Climate Change Science

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INTRODUCTION

CLIMATE CHANGE SCIENCE

Climate change science has advanced and evolved enormously over the past few decades, data collection and modelling are much more sophisticated, and new questions are being explored by scientists and governments alike.

This paper looks into, what are the key features of our evolving understanding of climate change science, in terms of the pace, effects, regional distribution and attribution of extreme events? And, what are the most important remaining uncertainties?

Sustainability Report

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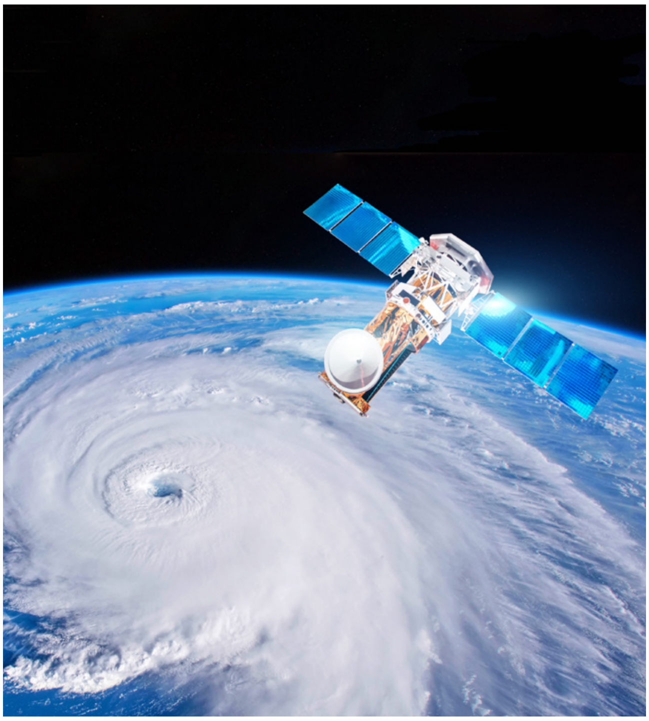
EXECUTIVE SUMMARY

- Research has narrowed uncertainty but not radically changed our understanding of climate change, global warming and the effect of CO_2 since the 1970s.
- Some high-case and low-case warming scenarios have been largely ruled out, but higher levels of warming than consensus remain a possibility.
- Understanding of key tipping points has improved but remains uncertain, leaving major risks of feedback cycles.
- Regional forecasts and extreme weather attribution have advanced substantially.
- Correct modelling of icesheets, carbon storage in the biosphere, and clouds remain key areas of focus and uncertainty.
- Understanding of climate damage is probably heavily underestimated and does not include microeconomic and socio-political effects that are plausible but impossible to model. On the other hand, damage estimates may inadequately account for adaptation.
- The progress of climate science strengthens the case for robust and urgent reductions in GHG emissions, and for adaptation to ongoing and anticipated climate changes.
- Direct removal of carbon dioxide from the atmosphere (CDR) will likely be necessary on a large scale to limit global warming as targeted.
- Geo-engineering should be prepared for, as it may be required to cool the Earth directly in case of some of the more disastrous scenarios of climatic feedback loops and tipping points.

THE HISTORY AND WORK OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

The IPCC was formed in 1988 as an intergovernmental panel of the United Nations (UN), to provide objective, scientific information on climate change. It does not conduct original research or acquire data, but, working through groups of national scientists paid by their home institutions, it synthesises published literature. Its reports include regular assessment reports, the first of which was released in 1990 and the sixth of which is due in 2022. The fifth assessment report (AR5)[i] in 2014 was particularly influential as it provided input to the Paris Agreement of 2015, which aims to limit global warming by 2100 to no more than 2°c and to attempt to keep it below 1.5°c. AR5 discussed representative concentration pathways (RCPs) for various combinations of economic and population growth and energy mix, and the estimated warming in each case.



The IPCC also publishes special reports (SR), including SR15[ii] in 2018, that followed the Paris Agreement and outlined the consequences of warming of 1.5°c and the paths that could be taken to limit warming to that level. Furthermore, the IPCC National Greenhouse Gas Inventories Programme develops methodologies for estimating greenhouse gas (GHG) emissions by countries.

The IPCC's reports have faced some criticisms over inaccuracies and research methods, especially from climate deniers and advocates that attempt to undermine mainstream climate science. The criticisms of IPCC work have generally been minor and not significant to undermine the broader conclusions in IPCC's reports. However, because of political pressures, the need for consensus, the lengthy gap between reports, and the large amount of research to be gathered and integrated, the IPCC reports often lag behind most recent findings, or tend to be conservative in understating the likely impacts of climate change.

