Climate Change:

Introduction to climate science
Economic effects of climate change

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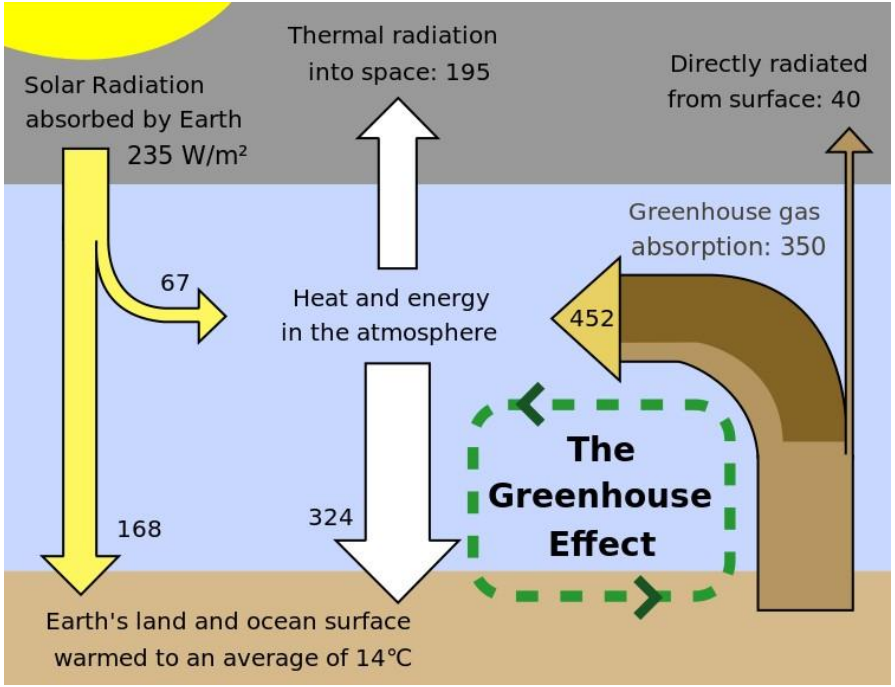
February 24, 2020

Outline

1. The physics of climate change
2. Is it induced by humans?
3. Climate science: Introduction
4. Climate projections for the future
5. Consequences of global warming
6. Tipping points in the climate system
7. International policy coordination

1. The physics of global warming

- CO_2 emissions + other greenhouse gases (methane) => distorsions to planet's energy balance.
- Accumulation of greenhouse gases blocks some of the re-radiation of sunlight back to the space, redirecting energy back toward the Earth's surface.
- Without greenhouse gases, the planet would be about 33˚C cooler.



By Robert A. Rohde (Wikipedia)

1. The physics of global warming

Evolution of the CO2 concentration

- 4000 parts per million in Cambrian period
- 180 PPM during Quarternary glaciation in mid Pliocene (2 mil years ago), i.e.
- 280 PPM pre-industrial levels, i.e., 0.028%
- 415 PPM as of May 2019, i.e., 0.04%
- (48% increase since pre-industrial level)
- It matters: Just from 1880, the surface temperature increased by 1˚C.

