Climate Change: Answers to common questions

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Climate Change: Answers to common questions

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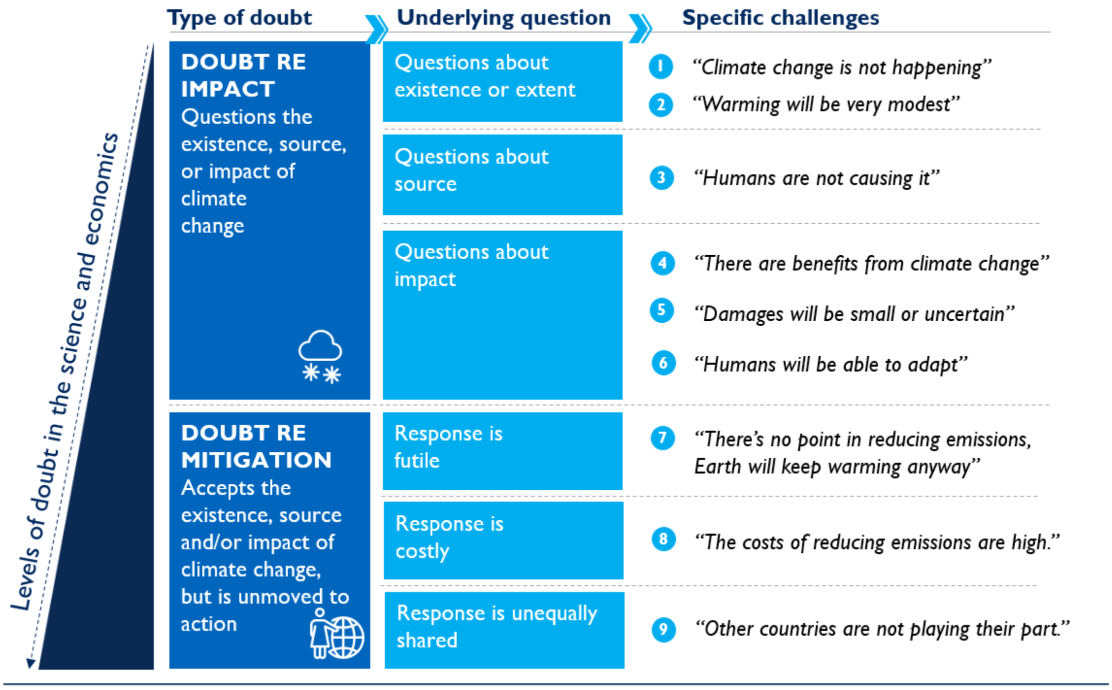
Overview

Uncertainty about climate science and economics poses challenges for business and finance. Reasonable and intelligent people frequently ask us for a reference document to set out what is known and not known about climate change, including research that is sometimes contrary to prevailing societal beliefs, if only to avoid to debates about areas that are settled and instead to direct attention to the areas where further research is valuable. We have structured the questions and answers into **nine areas of doubt** about climate science and economics that are commonly expressed. We also highlight key facts and estimates in which scholars have high levels of confidence. Each section begins with a common challenge about climate science of economics, expressed as a quotation.

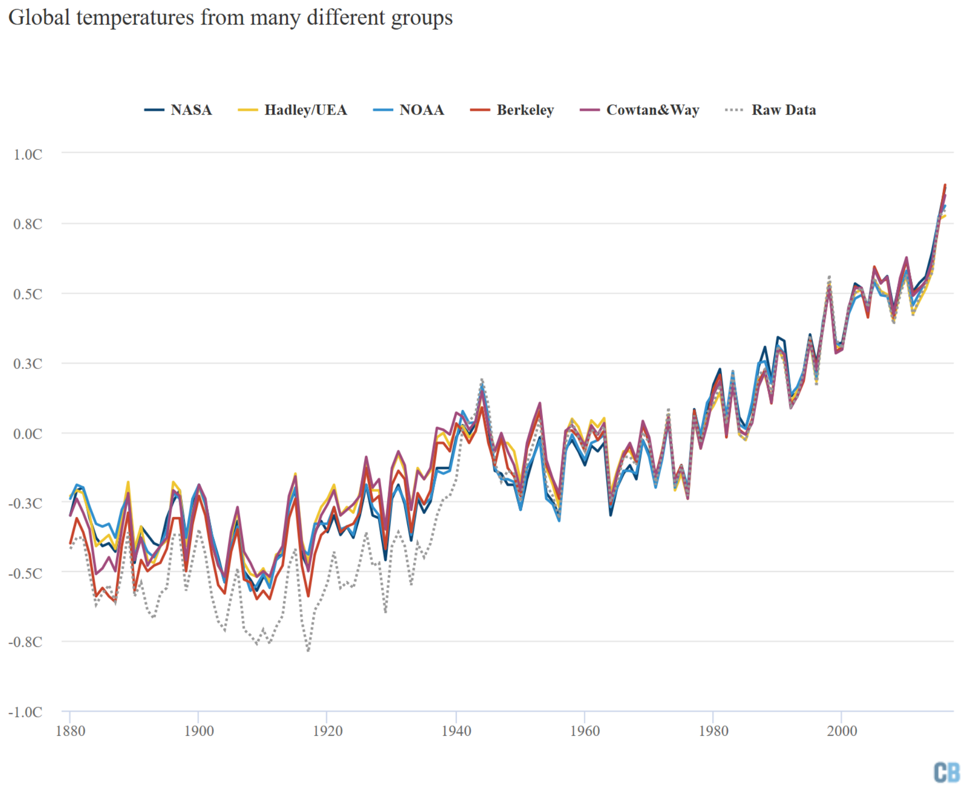


1. “Climate change is not happening”

“THE WORLD HAS NOT BECOME WARMER. ANY APPARENT TEMPERATURE INCREASE IS DUE TO ADJUSTMENTS TO THE DATA”

- The climate system has warmed about 1°C from pre-industrial levels (NASA, 2019). This warming is supported by multiple lines of evidence and unprecedented over decades to millennia. The atmosphere and the oceans have warmed, sea levels have risen and the amounts of snow and ice have decreased (IPCC, 2014).
- Historical data adjustments are undertaken for all major global surface temperature datasets. They are made to correct for moves in monitoring stations, an increase in the number of stations, instrument changes (e.g. how temperature over the oceans is measured), and changes in the time of observation. Temperature measurements would be less accurate without these adjustments (Hausfather *et al.*, 2016).