In 2007, the IPCC and former US Vice-President Al Gore were jointly awarded the Nobel Peace Prize for "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change"[iii]. Overall, the IPCC has been extremely important in assisting nations on reaching a fair degree of consensus on the forecast path of climate change and the underlying science. It has also had a significant role in catalysing research by pointing out areas of remaining uncertainty. In turn, other agencies, such as the International Energy Agency (IEA), do build on the IPCC's work in developing climate-related scenarios and policies.

KEY STAGES IN THE HISTORICAL UNDERSTANDING OF CLIMATE

The fundamental cause of climate change has been understood since 1859, when physicist John Tyndall discovered the absorption of infra-red radiation by certain atmospheric gases. In the 1890s, Swedish scientist Svante Arrhenius calculated the amount of global warming caused by a doubling of carbon dioxide, obtaining a result about double the modern accepted estimate, but still a remarkable achievement. In the 1920s, Serbian mathematician Milutin Milankovic conducted detailed calculations to show how slight periodic variations in the Earth's orbit and rotation had triggered the start and end of ice ages.

John Tyndall

Charles Keeling began recording atmospheric carbon dioxide in Hawaii in 1958, thus demonstrating the rising concentration of CO_2 from human activities. Space exploration from the 1950s onwards was important in improving our understanding of the sun, giving insights into the Earth's climate from observations of other planets, such as the CO_2-induced runaway greenhouse effect on Venus, and in establishing an ever-growing set of satellites providing critical information on the Earth's atmosphere, cryosphere, oceans and biosphere. The theory of plate tectonics, which gained acceptance in the 1950s and 1960s, gave coherence to past observations of varying

Milutin Milankovic

climates due to volcanism, plate motions and tectonic episodes, for instance the work of Maureen Raymo on the climatic impact of the uplift of the Himalayas[iv]. In 1975, pioneering climatologist Wally Broecker predicted global temperature rises to 2010 which have closely corresponded to reality[v].

Climate science was well-established by the 1980s, using ice cores from Antarctica to demonstrate how past lower levels of CO_2 had led to ice ages. General Circulation Models (GCMs), computer simulations of the Earth's weather and climate, which were introduced in 1956, became increasingly sophisticated by the 1980s. By the second IPCC report in 1995, it was well-established that it was not plausible to reproduce observed warming using only solar and volcanic forcings, without considering the growing share of anthropogenic CO_2 and other GHGs, and an estimate for the climate sensitivity had been obtained that remains close to estimates today.

The IPCC and the negotiations around the Rio Earth Summit (1992) and Kyoto Protocol (signed 1997, effective 2005) stimulated extensive research into forecasts of future GHG emissions under various technological and economic scenarios, which could then be used to derive the consequent level of warming. These were distilled into Representative Concentration Pathways (RCPs), covering several broad scenarios for future emissions.

William Nordhaus, who won the Nobel Prize for Economics in 2018, pioneered the use of economic models to calculate the cost of climate change and hence the 'social cost of carbon', the marginal economic damage caused by the emission of an additional tonne of carbon dioxide. This has been the basis for much policy aiming to set carbon prices. However, Nordhaus's work has been criticised for yielding very low estimates of damage and hence of the cost of carbon. In 2009, he obtained a figure of the social cost of carbon in 2025 of $16/tonne, and raised this to $44 in his 2016 estimate.

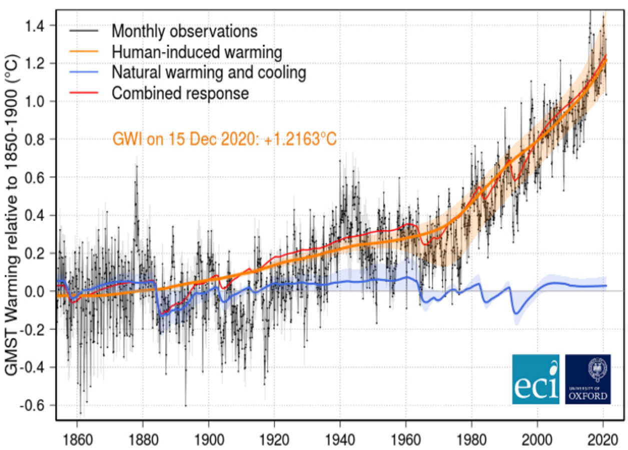
The Stern Report (latest update 2017), led by Sir Nicholas Stern, calculated $40-80/tonne in 2020 and $50-100/tonne in 2030[vii], partly down to justifying and choosing a much lower discount rate. On a different approach, Martin Weitzman concentrated on the risk of catastrophic climate damage[viii], posing the problem as one of insurance rather than optimisation, and arguing that the "correct" carbon price could be almost infinitely high given the small but non-negligible risks of destroying the global economy and civilisation.