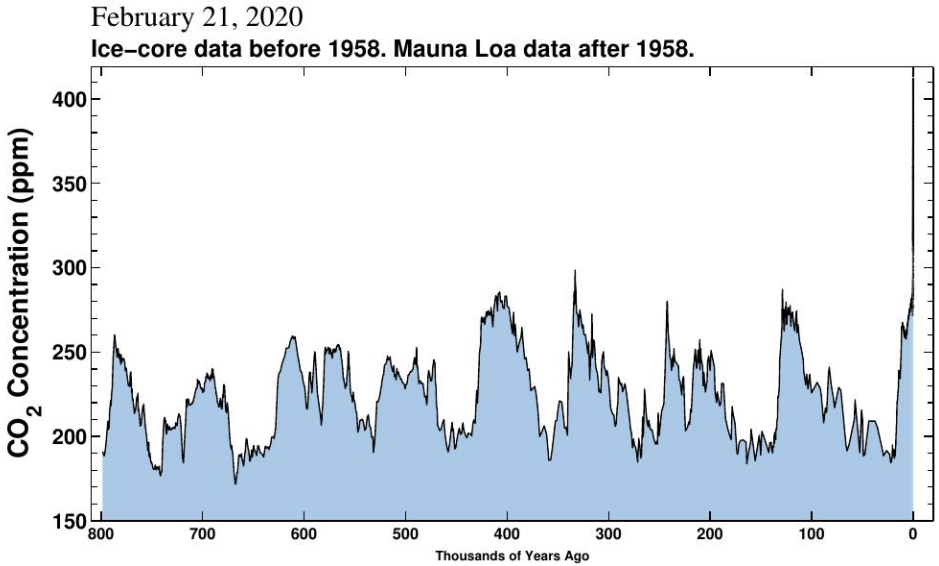
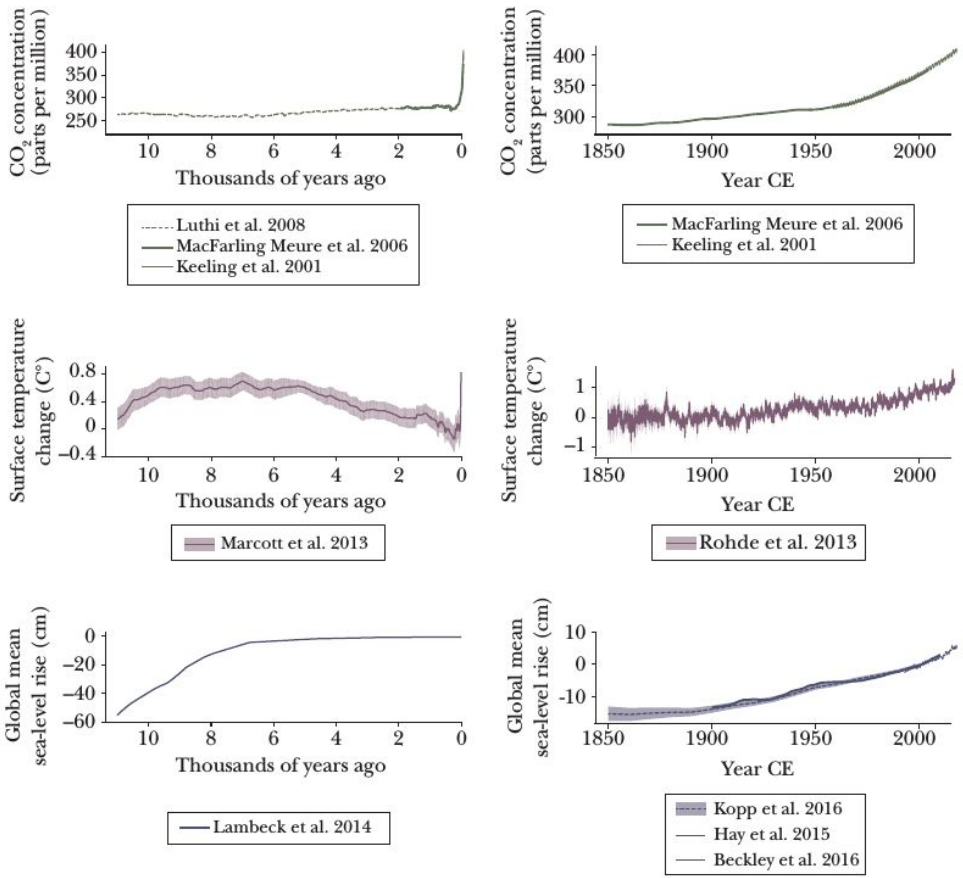


Figure 1

Atmospheric CO_2 Concentrations, Global-Mean Surface Temperature, and Global-Mean Sea Level



2. Is the climate change induced by humans?

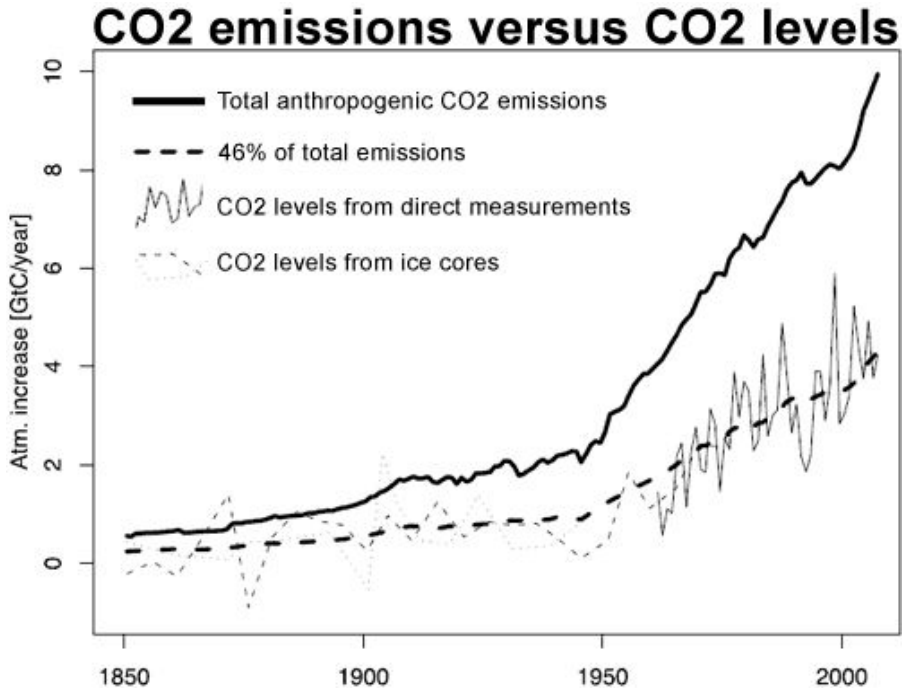
Given the magnitude of human-caused CO2 emissions, yes (probability above 99%).

