

# HUMAN IMPACTS by the numbers

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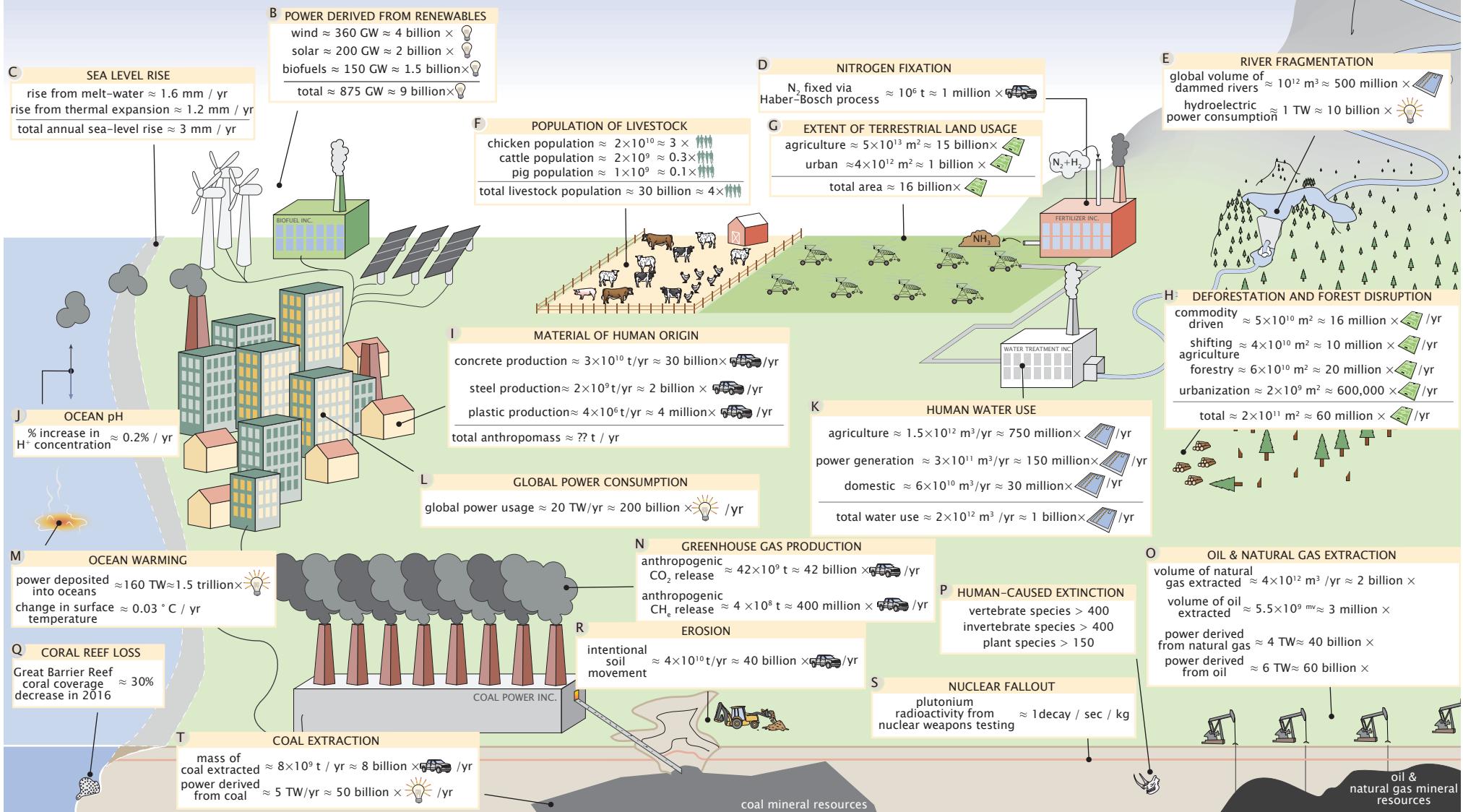
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## ABSTRACT

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. 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	=  ≈ $7 \times 10^9$	mass of a pick-up truck	=  ≈ 1 t
area of soccer pitch	=  ≈ 3000 m <sup>2</sup>	power of a lightbulb	=  ≈ 100 W
volume of olympic pool	=  ≈ 2000 m <sup>3</sup>		



