Supplemental File S2

World Scientists' Warning of a Climate Emergency 2021

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Supplemental Tables

Table S1. Summary of variables shown in Figures 1 and 2. Table columns show the variable name, update frequency, number of years with data, time of most recent data point, current value of the variable, change relative to the previous value, and rank (where rank 1 indicates the highest value to date). For variables with subannual frequency, the value, change, and rank are all based on year-to-date data. For example, they are based on the first 29.2% of each year for the variable "Carbon dioxide (CO_2 parts per million)" (since "Year" is equal to 2021.292). Note that variable time spans (# of years) differ significantly depending on the source. Variables that set all-time records are marked with asterisks.

Variable	Type	Years	Year	Value	Change	Rank
Human population (billion individuals)*	Annual	72	2021	7.87	0.0802	1
Total fertility rate (births per woman)*	Annual	60	2019	2.4	-0.0134	60
Ruminant livestock (billion individuals)*	Annual	59	2019	4.05	0.0727	1
Per capita meat production (kg/yr)	Annual	60	2020	48.2	-1.35	11
World GDP (trillion current US $/yr)*	Annual	62	2021	86.8	4.93	1
Global tree cover loss (million hectares/yr)	Annual	20	2020	25.8	1.63	3
Brazilian Amazon forest loss (million hectares/yr)	Annual	33	2020	1.11	0.0959	21
Coal consumption (Exajoules/yr)	Annual	57	2021	158	6.81	7
Oil consumption (Exajoules/yr)	Annual	57	2021	184	10.4	5
Gas consumption (Exajoules/yr)*	Annual	57	2021	142	4.4	1
Solar/wind consumption (Exajoules/yr)*	Annual	57	2021	25.5	3.77	1
Air transport (billion passengers carried/yr)	Annual	49	2021	2.8	1	9
Total institutional assets divested (trillion USD)*	Annual	8	2020	14	2.5	1
CO2 emissions (gigatonnes CO2 equivalent/yr)	Annual	57	2021	33.5	1.54	3
Per capita CO2 emissions (tonnes CO2 equivalent/yr)	Annual	57	2021	4.26	0.153	16
GHG emissions covered by carbon pricing (%)*	Annual	32	2021	21.5	6.59	1
Carbon price ($ per tonne CO2 emissions)	Annual	31	2020	15.9	0.133	21
Fossil fuel subsidies (billion USD/yr)*	Annual	11	2020	181	-131	11
Governments that have declared a climate emergency (#)*	Annual	5	2020	1890	420	1
Carbon dioxide (CO_2 parts per million)*	Subannual	42	2021.292	415	2.33	1
Methane (CH_4 parts per billion)*	Subannual	38	2021.208	1890	15.3	1
Nitrous oxide (N_2O parts per billion)*	Subannual	21	2021.208	334	1.4	1
Surface temperature change (°C)	Subannual	140	2021.37	0.782	-0.403	8
Minimum Arctic sea ice (million km^2)	Annual	42	2020	3.92	-0.44	41

Variable	Type	Years	Year	Value	Change	Rank
Greenland ice mass change (gigatonnes)*	Subannual	19	2021.29	-4880	-130	19
Antarctica ice mass change (gigatonnes)*	Subannual	19	2021.29	-2760	-88.3	19
Glacier thickness change (m of water equivalent)*	Annual	71	2020	-24.8	-0.982	71
Ocean heat content change (10^{22} joules)*	Annual	16	2020	25.5	0.089	1
Ocean acidity (pH)	Subannual	32	2019.964	8.07	-0.00194	31
Sea level change relative to 20-year mean (mm)*	Subannual	29	2021.272	50.3	4.38	1
Area burned in the United States (million hectares/yr)	Annual	38	2020	4.1	2.21	2

Table S2. Regional summaries for 24 countries and The European Union. Variables shown are "CO_2" (total CO_2 emissions associated with fossil fuel consumption in mega tonnes CO_2), "Population" (human population size in millions), "CO_2/capita" (CO_2 emissions per capita in tonnes per person), "Share" (percentage of all CO_2 emissions associated with fossil fuel consumption compared to the global total), and "GDP/capita" (per capita gross domestic product in US dollars per person). All data are for the year 2020 except GDP for Japan and the United Arab Emirates, which are for 2019. Additional details on these variables are provided in the supplementary information below. GDP/capita was calculated using FAOSTAT population estimates and World Bank GDP estimates.

	CO_2	**Population**	**CO_2/capita**	**Share**	**GDP/capita**
China	9894	1471	6.7	30.9%	$10,007
United States	4432	331	13.4	13.9%	$63,252
The European Union	2858	513	5.6	8.9%	$34,884
India	2298	1380	1.7	7.2%	$1,901
Russia	1432	146	9.8	4.5%	$10,166
Japan	1027	126	8.1	3.2%	$40,046
Iran	650	84	7.7	2.0%	$2,283
South Korea	578	51	11.3	1.8%	$31,803
Saudi Arabia	565	35	16.2	1.8%	$20,110
Indonesia	541	274	2.0	1.7%	$3,870
Canada	515	38	13.6	1.6%	$43,543
South Africa	434	59	7.3	1.4%	$5,091
Brazil	415	213	2.0	1.3%	$6,797
Australia	370	25	14.5	1.2%	$52,192
Turkey	369	84	4.4	1.2%	$8,538
Mexico	360	129	2.8	1.1%	$8,347
Vietnam	283	97	2.9	0.9%	$2,786
Thailand	276	70	4.0	0.9%	$7,189
Malaysia	251	32	7.7	0.8%	$10,402
United Arab Emirates	244	10	24.6	0.8%	$42,581
Kazakhstan	238	19	12.7	0.7%	$9,045
Singapore	211	6	36.1	0.7%	$58,116
Egypt	199	102	1.9	0.6%	$3,548
Pakistan	195	221	0.9	0.6%	$1,194
Ukraine	177	44	4.1	0.6%	$3,557
Top 25	**28813**	**5561**	**5.2**	**90.1%**	**$13,605**
World	**31984**	**7795**	**4.1**	**100.0%**	**$10,504**