Figure 1. Global Temperature Anomalies from a range of datasets, as well as the raw data Source: Hausfather (2017).



Global mean surface temperatures from NASA, NOAA, Hadley/UEA, Berkeley Earth, and Cowtan and Way. Anomalies plotted with respect to a 1961-1990 baseline. Chart by Carbon Brief using Highcharts.

- Some claim that data revisions have been made that adjust up recent land temperatures but adjust them down in the early 1900s, resulting in a stronger warming trend (Ekwurzel, 2017). However, data adjustments have also been carried out on ocean surface temperatures due to changes in the measurement techniques. These adjustments have if anything reduced the overall rate of global warming compared to the raw data (Figure 1).
- Overall, researchers have found that adjustments do not affect the existence of the warming trend and irrespective of the adjustments, the global surface temperature increase swamps the noise from these well-studied factors (Brohan *et al.*, 2006).

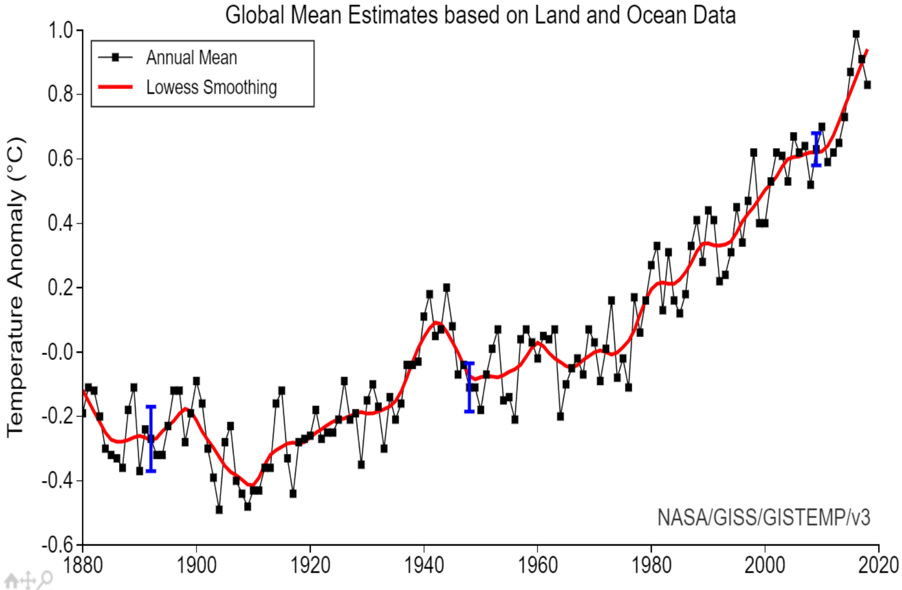
"THERE HAS BEEN A 15-YEAR PAUSE IN TEMPERATURE INCREASES"

- The rate of increase in global average temperature appeared to slow in some records between 1998 and 2012. This pause or 'hiatus' was the subject of great controversy and over 200 peer reviewed articles in scientific journals (Lewandowsky *et al.*, 2018).
- Updated ocean temperature measurements (Karl *et al.*, 2015) suggest that global temperatures in fact have not paused warming, corroborated by another study (Hausfather *et al.*, 2017).
- Warming increased again in 2013 to 2018, driven partly by the large 2015 to 2016 natural El Niño cycle (NOAA, 2018), highlighting that cherry-picking an arbitrary number of years to dispute the widely accepted long-term warming trend is not sustainable given the continued warming trend driven by human carbon emission.
- As Figure 2 demonstrates, average temperatures fluctuate but show a clear global warming trend.

"IT IS WARM/COLD TODAY. THEREFORE, CLIMATE CHANGE IS/IS NOT HAPPENING"

- Climate is the thirty-year average of the weather. The weather on any particular day is not an indicator of relevance to climate change trends (WMO, 2019).

Figure 2. Global Mean Estimates based on Land and Ocean Data (1880-2019)
Source: NASA Goddard Institute



"THERE IS NO TREND IN EXTREME EVENT OCCURRENCE."

- There is substantial regional variation when considering extreme events. More or fewer extreme events in one particular region or city is not indicative of global extreme event dynamics. The risks of extreme rainfall, drought and flood increase in some regions, but decrease in others with climate change (Otto *et al.*, 2018).
- Generally, a warmer planet implies more ambient energy and amplified risk factors for many extreme events. A warmer planet increases the rate of evapotranspiration, which has a direct effect on the frequency and intensity of droughts. Similarly, a warmer atmosphere can hold more water vapour increasing the potential for extreme rainfall events.
- A particular heatwave, flood, drought or other extreme event does not provide "proof" of climate change.
- However, scientists are increasingly using methods to estimate how human influence has shifted the probability of some extreme weather events occurring (Otto *et al.*, 2016; National Academies, 2016). Out of the 355 studies that have been published (and analysed by CarbonBrief, 2020 as of April 2020), 79 studies have found a clear human influence (Otto et al., 2012; Stott et al., 2016). Of course, it is important to note that there is a certain selection bias with regard to which extreme events are analysed, with an a priori suspicion of anthropogenic influence possibly playing a role.
- The IPCC Climate Change Synthesis Report (IPCC, 2014) finds that:

- It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale.
- It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia.
- It is likely that human influence has more than doubled the probability of occurrence of heat waves in some locations.
- There is medium confidence that the observed warming has increased heat-related human mortality in some regions.
- Recent detection of increasing trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (medium confidence).
- It is likely that extreme sea levels (as experienced for example in storm surges) have increased since 1970, being mainly a result of rising mean sea level.