Average human about 5 tonnes of CO2) every year, due to massive burning of fossil fuels.

About 46% of CO2 produced remains in the atmosphere (absorption by the oceans and plants).

The effect of CO2 emissions is persistent: About a quarter of today's' emissions will remain in the atmosphere for well over a millennium.

In total, humans are likely (with at least 66 % probability) responsible for 0.6°C–0.8°C of the observed 0.6°C of warming over 1951–2010.



2. Is the climate change induced by humans?

Table 2

Statements of the Intergovernmental Panel on Climate Change (IPCC) on Detection and Attribution of Global Climate Change

First Assessment Report (1990)	"Unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more."
Second Assessment Report (1995)	"The balance of evidence suggests a discernible human influence on global climate."
Third Assessment Report (2001)	"Most of the observed warming over the last 50 years is *likely** to have been due to the increase in greenhouse gas concentration."
Fourth Assessment Report (2007)	"Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations."
Fifth Assessment Report (2013)	"It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century."

Source: The IPCC Assessment Reports can be found at https://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml.

* The uncertainty language used by the IPCC is precisely defined: *likely* refers to an assessed probability of at least 66 percent, *very likely* implies at least 90 percent, and *extremely likely* means at least 95 percent.

3. Introduction to climate science

- Formal models: simulations of joint probability distributions of the state of the atmosphere, oceans, freshwater and ice.
- Outcome: global mean surface temperature - as a simplification of results in all highly multidimensional systems.
- Climate models highly complex. Thus, the climate models are suited for modelling non-linear and non-converging processes.
- Consequence: Initial conditions matter - projections depend on assumed emission scenarios (!).
- Not simple math: Change in CO_2 triggers feedbacks, in particular water vapor which increases with rising temperature.
- Water vapor is the most powerful absorber of infrared radiation (by which the energy is redirected back to the space.

3. Introduction to climate science

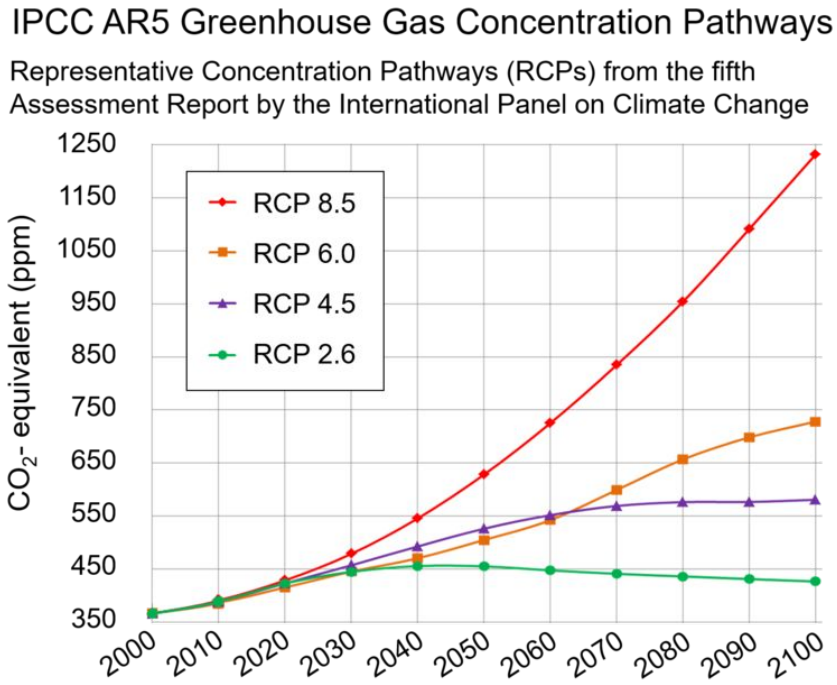
- In the absence of feedbacks, CO2 concentration increase of 50% would lead to warming of about 0.6˚C. With those feedbacks, the equilibrium warming associated with the current level of CO2 forcing is about 1.6˚C above the preindustrial baseline already (Hsiang and Kopp, 2018).
- Actual warming is slower, partly because deep oceans exchange the surface temperature slower.
- Hsiang and Kopp (2018): *"All climate change forecasts rely heavily and directly on economic forecasts for the world. On timescales of a half-century or longer, the largest source of uncertainty in climate science is not physics, but economics."*
- They also consider this point as being unappreciated by economists.