Supplemental Figures

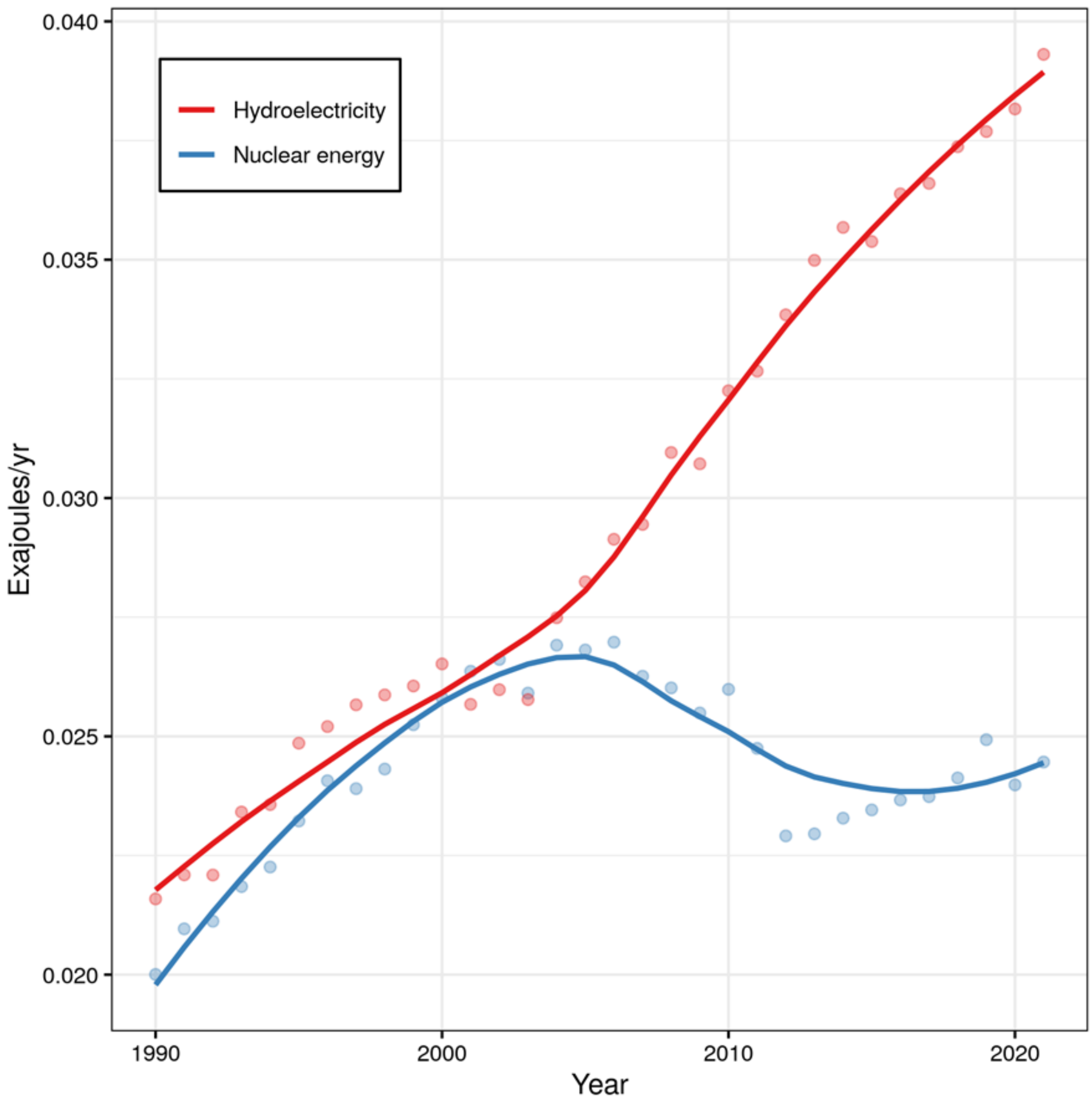

Figure S1. Annual consumption rates for nuclear energy and hydroelectricity (British Petroleum Company 2021). Non-fossil fuel energy supply pathways in the future may include hydro and nuclear power in addition to wind and solar power (IPCC 2018). See British Petroleum Company (2021) for other minor energy sources not shown in this figure. Figure 1h in the main text shows consumption of fossil fuels as well as solar/wind energy. Estimates for 2021 were calculated using percentage change data from the International Energy Agency (2021a).

