hold the view that because the world is so "huge", humans cannot really make a substantial impact. One way to organize our thinking about what these impacts might be, with tongue in cheek, is to focus on Empedocles's classic elements, earth, air, water and fire, with the idea being to explore how humans have altered the land and its inhabitants, the atmosphere, the oceans and how our quest for cheaper and cheaper energy (fire) from the world around us has altered that world. This snapshot represents a small collection of numbers that summarize the broad reach of human action across the planet, presenting a view of the impact of human presence on Earth.

UNITS OF REFERENCE

human population	=	$\approx 7 \times 10^9$	mass of a pick-up truck	=	$\approx 1\text{ t}$
area of soccer pitch	=	$\approx 3000\text{ m}^2$	power of a lightbulb	=	$\approx 100\text{ W}$
volume of olympic pool	=	$\approx 2000\text{ m}^3$			

A MELT WATER

glacial melt volume	$\approx 3 \times 10^{11}\text{ m}^3/\text{yr}$	$\approx 150\text{ million} \times$		/yr
ice-sheet melt volume	$\approx 5 \times 10^{11}\text{ m}^3/\text{yr}$	$\approx 250\text{ million} \times$		/yr
total melt volume	$\approx 10^{12}\text{ m}^3/\text{yr}$	$\approx 500\text{ million} \times$		/yr



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THE ANTHROPOCENE

A visit to any natural history museum will reveal that much about Earth's history can be learned by examining the geological and fossil record. As humans have made extensive changes to the Earth's chemistry and biology, in addition to the physical changes to the Earth's crust, the record of our existence will similarly be preserved in the geological record. The **Anthropomass Number** reveals that, as of 2020, the total mass of human-derived material (concrete, plastic, steel, etc.) is now approximately equal to the mass of the entire biosphere. The **Terra Number** illustrates that humans occupy or directly control $\approx 30\%$ of the terrestrial surface area, meaning artifacts of human society is widespread across the planet. The **Radionuclide Number** describes a radioactive signature of nuclear weapons testing in a 20,000 fold enrichment in plutonium isotope radioactivity that will be detectable in stratified soil several hundred thousand years into the future. Finally, the **Extinction Number** shows that the current extinction rate is at least several hundred times above the background extinction rate for plant and animal species, dictating the future fossil record. While incomplete, these dimensionless numbers represent the magnitude to which human activity will be evident in Earth's geological record beyond the existence of our species as we currently know it.

THE MAGNITUDE OF HUMAN WATER USAGE

Humans use more water than any other substance on the planet. Our requirement for water, both for personal use and for industrial purposes, coupled with changes in our atmospheric chemistry have substantially altered the hydrosphere from many angles. The **Niagara Number** captures the magnitude of human water usage, revealing that on a daily basis, humans use approximately $\approx 10^9 \text{ m}^3$ of water, which is equivalent to the volume of Niagara Falls' drainage rate. This use is dominated by power-plant usage (for cooling) and agriculture. The flow of water from high to low elevations can be used to generate hydroelectricity via river damming. The **Hoover Number** reveals that there is an approximately equal volume global river water used by hydroelectric dams as there are free-flowing rivers on Earth, which has strong implications on stability of watersheds and river ecosystems. Anthropogenic emission of CO₂ has lead to widespread warming of the climate, resulting in melting of glaciers and ice-caps. The **Ice-Melt Number** summarizes the extent as this melting as releasing ≈ 1 Grand Canyon's worth of water into the hydrosphere per year. Approximately 40% of CO₂ emissions are absorbed by Earth's oceans and seas, ultimately shifting the equilibrium of carbonic acid. The **Acidic Ocean Number** captures the extent of this effect, revealing a $\approx 30\%$ increase in hydrogen ion concentration in the oceans over the 60 year period of 1960 – present.