4. Climate projections for the future

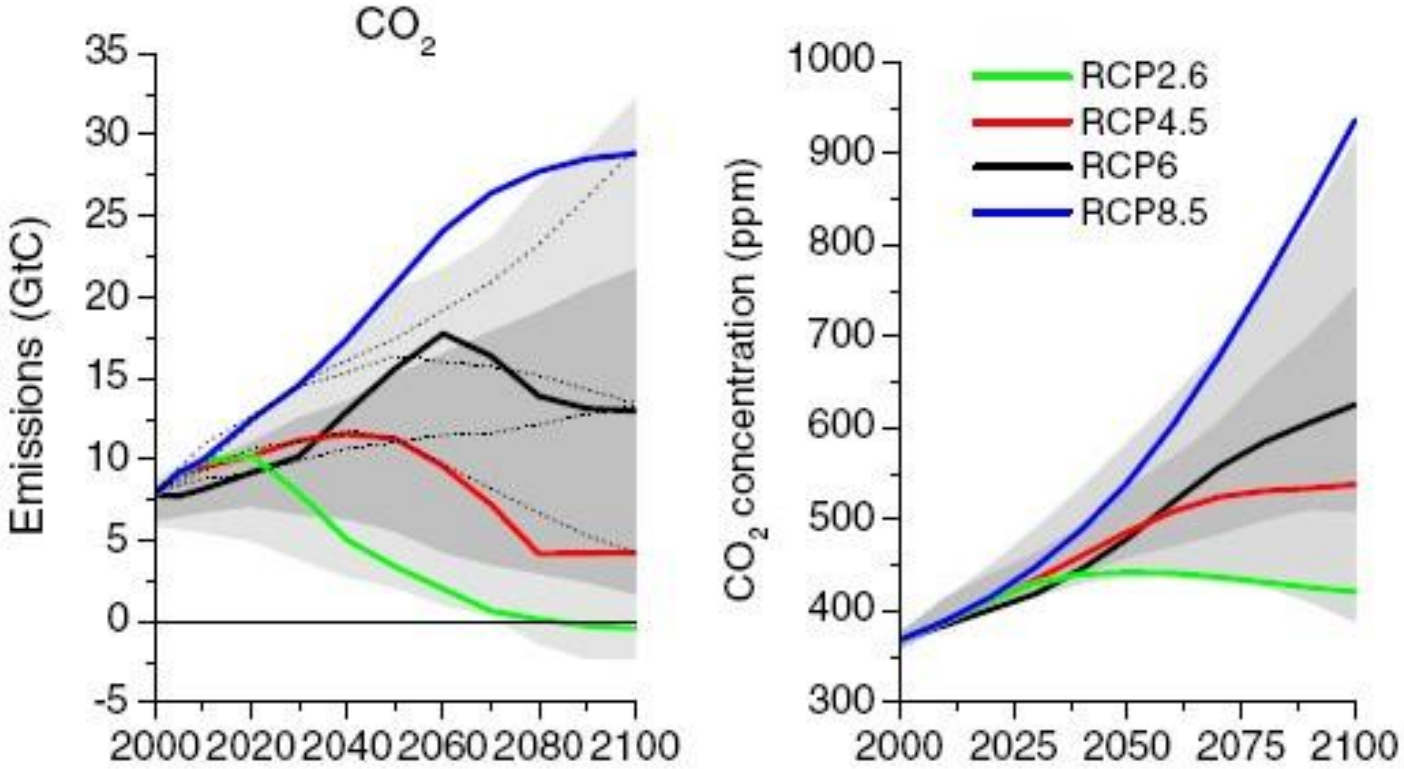
The IPCC reports are based on The Coupled Model Intercomparison Project (CMIP) that extracts outcomes of various models.

Emissions scenarios considered - so called Representative Concentration Pathways (RCPs).

Till 2100 increase below 1.5˚C in case of decreasing CO2 concentration since 2040.



4. Climate projections for the future



4. Climate projections for the future

Impact of emissions scenarios on temperature, difference over 1985-2005 average (add 0.6˚C to compare with the pre-industrial levels)

AR5 global warming increase (°C) projections[11]

	2046–2065	2081–2100
Scenario	Mean and *likely* range	Mean and *likely* range
RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
RCP4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
RCP6.0	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)
RCP8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)