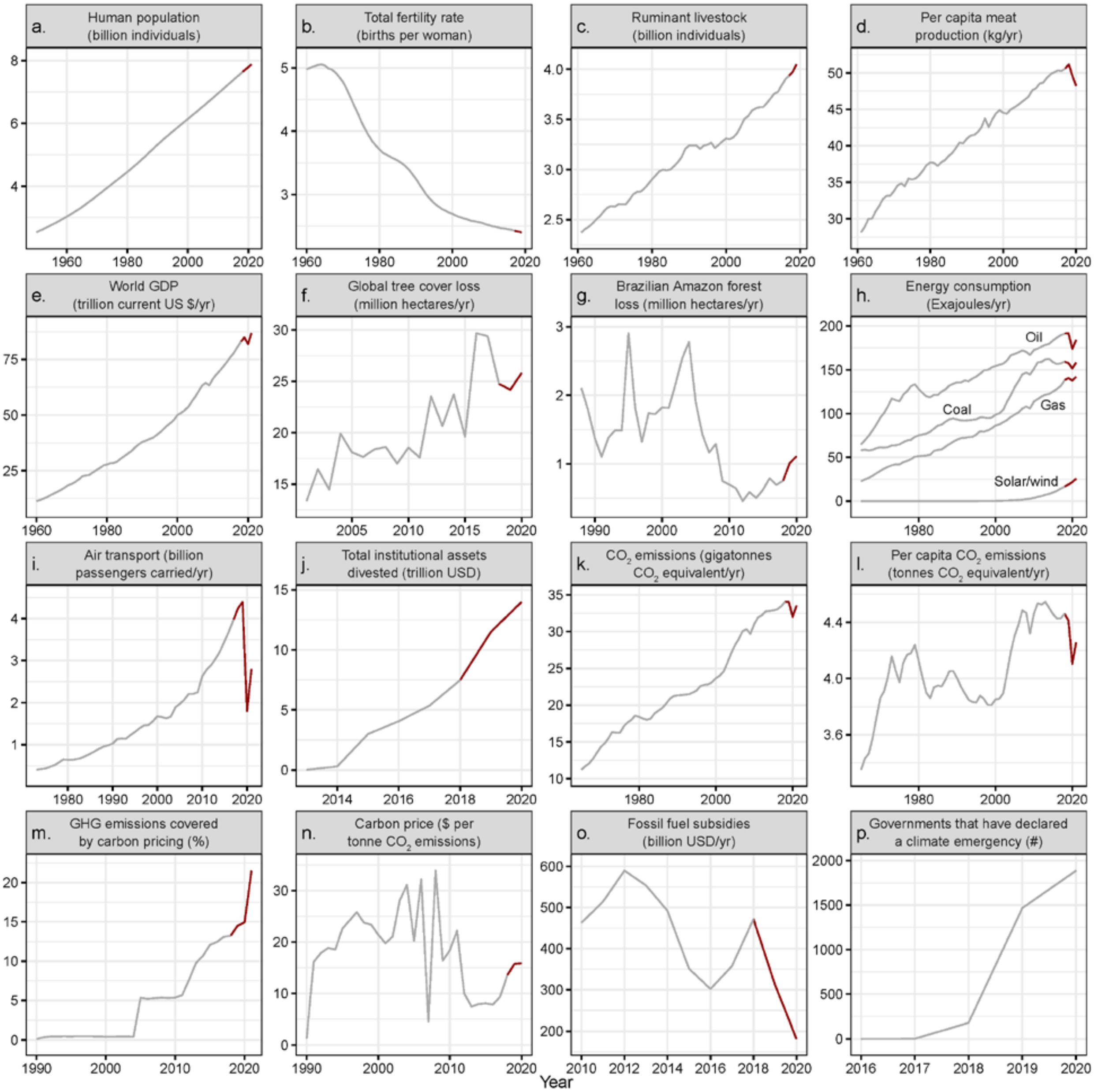

Figure S2. Complete time series of climate-related global human activities. Note that time spans vary depending on data availability. In panels (a), (d), (e), (i), and (m), the most recent one or two data points are a projection or preliminary estimate (see Supplement); in panel (f), tree cover loss does not account for forest gain and includes loss due to any cause. With the exception of panel (p), data obtained since the publication of Ripple et al. (2020) are shown in red. Sources and additional details about each variable are provided in the Supplementary Methods.

