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Climate change: Answers to common questions

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Oxford Smith School of Enterprise and the Environment

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Foreword

Amid the ongoing debate about climate change, investors often fail to appreciate the sheer weight of scientific evidence attesting to humanity's impact on the planet.

Equally, they might not know where further research is required before firm conclusions can be reached about how best to contain or reverse global warming.

This paper – authored by Oxford University and sponsored by Pictet – seeks to give a brief but firm grounding on the current state of knowledge about climate change, its implications and what sort of solutions might be possible.

Written in thoughtful, clear and unemotive language by Professor Cameron Hepburn and Moritz Schwarz of the university's Smith School of Enterprise and the Environment, it is an important resource for those of us who are not climate change specialists.

It addresses several contentions – that climate change is not happening or that, if it is, it will be mild – or that, in any event humans are not causing it. The authors also address questions about the impact of climate change – whether there might be benefits, the scale of likely damage, and humans' ability to adapt.

It's a document we at Pictet are proud to have sponsored. We understand that climate change affects all of our futures, wherever we are in the world, whatever our standing.

The better we all understand the settled facts, the better we can not only plan for the future, but change its course for the better.

Laurent Ramsey

Managing Partner
of Pictet Group

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 debates about areas that are settled and instead to direct attention to the areas where further research is valuable.

We have structured this document into *nine areas of doubt* commonly expressed about climate science and economics, each of which is broken down into points of contention. 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 and economics, expressed as a quotation.

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**Levels of doubt
in the science and economics**

Type of doubt	Underlying question	Specific challenges
DOUBT RE IMPACT	QUESTIONS ABOUT EXISTENCE OR EXTENT	1 "Climate change is not happening"
		2 "Warming will be very modest"
	QUESTIONS ABOUT SOURCE	3 "Humans are not causing climate change"
	QUESTIONS ABOUT IMPACT	4 "There are benefits from climate change"
		5 "Damages from climate change will be small or uncertain"
		6 "Humans will be able to adapt"
DOUBT RE MITIGATION	RESPONSE IS FUTILE	7 "There's no point in reducing emissions, Earth will keep warming anyway"
	RESPONSE IS COSTLY	8 "The costs of reducing emissions are very high"
	RESPONSE IS UNEQUALLY SHARED	9 "Other countries are not playing their part"

Degree of doubt: Lower → Higher

1

“Climate change is not happening”

Dead trees in flooded forestlands
as a result of dam construction
on the Rio Araguari, approximately
50 miles north of Macapa,
Brazil, 2017.

"The world has not become warmer. Any apparent temperature increase is due to adjustments to the data"

The average global surface temperatures have risen about 1°C from pre-industrial levels.[1] There are multiple lines of evidence for this warming, and the magnitude of warming is unprecedented over periods ranging from decades to millennia. The evidence is clear that the atmosphere and the oceans have warmed, sea levels have risen and the amounts of snow and ice have decreased.[2]

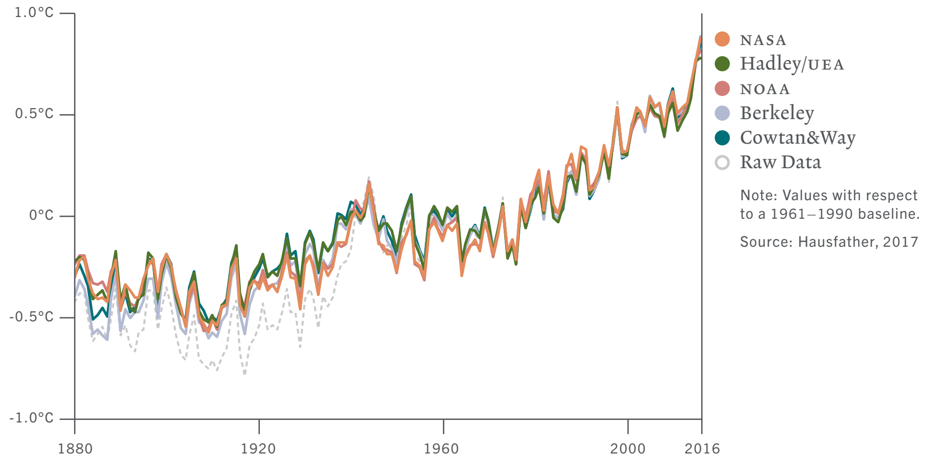
All major global surface temperature data sets have been subject to historic data adjustments. These adjustments have been made to correct for moves in monitoring stations, an increase in the number of stations, instrument changes (e.g. how temperature over the oceans is measured), and changes in the time of observation. Temperature measurements would be less accurate without these adjustments.[3]

Some claim that the strength of the warming trend is a result of data revisions that have adjusted up recent land temperatures while also adjusting them down for the period early in the 1900s, resulting in a stronger warming trend.[4] However, data adjustments have also been

1 NASA, 2019
2 IPCC, 2014
3 Hausfather et al., 2016
4 Ekwurzel, 2017

made on ocean surface temperatures to account for changes in measurement techniques. These adjustments have, if anything, resulted in a reduction of the overall rate of global warming compared to the raw data as is shown in FIGURE 1.

