

Taking Stock of Climate Change: Earth, Air, Fire and Water

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Webinar

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with **Jennifer L. Castle**

Summary

Crucial lessons from past mass extinctions of life on Earth.
Information from many sciences bears on causes and consequences of both climate change and mass extinctions.
Evidence from past 500 million years provides a warning: climate change is main culprit in past mass extinctions, humanity is just the latest trigger.

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Evidence from past 500 million years provides a warning: climate change is main culprit in past mass extinctions, humanity is just the latest trigger.

Approaches & evidence from many disciplines compelling: increasing levels of atmospheric greenhouse gases lead to world-wide temperatures slowly rising on a varying trend.

Use ancient framework of Earth, Air, Fire and Water as four ‘essential ingredients’ for life to explore climate change, and actions humanity can take to avoid disaster.

Adaptation not meaningful if food, water & land resources inadequate: yet first mitigation steps can be beneficial.

Econometric modelling toolkit effective in many applications

To establish robust empirical evidence, essential to account for:

cumulative effects of changes, turbulent periods and major shifts as well as relevant drivers like greenhouse gases.

- Confirmed that trend in atmospheric CO_2 is anthropogenic;
- showed future climate will be very different than paleoclimate from anthropogenic emissions;
- detected impacts of volcanic eruptions on global temperature;
- modelled UK CO_2 emissions over 160 years & evaluated impacts of policy despite major shifts;
- showed that improved forecast accuracy of hurricanes helps mitigate their damages;
- estimated costs of temperature changes of 1.5°C versus 2.0°C.

(1) **Can humanity really change the climate? Yes.**

(2) **Distant past: 500 million years of mass extinctions**

(3) **Last 800,000 years: Ice Ages, atmospheric CO_2 & sea-level**

(4) **Middle ages on: detecting impacts of volcanic eruptions**

(5) **Industrial Revolution–present: modelling UK CO_2 emissions**

(6) **Present: modelling the costs of mis-forecasting hurricanes**

(7) **Future: COP21–impacts of 1.5° versus 2° & sea-level rise**

(8) **Conclusions: what can be done?**

Our climate depends on energy balance between Sun's incoming radiation & re-radiation.

Atmospheric greenhouse gases (GHGs, like water vapour and carbon dioxide), crucial in retaining heat:
too depleted and the planet cools, (once being a 'snowball' with glaciation in Death Valley),
whereas excessive GHGs lead to very warm periods (e.g., Eocene about 50 million years ago).

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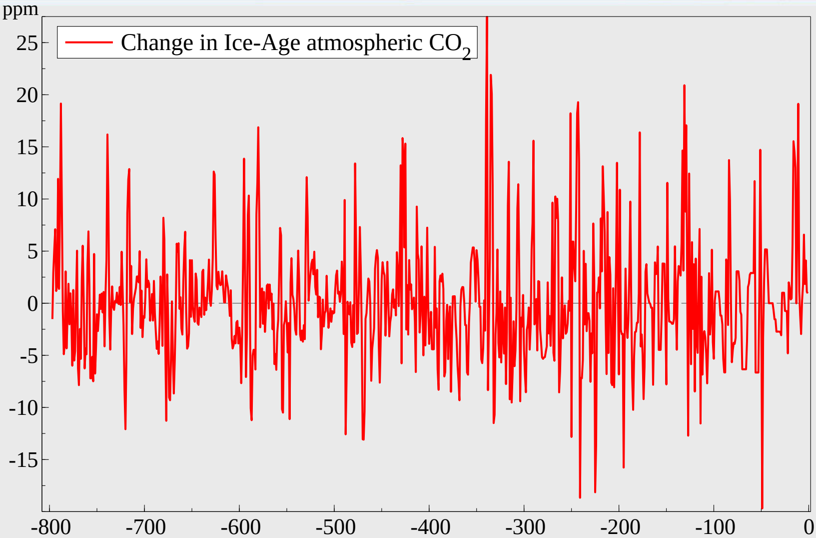
Past climate change driven by natural forces (plate tectonics, volcanism & orbital variations).

Life has survived great changes & thrived in very different global temperatures, but en route huge numbers of species went extinct, even if long after, new species evolved for the new environment.

Change is the key word—humanity is now changing the climate by vast emissions of GHGs mainly CO_2 from burning fossil fuels.