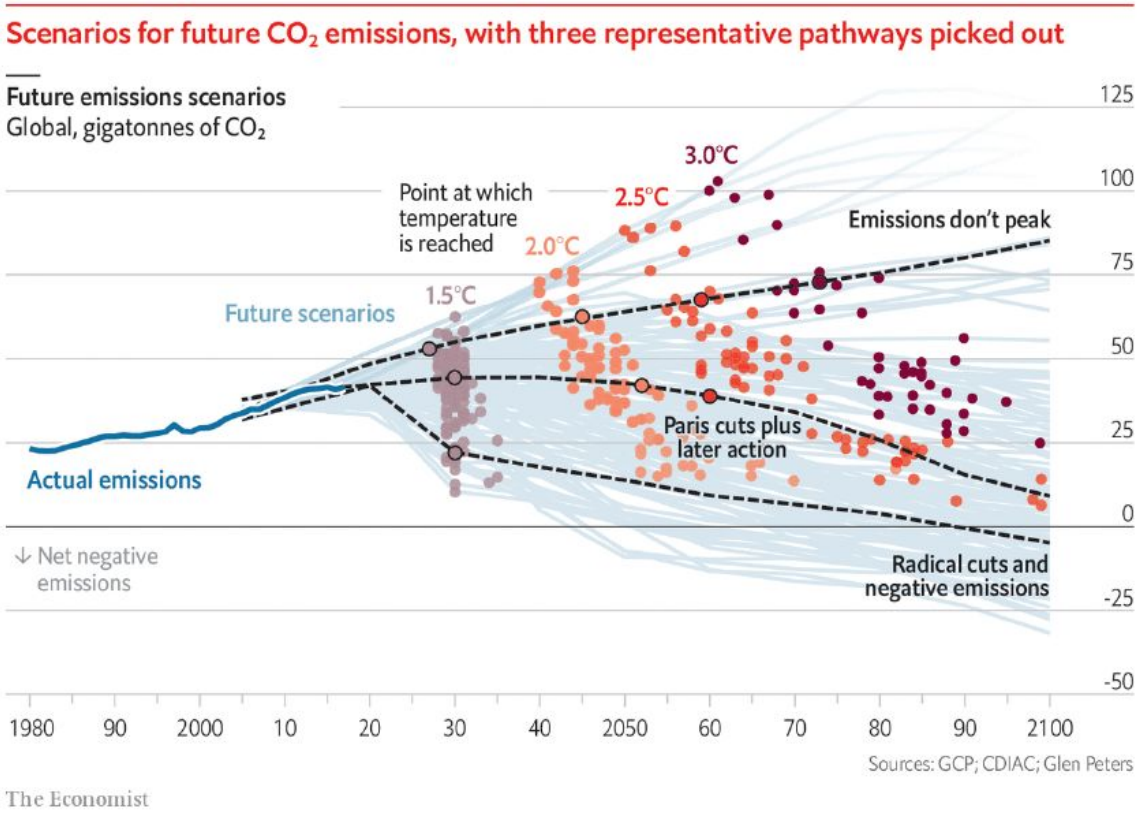
Across all RCPs, global mean temperature is projected to rise by 0.3 to 4.8 °C by the late-21st century.

AR5 global mean sea level (m) increase projections[11]

	2046–2065	2081–2100
Scenario	Mean and *likely* range	Mean and *likely* range
RCP2.6	0.24 (0.17 to 0.32)	0.40 (0.26 to 0.55)
RCP4.5	0.26 (0.19 to 0.33)	0.47 (0.32 to 0.63)
RCP6.0	0.25 (0.18 to 0.32)	0.48 (0.33 to 0.63)
RCP8.5	0.30 (0.22 to 0.38)	0.63 (0.45 to 0.82)

Across all RCPs, global mean sea level is projected to rise by 0.26 to 0.82 m by the late-21st century.