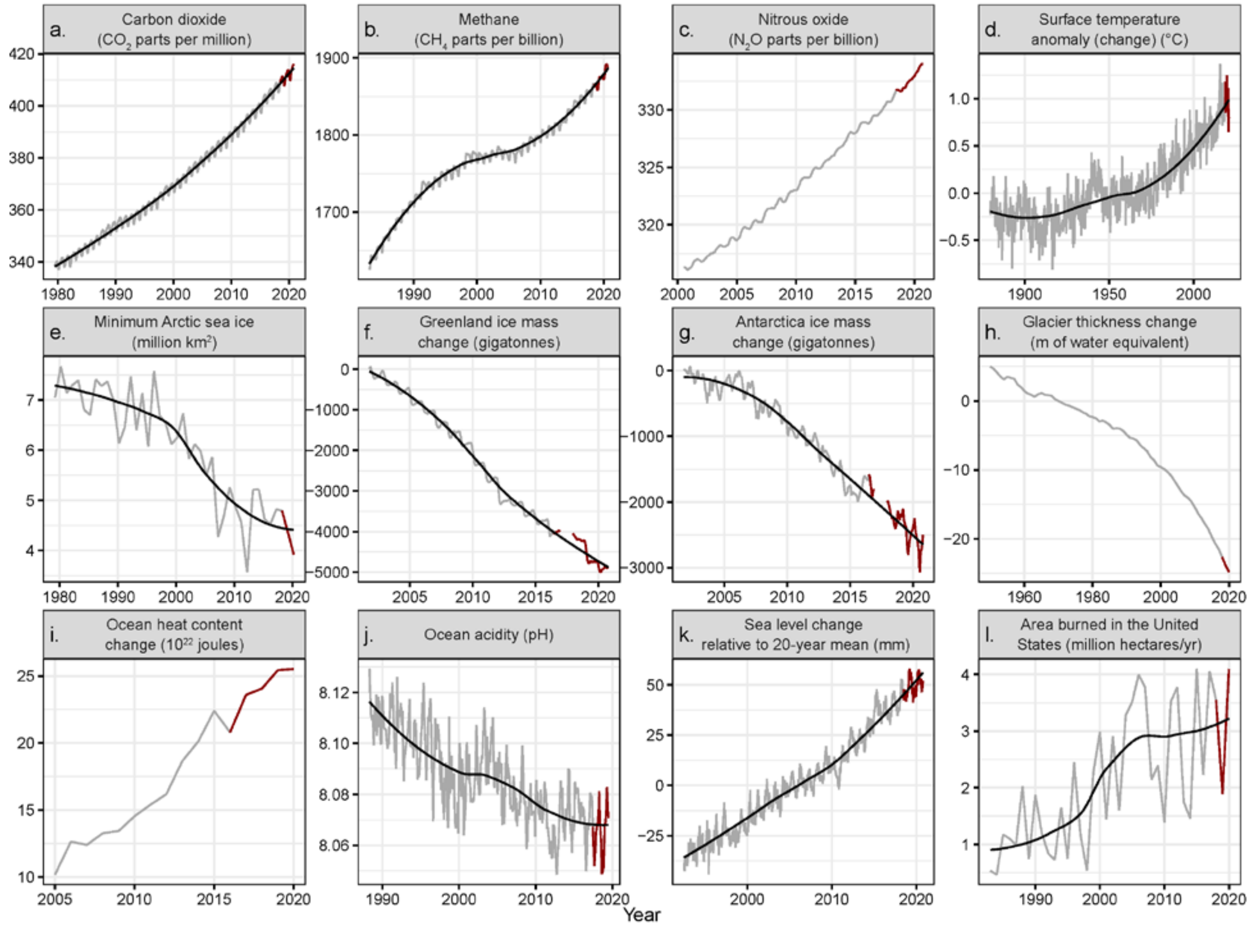

Figure S3. Complete time series of climate-related responses. Note that time spans vary depending on data availability. Data obtained before and after the publication of Ripple et al. (2020) are shown in gray and red respectively. For variables with relatively high variability, local regression trendlines are shown in black. Variables were measured at various frequencies (e.g., annual, monthly, weekly). Labels on the x-axis correspond to midpoints of years. Sources and additional details about each variable are provided in the Supplementary Methods.

Recent climate disasters

Below, we list several disasters that occurred in 2020 or later and may be at least partly related to climate change. This list is not intended to be exhaustive. Due to the recent nature of these events, our sources often include news media articles.

Because of the natural variability and stochasticity of the Earth system, attributing specific extreme events (or parts of their impacts) to climate change is an exceptionally challenging task (Stott et al. 2013; Trenberth et al. 2015), although it may be possible in some cases (e.g., Strauss et al. 2021). For simplicity, we have generally adopted the framework of Stott et al. (2013), which is described by Trenberth et al. (2015 p. 725) as follows:

> "[T]he approach is to characterize the event and ask (i) whether the likelihood or strength of such events has changed in the observational record, and (ii) whether this change is consistent with the anthropogenic influence as found in one or more climate models, and thereby assess the 'fraction of attributable risk'."

Thus, for each event, we provide references indicating that the likelihood or strength of such an event may have become more common due to anthropogenic climate change. For certain types of events (e.g., rainfall), this can be difficult to establish conclusively. Because of this potential issue, we have indicated cases where attribution (in the general sense described above) has a high degree of uncertainty. Since our intention is to provide a brief overview of potentially climate related disasters, we have opted not to assess the "fraction of attributable risk" for each event.

- (January, 2020) Megafires in Australia following a prolonged drought which burnt approximately 18.6 m hectares of land, of which 11.5 m hectares was in forest and woodland areas. The fire was estimated to have killed or displaced 143 million mammals, 2.46 billion reptiles, 180 million birds, and 51 million frogs (van Eeden et al. 2020). These wildfires (and the 2019 and 2020 Australian wildfire seasons in general) are believed to be connected to unusual weather conditions (heat and dryness) that may be linked to climate change (Deb et al. 2020; Kemter et al. 2021).
- (May-November, 2020) The Atlantic hurricane season was the fifth costliest on record, with more than 51 billion US dollars in damages and at least 442 fatalities (Wikipedia 2021a). There is strong evidence that tropical cyclone intensity has increased globally (from 1979 to 2017), which is expected given anthropogenic warming (Kossin et al. 2020).
- (November 2020) Much of Australia experienced an extreme heat wave (Guardian staff with AAP 2020). For example, temperatures in the town of Coober Pedy in northern South Australia reached 46 °C (Guardian staff with AAP 2020). In general, climate change is leading to warmer temperatures and thus increasing the frequency and intensity of such heat waves (Hanna et al. 2011).
- (July-December, 2020) Major wildfires occurred in the Western United States, causing 47 direct deaths, burning roughly 4,100,000 ha, and causing more than 19.9 billion US dollars in damages. (Wikipedia 2021b). Such wildfires are likely becoming more common due to climate change causing warming and drying of vegetation and air (NASA 2021).