Changes in atmospheric CO_2 over Ice Ages—and now



Thousand-year changes in parts per million (ppm) in atmosphere.

1 ppm = 7800 billion kg of CO_2

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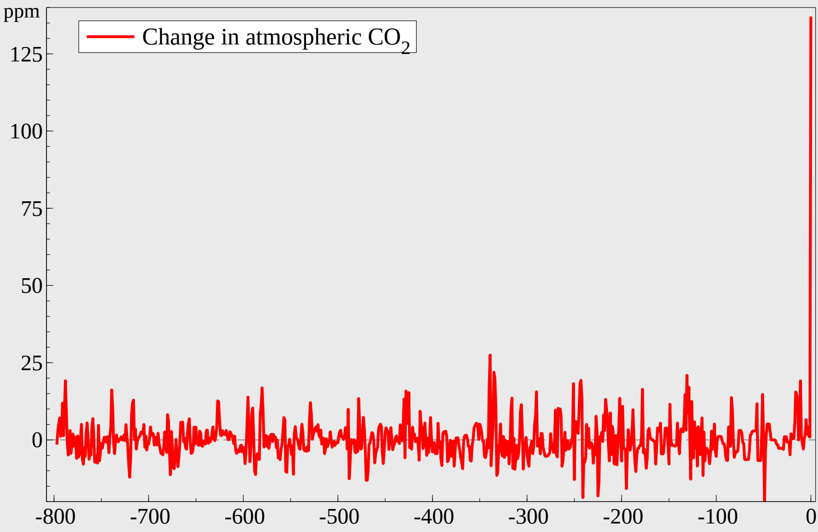

Now: CO_2 changes in under 250 years.

Earth: place holder for our planet's land as both living space and soil for agriculture, forests and other 'wild' areas.

Continents & topography shaped by plate tectonics & volcanoes — both affect climate & played key roles in mass extinctions.

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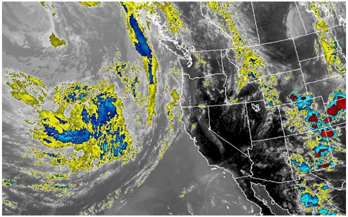
Climate change is:
increasing **land flooding**—'rivers in the sky' can hold more water than the Mississippi River, creating damage & loss of soil;
but also causing **drought**, leading to loss of crops, **dust storms**, & **wild fires** from Australia, Amazon, & California to Siberia, a potential tipping point from tundra melting.

Crops grown using **artificial fertilizers** & farmland created by **deforestation**, plus **animal husbandry** all lead to CO_2 emissions.

Sea level rises cause coastal flooding, reducing **usable land area**.

Rivers-in-the-sky; dust-storm; wild fire; coastal flooding



https:/://www.psl.noaa.gov/arportal

https://public.wmo.int/en/our-mandate/focus-areas/environment/SDS

https://earthobservatory.nasa.gov/images/81919/rim-fire-california

https://en.wikipedia.org/wiki/Coastal_flooding

Air: place holder for our atmosphere of nitrogen (78%) & oxygen (21%), with GHGs water vapour (0.4%), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone + some noble gasses.

http://spaceflight.nasa.gov/gallery/images/station/crew-22/lores/s130e009730

Earth's gravity & magnetic field essential to retain atmosphere against solar wind & protect ozone layer from damaging radiation.

Atmospheric gases

Atmospheric gases have changed greatly over deep time, especially from volcanism & exchange of CO_2 for oxygen through photosynthesis.

Atmospheric blanket essential to life
but 'greenhouse gases' receive then radiate energy at **different wavelengths** between ultraviolet and infrared.

In 1856, Eunice Foote showed that a flask of CO_2 heated greatly in the sun, whereas those of water vapour and dry air did not: see https://doi.org/10.1098/rsnr.2020.0031.

Longwave infrared (IR) re-radiation from GHGs is responsible for the atmospheric greenhouse effect.

Mars and Venus suggest atmospheric protection needs to be 'just right': but Earth's range has included Ice Ages and tropical conditions.

Other anthropogenic greenhouse gas emissions

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now about 7% of greenhouse gas emissions.
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Atmospheric **methane** now **double levels over past 800,000** years.
CH_4 about **20** times as powerful as CO_2 as a GHG: half-life in upper atmosphere of around **15** years getting converted to CO_2.