DEVELOPMENTS IN UNDERSTANDING CLIMATE SCIENCE

More recent work has not materially changed the key conclusions of climate science over the past half-century. But it has greatly refined the understanding and forecasting of climatic systems. The following areas are particularly important.

Measurement and monitoring have advanced through development of a worldwide network of sensors, including emerging data such as that recorded by smartphones and autonomous marine and aerial vehicles. This data includes temperature at a wide range of land and sea geographic locations and at different levels in the atmosphere and oceans, precipitation, ground-water levels, oceanic currents and salinity, atmospheric concentrations and isotopic compositions of GHGs, ice-cover and vegetation on land and oceans, and many others. Latest updates of measurements, combined with modelling, confirm both the warming trend and that it cannot be explained by natural factors alone (Figure 1).

figure 1 Global warming index to december 2020[ix]



Satellite data with more spectral bands and more comprehensive global coverage has been particularly important, for instance those used by companies such as Kayrros and the EU's Copernicus programme[x] to track gas flaring, methane leakage and other air pollution. GHGSat[xi], backed by organisations including the Oil and Gas Climate Initiative (OGCI), has launched two satellites and plans to have 10 in orbit by 2020, observing CO_2 and methane emissions and able to resolve small point sources. Such monitoring is supplemented with ground-truthing and very granular studies, for instance of carbon storage in forests, shifting populations of migratory birds, and CO_2 uptake by plants under different levels of atmospheric carbon dioxide, temperature and humidity.

Ecosystem carbon storage is a key part of future climate predictions, for understanding how much carbon biological systems take up and retain, whether this is increasing or decreasing as atmospheric CO_2 levels rise, and how it is affected by events such as droughts and forest fires. This has an important bearing on equilibrium climate sensitivity and tipping points, as discussed below.

Modelling remains the key tool for predicting future climate change in response to the accumulation of GHGs. GCMs have become more powerful because of greater computing capacity, allowing finer-scale representation of the Earth. They have also become more sophisticated because of better representation of key processes such as icesheets, clouds and carbon-cycle feedbacks.

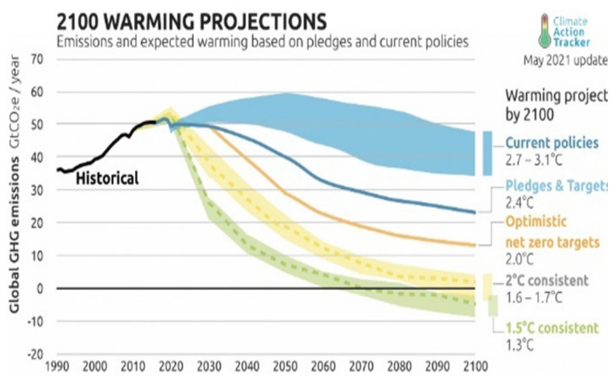
Modelling showed that between 1998 and 2013, global warming slowed from the rate observed in the 1980s and 1990, despite rising GHG concentrations. This was used by some "deniers" to argue that climate science or models were unreliable. From 2014, warming has continued again so that the overall rate since 1998 is similar to that in the second half of the twentieth century[xii].

The equilibrium climate sensitivity is a key parameter describing the steady-state amount of global warming caused by a doubling of atmospheric CO_2. For comparison, pre-industrial CO_2 was 280 parts per million (ppm) and has now risen to 419 ppm in May 2021. A recent paper[xiii] combined multiple lines of evidence from past and recent climates and modelling with Bayesian analysis of probabilities, to determine that there is a 66% chance climate sensitivity is between 2.6-3.9°c and a 95% chance it is between 2.3-4.7°c. There is also some evidence that the climate sensitivity may itself increase with higher levels of warming[xiv]. Such ranges then inform climate negotiations such as the Paris Agreement, given its target to limit warming to no more than 2°c and attempt to hold it below 1.5°c.

Related to this is work on the carbon budget. The level of eventual warming is related to the total release of CO_2 rather than to the level of emissions in any particular year, or the year in which emissions reach net-zero. Figure 2, based on the IPCC's MAGIC model (a simplified climate model[xv]), shows the trajectories of emissions under various scenarios and the associated level of warming by 2100.