"LEAKED E-MAILS REVEAL THAT SCIENTIST ARE MANIPULATING DATA"

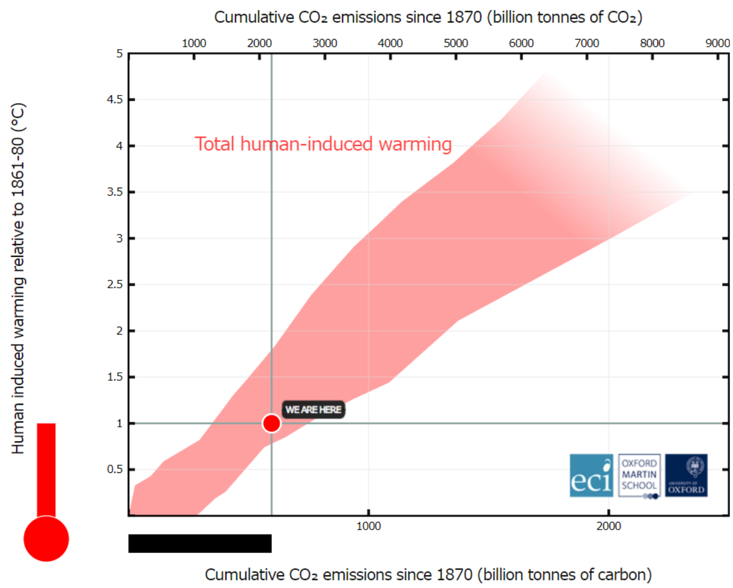
- A number of independent investigations from different countries were launched into the concerns around leaked emails from the University of East Anglia in 2009. The emails consisted mainly of conversations among colleagues that some people claimed constitute evidence that scientists were trying to hide a decline in real temperatures. These investigations found as follows:
  - The National Science Foundation (2011, p. 5) concluded: *"no research misconduct or other matter raised by the various regulations and laws discussed above, this case is closed."*
  - An International Scientific Assessment Panel set up by the University of East Anglia, in consultation with the Royal Society (Oxburgh *et al.*, 2010, p. 5) found: "*no evidence of any deliberate scientific malpractice in any of the work of the Climatic Research Unit."*
  - Final Investigation Report by the Pennsylvania State University (Assmann *et al.*, 2010, p. 19): "*there is no substance to the allegation against Dr. Michael E. Mann."*
  - United States Environmental Protection Agency (2010, p. 1): *"found this was simply a candid discussion of scientists working through issues that arise in compiling and presenting large complex data sets."*

2. “Warming will be very modest.”

“WARMING MIGHT END UP BEING 1.5°C”

- Warming since 1861-1880 is now around 1°C (NASA, 2019).
- Assuming a path of global emissions based on current levels of effort, estimates suggest global temperature could rise by around 3°C (estimated range 2.3°C – 4.1°C) by the end of the century (Climate Action Tracker, 2019)
- Keeping warming to less than 1.5°C is not physically impossible, depending upon the climate response and upon human actions (Millar *et al.*, 2017). Given existing fossil infrastructure, however, it currently appears unlikely that such goals will be achieved without major additional action (Pfeiffer *et al.*, 2018).
- On this topic, the IPCC Special report on Global Warming of 1.5°C (Masson-Delmotte *et al.*, 2018, p.15) states that “Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (*high confidence*). These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed”.
- For a greater than 66% chance of keeping warming to under 1.5°C, net human emissions could continue at present levels for a decade or so before they would need to suddenly fall to net zero to stabilize temperatures. (Near net-zero emissions is required to stabilize temperatures at any level (Matthews & Caldeira, 2008)). Alternatively, net emissions might be reduced linearly to zero over a period of two decades or so.
- For a greater than 66% chance of keeping warming under 2°C, net human emissions could continue at present levels for ~25 years before they would need to suddenly fall to net zero. Alternatively, net emissions might be reduced linearly to zero over a period of four decades or so. (Millar *et al.*, 2017).
- There is significant uncertainty in these estimates (illustrated in Figure 3 below).

- **Figure 3. Human induced warming and cumulative CO_2 emissions. Source: http://www.safecarbon.org/**



3. "Humans are not causing climate change."

"THE CLIMATE HAS ALWAYS BEEN CHANGING, AND WELL BEFORE HUMANS WERE AROUND"

- Earth's climate has always been changing. Earth has been in a long-term cooling trend for the past 50 million years (Hansen & Sato, 2012). However, over the past 420,000 years, Antarctic air temperatures (in the Vostok ice cores) are estimated to have been ~8°C cooler and ~2°C warmer at various times than today (Petit *et al.*, 1999).
- These changes in average temperature on Earth have had geographical consequences. For instance, in the last glacial maximum (21,000 years ago), global average temperatures were 3-7°C lower and Arctic ice sheets covered most of Britain and extended down to Northern Germany (Clark & Mix, 2002).
- Human civilization has developed in a stable and relatively warm climate epoch since the last glacial maximum (the Holocene).
- These temperature variations were caused by various long-term geophysical dynamics, such as changes in the Earth's orbit and tilt, but they were occurring at time scales several orders of magnitude slower than the changes we have been observing in the Earth's climate over the past centuries. The current rate of warming (post industrial revolution) is historically unprecedented (Waters *et al.*, 2016).

"We don't know how emissions are affecting temperatures"

- Carbon dioxide traps infra-red radiation, such as that emitted from the surface of Earth. This can be measured (Foote, 1856; Tyndall, 1861) and has been confirmed by decades of laboratory measurements (Jokimäki, 2009). The precise relationship between total CO_2 emissions and total warming is uncertain. The relationship is roughly linear (at current CO_2 concentrations); the uncertainty is shown in the coloured plume in Figure 3.
- Uncertainty arises from various feedbacks, including how cloud formation and movement is affected by temperature and vice versa. But natural cloud variation has not caused climate change, as has been suggested (Dessler, 2011; Borenstein, 2011).
- Further uncertainty is caused by the amount of total incoming solar energy absorbed by the Earth. These include changes in the coverage of ice sheets (Clark *et al.*, 1999) and vegetation (Cox *et al.*, 2000).