FIGURE 1
Global Temperature Anomalies from a range of data sets, as well as the raw data



Researchers have found that these adjustments do nothing to undermine the case for the existence of a warming trend. Irrespective of the adjustments, the increase in global surface temperature swamps the noise from these well-studied factors relating to measurement.[5]

"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.[6]

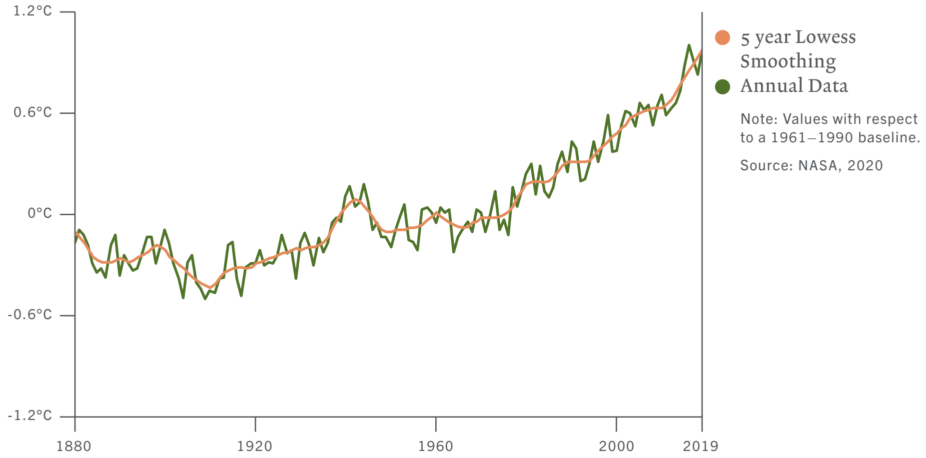
5 Brohan et al., 2006
6 Lewandowsky et al., 2018

Updated ocean temperature measurements[7] suggest that the rise in global temperatures has not paused, in fact, which is corroborated by further evidence.[8]

Warming increased again from 2013 to 2018, driven partly by the large but natural 2015 to 2016 El Niño cycle.[9] This highlights the fallacy of cherry-picking an arbitrary time range to dispute the widely-accepted stance that, long-term, the warming trend driven by human carbon emissions is not sustainable.

As FIGURE 2 demonstrates, average temperatures fluctuate from year to year, but show a clear global warming trend over the past century.

FIGURE 2
Global Mean Estimates based on Land and Ocean Data of Temperature (1880–2019)



"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.[10]

7 Karl et al., 2015
8 Hausfather et al., 2017
9 NOAA, 2018
10 WMO, 2019

"There is no trend in how often extreme events occur"

There is substantial regional variation when considering extreme events. Whether one particular region or city has more or fewer extreme events is not indicative of global extreme event dynamics. Climate change increases the risks of extreme rainfall, drought and floods in some regions, while simultaneously decreasing them in others.[11]

Generally, a warmer planet implies more ambient energy, which amplifies 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.

Any individual heatwave, flood, drought or other extreme event does not provide "proof" of climate change.

However, scientists are increasingly using methods to estimate how human activity influences the probability of some extreme weather events occurring.[12] Out of the 355 published studies analysed by CarbonBrief[13] (as of April 2020), 79 have found a clear human influence on extreme weather events.[14] Of course, it is important to note that there is a certain selection bias with regard to which extreme events are analysed, raising the possibility that a priori suspicion of anthropogenic influence played a role in which events were selected.

11 Otto et al., 2018
12 Otto et al., 2016; National Academies, 2016
13 CarbonBrief (2020a)
14 Otto et al., 2012; Stott et al., 2016

The IPCC Climate Change Synthesis Report[15] 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 globally.
- It is likely that the frequency of heatwaves has increased in large parts of Europe, Asia and Australia.
- It is likely that human influence has more than doubled the likelihood of heatwaves in some locations.
- There is medium confidence that the observed warming has increased heat-related human mortality in some regions.
- Recently detected increasing trends in extreme precipitation and discharge in some catchments imply greater risks of regional flooding (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 emails reveal that scientists are manipulating data"

Email exchanges among colleagues at the University of East Anglia in 2009 were interpreted by some people as evidence of collusion between scientists to hide a decline in real global temperatures. A number of independent investigations into the matter were launched from different countries. These investigations found as follows:

- The National Science Foundation[16] concluded: "no research misconduct or other matter raised by the various regulations and laws discussed above, this case is closed."

15 IPCC, 2014
16 National Science Foundation, 2011, p.5

- An International Scientific Assessment Panel set up by the University of East Anglia, in consultation with the Royal Society[17] 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:[18] "there is no substance to the allegation against Dr. Michael E. Mann."
- United States Environmental Protection Agency[19] found: "this was simply a candid discussion of scientists working through issues that arise in compiling and presenting large complex data sets."

17 Oxburgh et al., 2010, p. 5
18 Assmann et al., 2010, p. 19
19 United States Environmental Protection Agency, 2010, p.1

2

“Warming will be very modest”

A marooned boat rests on the
bottom of Curuai Lake, which was
almost completely dry during one
of the worst droughts ever recorded
in the Amazon region, 2005.

"Warming might end up being 1.5°C"

Warming since 1861–1880 is now around 1°C.[1]

Assuming a path of global emissions based on current levels of effort, estimates suggest global temperature could rise by around 2.9°C (estimated range 2.1°C – 3.9°C) by the end of the century.[2]

Keeping warming to less than 1.5°C is possible, depending upon the climate response and upon human actions,[3] but given existing fossil infrastructure, it currently appears unlikely that such a goal would be achieved without major additional effort by governments.[4]

The IPCC Special Report on Global Warming of 1.5°C states: "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 system transitions are unprecedented in terms of scale, but not necessarily in terms of speed".[5]