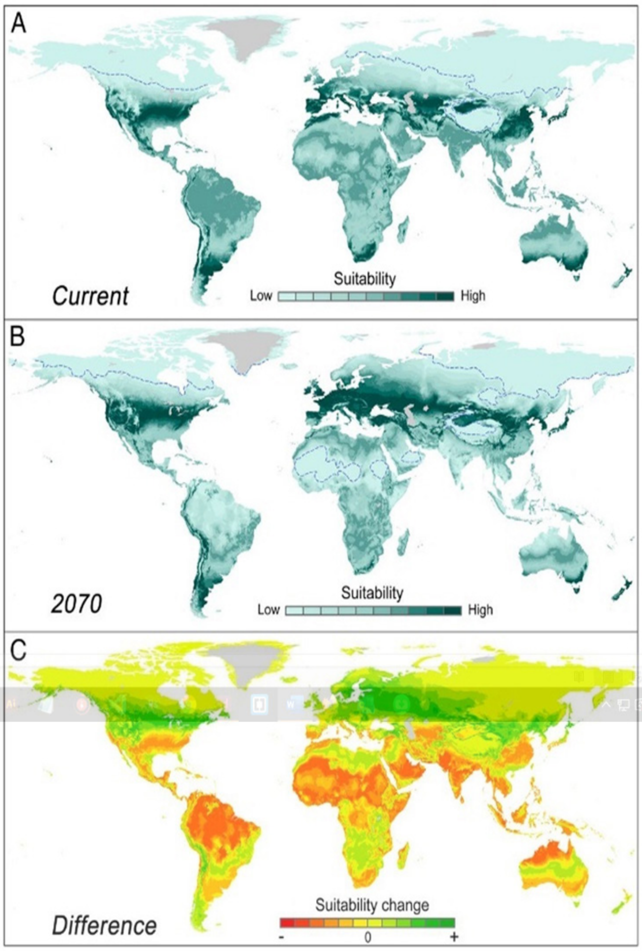
Regional modelling has become more detailed and precise. This allows predictions of the impact under different warming scenarios of the effects on local temperature and precipitation. These forecasts inevitably involve more uncertainty than global results, but their uncertainty can be quantified. They can be used to investigate key weather systems such as the El Niño-Southern Oscillation (ENSO), the West African and South Asian monsoons, arid episodes in the Mediterranean, Sahel and south-western US, and the Atlantic Meridional Overturning Circulation (AMOC).

Figure 2 Warming predictions with GHG emissions trajectories [xvi]



These regional forecasts can then be related to specific adaptation challenges. For instance, one study[xvii] finds that by 2050, 1-3 billion people will live in areas with a mean annual temperature greater than 29°c, currently only found in parts of the Sahara, and well outside the climates that most people have inhabited historically (Figure 3). However, this study

Figure 3 Change in suitability for human habitation from 2020-70, RCP8.5 emissions scenario



does rely on the very high RCP8.5 emissions scenario, which now seems unlikely.

Attribution is one of the major advances of recent years. This allows extreme weather to be precisely ascribed to climate change, by determining the probability that such an event would have taken place without anthropogenic climate change.

This has been particularly important and topical over the past couple of years. :

- Huge wildfires in Australia (2019-2000).
- Second-lowest recorded Arctic sea-ice extent (September 2020).
- Record US hurricane season, with 30 named storms of which 11 made US landfall (2020).[xviii]
- Freezing weather in Texas, as Arctic air moved south, leading to widespread power cuts and up to 700 deaths (February 2021).[xix]
- Extensive wildfires in California and the rest of the North American west coast, with continuing drought in the western US (2020 and 2021).
- Record temperatures in Canada at 49.6°c (June 2021).
- Highest reliably-recorded global temperature, Death Valley, at 54.4°c (July 2021).
- Record rainfall in Henan province, central China, causing widespread flooding and dam collapses (July 2021).[xx]
- Massive floods in Germany and neighbouring European countries (July 2021).
- Severe water shortages and heatwaves in south-western Iran, leading to widespread protests (July 2021).