"Increase in temperature causes increases in CO_2, not the other way around"

- There is a marked correlation between temperature and CO_2. Yet, correlation is not causation.
- Because CO_2 traps heat (see above), physics suggests that more atmospheric CO_2 would cause increased temperatures. Along these lines, the high surface temperature of Venus is thought to have been caused by a greenhouse effect caused by very high CO_2 concentrations (Pollack *et al.*, 1980).
- Causation in the reverse direction (increases in temperature increasing CO_2) is actively researched but would generally occur at vastly different time scales. It is noteworthy that in ice core records, temperatures often increased *before* CO_2 concentrations increase (Barnola, 2003; Caillon, 2003; Fischer *et al.*, 1999).
- The current status is that there is evidence of dual causality – an increase in CO_2 can increase temperature and vice versa (Lorius et al., 1990; Martin, 2005; Cuffey & Vimeux 2001). But it is known that human emissions of CO_2 are currently driving warming, rather than warming driving CO_2, because of the ratios of different types (isotopes) of carbon (^{13}C to ^{12}C) found in fossil fuels (Quay *et al.*, 1992; Levin & Hesshaimer, 2000).

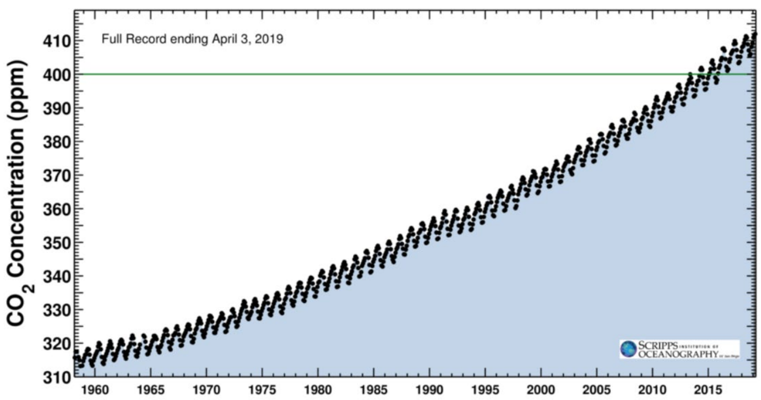
"HUMAN CO_2 EMISSIONS ARE INSIGNIFICANT COMPARED TO NATURALLY-OCCURRING PROCESSES"

- The proportion of different types (or isotopes) of carbon emitted from fossil fuels is different to that occurring in the natural carbon cycle. This enables scientists to be sure that almost all of the recent increases in CO_2 in the atmosphere is from old fossil carbon emitted by human activities (Levin & Hesshaimer, 2000).
- There are many natural sources and sinks of CO_2. Natural flows of CO_2 between the atmosphere and oceans are much larger than fossil carbon emissions. However, the natural sources and sinks are finely balanced, and emissions from fossil carbon are large compared to the net impact from natural sources (Falkowski, 2000), meaning that CO_2 is accumulating in the atmosphere (see Figure 4).
- The oceans will also absorb CO_2 more slowly as more CO_2 is dissolved in them, and more slowly as they warm (Sarmiento *et al.*, 1998; McKinley *et al.*, 2017).

"CO_2 LEVELS FLUCTUATE NATURALLY ANYWAY"

- There is a natural annual oscillation in atmospheric CO_2 levels, caused by the seasonal growth and receding of vegetation (Keeling, 1960). These annual oscillations are small compared to trend, as shown in Figure 4 below. There is also an oscillation in CO_2 levels between interglacial periods, but again these oscillations occur at much slower timescales than the changes observed today (Martin, 1990; Zeng, 2003).

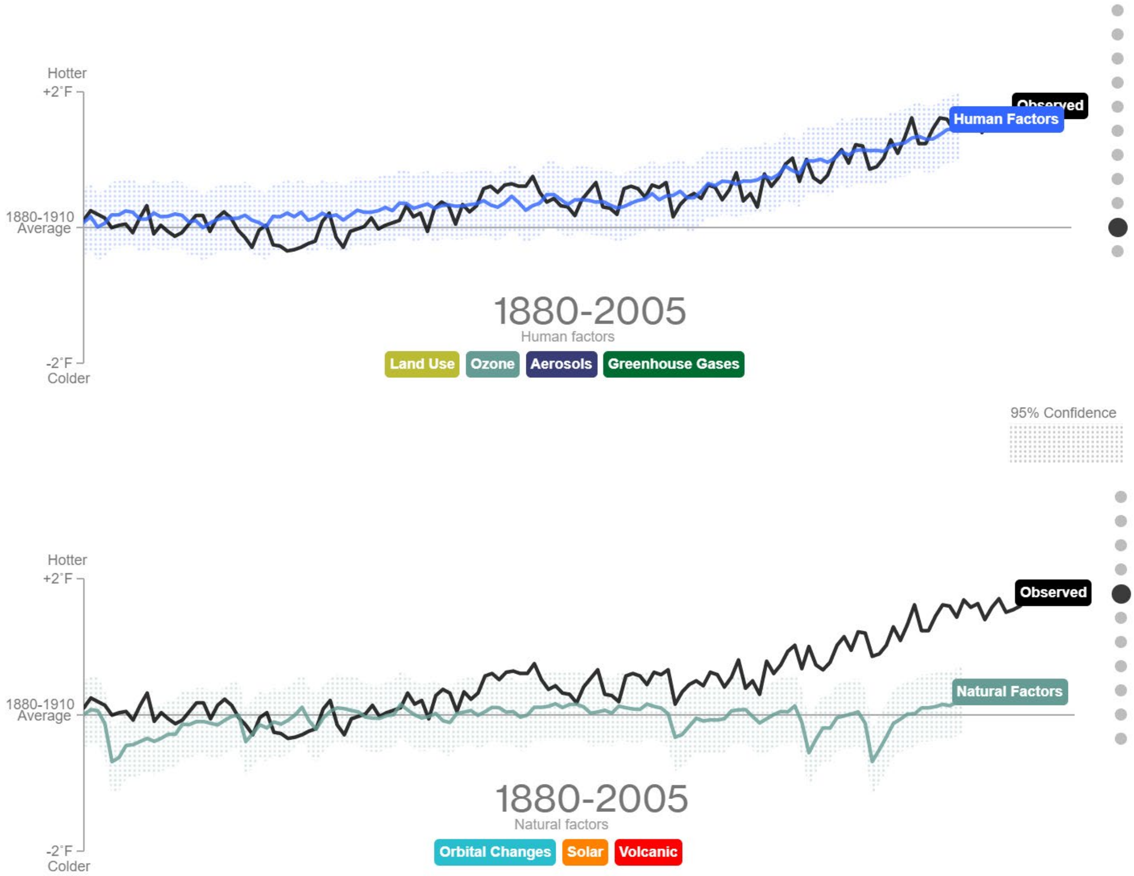
Figure 4. Measured concentrations of CO_2 showing annual oscillations.
Source: Scripps Institute (2019)