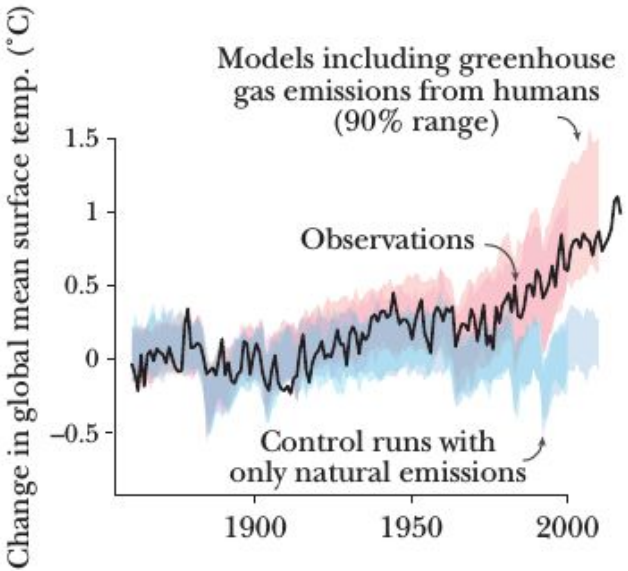
4. Climate projections for the future

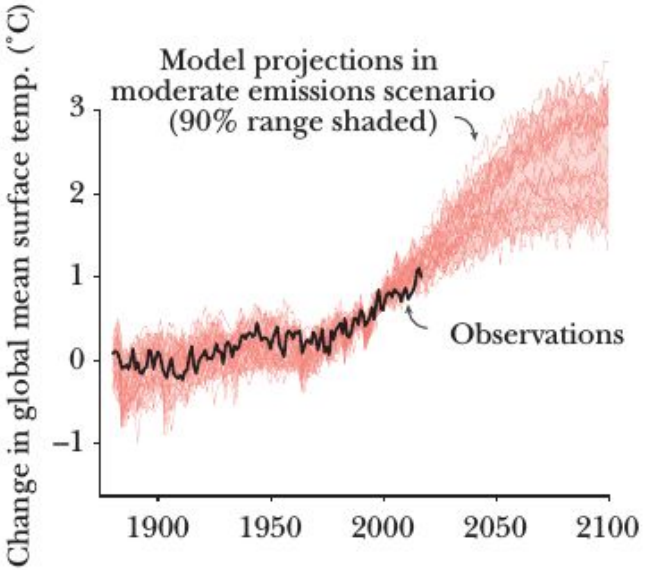


4. Are the projections correct?

Figure 2

Average Annual Global Mean Surface Temperature, Compared to Distributions of Climate Model Simulations



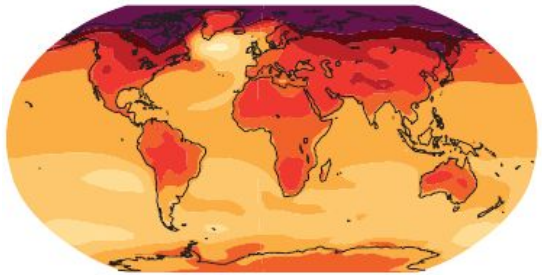


5. Consequences of global warming

Figure 3

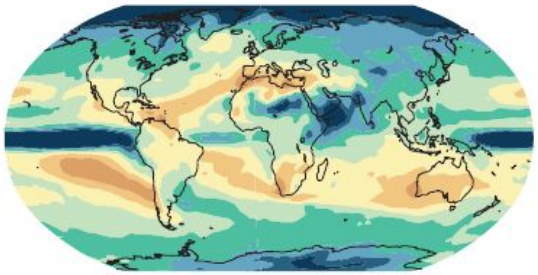
Projected Change in Local Average Temperatures and Local Average Rainfall per 1°C of Warming in Global Mean Temperatures

A: Temperature change



Δ local temperature (°C) per 1°C global temperature

B: Rainfall change



Δ local rainfall (%) per 1°C global temperature

Source: Collins, Knutti, et al. (2013).

Note: Changes are differences in means between 1986–2005 and 2081–2100 in CMIP5 simulations of RCP 4.5, scaled by the overall change in global mean temperature. These heatmaps should be viewed in color. See the electronic versions on the JEP website.

5. Consequences of global warming

The Guardian

JP Morgan economists warn climate crisis is threat to human race

Leaked report for world's major fossil fuel financier says Earth is on unsustainable trajectory

Patrick Greenfield *and* **Jonathan Watts**

Fri 21 Feb 2020 16.27 GMT

5. Consequences of global warming

- IPCC report 2019: large difference between +1.5˚C and +2˚C scenarios (see here https://www.ipcc.ch/sr15/chapter/spm/ for the details)
- The problem of CO2 emissions recognized already in the 1960s.
- 1977: William Nordhaus's speech at American Economic Association; analysis and management of climate change recognized as an important economic problem (that time considered as something with high risk but in distant future and low probability).
- However, the economic implications much less understood in comparison to the effects on climate as such (Auffhammer, JEconPersp 2018).

5. Consequences of global warming

Problems of economic models

- Greenhouse gases are longlived and damage even from local emissions is global.

  => The calculation of social costs of carbon very much depend on discount rates (how much we value consumption of the future generations that will be affected by todays' emissions).

- Thus, William Nordhaus, Nobel Prize 2018 for his research in the effects of climate change, finds the negative effects of climate change identified in the Stern report of 2006 exacerbated, claiming that they depend on very low discount rate. (https://www.nber.org/papers/w12741.pdf).

5. Consequences of global warming

Framework: Integrated Assessment Models.

- Most famous - DICE by William Norhdaus, FUND, PAGE and others.
- Emission scenarios => climate model to obtain future temperatures => set of damage functions.
- Wide range of estimated values of social values of carbon, ranging from about 5 USD per tCO_2 to almost 100 USD per tCO_2.
- Mean value for 3 % discount rate: $42 ($62 with 2.5 % discount rate)
- The IAMs often tend to predict losses resulting from a 2˚C increase in global mean temperature up to 2% of GDP.

5. Consequences of global warming

Framework: Integrated Assessment Models.

- Steve Keen: If the damage functions in those models are true, the same implication would hold for the opposite, cooling the Earth by 4˚C, which corresponds to the temperature during the ice age. That time, Canada, part of US and northern Europe were covered by a kilometer of ice, which does not seem to be consistent with a loss of 2% of GDP or so.

5. Consequences of global warming

Framework: Integrated Assessment Models.