Table 1 Potential tipping points[xxiii]

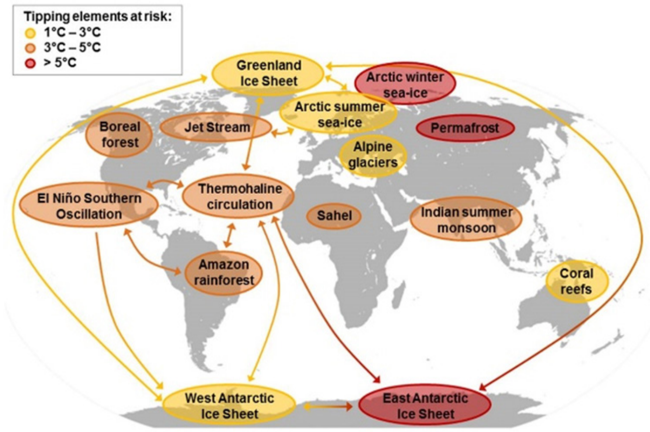
Tipping point	Sensitivity	Effects	Timescale
Collapse of West Antarctic ice-sheet	Likely already passed	3 metres sea-level rise	Centuries to millennia
Collapse of Wilkes Basin ice-sheet (East Antarctica)		3-4 metres sea-level rise	>1 century
Melting of Greenland ice-sheet	1.5°C warming (possible by 2030)	7 metres sea-level rise	Over millennia
Loss of 99% of tropical corals	2°C warming; 500 ppm CO_2	Loss of marine livelihoods and ecosystems	Caribbean corals within 15 years
Amazon rainforest die-back	20-40% deforestation (17% occurred since 1970); 3-4°c warming	Additional release of 90 Gt CO_2 to atmosphere; loss of biodiversity; interruption of hydrological cycle	Within 50 years of reaching the tipping point
Die-back of boreal forests		Release of 110 Gt CO_2 to atmosphere	
Permafrost melting	Gradual acceleration up to 5°c; possible tipping point beyond that	Release of 100 Gt CO_2 to atmosphere plus methane	
Shut-down of AMOC	15% weaker since mid-20th century; could shut-down entirely with 3-4°c warming	Cooling up to 5°c in western Europe and eastern North America; drying of those areas; severe agricultural losses; knock-on effects such as dieback of the Amazon and shrinkage of the West Antarctic ice-sheet	Over decades-centuries after 2100

DEVELOPMENTS IN UNDERSTANDING CLIMATE SCIENCE

Tipping points and positive feedbacks have been a topic of concern for decades, but understanding has improved recently. Tipping points are climatic changes which, once triggered, cannot be reversed even if atmospheric GHGs are then held steady or even reduced, i.e. they show hysteresis (dependence on the path or initial state). AR4 (2007) was the first IPCC report to use the term "tipping points" but AR3 in 2001 had referred to the same phenomenon. They could include the breakdown of the AMOC, the melting of the Greenland or West Antarctic Ice Sheets, or the die-back of the Amazon rainforest (Table 1). On the other hand, recent work has suggested that destabilisation of methane-containing oceanic hydrates, a possible driver for runaway global warming, is not likely. Other tipping points such as ocean anoxia[xxi], or changes in ENSO triggering other tipping points[xxii], remain uncertain or speculative.

Positive feedbacks, which may also be tipping points, are situations in which global warming causes the further emission of GHGs (or, reduces GHG sinks), so that warming accelerates even if human emissions are then reduced.

Figure 4 Interconnections and cascades of tipping points[xxiv]



Some positive feedbacks are already well-known and accounted for in climate models. For instance, warm air holds more water vapour, itself a powerful greenhouse gas. Ice and snow reflects sunlight more effectively than open ocean, bare rock or forest, so melting leads to faster warming of the Arctic.

Different tipping points can interact in a cascading system of feedbacks (Figure 4). Models have only recently become able to simulate such cascades.

The existence of tipping points and positive feedbacks is a major risk. "Over-shooting" emissions trajectories, where atmospheric GHG concentrations rise above a "safe" level before being reduced, become very risky.

Finally, emissions scenarios have been narrowed. Largely, this is due to the growing effect of climate policy and the improvements in low-carbon energy sources, which diminish the likelihood of very high emissions scenarios. Conversely, the legacy of emissions means that low-emissions scenarios derived in the 1990s and early 2000s are already implausible.