“ANY WARMING IS DUE TO THE SUN AND OTHER NATURAL DRIVERS, NOT DUE TO HUMAN CO_2”

- Natural factors affect the climate.
- Variation in natural factors like volcanic eruptions and solar variability does not explain the warming trend observed since the industrial revolution.
- Scientific models of global temperature change attribute 1.01°C of warming between 1850-79 and May 2017 to human emissions (5-95% confidence interval is +0.87 to +1.22 °C). Essentially all the observed warming is attributed to human activities; natural factors such as volcanoes have actually slightly decreased the net amount of warming (Haustein *et al.*, 2017).
- Solar fluctuations have contributed to observed warming since 1950. However, the magnitude of the contribution is small, about 0.1°C at most (Lean & Rind, 2008; Foster & Rahmstorf, 2011). The increase in global surface temperature has been largest since 1980 – a time during which solar activity has been decreasing (Lockwood, 2008).
- Bloomberg provides a dynamic interactive version of the finding that the observed increase in temperatures is driven by human rather than natural factors (see Figure 5 as a static example):

Figure 5. Contributions of human and natural factors to warming.
Source: Bloomberg Business Week



4. "There are benefits from climate change."

"MORE CO_2 WILL HELP TREES GROW AND WILL GREEN THE EARTH"

- Higher CO_2 concentrations directly increase plant growth, ignoring other climate impacts (Kimball, 2016), however, the biosphere is projected to be severely impacted by a changing climate, possibly reducing its overall capacity to absorb CO_2 from the atmosphere (Körner, 2000).
- Science on agricultural impacts shows that climate change has overall had a negative impact on crop yields (Schleussner *et al.*, 2018), in part due to increased heat and water stresses (Lobell *et al.*, 2011), and in part due to damages to biodiversity (Bélanger & Pilling, 2019). This trend is projected to continue, with a ~7% net yield reduction for staple crops (wheat, rice, maize, and soybean) for every 1°C temperature increase (Zhao *et al.*, 2017).

"OPPORTUNITIES WILL OPEN UP IN NORTHERN LATITUDES"

- As Arctic ice melts, the Northwest Passage opens, cutting shipping distance from Asia to Europe by 7,000 km.
- New fossil reserves may be recoverable in the Arctic as the ice retreats, but these will be relatively expensive to existing fossil reserves (Emmerson & Lahn, 2012).
- More arable land is likely to be available in Russia, Canada, and Northern United States (Zabel *et al.*, 2014). However, decreases in agricultural land in the global south (Im *et al.*, 2017), and Central America, will outweigh the increases in viability in the global north, creating risks of food shortages and international security challenges (NATO, 2015).
- There will be fewer deaths of those vulnerable to extreme cold in the Northern Hemisphere, however, a greater number of heat wave deaths outweighs those saved by warmer northern winters (Gasparrini *et. al.*, 2017) considerably. The net impacts will vary according to region (Vicedo-Cabrera *et al.*, 2018).
- Warmer winters in northern regions will reduce energy demand for heating by 34% by 2100, but would be more than offset by a 72% increase in cooling demand (Isaac & Van Vuuren, 2009).

5. "Damages from climate change will be small or uncertain."

"WARMING BY 2°C ISN'T VERY SIGNIFICANT"

- Global mean warming hides regional variation, and large shifts in extreme events. Elements of the climate system are capable not only of steady, gradual change over long periods, but also of rapid, non-linear change when critical thresholds are passed. Some may result in abrupt further temperature increase and some may be irreversible (Bathiany *et al.*, 2018).
- There is uncertainty over when, or at what degree of global temperature rise, these tipping points might be triggered, however evidence suggests that some may be tipped should we cause more than 2°C warming, and many if we cause more than 3°C warming (Masson-Delmotte *et al.*, 2018).
- Scientists are working on identifying early warning signals for such tipping points (Lenton *et al.*, 2012).
- For some of these changes, the magnitude of impact is estimated to be very high. For example, a complete thaw of permafrost carbon stores could release up to 5,500 Gt CO_2, or roughly 2 times the total amount of CO_2 in the atmosphere today (Shurr *et al.*, 2015).

- In addition to the risk of non-linear thresholds and tipping points, a set of risks is set out in Figure 6 from the Chief Risk Officer Forum (CRO Forum, 2019).

Figure 6. Indicative summary of possible impacts for different levels of warming by 2100 Source: (partial extract) CRO Forum, 2019, p 5.

Warming by 2100	<2 °C		3 °C	5 °C
Physical impacts	1.5 °C	2 °C		
Sea-Level Rise (cm)	0.3-0.6 m	0.4-0.8 m	0.4-0.9 m	0.5-1.7 m
Coastal assets to defend ($tn)	$10.2tn	$11.7tn	$14.6tn	$27.5tn
Chance of ice-free Arctic summer	1 in 30	1 in 6	4 in 6 (63%)	6 in 6 (100%)
Tropical cyclones: Fewer (#cat 1-5)	-1%	-6%	-16%	Unknown
Stronger (# cat 4-5)	+24%*	+16%	+28%	+55%
Wetter (total rain)	+6%	+12%	+18%	+35%
Frequency of extreme rainfall	+17%	+36%	+70%	+150%
Increase in wildfire extent	x1.4	x1.6	x2.0	x2.6
People facing extreme heatwaves	x22	x27	x80	x300
Land area hospitable to malaria	+12%	+18%	+29%	+46%
Economic impacts				
Global GDP impact (2018: $80tn)	-10%	-13%	-23%	-45%
Stranded assets	Transition: fossil fuel assets (supply, power, transport, industry)		Mixed: some fossil fuel assets mothballed, some physical stranding	Physical: uninhabitable zones, agriculture, water-intense industry, lost tourism etc
Food supply	Changing diets, some yield loss in tropics		24% yield loss	60% yield loss, 60% demand increase
Insurance opportunities	New low-carbon assets and infrastructure investment (e.g. CCS)		Increasing demand to manage growing risks	Minimal: recession, tensions, high and unpredictable risks

"THE IMPACTS ARE SMALL"

- It is possible that the economic impacts of climate change will be single digit percentages of GDP, but it is also possible that the economic impacts will be extremely damaging (Burke *et al.*, 2015; Pretis *et al.*, 2018). Given the risk of catastrophic impacts, economists conclude that hedging those risks is optimal (Litterman, 2013; Daniel *et al.*, 2016).
- Globally, protecting the coast with dikes has been estimated to require annual investment and maintenance costs of US$ 12–71 billion in 2100, which is much smaller than the global damages that can be avoided with these measures (Hinkel *et al.*, 2014).