- Auffhammer, JEconPersp 2018:

  "The damage functions in the Integrated Assessment Models, which are used to calculate the social cost of carbon, are outdated. (...) The most recent studies in the FUND model stem from 2009, with the majority of the literature cited stemming from the early and mid-1990s.

  For example, the damage function for agriculture in the FUND model implies that warming up to roughly 5˚C produces benefits for the sector.

  This is not consistent with the recent literature on agricultural impacts, which for example, points at the significant negative impact of extreme heat days."

5. Consequences of global warming

Framework: Integrated Assessment Models.

- Pindyck, 2013 (https://www.nber.org/papers/w19244.pdf):

  "A plethora of integrated assessment models (IAMs) have been constructed and used to estimate the social cost of carbon (SCC) and evaluate alternative abatement policies.

  These models have crucial flaws that make them close to useless as tools for policy analysis: certain inputs (e.g. the discount rate) are arbitrary, but have huge effects on the SCC estimates the models produce; the models' descriptions of the impact of climate change are completely ad hoc, with no theoretical or empirical foundation; and the models can tell us nothing about the most important driver of the SCC, the possibility of a catastrophic climate outcome.

  IAM-based analyses of climate policy create a perception of knowledge and precision, but that perception is illusory and misleading."

5. Consequences of global warming

Framework: Integrated Assessment Models.

- Nicolas Stern (Nature, 2016) believes that the current climate models are grossly misleading: *"the literature (has) systematically and grossly underestimated the risks of unmanaged climate change.*
- *(It) had failed to capture the learning processes and economies of scale involved in radical structural and technical change, and the benefits of reducing fossil-fuel pollution, protecting biodiversity and forests, and so on. (...)*
- *Furthermore, many of the largest potential impacts are omitted, such as widespread conflict as a result of large-scale human migration to escape the worst-affected areas."*
- https://www.nature.com/news/economics-current-climate-models-are-grossly-misleading-1.19416

5. Consequences of global warming

Framework: Integrated Assessment Models.

- The problem of uncertainty is addressed by Martin Weitzman, On modeling and interpreting the economics of catastrophic climate change (REconStat, 2009, https://www.mitpressjournals.org/doi/pdfplus/10.1162/rest.91.1.1).
- The problem in estimation is that prior knowledge cannot place sufficiently narrow bounds on overall damages => fat tails in p.d.f. => Econ. implications of this fat tail uncertainty outweighs the effect of discounting in climate change models.

5. Consequences of global warming

Framework: Integrated Assessment Models.

- Thus, some alternative models of economic impacts are yet to be developed.
- They should account for:

  (1) uncertainty,
  (2) aggregation, heterogeneity and distributional implications
  (3) technological change, and most of all,
  (4) realistic damage functions for the economic impact of the physical consequences of climate change.

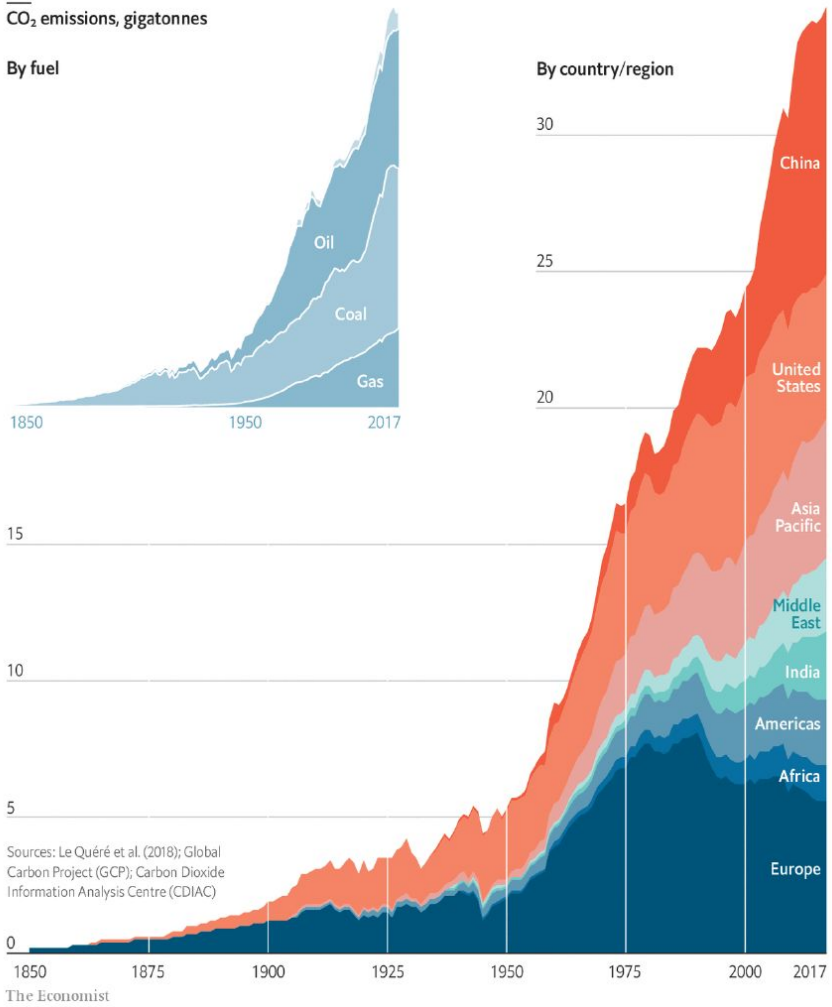
  See Farmer, Hepburn, Mealy, Teytelboym: A THird Wave in Economics of Climate Change, 2015.