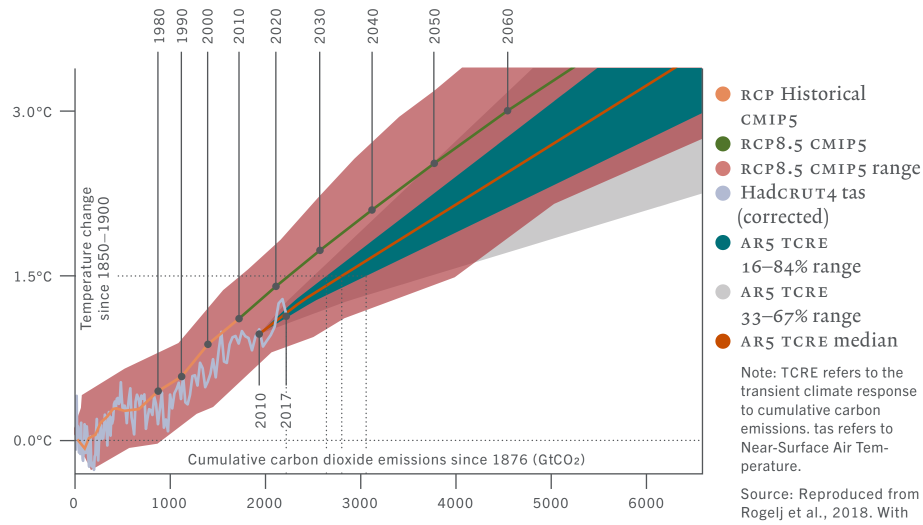
For a greater than 66 per cent chance of keeping warming to under 1.5°C, net human emissions could continue at present levels for only a decade or so and then immediately have to drop to net zero to stabilize temperatures — near net-zero emissions are required to stabilize temperatures at any level.[6] Alternatively, net emissions might be reduced linearly to zero over a period of two decades or so.

1 NASA, 2019
2 Climate Action Tracker, 2020
3 Millar et al., 2017
4 Pfeiffer et al., 2018
5 Masson-Delmotte et al., 2018, p.15
6 Matthews & Caldeira, 2008

For a greater than 66 per cent chance of keeping warming under 2°C, net human emissions could continue at present levels for ~25 years after which they would immediately need to fall to net zero. Alternatively, net emissions might be reduced linearly to zero over a period of four decades or so.[7]

There is significant uncertainty in these estimates (illustrated in FIGURE 3 below).

FIGURE 3
Human induced warming and cumulative CO_2 emissions



Note: TCRE refers to the transient climate response to cumulative carbon emissions. tas refers to Near-Surface Air Temperature.

Source: Reproduced from Rogelj et al., 2018. With thanks to Dr Chris Smith, University of Leeds

7 Millar et al., 2017

3

“Humans are not causing climate change”

Concentrated animal feeding operations, like this one in Agua Boa, Mato Grosso, Brazil, during August 2008, are environmentally destructive and require the use of more medications and hormones for food production. Brazil has a cattle herd of over 225 million (as of 2017).

"The climate has always been changing, and well before humans were around"

The Earth's climate has always been changing. Earth has been in a long-term cooling trend for the past 50 million years.[1] However, over the past 420,000 years, Antarctic air temperatures (in the Vostok ice cores) are estimated to have been, at various times, between ~8°C cooler and ~2°C warmer than today.[2]

These changes in the Earth's average temperature have had geographical consequences. For instance, in the last glacial maximum (21,000 years ago), global average temperatures were 3-7°C lower than they are now, with Arctic ice sheets covering most of Britain and extending down to Northern Germany.[3]

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 timescales several orders of magnitude slower than the changes we have been observing in the Earth's climate over the past two centuries. The current rate of warming (post-industrial revolution) is historically unprecedented.[4]

1 Hansen & Sato, 2012
2 Petit et al., 1999
3 Clark & Mix, 2002
4 Waters et al., 2016

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

Carbon dioxide traps infrared radiation, such as that emitted from the surface of Earth. This can be measured[5] and has been confirmed by decades of laboratory measurements.[6] The precise relationship between total CO_2 emissions and total warming is uncertain, but we know the relationship is roughly linear at current CO_2 concentrations; the uncertainty is shown in the coloured plume in FIGURE 3.

Uncertainty arises from an inexact understanding of various feedback mechanisms, including how cloud formation and movement is affected by temperature and vice versa. But, contrary to some speculation, natural cloud variation has not caused climate change.[7]

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[8] and vegetation.[9]

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

There is a marked correlation between temperature and CO_2 concentrations. 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 driven by very high CO_2 concentrations.[10]

5 Foote, 1856; Tyndall, 1861
6 Jokimäki, 2009
7 Dessler, 2011; Borenstein, 2011
8 Clark et al., 1999
9 Cox et al., 2000
10 Pollack et al., 1980

Causation in the reverse direction (increases in temperature increasing CO_2) is actively researched but would generally only occur over vastly longer timescales. It is noteworthy that in ice core records, temperatures often increased *before* CO_2 concentrations started to rise.[11]

The current status is that there is evidence of dual causality — an increase in CO_2 can increase temperature and vice versa[12]. But it is known that human emissions of CO_2 are currently driving warming, rather than warming driving CO_2, because the ratios of different types (isotopes) of carbon (^{13}C to ^{12}C) found in fossil fuels[13] are reflected in atmospheric CO_2, which would not be the case if causality were reversed or the increase in atmospheric CO_2 was caused by natural processes (see below).