- It is likely that there will be significant impacts on agriculture, because an estimated 4% of the global terrestrial land area will change its ecosystem type at 1.5°C, and 13% at 2°C (Hoegh-Guldberg *et al.*, 2018), and an estimated 18% of insects, 16% of plants, and 8% of vertebrates are projected to lose over half of their climatically determined geographic range under 2°C warming (Warren *et al.*, 2018). However, some projections envisage 'peak farmland' demand in the coming decades, driven by increasing efficiencies and declining population growth (Ausubel *et al.*, 2013).
- At 4 °C global warming, humid heat waves with apparent temperatures over 55 °C (above that ever recorded and likely to cause heat stroke) would be expected every second year (Russo *et al.*, 2017).
- If global average temperature increase exceeds 6°C, wet-bulb temperatures will begin to permanently exceed skin temperature in some areas of the globe (i.e., the human body will lose its ability shed heat as sweating is ineffective), precluding any outdoor activities in those areas. Temperature rise exceeding 10°C would expose most of the large populated areas of Earth to these conditions. (Sherwood & Huber 2010).
- Outdoor labour productivity appears to be negatively affected well before heat stroke occurs (Sahu *et al.*, 2013).

"CLIMATE CHANGE HAS LITTLE TO DO WITH NEAR-TERM BUSINESS RISKS"

- Emissions of CO_2 accumulate in the atmosphere over time, implying that climate change involves greater impacts in the far term than the near term. Many of the largest risks and impacts are projected to materialise by 2050 or 2100, but there are also very significant business risks in the shorter term (Woetzel, 2020).
- Short-term impacts are related to fossil fuel use rather than climate change directly: air pollution, often from fossil fuels, kills 5.5 million people globally per annum (Global Burden of Disease, 2016). In the USA, around 200,000 people per annum die early from air pollution, which economists have monetized as being equivalent to losses of US$250 billion per annum (Caiazzo *et al.*, 2013).
- Losses from extreme weather events in 2017 were estimated at US$330 billion, although of course these are not all directly attributable to climate change. Insurance covered less than half of those costs, "leaving a global protection gap of US$192 billion" (Swiss Re, 2018).
- Near term risks for business include policy changes intended to reduce future impacts.

“MODELS OF ECONOMIC DAMAGE ARE HOPELESSLY UNCERTAIN AND DON’T TELL US ANYTHING”

- Economic models of climate change, referred to as Integrated assessment models (IAMs) are widely considered to be weak (Farmer *et al.*, 2015). Such models attempt to combine climate science, climate impacts and economic models to project the costs and benefits of different temperature changes.
    - These models tend to calculate first-order or “direct” impacts of climate change (such as damages due to extreme weather events or heat stroke), and neglect effects due to migration, conflict (Hsiang *et al.*, 2013), and long-lasting catastrophes.
    - IAMs tend to assume that climate change will not affect overall economic growth rates, but large temperature changes are expected to negatively affect economic growth (Pindyck, 2013).
    - IAMs generally do not account for permanent damages to capital stocks or long-term decreases in productivity or the rate of technological development, all of which could be incurred by climate change (Stern, 2013).
    - Models have also underestimated the rate of development of clean energy technology, making energy transitions appear overly costly (Creutzig *et al.*, 2017).

6. “Humans will be able to adapt.”

“HUMANS HAVE ADAPTED TO MUCH GREATER CHALLENGES”

- Humans will adapt to climate impacts using technologies like dykes, improved flood management, storm-proofed buildings, and air conditioning. Hot days have a lower economic impact in areas where heat stress is common (e.g. Houston) compared to those where it is not (e.g. Boston), suggesting that long-run adaptation might be viable (Heal & Park, 2016).
- However, most research shows that adaptation cannot eliminate all negative effects (Adger *et al.*, 2009; Moser & Ekstrom, 2010; Dow *et al.*, 2013).

“SOLAR GEOENGINEERING WILL SOLVE CLIMATE CHANGE”

- Recent modelling suggests that a solar radiation management programme (i.e. reducing incoming sunlight) could temporarily reduce human-induced warming by about half (Irvine *et al.*, 2019).

- The relevant effects and consequences of various forms of geoengineering (such as impacts from spraying sulphur aerosols into the stratosphere) on the global climate and the biosphere are still highly unclear, with possible increases of tropical cyclone frequency and geopolitical challenges highlighted in the literature (Jones *et al.*, 2017).
- Effects such as 'termination shock,' in which there is very rapid global warming after a solar geoengineering programme halts suddenly, could pose significant risks (Trisos *et al.*, 2018). Solar geoengineering would not counteract the impacts of ocean acidification, caused by absorption of atmospheric CO_2 by seawater.

7. "There's no point in reducing emissions, Earth will keep warming anyway."

"WE'VE STARTED A PROCESS WE CAN'T STOP, SO WE MIGHT AS WELL KEEP EMITTING"

- The maximum average global temperature reached is affected by atmospheric CO_2 (and other greenhouse gas) concentrations. If other atmospheric gases and conditions remain constant, increases in CO_2 will increase temperatures.
- 75% of CO_2 that reaches the atmosphere will persist there for ~300 years, with up to 25% remaining in the atmosphere for up to 10,000 years – hence warming is permanent on timescales relevant to humans.
- In order to halt warming, humans will need to eventually reduce net CO_2 emissions to (very close to) zero (Wigley, 2018).
- Efforts to stabilize temperatures by reducing net human emissions to zero should be successful provided there are no major active feedback loops; these feedback loops become more likely at higher temperatures (Lowe & Bernie, 2018).