- (January, 2021) Flash flooding in the South Kalimantan province of Indonesia temporarily displaced thousands of people (Malhotra 2021). Because climate change can affect precipitation in this region (Loo et al. 2015), it may have contributed to an increase in the frequency of such events. However, this can be difficult to prove due to the many other factors involved such as deforestation, various weather systems, and topography.
- (January, 2021) Cyclone Eloise displaced more than 18,000 people in Africa, destroying important infrastructure and resulting in 27 fatalities (Malhotra 2021). See note under Atlantic hurricane season for potential link to climate change.
- (February, 2021) A melting glacier in the Himalayas killed dozens of people; hundreds more were missing (Fountain 2021). It is not currently known whether climate change caused this particular disaster (Ghosal 2021). However, it may have at least been a contributing factor since climate change can cause glaciers to melt and increase landslide and avalanche frequency (Ghosal 2021).
- (February, 2021) Several cities in the Brazilian state of Acre experienced major flooding (Malhotra 2021). Climate change has been linked to increases in flood frequency and intensity in some cases (Degrossi et al. 2014). However, rigorous attribution is difficult here. For example, recent evidence suggests that the increase in severe flood frequency and intensity in the Amazon may be related to the Walker circulation becoming stronger (Barichivich et al. 2018).
- (April, 2021) Typhoon Surigae killed 10 people (8 more were missing) in the West Pacific and caused more than 10 million US dollars in damages (Wikipedia 2021c). Typhoon Surigae is one of the strongest tropical cyclones on record, and the strongest ever observed to form before the month of May. (Wikipedia 2021c). See note under Atlantic hurricane season for potential link to climate change.
- (May, 2021) India's west coast was struck by the strongest storm ever recorded there, Tropical Cyclone Tauktae, which killed at least 26 people (Yeung & Mitra 2021). See note under Atlantic hurricane season for potential link to climate change.
- (June, 2021) The southwestern United States experienced a record-breaking heat wave due to a massive ridge of high pressure, which is commonly known as a heat dome (Javaheri et al. 2021; Landi 2021). Ridges of this type are likely becoming stronger and lasting longer due to climate change (Javaheri et al. 2021).

Climate tipping points

Here, we briefly review recent developments indicating that various tipping points may have already been or will soon be crossed. For reference, Lenton et al. (2008 p. 1786) defined “tipping elements” and “tipping points” as follows:

“We offer a formal definition, introducing the term ‘**tipping element**’ to describe subsystems of the Earth system that are at least subcontinental in scale and can be switched—under certain circumstances—into a qualitatively different state by small perturbations. The **tipping point** is the corresponding critical point—in forcing and a feature of the system—at which the future state of the system is qualitatively altered.”

1. A tipping point ultimately leading to irreversible loss of the **West Antarctic Ice Sheet (WAIS)** could be crossed at approximately 1.5-2 °C warming, which may be reached in the near future (Hulbe 2021).
2. The **Greenland Ice Sheet** may also have a tipping point wherein collapse beings at 1.5°C; however, as with the WAIS, total collapse in this case would require a significant amount of time (Lenton et al. 2019).
3. The **Amazon rainforest** has switched from a carbon sink to a carbon source in some cases (Yang et al. 2018), and may be near a tipping point linked to the combined pressures of deforestation and climate change (Lenton et al. 2019).
4. Ocean warming and acidification are causing mass bleaching of **warm-water coral reefs**, and there may be an associated tipping point beyond which the destruction could be difficult to reverse (Lenton et al. 2019).

Methods for planetary vital signs

Ripple et al. (2020) compiled a set of global time series related to human actions that affect the environment (e.g. fossil fuel consumption) and environmental and climatic responses (e.g. temperature change). We have made a number of updates to this set of variables, which are described below. For completeness, we also describe all relevant methods, variables, and sources in full here, but note that there may be some overlap with Ripple et al. (2020) given the nature of this update.

Although the data used are from sources believed to be reliable, no formal accuracy assessment for these datasets has been made by us and users should proceed with caution. We only considered indicator variables that are updated at least every year. With the exception of climate emergency declarations (see next section), all the "human actions" time series are annual. However, eight of the "environmental and climatic responses" time series are subannual (e.g., monthly). In contrast to Ripple et al. (2020), we opted to keep these eight time series at their original (source) frequency rather than resampling to annual frequency.

For each variable, we calculated the following statistics:

1. The number of years with data (e.g., a variable with data from 1960 to 2021 would have 62 years of data)
2. The most recent year with data (can be fractional for subannual frequency variables – for example, 2021.35)
3. The most recent value of the variable (year-to-date average for subannual variables)
4. The most recent change in the variable (between current and preceding year-to-date averages for subannual variables)
5. The rank associated with the most recent value (#3) based on the entire time series. For example, a rank of 2 means the variable is at its second highest level ever (second highest year-to-date average for subannual variables).

While we only plotted data between 2000 and the present (2021), we included data from before 2000 (if available) when calculating the above statistics. For the plots of "environmental and climatic responses" variables with high variance, we included smooth trend lines calculated using locally estimated scatterplot smoothing. We fit the trend lines in R using the 'loess' function with default settings (degree 2, span 0.75) (R Core Team 2018).

Indicators of climate-related global human activities (Figure 1)

Below, we list sources and provide brief descriptions of indicators in our analysis. Full methods for each indicator are available at the provided sources.

Human population (Figure 1a)

We used the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) as our source of human population data (FAOSTAT 2021a). For human population estimates, the source data used by FAOSTAT are derived from national population censuses. For 2019 through 2021, these estimates are classified as "year projections."