HUMANS AS THE EARTH'S GREATEST EVOLUTIONARY FORCE

Biology's greatest idea is evolution, the fact that over time, the living world has always and will continue to always change. Species come and species go. Natural forces, such as the closing of the Isthmus of Panama, result in profound changes to the living world. As humans have increased in population and technological prowess, so too has their impact on the evolutionary process. The **Barnyard Number** captures the magnitude of animal husbandry by humans by measuring the relative population sizes of the entirety of our domesticated animals relative to the size of the human population itself. Natural habitats across the globe have been altered significantly by human action. The **Deforestation Number** compares the loss of forest resulting from human activity to that which occurs naturally.

ANTHROPOMASS NUMBER		TERRA NUMBER	
$\text{Am} = \frac{\text{total anthropomass}}{\text{total biomass}}$	$\approx \frac{\text{city}}{\text{tree}} \approx 550 \text{ Gt C}$	$\text{Te} = \frac{\text{land area used by humans}}{\text{land area of Earth}}$	$\approx \frac{5 \times 10^{13} \text{ m}^2}{1.5 \times 10^{14} \text{ m}^2} \approx 0.3$
RADIONUCLIDE NUMBER		EXTINCTION NUMBER	
$\text{Rn} = \frac{\text{anthropogenic } ^{239/40}\text{Pu in soil}}{\text{naturally occurring } ^{239/40}\text{Pu in soil}}$	$\approx \frac{\text{tree}}{\text{soil}} \approx \frac{1000 \text{ mBq / kg}}{0.05 \text{ mBq / kg}} \approx 2 \times 10^4$	$\text{Ex} = \frac{\text{human-induced extinction rate}}{\text{background extinction rate}}$	$\approx \frac{\text{dodo}}{\text{trilobite? non-mass ex}} > 200$

NIAGARA NUMBER		HOOVER NUMBER	
$\text{Ni} = \frac{\text{daily human water use}}{\text{Niagara Falls drainage rate}}$	$\approx \frac{\text{boat + factory}}{\text{Niagara Falls}} \approx \frac{10^{10} \text{ m}^3/\text{day}}{10^9 \text{ m}^3/\text{day}} \approx 10$	$\text{Hv} = \frac{\text{fragmented river volume}}{\text{free-flowing river volume}}$	$\approx \frac{\text{dam}}{\text{river}} \approx \frac{10^{12} \text{ m}^3}{10^{12} \text{ m}^3} \approx 1$
ICE-MELT NUMBER		ACIDIC OCEAN NUMBER	
$\text{Ic} = \frac{\text{annual melt volume from glaciers \& ice-caps}}{\text{volume of Grand Canyon}}$	$\approx \frac{\text{iceberg}}{\text{Grand Canyon}} \approx \frac{10^{12} \text{ m}^3/\text{yr}}{10^{12} \text{ m}^3} \approx 1/\text{yr}$	$\text{Ac} = \frac{\text{ocean [H}^+ \text{] in 1960}}{\text{ocean [H}^+ \text{] today}}$	$\approx \frac{1 \text{M} \times 10^{-8.2}}{1 \text{M} \times 10^{-8.1}} \approx 0.7$

BARNYARD NUMBER		DEFORESTATION NUMBER	
$\text{By} = \frac{\text{livestock population}}{\text{human population}}$	$\approx \frac{\text{pig + cow}}{\text{person}} \approx \frac{30 \times 10^9}{7 \times 10^9} \approx 4$	$\text{Df} = \frac{\text{human-caused forest area loss}}{\text{natural forest area loss}}$	$\approx \frac{\text{logs}}{\text{tree}} \approx \frac{10^7 \text{ ha/year}}{3 \times 10^6 \text{ ha/year}} \approx 3$
NUMBER RELEVANT TO ECOLOGY		NUMBER RELEVANT TO MARINE LIFE	

HUMAN IMPACTS ON ATMOSPHERIC AND BIOGEOCHEMICAL CYCLES

The Keeling curve has the same iconic status as the DNA double helix. Beginning in the 1950s, we have had a largely uninterrupted quantitative glimpse into the atmospheric concentration of CO₂. To get an impression of the human-induced increase in atmospheric CO₂, the **Keeling Number** compares the total anthropogenic CO₂ released in comparison with the CO₂ released from the eruption of Mt. St. Helens, revealing humans have released 200,000 times the amount of CO₂ as this infamous eruption. Perhaps even more dramatic than our impact on the CO₂ budget of the atmosphere is our role in nitrogen fixation. The **Haber-Bosch Number** measures the ratio of atmospheric nitrogen fixed through the Haber-Bosch process to that occurring naturally in the rhizosphere due to microbes. The **Volta Number** characterizes a less well-known example, namely, the volume of anthropogenic methane in comparison with the methane of XXXX. The **Erosion Number** compares the volume of soil moved by humans to that moved by rivers.