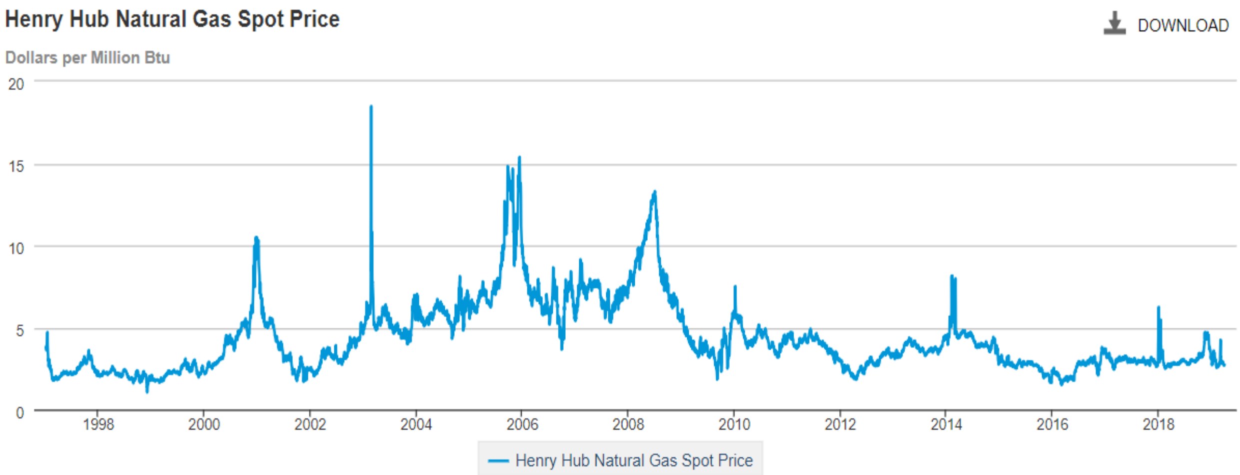
8. "The costs of reducing emissions are very high."

"VAST SUMS HAVE BEEN SPENT ON RENEWABLES AND THEY ARE STILL MORE EXPENSIVE"

- Global renewable energy subsidies are approximately in the order of US$100 billion each year, excluding the implicit subsidy that renewable energy often receives by way of public spending on electricity grid connections and costs for the management of intermittency.
- Global fossil-fuel consumption subsidies tend to be around US$100 to US$500 billion each year, depending upon fossil energy prices. Subsidies in 2017 were estimated to be around US$300 billion (IEA, 2018).

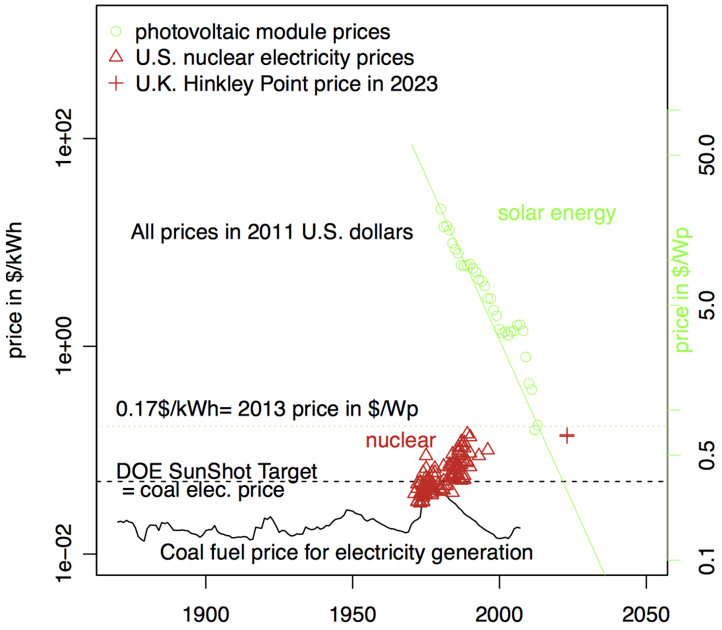
- If the costs of damage to the environment are included as an implicit subsidy, the subsidy to fossil fuels is around US$5 trillion each year (Coady *et al.*, 2015). Note, however, that fossil fuels currently provide significantly more energy – indeed the vast majority – for the global economy.
- Technological progress in horizontal drilling and hydraulic fracturing have led to significant declines in the cost of oil and gas extraction from 2008 onwards in the USA, as shown in Figure 7.

Figure 7. Two decades of US natural gas prices.
Source: (US Energy Information Agency, 2019)



- Viewed over the long-term (see Figure 8), the cost of fossil fuels has been approximately stationary in real terms for around 100 years (Farmer & Lafond, 2016), compared to increases in the costs of nuclear and declines in the cost of solar PV.

Figure 8. Long-run costs of electricity generation inputs.
Source: (Farmer & Lafond, 2016)



- The costs of solar PV have been falling at an average rate of 10% p.a. (Farmer & Lafond, 2016). There have been similar consistent cost declines in wind energy (both onshore and offshore) and batteries. Solar PV and wind costs have fallen 89% and 70% since 2009, respectively (Lazard, 2019).
- Even without subsidies, new renewables can now be cheaper than the construction of new fossil fuel power plants (depending on location and system). Lazard, 2019 estimates that the lower bound estimates for wind (28 US$/MWh) and solar PV (32 US$/MWh) are now cheaper than the same estimates for coal (66 $/MWh), and gas combined cycle plants (44 $/MWh).
- Decarbonising the first 50 to 60 percent of power systems is already potentially cheaper than fossil fuel generation (Finkelstein et al, 2020).
- In some locations, total costs for new wind and solar PV installations are now lower than marginal costs of conventional power plants, seriously challenging the profitability of fossil fuel electricity generation.
    - Full cost analysis requires adjusting these costs for all externalities (deaths from air pollution from fossil fuels, grid balancing for renewables, damages from climate change), which will vary by location and electricity system. Grid balancing costs are expected to increase as renewables penetration increases.