"Human CO_2 emissions are insignificant compared to naturally-occurring processes"

The proportion of different types (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 are from old fossil carbon emitted by human activities.[14]

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

11 Barnola, 2003; Caillon, 2003; Fischer et al., 1999
12 Lorius et al., 1990; Martin, 2005; Cuffey & Vimeux 2001
13 Quay et al., 1992; Levin & Hesshaimer, 2000
14 Levin & Hesshaimer, 2000

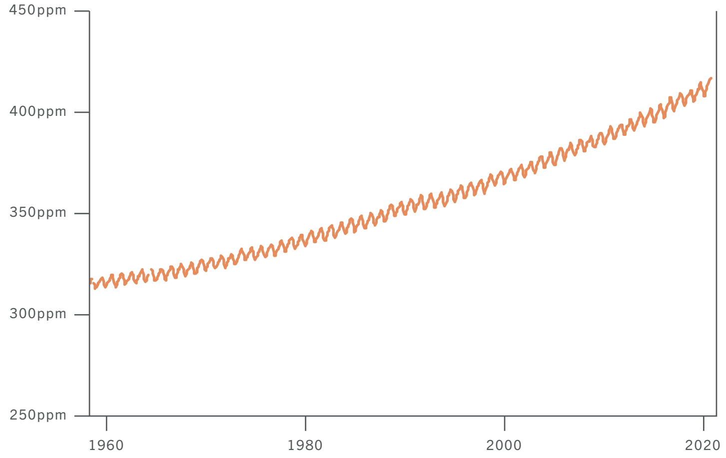
human-generated emissions from fossil carbon are large compared to the net impact from natural sources,[15] meaning that CO_2 is accumulating in the atmosphere (see FIGURE 4).

The warming oceans will also absorb CO_2 more slowly as their concentration of dissolved CO_2 rises.[16]

"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[17]. These annual oscillations are small compared to the 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.[18]

FIGURE 4
Measured concentrations of CO_2 showing annual oscillations



Scripps Institute, 2020.

15 Falkowski, 2000
16 Sarmiento et al., 1998; McKinley et al., 2017
17 Keeling, 1960
18 Martin, 1990; Zeng, 2003

"Any warming is due to the sun and other natural drivers, not 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.

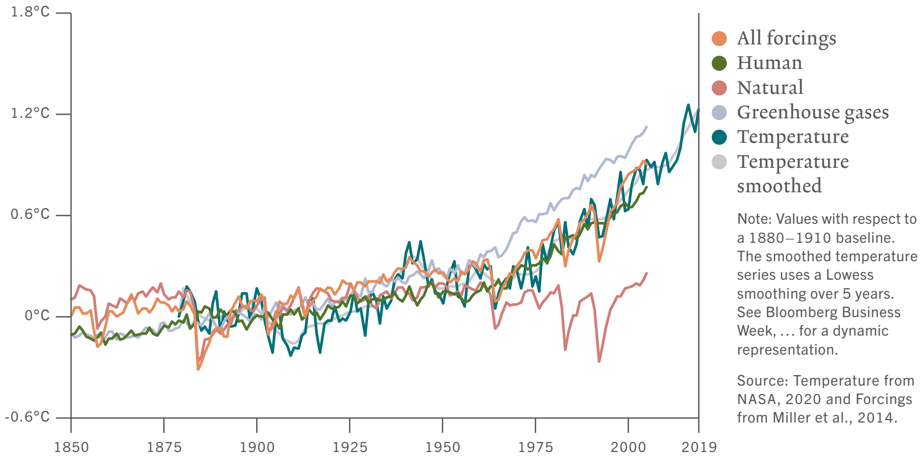
Scientific models of global temperature change attribute 1.01°C of warming between 1850–79 and May 2017 to human emissions (5–95 per cent confidence interval is +0.87 to +1.22 °C). Essentially all the observed warming is attributed to human activities; natural factors such as volcanoes have, in fact, slightly decreased the net amount of warming.[19]

Solar fluctuations have contributed to observed warming since 1950. However, the magnitude of the contribution is small, about 0.1°C at most.[20] The increase in global surface temperature has been largest since 1980 — a time during which solar activity has been decreasing.[21]

19 Haustein et al., 2017
20 Lean & Rind, 2008; Foster & Rahmstorf, 2011
21 Lockwood, 2008

The observed increase in temperature is predominantly driven by human rather than natural factors (see FIGURE 5; see Bloomberg[22] for a dynamic representation).

FIGURE 5
Contributions of human and natural factors to warming



22 Bloomberg Business Week

4

“There are benefits from climate change”

Remnants of Amazon rainforest line an agricultural field in Mato Grosso, Brazil, in 2008.

“More CO_2 will help trees grow and will green the Earth”

Higher CO_2 concentrations directly increase plant growth, ignoring other climate impacts.[1] 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.[2]

Research shows that climate change has overall had a negative impact on crop yields,[3] in part due to increased heat and water stresses,[4] and in part as a result of decreasing biodiversity.[5] 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.[6]

“Opportunities will open up in northern latitudes”

As Arctic ice melts, the Northwest Passage opens, cutting the 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 expensive to exploit relative to existing fossil reserves.[7]

More arable land is likely to be available in Russia, Canada, and Northern United States.[8] However, decreases in agricultural land in the global south,[9] and Central America, will outweigh increases in the global north’s agricultural viability, creating risks of food shortages and international security challenges.[10]

1 Kimball, 2016
2 Körner, 2000
3 Schleussner et al., 2018
4 Lobell et al., 2011
5 Bélanger & Pilling, 2019
6 Zhao et al., 2017
7 Emmerson & Lahn, 2012
8 Zabel et al., 2014
9 Im et al., 2017
10 NATO, 2015

There will be fewer deaths of those vulnerable to extreme cold in the Northern Hemisphere. However, a greater number of deaths caused by heatwaves elsewhere will offset the numbers saved by warmer northern winters[11] by a considerable degree. The net impacts will vary according to region.[12]

Warmer winters in northern regions will reduce energy demand for heating by 34 per cent by 2100, but would be more than offset by a 72 per cent increase in cooling demand elsewhere.[13]

11 Gasparrini et. al., 2017
12 Vicedo-Cabrera et al., 2018
13 Isaac & Van Vuuren, 2009

5

“Damages from climate change will be small or uncertain”

Aerial view of damage from
Hurricane Charley suffered by
a mobile home park in
Punta Gorda, Florida, 2004.