KEELING NUMBER		HABER-BOSCH NUMBER	
$\text{Ke} = \frac{\text{anthropogenic CO}_2 \text{ since 1880}}{\text{CO}_2 \text{ released from Mt. St. Helens}}$	$\approx \frac{\text{trees}}{\text{volcano}} \approx \frac{2 \times 10^{15} \text{ kg CO}_2}{10^{10} \text{ kg CO}_2} \approx 2 \times 10^5$	$\text{Ha} = \frac{\text{N}_2 \text{ fixation through Haber-Bosch process}}{\text{N}_2 \text{ fixation through biological processes}}$	$\approx \frac{\text{Haber-Bosch}}{\text{biological}} \approx \frac{200 \text{ Tg N}}{200 \text{ Tg N}} \approx 1$
VOLTA NUMBER		EROSION NUMBER	
$\text{V} = \frac{\text{volume of anthropogenic CH}_4}{\text{volume of biological CH}_4}$	$\approx \frac{\text{cow}}{\text{mud}} \approx \frac{??}{??}$	$\text{Er} = \frac{\text{soil moved by humans}}{\text{soil moved by rivers}}$	$\approx \frac{\text{bulldozer + truck}}{\text{muddy river}} \approx \frac{40 \text{ Gt / yr}}{5 \text{ Gt / yr}} \approx 8$

THE MAGNITUDE OF HUMAN ENERGY USAGE

Finding new ways to extract useful work from the world is one of the signature achievements of the human condition. And yet, this act of learning how to extract energy from the environment is a large part of the story of human impacts, whether in the burning of various fuels that change the atmosphere, or the damming of the world's rivers to produce electricity. The **Solar Number** is one of the most important human impacts numbers of all and compares the 20 TW per year energy use of humans to the 10,000 fold higher incident power from the sun. The **Fossil Fuel Number**

SOLAR NUMBER		FOSSIL FUEL NUMBER	
$\text{Su} = \frac{\text{annual human energy usage}}{\text{annual incident solar energy}}$	$\approx \frac{\text{lightbulb}}{\text{sun}} \approx \frac{20 \text{ TW}}{2 \times 10^5 \text{ TW}} \approx 0.0001$	$\text{Fo} = \frac{\text{volume of fossil fuels mined annually}}{\text{volume of fossil fuels in proven resources}}$	$\approx \frac{20 \text{ TW}}{2 \times 10^5 \text{ TW}} \approx 0.0001$
NUMBER RELEVANT TO OTHER MINING		NUMBER RELEVANT TO RENEWABLE USE	

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SUPPORTING INFORMATION

A MELTWATER

glacial melt rate	HulD: 32459
ice-sheet melt rate	HulD: 44746; 88530
total melt rate	HulD: 000000

Data Source(s):

Notes:

B RENEWABLE POWER GENERATION

wind	HulD: 30581
solar	HulD: 99885
biofuels	HulD: 89570
total	HulD: 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, and does not include hydroelectric power generation.

C NITROGEN FIXATION

N_2 flux through Haber-Bosch [HulD: 000000](#)

Data Source(s):

Notes:

D RIVER FRAGMENTATION

dammed river volume [HulD: 000000](#)

Data Source(s): Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed diam nonumy nibh euismod tincidunt ut laboreet dolore magna aliquam erat volutpat. Ut wisi enim ad minim veniam, quis nostrud exercitiation ullamcorper suscipit lobortis nisl ut

hydroelectric power [HulD: 27945](#)

Data Source(s): bp Statistical Review of World Energy, 2020.