6. Tipping points in the climate system

- Multiple stable states of different parts of the Earth system, with potentially rapid lock-in of a state shift once critical thresholds are crossed.
- In particular:
    - shifts in large-scale ocean circulations (Atlantic Meridional Overturning Circulation),
    - shifts in climate oscillation (El Nino),
    - meltening of permafrost leading to releases of methane.
- However, there is no scientific consensus whether they will occur and what will be their effects. Thus, these tipping points are not considered in the IPCC projections.

7. International policy coordination

- Paris agreement (2015): agreement to limit the global temperature rise well below 2°C, however, the U.S. set back and the progress on climate action has been limtied.
- Commitment towards carbon neutrality by 2050 - 121 countries but less than 25% of emissions.
- Much less number of countries have already adopted policies leading towards that goal (Netherlands, Sweden and Finland belong to the early adopters).
- Limited effort described in the WEF report The Net Zero Challenge 2020, https://www.weforum.org/reports/the-net-zero-challenge-fast-forward-to-decisive-climate-action => call for unilateral action.



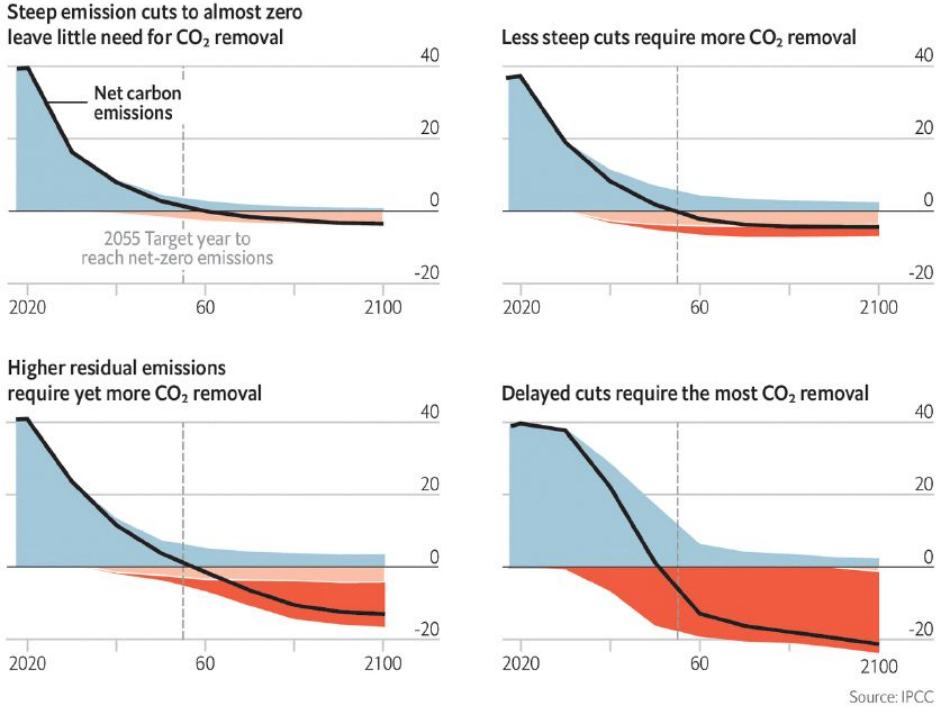
The Economist

Four futures: the sooner and deeper you cut, the less CO_2 removal you need

Emissions scenarios to stay below 1.5°C warming
Gigatonnes of CO_2

CO_2 emissions from fossil fuels, industry and land-use change

CO_2 removal by: Storage in soil and plants; Technology for negative emissions



Source: IPCC

The Economist

Summary

- The evidence of human contribution to climate change is overwhelming.
- CO_2 particles in the atmosphere are very persistent.
- The projections of the climate are based on emission scenarios.
- Only rapid emission reduction towards low carbon economy within the next two decades allows to avoid rising temperature above 1.5˚C in comparison to the pre-industrial levels by the end of the 21st century.
- There's no consensus on the economic impact of the climate crisis. The existing model differ in the implied social cost of carbon and are being criticized for not accounting of technological change and dramatic events properly.
- So far, the agreement on internationally coordinated actions hasn't been reached.

Main references

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