"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 an abrupt further temperature increase and some may be irreversible.[1]

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 reached once warming rises to 2°C above pre-industrial levels, and many more will at 3°C of warming.[2]

Scientists are working on identifying early warning signals for such tipping points.[3]

The magnitude of impact of some of these changes is estimated to be very high. For example, a complete thaw of permafrost carbon stores could release up to 5,500 gigatonnes of CO_2, or roughly twice the total amount of CO_2 in the atmosphere today.[4]

1 Bathiany et al., 2018
2 Masson-Delmotte et al., 2018
3 Lenton et al., 2012
4 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).[5]

FIGURE 6
Indicative summary of
possible impacts for different levels of warming
by 2100 (change vs 2018 levels)

	1.5°C	2°C	3°C	5°C
Physical impacts	!	!	!!	!!!
Sea-level rise	0.3–0.6m	0.4–0.8m	0.4–0.9m	0.5–1.7m
Coastal assets to defend	$10.2tn	$11.7tn	$14.6tn	$27.5tn
Chance of ice-free Arctic summer	1 in 30	1 in 6	2 in 3 (63%)	≈100%
Tropical cyclones (fewer but stronger and wetter storms)				
– Category 1–5 storms	-1%	-6%	-16%	Unknown
– Category 4–5 storms	+24%	+16%	+28%	+55%
– Total rainfall during storms	+6%	+12%	+18%	+35%
Days of extreme rainfall	+17%	+36%	+70%	+150%
Increase in land area affected by wildfire	x1.4	x1.6	x2.0	x2.6
Rise in number of people affected by extreme heatwaves	x22	x27	x80	x300
Land area susceptible 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

Source: CRO Forum, 2019, p.5

5 CRO Forum, 2019

"The economic 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.[6] Given the prospect of catastrophic impacts, economists conclude that it is optimal to hedge these.[7]

Globally, protecting coasts with dykes has been estimated to require annual investment and maintenance costs of USD12–71 billion by 2100, which is much smaller than the global damages that can be avoided with these measures.[8]

It is likely that there will be significant effects on agriculture, because the type of ecosystem of an estimated 4 per cent of the world's land area will change at 1.5°C of warming, and 13 per cent at 2°C.[9] An estimated 18 per cent of insects, 16 per cent of plants, and 8 per cent of vertebrates are projected to lose over half of their climatically determined geographic range at 2°C warming.[10] However, some projections envisage 'peak farmland' demand in the coming decades, driven by increasing efficiencies and declining population growth.[11]

At 4 °C of global warming, humid heatwaves with apparent temperatures over 55 °C would be expected every second year.[12]

If the increase in global average temperature 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 to shed heat as sweating becomes

6 Burke et al., 2015; Pretis et al., 2018
7 Litterman, 2013; Daniel et al., 2016
8 Hinkel et al., 2014
9 Hoegh-Guldberg et al., 2018
10 Warren et al., 2018
11 Ausubel et al., 2013
12 Russo et al., 2017

ineffective above those temperatures), precluding any outdoor activities in those areas. A temperature rise exceeding 10°C would expose most of the large populated areas of Earth to these conditions.[13]

Outdoor labour productivity appears to be negatively affected well before people succumb to heat stroke.[14]

"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 during the second half of this century, but there are also very significant business risks in the shorter term.[15]

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.[16] In the USA, around 200,000 people die early each year from air pollution, an annual loss that economists have valued at USD250 billion.[17]

13 Sherwood & Huber 2010
14 Sahu et al., 2013
15 Woetzel, 2020
16 Global Burden of Disease, 2016
17 Caiazzo et al., 2013

Losses from extreme weather events in 2017 were estimated at USD330 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 USD192 billion".[18]

Near-term risks for business include policy changes intended to reduce future impacts of climate change.

"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.[19] 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,[20] and long-lasting catastrophes.
- IAMs tend to assume that climate change will not affect overall economic growth rates. This is contrary to the view that large temperature changes would negatively affect economic growth, which a growing literature suggests.[21]

18 Swiss Re, 2018
19 Farmer et al., 2015
20 Hsiang et al., 2013
21 Pindyck, 2013; Burke et al., 2015; Pretis et al., 2018

- IAMs generally do not account for permanent damages to capital stocks or long-term decreases in productivity or falls in the rate of technological development, all of which climate change could reasonably be expected to cause.[22]
- Models have also underestimated the rate of development of clean energy technology, making energy transitions appear overly costly.[23]

22 Stern, 2013
23 Creutzig et al., 2017

6

“Humans will be able to adapt”

Residencial Salvaçao, a government
housing development for the
rural migrants and the poor on the
outskirts of Santarem in Brazil.
It opened at the edge of rainforest
land in May 2016 and can
house up to 15,000 people in its
3,000 units. Seen here in 2017.

"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.[1]

However, most research shows that adaptation cannot eliminate all negative effects.[2]

"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.[3]

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. Possible side-effects including increases of tropical cyclone frequency and other geopolitical challenges are highlighted in the literature.[4]

1 Heal & Park, 2016
2 Adger et al., 2009; Moser & Ekstrom, 2010; Dow et al., 2013
3 Irvine et al., 2019
4 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.[5] Solar geoengineering would not counteract the impacts of ocean acidification, caused by absorption of atmospheric CO_2 by seawater.

5 Trisos et al., 2018

7

“There’s no point in reducing emissions, Earth will keep warming anyway”

Fire burns former Amazon rain-
forest land southeast of Manaus,
Brazil, 2018.

"We've started a process we can't stop, so we might as well keep emitting"

The maximum average global temperature is in part determined by atmospheric CO_2 (and other greenhouse gas) concentrations. If other conditions, including the concentration of other atmospheric gases remain constant, rising CO_2 concentrations will lead to rising temperatures.

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75 per cent of the CO_2 that reaches the atmosphere will persist there for ~300 years, with up to 25 per cent remaining in the atmosphere for up to 10,000 years — which is to say warming is permanent on timescales relevant to humans.