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## THE ANTHROPOCENE

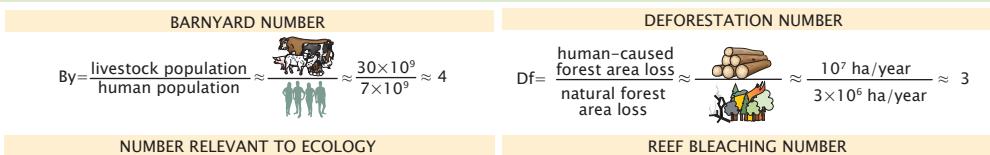
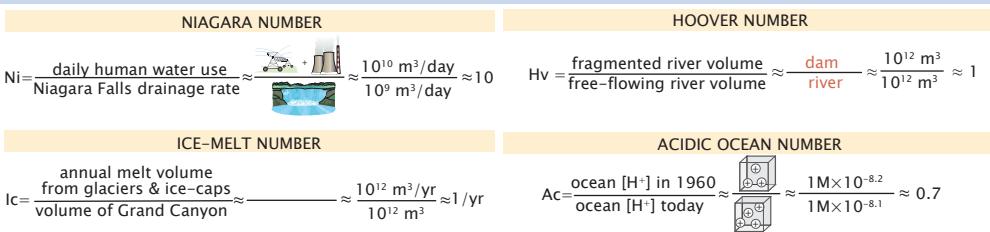
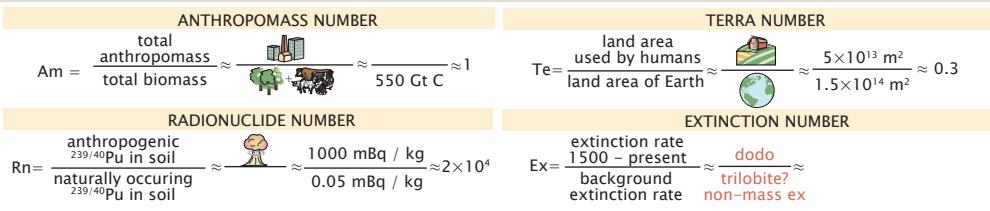
A visit to any natural history museum will reveal that much about Earth's history can be learned by examining the geological and fossil record. As humans have made extensive changes to the Earth's chemistry and biology, in addition to the physical changes to the Earth's crust, the record of our existence 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 and order of magnitude more water than falls over Niagara falls in a single day. 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 CO<sub>2</sub> 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  $\approx 1$  Grand Canyon's worth of water into the hydrosphere per year. Approximately 40% of CO<sub>2</sub> 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.

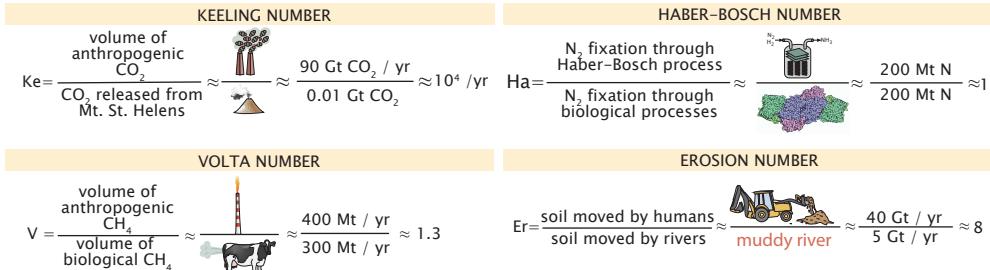
## HUMANS AS THE EARTH'S GREATEST EVOLUTIONARY FORCE

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.



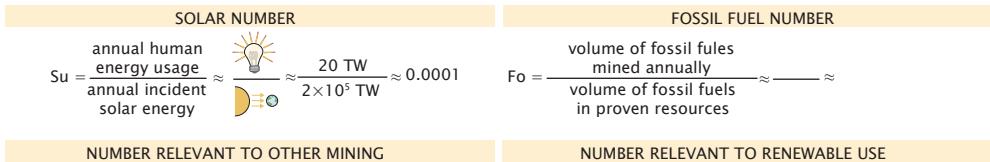
## HUMAN IMPACTS ON ATMOSPHERIC AND BIOGEOCHEMICAL CYCLES

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 CO<sub>2</sub>. To get an impression of the human-induced increase in atmospheric CO<sub>2</sub>, the **Keeling Number** compares the total anthropogenic CO<sub>2</sub> released in comparison with the CO<sub>2</sub> released from the eruption of Mt. St. Helens, revealing humans have released 200,000 times the amount of CO<sub>2</sub> as this infamous eruption. Perhaps even more dramatic than our impact on the CO<sub>2</sub> 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.