Total fertility rate (Figure 1b)

We obtained this variable from the World Bank (The World Bank 2021a). The full variable name is "Fertility rate, total (births per woman)" and the World Bank variables ID is SP.DYN.TFRT.IN. This variable was derived using data from multiple sources, including the United Nations Population Division. The full list of original sources is available at The World Bank (2021a). Total fertility rate is defined as "the number of children that would be born to a woman if she were to live to the end of her childbearing years and bear children in accordance with age-specific fertility rates of the specified year" (The World Bank 2021a).

Ruminant livestock population (Figure 1c)

We used the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) as our source of ruminant livestock population data (FAOSTAT 2021a). We considered ruminants to be members of the following groups: cattle, buffaloes, sheep, and goats. For livestock estimates, the primary data sources are national statistics obtained using questionnaires or collected from countries' websites or reports. When national livestock statistics were unavailable, they were estimated by FAOSTAT using imputation (FAOSTAT 2021a).

Per capita meat production (Figure 1d)

We used total meat production data from FAOSTAT along with FAOSTAT human population size estimates (Figure 1a) to estimate per capita meat production (FAOSTAT 2021a). These data "are given in terms of dressed carcass weight, excluding offal and slaughter fats" and extend through 2019 (FAOSTAT 2021a). We used the FAOSTAT's projection of a 1.7% drop in total meat production globally in 2020 to estimate per capita meat production for this year (FAOSTAT 2021b). The recent drop in meat production is partly a consequence of African swine fever leading to a drop in pork production in China (Reuters Staff 2020). Additionally, COVID-19 may have contributed to the decline in 2020 (FAO 2021).

Gross domestic product (Figure 1e)

We obtained this variable from the World Bank (2021b) for the years 1960 to 2020. The full variable name is "GDP (constant 2010 US$)" and the World Bank variable ID is NY.GDP.MKTP.KD. This variable was derived from multiple sources such as World Bank national accounts. For details, including limitations and exceptions, see The World Bank (2021b). Gross domestic product (at purchaser's prices) is defined as "the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products" (The World Bank 2021b).

We calculated a projection for 2021 gross domestic product (GDP) using the April 2021 edition of the International Monetary Fund's World Economic Outlook Database (IMF 2021). We first obtained the year 2020 percentage change estimate based on the variable "Gross domestic product, constant prices" in units "Percent change" (IMF 2021). We then used this percentage change estimate to predict total GDP (as measured by the World Bank in constant 2010 US dollars) in 2021. Because IMF projections and World Bank and World Economic Outlook GDP estimates likely differ in methodology, this 2021 estimate should only be considered an approximation.

Global tree cover loss (Figure 1f)

We obtained data on annual global tree cover loss from Global Forest Watch (Hansen et al. 2013). These data express loss globally in million hectares (Mha) and were derived from remotely-sensed forest change maps. It should be noted that loss is general and not linked to a specific type of deforestation. So, it includes wildlife, conversion to agriculture, disease, etc. Additionally, tree cover loss does not take tree cover gain into account. Thus, net forest loss may be lower than the reported numbers.

Brazilian Amazon forest loss (Figure 1g)

We obtained annual Brazilian Amazon forest loss estimates from Butler (2020). Brazil contains about 60% of the Amazon rainforest. We used annual deforestation estimates rather than monthly ones because of high month-to-month variability. The original providers of the data are Brazil's National Institute for Space Research (INPE) and Imazon (a non-governmental organization).

Energy consumption (Figure 1h)

We used the British Petroleum Company's 2021 Statistical Review of World Energy as our primary source of data on energy consumption (British Petroleum Company 2021). For energy consumption, we used the following time series: coal, oil, natural gas, solar, and wind. We grouped solar and wind together into a single category. Coal consumption data are only for commercial solid fuels. In each case, the units of energy consumption are exajoules (per year). Other sources of low carbon energy such as hydropower and nuclear power are shown in Figure S3.

Because the BP data only extend through 2020, we estimated energy consumption in 2021 using percentage change estimates from the International Energy Agency's 2021 Global Energy Review, which was published in April 2021 (IEA 2021a). Note that these projections may have substantial uncertainty. Moreover, there are some differences in methodology compared to our primary source, especially with regard to what exactly is being measured; see IEA (2021a) for details.

Air transport (Figure 1i)

We obtained estimated up to 2019 from the World Bank (The World Bank 2021c). The full variable name is "Air transport, passengers carried." The corresponding World Bank variable ID is IS.AIR.PSGR. This variable was derived from multiple sources, including the International Civil Aviation Organization. The full lists of sources is available at The World Bank (2021c). Air transport includes both domestic and international travelers. For 2020 and 2021, we used projections from the International Air Transport Association (IATA) for passengers carried (IATA 2020). Note that these projections may be moderately uncertain and have different associated methodology than the World Bank estimates.

Divestment (Figure 1j)

Divestment data were obtained from 350.org (350.org 2021; Fossil Free 2021). They cover institutional divestment by 1,117 organizations. The most commonly represented institutions were faith-based organizations, philanthropic foundations, educational institutions, governments, and pension funds (Fossil Free 2021). Using 350.org's divestment database, we calculated cumulative total institutional divestment by year (since 2013) based on the "date of record" variable, which "generally represents the organization's divestment commitment announcement date" (350.org 2021).

Note that more sophisticated metrics are needed to determine which companies should be subject to divestment (Mormann 2020).