In order to halt warming at any point, humans would need to reduce net CO_2 emissions to (very close to) zero.[1] (see FIGURE 3)

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.[2]

1 Wigley, 2018
2 Lowe & Bernie, 2018

8

“The costs of reducing emissions are very high”

A plume of smoke rises from a burn of collected oil in the Gulf of Mexico. A total of 411 controlled burns were used to try to rid the Gulf of the most visible surface oil leaked from the BP Deep Water Horizon rig in 2010.

"Vast sums have been spent on renewables and they are still more expensive"

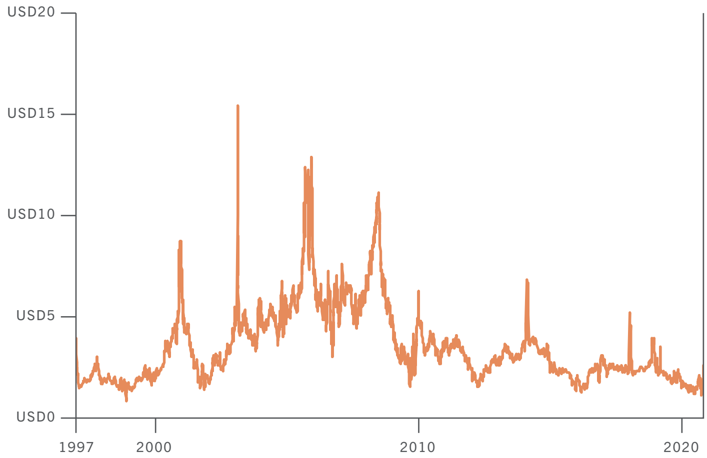
Global renewable energy subsidies are approximately in the order of USD100 billion each year, excluding the implicit subsidy that renewable energy often receives by way of public spending on electricity grid connections and costs for the management of intermittency.

Global fossil fuel consumption subsidies tend to be around USD100–500 billion each year, depending upon fossil energy prices. Subsidies in 2017 were estimated to be around USD300 billion.[1]

If the costs of damage to the environment are included as an implicit subsidy, the subsidy to fossil fuels is around USD5 trillion each year.[2] 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
Henry Hub Natural Gas Spot Price
(USD per million BTU)

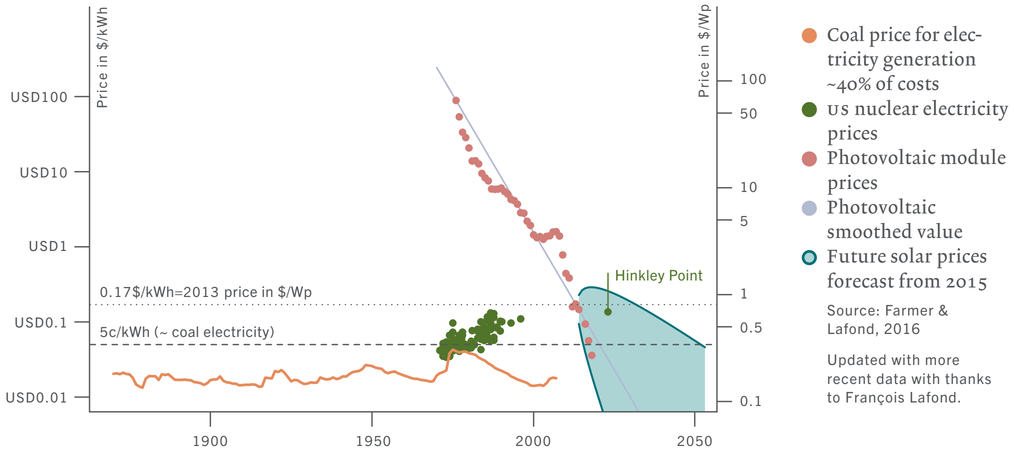


Source: US Energy Information Agency (26.10.2020). https://www.eia.gov/dnav/ng/hist/rngwhhdD.htm

1 IEA, 2018
2 Coady et al., 2015

Viewed over the long term (see FIGURE 8), the cost of fossil fuels has been approximately stationary in real terms for around 100 years,[3] compared to increases in the costs of nuclear and declines in the cost of solar photovoltaic (PV).

FIGURE 8
Long-run costs of electricity generation inputs in kWh



The cost of solar PV has been falling at an average annual rate of 10 per cent.[4] There have been similar consistent cost declines in wind energy (both onshore and offshore) and batteries. Solar PV and wind costs have fallen 89 per cent and 70 per cent since 2009, respectively.[5]

Even without subsidies, new renewables can now be cheaper than the construction of new fossil fuel power plants, depending on location and system. Lazard estimated in 2019[6] that the lower bound estimates for wind (USD28/MWh) and solar PV (USD32/MWh) are now cheaper than the same estimates for coal (USD66/MWh), and gas combined cycle plants (USD44/MWh).

3 Farmer & Lafond, 2016
4 ibid
5 Lazard, 2019
6 ibid

Decarbonising the first 50–60 per cent of power systems is already potentially cheaper than fossil fuel generation.[7]

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 caused by 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 use of renewables increases.

Large investments are needed across the wider economy — not just in 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 that of new high-carbon infrastructure.[8]

The costs of decarbonising during the recession induced by the Covid-19 pandemic 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.[9]

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 currently unlikely to yield an economic return on energy savings alone without government subsidy or regulatory intervention.

7 Finkelstein et al, 2020
8 New Climate Economy, 2016
9 Hepburn et al., 2020

"We should just remove carbon dioxide from the air instead"

It is possible to pull CO_2 back out of the air,[10] a procedure termed "Direct Air Capture" (DAC).