## 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**



# HUMAN IMPACTS by the numbers

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## SUPPORTING INFORMATION

A	MELTWATER	G	EXTENT OF TERRESTRIAL LAND USAGE	I	MATERIAL OF HUMAN ORIGIN (continued)	N	GREENHOUSE GAS EMISSIONS	S	NUCLEAR FALLOUT	
glacial melt rate	HuID: 32459	agriculture	HuID: 29582	plastic production	HuID: 97241	yearly CO <sub>2</sub> released	HuID: 47200	plutonium activity in soil	HuID: 0000	
ice-sheet melt rate	HuID: 44746; 88530	Data Source(s):	Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT)	Data Source(s):	Table S2 of Geyer et al. 2017. DOI:10.1126/sciadv.1700782.	Data Source(s):		Data Source(s):	Figure 4 and Figure 5 in Hancock et al. 2014. DOI:10.1144/SP39.15	
total melt rate	HuID: 000000	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.	Notes:	Value represents the sum total global production of plastic fibers and plastic resin during calendar year 2015.	Notes:		Notes:	Value corresponds to current-day detectable combined radioactivity of <sup>239</sup> Pu and <sup>240</sup> Pu present in cores of stratified soil with estimated date of ≈ 1963 CE during the peak of atmospheric nuclear weapons testing.	
B	POWER DERIVED FROM RENEWABLES				total anthropomass production	HuID: 00000	yearly CH <sub>4</sub> released	HuID: 96837		
wind	HuID: 30581	Data Source(s):	World Bank and Center for International Earth Science Information Network (CIESIN)–Columbia University. 2013	Data Source(s):		Data Source(s):		Data Source(s):		
solar	HuID: 99885	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.	Notes:		Notes:		Notes:		
biofuels	HuID: 89570	total	HuID: 20246	Data Source(s):	Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT)	OCEAN pH	HuID: 19394	O	OIL & NATURAL GAS EXTRACTION	
		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.	Notes:	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.	yearly change in [H <sup>+</sup> ]	HuID: 19394	power derived from nat. gas	HuID: 49947	
		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.	Notes:	Notes: Reported value is calculated from the average annual change in pH over years 1985–2018. Annual change in pH is ≈ 0.001 pH units, corresponding to a change in [H <sup>+</sup> ] of ≈ 0.2 % / yr.	Data Source(s):		power derived from oil	HuID: 42121	
C	SEA LEVEL RISE				K	HUMAN WATER USE			volume of nat. gas extraction	HuID: 11468
rise due to meltwater	HuID: 97108	Data Source(s):	Table 1 of Frederikse et al. 2020. DOI:10.4689.	HuID: 96098	agriculture	HuID: 43593	Data Source(s):	volume of oil extraction	HuID: 66789	
rise due to thermal expansion	HuID: 97688	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 antarctic ice sheet.	shifting agriculture	HuID: 24388	power generation	HuID: 78784	Data Source(s):	bp Statistical Review of World Energy, 2020.	
total annual sea-level rise	HuID: 81373	Data Source(s):		forestry	HuID: 38352	domestic	HuID: 69424	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.	
		Notes:		urbanization	HuID: 19429	total	HuID: 27342	Notes:	Values 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.	
D	NITROGEN FIXATION				L	GLOBAL POWER CONSUMPTION			P	HUMAN CAUSED EXTINCTION
N <sub>2</sub> flux through Haber-Bosch	HuID: 000000	Data Source(s):		HuID: 78576	global power consumption	HuID: 31373	Data Source(s):	animal species recently extinct	HuID: 44641	
Notes:		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.	Data Source(s):	Figure 1 of Qin et al. 2019. DOI:10.1038/s41893-019-0294-2.	Data Source(s):	plant species recently extinct	HuID: 86866		
		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 "small-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." Total value of deforested and disrupted forest land includes wildfires of both human and natural causes. Values correspond to calendar year 2015 and are calculated from the statistic that ≈ 25% of total deforested and disrupted forest land sums to ≈ 5 Mha/yr. See Table 1 and Figure 3 of Curtis et al. 2018.	Data Source(s):		Data Source(s):	The IUCN Red List of Threatened Species. Version 2020-2.	Data Source(s):		