- Large investments are needed more generally (beyond the power sector) in low-carbon infrastructure, which is expensive if forced as a retrofit. However, the overall cost of new low-carbon infrastructure is roughly the same as new high-carbon infrastructure (New Climate Economy, 2016).
- The costs of decarbonising during the COVID-19 induced recession may be even lower given greater unused capacity in the economy. Central bank and finance ministry officials see such action as desirable, and a green recovery might achieve economic objectives, including job creation, more successfully than a brown recovery (Hepburn *et al.*, 2020).
- Estimates of the costs of decarbonizing the entire economy remain preliminary; some sectors (such as long-term energy storage, industrial heat, aviation) require technological and cost advances before costs are likely to be low enough to be politically feasible.
    - For instance, a complete retrofit of a domestic house in the United Kingdom is unlikely, currently, to yield an economic return on energy savings alone without government subsidy or regulatory intervention.

"WE SHOULD JUST REMOVE CARBON DIOXIDE FROM THE AIR INSTEAD"

- It is possible to pull CO_2 back out of the air (Kriegler *et al.*, 2017), termed "Direct Air Capture" (DAC).
- The removed CO_2 could potentially serve as a useful input into new and existing manufacturing processes (Hepburn *et al.*, 2019).
- Removing CO_2 from the atmosphere currently cost perhaps US$92 to US$232 per tonne of CO_2, and costs might be expected to fall over time (Keith *et al.*, 2018).
- While DAC may help address climate change, it is unlikely to be economically sensible to create a global industry capable of removing CO_2 at the same scale and pace as we are currently emitting it. It is generally expected that not emitting CO_2 in the first place is cheaper than removing it afterwards.
- Further, to provide a long-term solution to climate change, the CO_2 removed would need to be permanently stored in a manner so that it cannot return to the atmosphere.
- If such efforts used trees and other agricultural methods, they could potentially use a significant fraction of global agricultural land (Smith *et al.*, 2015), although land might become available with efficiencies in farming (Ausubel *et al.*, 2013).

9. “Other countries are not playing their part.”

“CHINA IS THE WORST POLLUTER AND THEY ARE NOT DOING ANYTHING”

- China is the largest current polluter in total. Per capita, China emits less than half the emissions of the USA. Since the industrial revolution, the USA has had the highest cumulative emissions (Frumhoff *et al.*, 2015; Baer *et al.*, 2000).
- China has the largest solar, wind, nuclear and hydro deployment programme in the world (IRENA, 2016; IEA, 2017) and is in the process of implementing a CO_2 trading scheme (World Bank & Ecofys, 2018). In 2015, China accounted for 36% of the global total renewable energy investment, with over half of the world’s new solar capacity in 2017 (BNEF, 2018).
- However, China is also continuing to build new coal-fired power plants, with the China Electricity Council having suggested that another nearly 300 GW may be built, to reach a cap of 1,300 gigawatts (GW) of capacity in 2030 (Shearer *et al.*, 2019).

“OTHER COUNTRIES ARE NOT ON BOARD”

- 197 countries have signed the Paris Agreement committing to keep temperatures “well below 2°C” and they will “pursue efforts” to 1.5°C. As of 2020, 189 countries have ratified the agreement (United Nations, 2020).
- The USA declared that it will exit the Paris Agreement (going into effect on November 4th, 2020) but many subnational governments within the US have made pledges to uphold the targets (UNFCCC, 2017, Hale *et al.*, 2018).
- Many of the actual commitments under Paris Agreement are modest, and many of these are not being delivered upon (Victor *et al.*, 2017), although a number of countries have announced their intention to scale up their climate action ahead of COP26 with now 73 Parties to the Paris Agreement working towards achieving Net-Zero emissions by 2050 (Benson Wahlén, 2019).
- The Paris Agreement architecture allows for multiple levels of action, including action by corporations, states and cities. Climate action pledges have been taken by 6,225 companies and 7,000 cities headquartered in over 100 countries, representing US$36.5 trillion in revenue, larger than the combined GDP of the US and China. Together these pledges account for reductions of 1.5 - 2.2 $GtCO_2eq$ by 2030 (UN Environment, 2018).

“COUNTRIES ARE MAKING PLEDGES BUT NOT DOING ANYTHING”

- Overall, Earth is on track to warm 3°C (estimated range 2.3°C - 4.1°C) (Climate Action Tracker, 2019), if current policies were to be implemented.
- Global CO_2 emissions are still increasing; the estimated increase was 2.7% in 2018 (Global Carbon Budget, 2018).
- Progress varies across countries. Chinese emissions are projected to have increased by 4.7% in 2018 (Global Carbon Budget, 2018), while EU28 emissions fell 0.7% – the EU is the only major global region to be reducing emissions. The United Kingdom has reduced emissions from around 800 Mt CO_2eq in 1990 to around 500 Mt CO_2eq today, with a legal requirement to reduce emissions to Net-Zero by 2050 (UK Statutory Instruments, 2019).
- More than 52 other countries, states, and provinces have joined an agreement to completely phase out coal before 2030 (Powering Past Coal Alliance, 2018). In particular:
    - The UK Secretary of State announced in 2015 that coal-fired power will be closed entirely by 2025; and coal has already declined from 11.4 million tonnes in 2010 to 1.9 million tonnes in 2017 (Twidale, 2015; UK Energy Brief, 2018).
    - The Canadian Government announced in 2018 that coal-fired power will be phased out and closed entirely by 2030 (Government of Canada, 2018).
    - The German Government announced in 2019 that coal-fired power will be phased out and closed entirely by 2038 (Wacket, 2019).
- Carbon prices are now in place in 52 countries and 24 subnational regions, raising $79.62 billion of revenue in 2018, and covering roughly 20%of global emissions (World Bank, 2019). Most carbon prices in such schemes are far too low to deliver the necessary abatement.
- Since 2016, investment in renewable energy has exceeded than in fossil fuels. In 2018, global clean energy investment exceeded $300 billion for the fifth year in a row, and there was a record 100 GW of photovoltaic capacity installed (UNEP/BNEF, 2019).

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