CO_2 emissions (Figure 1k)

We used the British Petroleum Company's 2021 Statistical Review of World Energy as our source of data on CO_2 emissions (British Petroleum Company 2021). These CO_2 emissions data "reflect only […] consumption of oil, gas and coal for combustion related activities" (British Petroleum Company 2021). They do not account for carbon sequestration, other CO2 emissions, or other greenhouse gas emissions. Because these data only extend through 2020, we estimated CO_2 emissions in 2021 using percentage change estimates from the International Energy Agency's 2021 Global Energy Review, which was published in April 2021 (IEA 2021a). Note that these data may have substantial uncertainty. Moreover, there are some differences in methodology compared to our primary source, especially with regard to what exactly is being measured; see IEA (2021a) for details.

Per capita CO_2 emissions (Figure 1l)

We converted total CO_2 emissions (Figure 1k) to per capita CO_2 emissions using FAOSTAT human population size estimates (Figure 1a).

Greenhouse gas emissions covered by carbon pricing (Figure 1m)

The data on percentage of greenhouse gas emissions covered by carbon pricing schemes are taken directly from World Bank Group (2020). When multiple schemes covered the same emissions, the emissions were associated with the earliest of the schemes. The data were accessed using the Carbon Pricing Dashboard. They were last updated on April 1, 2021.

Carbon price and share of greenhouse gas emissions covered by carbon pricing (Figure 1n)

These data were derived from World Bank Group (2020). To estimate the global carbon price, we used the average of the individual scheme prices weighted by the percentage of greenhouse gas emissions covered by each scheme. When multiple schemes covered the same emissions, the emissions were associated with the earliest of the schemes. The data were accessed using the Carbon Pricing Dashboard. They were last updated on April 1, 2021.

Fossil fuel subsidies (Figure 1o)

We obtained data on fossil fuel subsidies between 2010 and 2020 using the International Energy Agency subsidies database (IEA 2021b). Fossil fuel consumption subsidies are global totals in 2020 billion US dollars. They cover oil, electricity, natural gas, and coal.

Subsidy values are estimated using the price-gap approach, which involves comparing "average end-user prices paid by consumers with reference prices that correspond to the full cost of supply" (IEA 2021b). The subsidy amount is equal to the product of this price gap and the amount consumed (IEA 2021b).

Climate emergency declarations (Figure 1p)

We obtained data on climate emergency declarations from the International Climate Emergency Forum (ICEF) "Governments emergency declaration spreadsheet" (Climate Emergency Declaration 2021). These data track governments that have either declared or recognized a climate emergency. The first declaration in the dataset occurred on December 5, 2016. We converted these data to annual totals by considering only cumulative total declarations at the end of each year. For example, the total number of declarations by 2018 corresponds to the number of declarations made prior to December 31, 2018 (including those made in preceding years).

In the manuscript text, we present the number of countries in which one or more jurisdictions have declared a climate emergency. We obtained this information from the International Climate Emergency Forum (ICEF) "Governments emergency declaration spreadsheet" (Climate Emergency Declaration 2021).

Indicators of climate-related responses (Figure 2)

Atmospheric CO_2 (Figure 2a)

We obtained globally averaged monthly estimates of atmospheric CO_2 concentration from NOAA's Global Monitoring Laboratory (Dlugokencky & Tans 2021). Specifically, we used the dataset "Globally averaged marine surface monthly mean data." Note that data for the most recent year are subject to change; potential changes are typically minor. Beginning on February 10, 2021, these CO_2 data are on the WMO X2019 scale. See Global Monitoring Laboratory (2021) for details on the difficulty in attributing a change in atmospheric CO_2 concentration to COVID-19.

Atmospheric methane (Figure 2b)

We obtained globally-averaged monthly estimates of atmospheric methane (CH_4) concentration from NOAA (Ed Dlugokencky, NOAA/ESRL 2021). We used the "Globally averaged marine surface monthly mean data" dataset. These data are derived from measurements made at a global network of sampling sites that were smoothed across time and plotted versus latitude (Dlugokencky et al. 1994; Masarie & Tans 1995). The data are reported as a "dry air mole fraction" (Ed Dlugokencky, NOAA/ESRL 2021).

Atmospheric nitrous oxide (Figure 2c)

We obtained data on nitrous oxide (N_2O) concentration from the NOAA/ESRL Global Monitoring Laboratory ("Globally averaged marine surface monthly mean data") (Ed Dlugokencky, NOAA/GML 2021). These global monthly mean estimates are measured in parts per billion and are derived by smoothing data collected from a global network of airs sampling sites (Dlugokencky et al. 1994; Masarie & Tans 1995).

Surface temperature anomaly (change) (Figure 2d)

We obtained global monthly mean surface temperature anomaly data from the NASA GISS Surface Temperature Analysis (GISTEMP v4) dataset (GISTEMP Team 2021). We used the "Combined Land-Surface Air and Sea-Surface Water Temperature Anomalies (Land-Ocean Temperature Index, L-OTI)" "Global-mean monthly, seasonal, and annual means" variable. These temperature anomaly/change estimates combine land and ocean surface temperatures. The baseline period used for setting zero is the 1951-1980 mean.

Minimum Arctic sea ice (Figures 2e)

We obtained minimum Arctic sea ice estimates from (Wiese et al. 2019) NSIDC/NASA (2021). They are derived from satellite observations. For each year, the data indicate the average Arctic sea ice extent for the month of September, which is when the annual minimum occurs. According to NSIDC/NASA (2021), "Arctic sea ice reaches its minimum each September. September Arctic sea ice is now declining at a rate of 13.1 percent per decade, relative to the 1981 to 2010 average." For plotting purposes, we associated each observation with September 15 (the approximate midpoint of the month)

Greenland ice mass (Figure 2f)

We obtained total land ice mass change measurements for Greenland from Wiese (2019). These data show changes in ice sheet mass (in Gt) since April 2002. They come from NASA's GRACE satellites (GRACE and GRACE-FO JPL RL06Mv2 Mascon Solution). The data are in the form of anomalies relative to April 2002. The measurement frequency is roughly monthly. The gap in the data between June 10, 2017 and June 14, 2018 corresponds to the time between missions, and should be kept in mind when interpreting the year-to-date means that we present. For more details on these data, see Watkins et al. (2015).