Notes: Value corresponds to the reported value of global hydroelectricity production for 2019.

E LIVESTOCK POPULATION

chicken	HulD: 94934
cattle	HulD: 92006
swine	HulD: 21368
total	HulD: 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.

F EXTENT OF TERRESTRIAL LAND USAGE

agriculture [HulD: 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 the FAO.

urban [HulD: 00000](#)

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. Rural land is defined as Urban and value corresponds to the most recent estimate from 2010.

total [HulD: 15765](#)

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.

G OCEAN pH

yearly change in $[H^+]$ [HulD: 00000](#)

Data Source(s):

Notes:

N OIL & NATURAL GAS MINING

oil & n.g. volume	HulD: 00000
oil & n.g. power production	HulD: 00000

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.

H DEFORESTATION

commodity-driven	HulD: 96098
shifting agriculture	HulD: 24388
forestry	HulD: 38352
urbanization	HulD: 19429
total	HulD: 78576

Data Source(s): Table 1 and Figure 3 of Curtis et al. 2018 DOI:10.1126/science.aau3445.

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.

I MATERIAL OF HUMAN ORIGIN

concrete production [HulD: 25488](#)

steel production [HulD: 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 corresponds to the USGS estimated value for 2019.

plastic production [HulD: 97241](#)

Data Source(s): Geyer et al. 2017.

DOI:10.1126/sciadv.1700782, Table S2.

Notes: Value represents the sum total global production of plastic fibers and plastic resin during calendar year 2015. Original data set reports data from 1950 – 2015.

total anthropomass production [HulD: 00000](#)

Data Source(s):

Notes:

J HUMAN WATER USE

agriculture	HulD: 43593
power generation	HulD: 78784
domestic	HulD: 69424
total	HulD: 27342

Data Source(s): Figure 1 of Qin et al. 2019.

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 most recent estimates for 2016.

K GLOBAL POWER CONSUMPTION

global power consumption [HulD: 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 OCEAN WARMING

power deposition [HulD: 00000](#)

Data Source(s):

Notes:

M GREENHOUSE GAS EMISSIONS

yearly CO_2 released [HulD: 00000](#)

Data Source(s):

Notes:

O HUMAN CAUSED EXTINCTION

animal species recently extinct [HulD: 44641](#)

plant species recently extinct [HulD: 86866](#)

Data Source(s): The IUCN Red List of Threatened Species. Version 2020-2. <https://www.iucnredlist.org>.

Notes: Values correspond to absolute lower-bound measurements of extinctions caused over the past ≈ 500 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 ($>$).

P EROSION

intentional soil movement [HulD: 0000](#)

Data Source(s): Table 1 and Figure 4 of Hooke 2000. DOI:10/bdnqv9. K-Tec Earthmovers Inc. March 2018 Newsletter URL:<https://tinyurl.com/y5tkm98j> (accessed 08/2020). Grand View Research Construction Industry Analysis, April 2020. URL:<https://tinyurl.com/y2jxxpv3>

Notes: Hooke 2000 estimates ≈ 35 Gt of soil moved annually in latter years of 20th century. This is in agreement with reported soil volume moved by industry member (K-Tec) and total revenue of soil movement and construction industry as reported by Grand View Research in April 2020. This value accounts for intentional soil movement only (such as mining and construction) and does not include agricultural soil movement, which is more difficult to confidently quantify.

Q SEA LEVEL RISE

rise due to meltwater [HulD: 0000](#)

rise due to thermal expansion [HulD: 0000](#)

Data Source(s):

Notes:

R NUCLEAR FALLOUT

plutonium activity in soil [HulD: 0000](#)

Data Source(s): Figure 4 and Figure 5 in Hancock et al. 2014. DOI:10.1144/SP395.15

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 ≈ 1963 CE during the peak of atmospheric nuclear weapons testing.

S COAL POWER PRODUCTION

coal power produced [HulD: 10400](#)

Data Source(s): bp Statistical Review of World Energy, 2020.

Notes: 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.