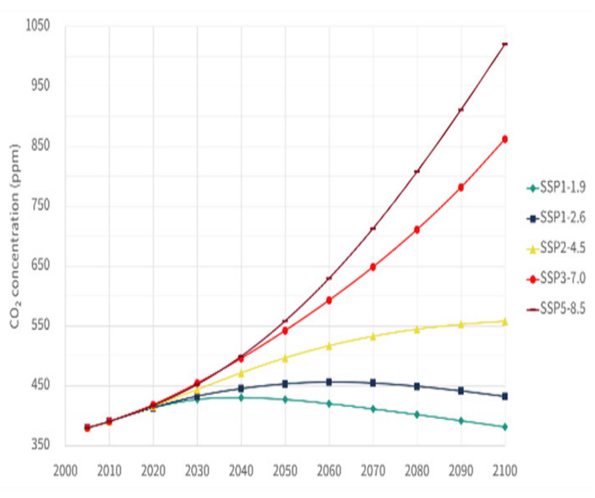
IPCC ASSESSMENT REPORTS AND REPRESENTATIVE CONCENTRATION PATHWAYS

The original RCPs in AR5 were labelled 2.6, 4.5, 6 and 8.5 based on the level of radiative forcing (in W/m2) from GHGs in the year 2100. Additional RCPs have been defined subsequently: 1.9, 3.4 and 7. RCP1.9 is consistent with the 1.5°c aspiration of the Paris Agreement, in which atmospheric CO_2 levels would peak around 2040. RCP 8.5 is sometimes wrongly referred to as "business-as-usual", i.e. without emissions mitigation, but in fact it represents a very high case with enormous quantities of coal use[xxv].

AR6, due in 2022, will cover five Shared Socioeconomic Pathways (SSPs), each with an internally consistent set of assumptions on the global population, economy, politics, technology and climate policies. These reflect developments since 2014's AR5, particularly relating to trade tensions, the China-US rivalry, growing economic inequality within countries, and major advances in low-carbon technologies.

- SSP1 – Sustainability
- SSP2 – Middle of the Road
- SSP3 – Regional Rivalry
- SSP4 – Inequality
- SSP5 – Fossil-fuelled Development

Figure 5 Atmospheric concentration by SSP, 2000-2100[xxvi]



These can be used in Integrated Assessment Models (IAMs) to derive carbon dioxide concentrations (Figure 5) and from those, the forecast range of temperature increases with uncertainty bands.

UNCERTAINTIES AND CONTROVERSIES STILL REMAIN

Climate change deniers may have shrunk in number but remain politically important, particularly in the US but also in the UK, Canada, Australia and elsewhere. Different types of denial argument (often held together by the same people or organisations) include:

1) Global warming is not happening or is inconclusive (e.g. poor data, scientific conspiracy), or models predicting future warming are biased or unreliable;

2) Future global warming will be low/not serious;

3) Warming is not human-caused but natural (solar variation, natural cycles, volcanoes, etc.);

4) Warming and higher CO2 will be beneficial (milder high-latitude climates, faster plant growth);

5) Current global climate policy is unfair to developed countries, notably the US, and lets off China and India;

6) Alternatives to fossil fuels are unready, unreliable, not scalable or in other ways unsuitable;

7) It is too late to take any serious action against climate change / it would be too costly and economically damaging.

With the exception of (5), all these arguments have been repeatedly debunked by scientists, including in the IPCC reports, and communicators[xxvii]. The assertion that global climate policy is unfair to developed countries (5), has been substantially weakened by the structure of the Paris Agreement and by China's net-zero commitment, which exceeds that of the US, Australia and several other high-income countries.

Apart from the climate denier arguments above, there are real and important areas of remaining uncertainty. These do not relate to the overall picture of warming, but to aspects of modelling and forecasting, particularly positive feedback loops, and including regional effects of warming, the impact on ecosystems and carbon storage, and the role of clouds. The more significant challenges of the broader suite of climate science concern the size and nature of climate change damages and their wider socio-political consequences.

For global climate policy, ruling out – or ruling in – the high scenarios of global warming is most influential. The Paris Agreement's target of no more than 2°c and an aspiration of less than 1.5°c of warming was set on the basis of scientific advice that this level of warming was damaging but likely not catastrophic – and also, that it was just about within the bounds of technological, economic and social feasibility.[xxviii]

Carbon fertilisation is important for feedback cycles. Plants grow faster by taking up more CO_2 in a world with higher atmospheric concentrations. But plants also respond to higher temperatures by closing their stomata (pores) to limit water loss, reducing their growth. The combined effect of these competing processes is not well-understood, particularly for tropical areas such as the Amazon.

Clouds remain a key source of uncertainty because they have competing effects: they cool the Earth by reflecting sunlight into space, but they warm it by transferring infra-red radiation to the surface. Some studies suggest the equilibrium climate sensitivity could be much higher than the generally-accepted 2-4.6°c, possibly 5-5.3°c, if the effects of clouds are properly modelled[xxix].