Antarctica ice mass (Figure 2g)

We obtained total land ice mass change measurements for Antarctica from Wiese (2019). These data show the changes in ice sheet mass (in Gt) since April 2002. They come from NASA's GRACE satellites (GRACE and GRACE-FO JPL RL06Mv2 Mascon Solution). The measurement frequency is roughly monthly. The gap in the data between June 10, 2017 and June 14, 2018 corresponds to the time between missions, and should be kept in mind when interpreting the year-to-date means that we present. For more details on these data, see Watkins et al. (2015).

Cumulative glacier thickness change (Figure 2h)

We obtained cumulative glacier mass balance data from the World Glacier Monitoring Service (WGMS 2021). These data were derived from a database with information about changes in mass, volume, etc. of individual glaciers over time. They are based on averaging over a global set of reference glaciers and are measured relative to 1970.

The units of these data are meters of water equivalent. According to the World Glacier Monitoring Service, "A value of -1.0 [meter of water equivalent] per year is representing a mass loss of 1,000 kg per square meter of ice cover or an annual glacier-wide ice thickness loss of about 1.1 m per year, as the density of ice is only 0.9 times the density of water" (WGMS 2021).

For plotting, we associated each value with the midpoint of the corresponding year.

Ocean heat content (Figure 2i)

We obtained yearly (not pentadal) ocean heat content time series data from NOAA's National Centers for Environmental Information (NCEI) (NOAA 2021). These data are in units of 10^{22} joules and cover the depth range 0-2000 m. The reference period is 1955-2006 (Levitus et al. 2012).

For plotting, we associated each value with the midpoint of the corresponding year (as in the dataset).

Ocean acidity (Figure 2j)

As a proxy for global ocean acidity, we used a time series of seawater pH from the Hawaii Ocean Time-series surface CO2 system data product (HOT 2021). This data product was adapted from Dore et al.

(2009). The data were collected at Station ALOHA (22°45'N, 158°00'W). We used the variable “pHmeas_insitu,” which is described as the “mean measured seawater pH, adjusted to in situ temperature, on the total scale” (HOT 2021).

Sea level change (Figure 2k)

We obtained data on global mean sea level from GSFC (2021). The variable we used was “GMSL (Global Isostatic Adjustment (GIA) not applied) variation (mm) with respect to 20-year TOPEX/Jason collinear mean reference.” According to the dataset description, the “TOPEX/Jason 20 year collinear mean reference is derived from cycles 121 to 858, years 1996-2016” (GSFC 2021).

It should be noted that temperature increase and the warming of the entire ocean is a major contributor to sea-level rise (WCRP Global Sea Level Budget Group 2018).

Total area burned by wildfires in the United States (Figure 2l)

These data come from the National Interagency Coordination Center at The National Interagency Fire Center (National Interagency Coordination Center 2021) and include Alaska and Hawaii. The total for 2004 does not include state lands within North Carolina.

Climate Change Education

In this work, we have reviewed the six areas introduced by Ripple et al. (2020): energy, short-lived air pollutants, nature, food, economy and human population, around which transformative changes are needed to solve the climate emergency we live in. Here, we introduce one more dimension, climate change education, which we believe is ultimately needed to underpin changes in these six areas. The reluctance to take action on climate change is often explained by an information deficit model or the lack of experience of climate change events (Bell 2005; Lorenzoni & Pidgeon 2006; Akerlof et al. 2013; Reser et al. 2014; Demski et al. 2017). This puts climate change education as a "*big and bold policy*" that could catalyze the needed mitigation actions at multiple levels of society (Anderson 2012; Monroe et al. 2019). Ideally, effective policy related to climate change education requires not only a commitment to teach and learn but a commitment to act (Vaughter 2016). Broadly understood, climate change education should consider humans as individuals capable of changing their behaviours to reduce risks; integrate the economic, political, cultural, psychological, and emotional dimensions of climate change; and provide opportunities to engage in climate change adaptation and mitigation (Leichenko & O'Brien 2020).

Overall, climate change education results in higher awareness of climate change and it empowers learners to take action (Stevenson et al. 2017; Monroe et al. 2019). Democratic learning on climate change, as exemplified by Fridays for Future (FFF), has resulted not only in higher climate change awareness, but also in climate-friendly behaviours (Deisenrieder et al. 2020).

The flexibility of climate change education leaves a broad space for the creation of policies to promote it in very diverse contexts. Some countries, including Singapore, have introduced climate change education in the curriculum of school subjects (Chang & Pascua 2017). In America, citizens would endorse stronger climate change education (Pizmony-Levy & Pallas 2019). In a different context, weather attribution to climate change during daily weather forecasts (Edmond 2019), a policy that could be promoted in public television, has shown to result in science-based beliefs on climate change (Zhao et al. 2014). Even if we think that climate change education would only produce results in the long term, research shows that, on the contrary, positive behavior changes follow in the short term. More importantly, a population aware of the science and severity of climate change would be more inclined to support appropriate climate change policies now.

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