E	RIVER FRAGMENTATION				M	OCEAN WARMING			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 ≈ 900,000 with only ≈ 75,000 being assigned a conservation status. Representation of plants and fungi is even more sparse with only ≈ 40,000 and ≈ 285 being assigned a conservation status, respectively. The number of extinct animal species is undoubtedly higher than these reported values, as signified by an inequality symbol (>).
dammed river volume	HuID: 000000	Data Source(s):		HuID: 25488	power deposition	HuID: 59201	Data Source(s):	2016 Great Barrier Reef coverage loss	HuID: 90720	
Notes:		Data Source(s):		HuID: 51453	ocean surface warming	HuID: 87228	Data Source(s):	Figures 1A, S1, and S2 of Hughes et al. 2018, DOI:10.1038/s41586-018-0041-2.	Data Source(s):	
		Data Source(s):	bp Statistical Review of World Energy, 2020.	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.	Data Source(s):	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.	Data Source(s):	
hydroelectric power	HuID: 27945	Data Source(s):		Data Source(s):	Notes:	Data Source(s):	Notes:	Notes:	Notes:	
Data Source(s):	bp Statistical Review of World Energy, 2020.	Notes:		Notes:	Value is calculated from the reported annual heat uptake of ≈ 5 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 ≈ 5 ZJ/yr heat uptake by noting that deposition of ≈ 144 ZJ/yr raises the temperature of the top 100 m of ocean by ≈ 1 °C. See the complete report or section 5.2.2 of the source material for more information.	Data Source(s):	Notes:	Notes:	Notes:	
F	LIVESTOCK POPULATION	G	MATERIAL OF HUMAN ORIGIN	I	Notes:	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.	Data Source(s):	Notes:	
chicken	HuID: 94934	concrete production	HuID: 25488	Data Source(s):	Notes:	Data Source(s):	Notes:	Data Source(s):	Notes:	
cattle	HuID: 92006	steel production	HuID: 51453	Data Source(s):	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 by FAO uses non-governmental statistical sources to Monteiro et al. 2017. Steel production corresponds to the USGS 2019 value.	Data Source(s):	Notes:	Data Source(s):	Notes:	
swine	HuID: 21368		HuID: 10.3133/mcs2020;	Data Source(s):		Data Source(s):		Data Source(s):		
total	HuID: 15765	Monteiro et al. 2017, DOI:10.138/nmat4930;		Data Source(s):		Data Source(s):		Data Source(s):		
Data Source(s):	Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT).	Notes:		Data Source(s):		Data Source(s):		Data Source(s):		
	Counts correspond to the approximate average of the standing populations reported between 2010 and 2018. Values are reported directly by countries, yet a multiplicative conversion factor of ≈ 7 as described by FAO uses non-governmental statistical sources to Monteiro et al. 2017. Steel production corresponds to the USGS 2019 value.	Notes:		Data Source(s):		Data Source(s):		Data Source(s):		
T	COAL EXTRACTION									
		mass of coal extracted	HuID: 78435							
		power derived from coal	HuID: 10400							
		Data Source(s):	bp Statistical Review of World Energy, 2020.							
		Notes:								
O	OIL & NATURAL GAS EXTRACTION									
		power derived from nat. gas	HuID: 49947							
		power derived from oil	HuID: 42121							
		volume of nat. gas extraction	HuID: 11468							
		volume of oil extraction	HuID: 66789							
		Data Source(s):	bp Statistical Review of World Energy, 2020.							
		Notes:								
P	HUMAN CAUSED EXTINCTION									
		animal species recently extinct	HuID: 44641							
		plant species recently extinct	HuID: 86866							
		Data Source(s):	The IUCN Red List of Threatened Species. Version 2020-2.							
		Notes:								
Q	CORAL REEF LOSS									
		2016 Great Barrier Reef coverage loss	HuID: 90720							
		Data Source(s):	Figures 1A, S1, and S2 of Hughes et al. 2018, DOI:10.1038/s41586-018-0041-2.							
		Notes:								
R	EROSION									
		intentional soil movement	HuID: 59841							
		Data Source(s):	Table 1 and Figure 4 of Hooke 2000, DOI:10/bdnqv9. K-Tec Earthmovers Inc. March 2018 Newsletter URL: <a href="https://tinyurl.com/y5tkm98j">https://tinyurl.com/y5tkm98j</a> (accessed 08/2020). Grand View Research Construction Industry Analysis, April 2020. URL: <a href="https://tinyurl.com/y2jxxpv3">https://tinyurl.com/y2jxxpv3</a>							
		Notes:								