Some important areas requiring further research, to address uncertainties, include:

- The real effect of climate variability and extreme weather events.
- Ensuring that climate-economic models fully cover adaptation.
- The complexity of socio-economic effects of climate change.
- Assessing and understanding the full impact of low-carbon technologies.

POLITICAL IMPLICATIONS AND RESPONSES TO CLIMATE SCIENCE

As noted, recent climate work has not radically changed the big picture of global warming, but it has filled in many details. Continuing to improve the reliability and robustness of climate forecasts is important for supporting the political process, particularly given the continuing influence of climate "deniers" or at least those who still argue against robust action.

The IPCC's publications, underpinned by extensive research, were essential for laying out the scientific basis leading to the Paris Agreement of 2015 and its choice of 1.5°c and 2°c warming limits, and to a growing number of "net-zero" commitments by countries (China, the EU, Japan, Norway, South Korea, UK, and others) and companies. The work by researchers such as David Victor on "climate clubs" was important in encouraging the Paris approach of "nationally-determined contributions" (NDCs), which should be strengthened every five years. The next round of updates is due for COP26 to be hosted by the UK in October-November 2021.

Attribution is important because it links people's experience of extreme weather, often disastrous, to their understanding of climate change as a major problem. This puts pressure on governments to act and can expose companies to legal liability for their contribution to global warming[xxx]. The case of Shell, ordered by a Dutch court in May 2021 to cut direct and indirect GHG emissions from its products by 45% by 2030, and the late 2019 ruling on appeal upholding a judgement against the Netherlands government for not protecting its citizens from the harmful effects of climate change[xxxi], are some examples. Financial regulators increasingly require companies to assess and disclose their exposure to climate risks. Insurance companies also use such methods to set policy premia, and areas exposed to climate effects, such as low-lying coastlines, river floodplains or houses in fire-prone forests, may increasingly become uninsurable.

VIEWS ON CARBON REMOVAL AND CLIMATE ADAPTATION

The combination of recent climate science findings with continuing rising levels of GHG emissions emphasise the need for progress in five areas:

1. Communicating the latest findings clearly to the general public, with clear and truthful messages that appropriately acknowledge risks and uncertainties, tailored to specific audiences.
2. Greater urgency on GHG emissions cuts, at least bringing all national ambitions and actions in line with the Paris Agreement, and showing concrete progress on the right timeline to its achievement. Most countries need realistic plans and intermediate goals to reach net-zero by 2050-2060.
3. Better planning and greater funding for climate adaptation, with due regard to regional climate models, the possibility of extreme weather outside mainstream climate model predictions, and overall uncertainty.
4. Accelerating progress on researching and deploying carbon dioxide removal (CDR). Most climate models that achieve stabilisation and net-zero around mid-century incorporate huge quantities of CDR from bio-sequestration (forestry, agriculture, soil carbon) and technological methods.

5. Carrying out serious research and preparation for geo-engineering. Geo-engineering covers techniques that reduce global warming by reducing solar insolation or otherwise modifying large-scale features of the Earth. For instance, small particles injected in the stratosphere, or mirrors in space, could slightly reduce incoming radiation to offset trapping by GHGs.

IMPLICATIONS FOR LEADING OIL AND GAS PRODUCERS

Climate science is building an increasingly solid and urgent case for rapid reductions in GHG emissions and remaining uncertainties do not alter the situation. If some of the more extreme climate change scenarios are ruled out, other dangerous possibilities are seen now to be more likely. At the same time, low-carbon energies are making impressive gains in performance and cost. Satellite monitoring is increasingly revealing methane leakage from some oil and gas operators and will likely turn to exposing other examples of poor environmental practices.

Climate policy and activism, such as opposition to oil and gas production and leasing, pipeline bans, prohibition of internal combustion engine vehicles, carbon pricing, and zero-carbon fuel standards, is increasingly stringent. Funding anti-climate science and policy[xxxii] is counter-productive and risks litigation and penalties.

This means that transitions such as those envisaged by the major European oil firms, Shell, BP, Total, ENI, Equinor, Repsol and others, are increasingly important. National oil companies have a different focus, but they also need to pay attention to non-emitting uses of their resources, notably: long-lived plastics and other materials, carbon capture and storage (CCS), and hydrogen with CCS.