The removed CO_2 could potentially serve as a useful input into new and existing manufacturing processes.[11]

Removing CO_2 from the atmosphere currently costs some USD92–232 per tonne of CO_2, and costs are expected to fall over time.[12]

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.

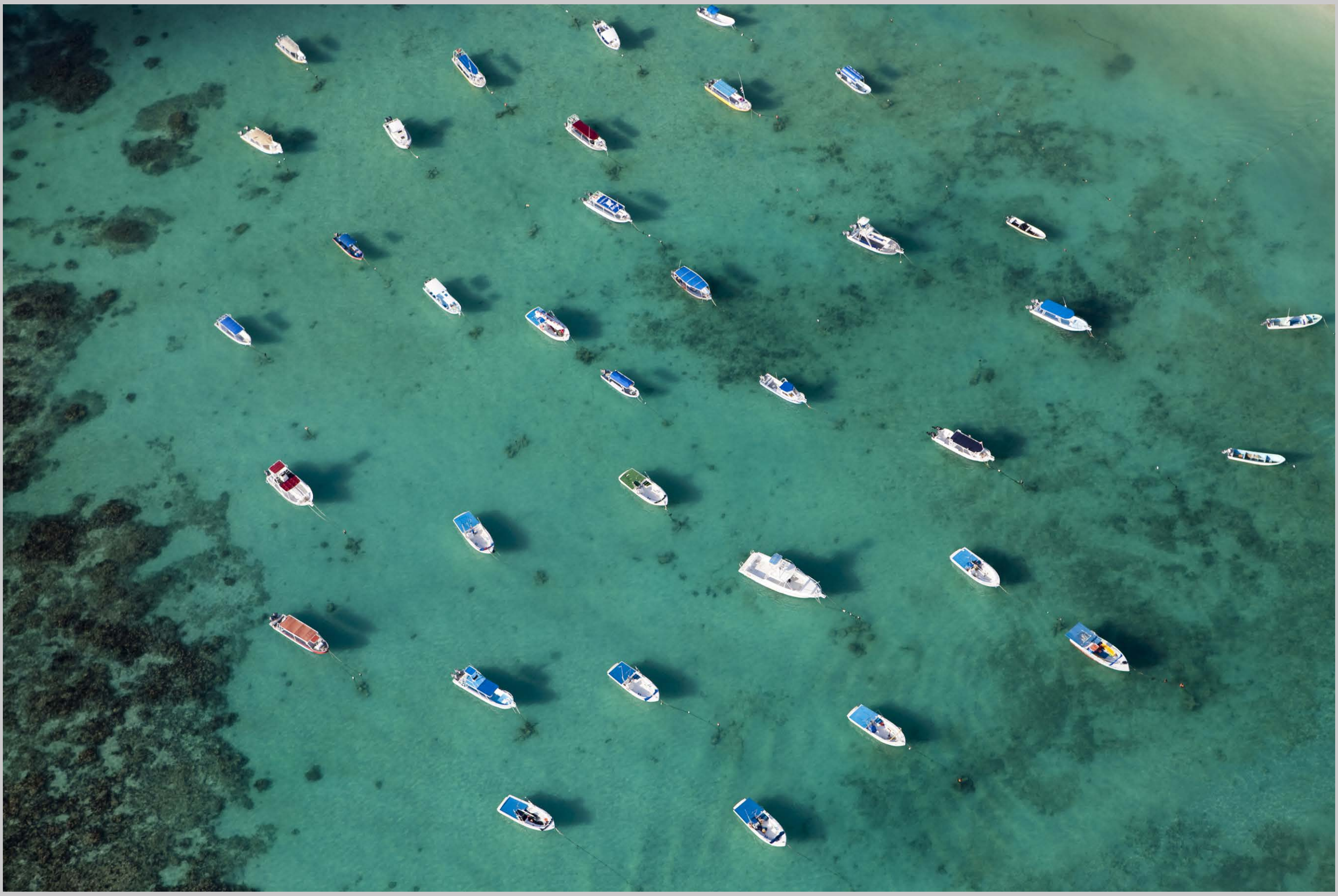
Further, to provide a long-term solution to climate change, the CO_2 removed would need to be permanently stored in a manner so that it cannot return to the atmosphere.

If such efforts were to use trees and other agricultural methods, they would potentially use a significant fraction of global agricultural land,[13] although more of this land might become available for such use with rising efficiencies in farming.[14]

10 Kriegler et al., 2017
11 Hepburn et al., 2019
12 Keith et al., 2018
13 Smith et al., 2015
14 Ausubel et al., 2013

9

“Other countries are not playing their part”



Aerial view of tour boats anchored
near the reef offshore of Mexico’s
Yucatan peninsula in 2009.

"China is the worst polluter and they are not doing anything"

China is currently the world's largest polluter in total. Per capita, China emits less than half the emissions of the US. Since the industrial revolution, the US has had the highest cumulative emissions.[1]

China has the largest solar, wind, nuclear and hydro deployment programme in the world[2] and is in the process of implementing a CO_2 trading scheme.[3] China accounted for 36 per cent of the world's total renewable energy investment in 2015, and over half of its new solar capacity in 2017.[4]

However, China also continues to build new coal-fired power plants. The China Electricity Council has suggested that the country could build a further 300 gigawatts (GW) of capacity, to reach a total capacity of 1,300 GW in 2030.[5]

"Other countries are not on board"

197 countries have signed the Paris Agreement which commits them to keeping temperatures "well below 2°C". They will also "pursue efforts" to limit warming to 1.5°C from pre-industrial levels. As of 2020, 189 countries have ratified the agreement.[6]