Publicly listed corporations will face legal cases and shareholder pressure, and all fossil fuel companies are likely to have to deal with an increasing shortage of financing, insurance and other business services. If they cannot provide these services in-house or from their host governments, they will have to define strategies towards net-zero to maintain market access.

Climate change will have an impact on oil companies' operations, such as, impact of heat waves or cold snaps on facilities in some locations, and devastating effects of floods and storms on offshore, coastal and riverine installations.

CDR will become increasingly important and is likely to attract growing policy support, both directly and via higher carbon prices. CDR fits well with oil companies' existing businesses and could be a growing area of focus for them. They will in any case need to make use of CDR and bio-based offsets to cancel out their residual GHG emissions.

CONCLUSIONS

Climate science has become increasingly sophisticated and capable of making detailed predictions on a regional scale. But the underlying scientific understanding has not changed, and the estimates of warming and climate sensitivity made as far back as the 1950s, and certainly the 1980s, remain surprisingly robust today. Attribution of extreme weather opens up a field of insurance and legal liability for companies and governments.

Further progress will likely come in the areas of improving resolution of specific areas and systems, such as icesheets, large-scale atmospheric-oceanic coupled circulation systems, rainforests and other ecosystems, and of stored carbon. Linking these better to economic models may improve estimates of climate damage, which remain highly uncertain. The socio-political impacts of global warming are even harder to understand, even in retrospect, and certainly in prediction.

Questions about overall climate science and policy are now political and normative, not of measurement or scientific fact. But further progress in climate science is important for driving continuing commitments to emissions reductions, and in guiding adaptation measures. It also points to the near-certain need for large-scale CDR, and the likely requirement for geo-engineering.

Energy companies and fossil fuel-exporting countries should continue to engage closely in understanding the latest findings of climate science and the implications for them. This can point out areas in which they can develop greater societal and economic resilience, as well as negotiating effectively within the Paris process and tailoring their NDC updates to be ambitious but achievable.

APPENDIX

i. https://www.ipcc.ch/assessment-report/ar5/
ii. https://www.ipcc.ch/sr15/
iii. https://www.ipcc.ch/site/assets/uploads/2018/02/Nobel_statement_final.pdf
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xxvi. Based on data from https://tntcat.iiasa.ac.at/SspDb/
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xxxi. https://www.worldoil.com/news/2021/7/20/shell-to-appeal-dutch-court-decision-mandating-faster-carbon-cuts
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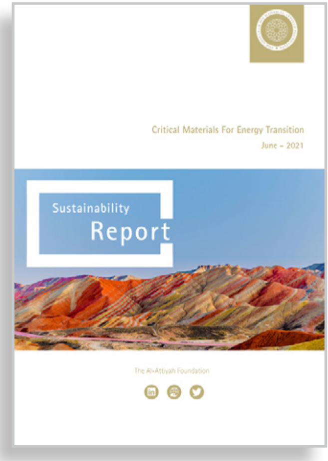
PAST ISSUES

Have you missed a previous issue? All past issues of The Al-Attiyah Foundation's Research Series, both Energy and Sustainability Development, can be found on the Foundation's website at www.abhafoundation.org/publications



June- 2021

Critical Materials For Energy Transition

The emerging new global energy system requires new materials that were not traditionally in high demand. Their currently known reserves are often small, technically difficult to obtain, or concentrated in politically challenging countries.

(QRCO.DE)

May - 2021

Strategies for Sustainable Production and Consumption of Natural Resources

Natural resources encompass a wide range of physical and biological materials, entities and systems, from coal or iron ore, to a freshwater lake, North Atlantic cod, the Amazon rainforest, sunlight or the atmosphere.

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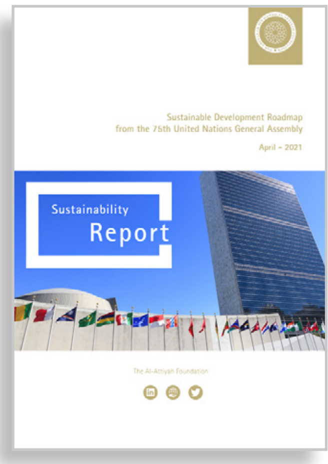

April - 2021

Sustainable Development Roadmap from the 75th United Nations General Assembly

The United Nations' Sustainable Development Roadmap is the blueprint for fighting poverty and hunger, confronting the climate crisis, achieving gender equality, and much more, within the next ten years, the Decade of Action.

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Our partners collaborate with The Al-Attiyah Foundation on various projects and research within the themes of energy and sustainable development.

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GORD – Gulf Organisation for Research & Development

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