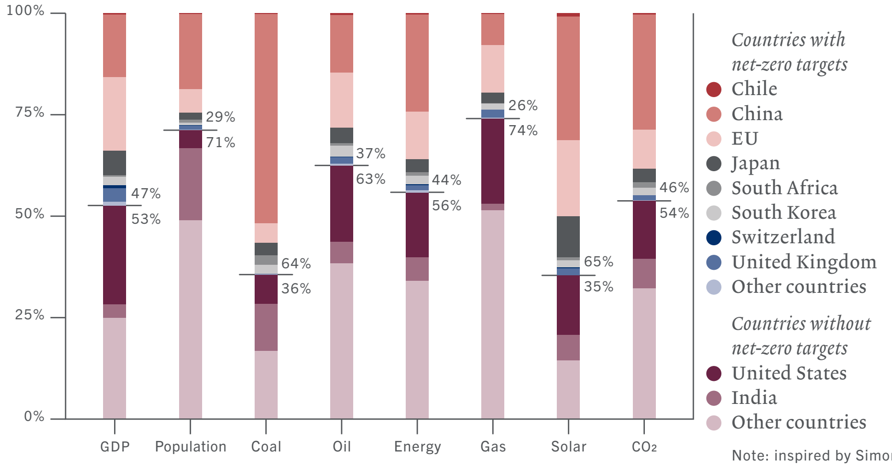
The US exited the Paris Agreement on November 4th, 2020, but many subnational governments within the US have made pledges to uphold the targets.[7] President-elect Biden announced his administration would re-join the Paris Agreement by executive order on his first day in office.[8]

1 Frumhoff et al., 2015; Baer et al., 2000
2 IRENA, 2016; IEA, 2017
3 World Bank & Ecofys, 2018
4 BNEF, 2018
5 Shearer et al., 2019
6 United Nations, 2020
7 UNFCCC, 2017, Hale et al., 2018
8 Reagan, 2020

Many of the actual commitments under the Paris Agreement are modest, and many of these are not being delivered upon,[9] although a number of countries have announced their intention to scale up their climate action ahead of COP26. As of November 2020, eight countries have either achieved or legislated for net-zero emissions by 2045 or 2050. A further 18 countries and the EU as a whole are actively working towards net-zero legislation. Since autumn 2020, this group covers more than half of global CO_2 as well as two-thirds of global coal consumption, as major East Asian emitters China, Korea and Japan have announced their net-zero intentions.[10] Additionally, 99 countries are currently discussing similar efforts.[11] (see FIGURE 9)

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 headquartered in over 100 countries and 7,000 cities, representing USD36.5 trillion in revenue, larger than the combined GDP of the US and China. Together these pledges account for reductions of 1.5–2.2 gigatonnes of CO_2 equivalent by 2030.[12]

FIGURE 9
Key economic indicators covered by net-zero targets



Note: inspired by Simon Evans at CarbonBrief. Data retrieved from ECIU, BP, and the World Bank World Development Indicators.

Source: CarbonBrief – Simon Evans

9 Victor et al., 2017
10 CarbonBrief, 2020
11 ECIU, 2020
12 UN Environment, 2018

"Countries are making pledges but not doing anything"

Overall, Earth is on track to warm 2.9°C (estimated range 2.1°C – 3.9°C),[13] if current policies were to be implemented. If all nations fulfill their currently stated targets, then warming could be limited to 2.1°C.

Global CO_2 emissions are still increasing; the estimated increase was 2.7 per cent in 2018.[14]

Progress varies across countries. Chinese emissions are projected to have increased by 4.7 per cent in 2018,[15] while EU28 emissions fell 0.7 per cent — the EU is the only major global region to reduce emissions. The United Kingdom has reduced emissions from around 800 million tonnes (Mt) CO_2eq in 1990 to around 500 Mt CO_2eq today, with a legal requirement to reduce emissions to net-zero by 2050.[16]

More than 52 other countries, states, and provinces have joined an agreement to completely phase out coal before 2030.[17] 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 Mt in 2010 to 1.9 Mt in 2017.[18]
- The Canadian Government announced in 2018 that coal-fired power will be phased out and closed entirely by 2030.[19]
- The German Government announced in 2019 that coal-fired power will be phased out and closed entirely by 2038.[20]

13 Climate Action Tracker, 2020
14 Global Carbon Budget, 2018
15 ibid
16 UK Statutory Instruments, 2019
17 Powering Past Coal Alliance, 2018
18 Twidale, 2015; UK Energy Brief, 2018
19 Government of Canada, 2018
20 Wacket, 2019

Carbon prices are now in place in 52 countries and 24 subnational regions, raising USD79.62 billion of revenue in 2018, and covering roughly 20 per cent of global emissions.[21] Most carbon prices in such schemes are far too low to deliver the necessary abatement.

Since 2016, investment in renewable energy has exceeded that in fossil fuels. In 2018, global clean energy investment exceeded USD300 billion for the fifth year in a row, and there was a record 100 GW of photovoltaic capacity installed.[22]

21 World Bank, 2019
22 UNEP/BNEF, 2019

The photographer

The pictures featured in this brochure are the work of Daniel Beltrá, a Seattle-based, multiple award-winning photographer.

Daniel Beltrá was born in Madrid, Spain in 1964. His passion for conservation is evident in images of our environment that are evocatively poignant. In 2011 he received the Wildlife Photographer of the Year Award for his work on the Gulf Oil Spill. Daniel's work has been published by the most prominent international publications, including The New Yorker, Time, Newsweek, The New York Times, Le Monde, and El País.

The Prix Pictet

Daniel Beltrá was short-listed for the "Power" cycle of the Prix Pictet's 2012 edition.

The Prix Pictet is the world's leading award for photography and sustainability. Launched in 2008, the award aims to draw global attention to these issues. There have been eight cycles of the award so far — each of which has highlighted a particular facet of sustainability. The photographers are nominated by a worldwide network of experts.

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