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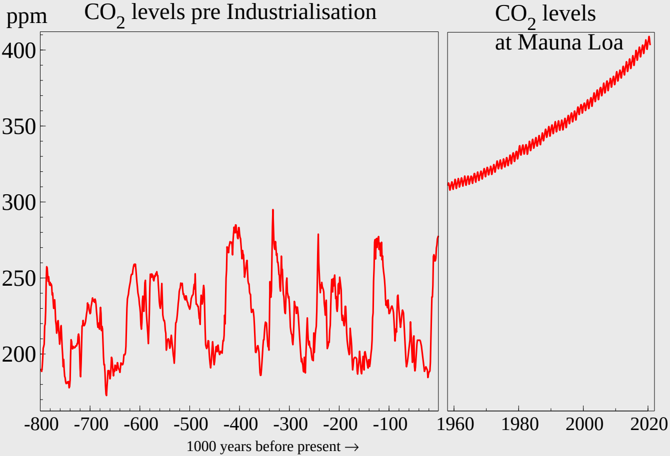
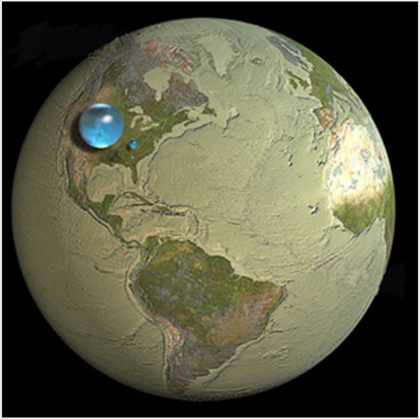
Melting Siberia's permafrost would lead to a marked increase in global temperatures. Go to any lake in northern Siberia, hold a flame over a hole drilled in ice, but jump back quickly as the methane catches fire. Possible collapse in rainforest ecology from resulting changes in rainfall patterns.

Fire: place holder for energy, presently from burning fossil fuels releasing GHGs in vast volumes.

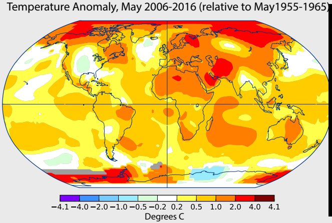


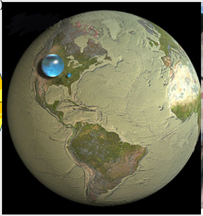
Cannot continue to consume within ‘carbon budget’ for ‘net zero’, so face dangerous changes. Hope from renewable energy drawing on fire (sunlight) and air (wind).

Fooled by widespread shallow oceans: largest sphere of all water just 860 miles in diameter. Easy to heat, pollute, fill with plastic waste, and turn to weak carbonic acid.



Credit: Howard Perlman, USGS; globe illustration by Jack Cook, Woods Hole Oceanographic Institution © Adam Nieman.





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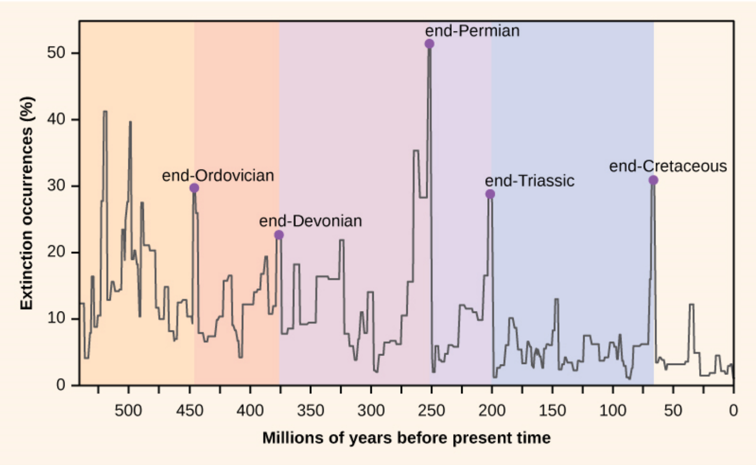
Fossil record disappearances: 'extinctions timeline' at boundaries with Ordovician, Devonian, Permian,Triassic and Cretaceous.



Percent of species vanishing from fossil record reveals fragility of life forms to major climate changes.

Five mass extinctions over 500 million years

First mass extinction at end of **Ordovician** period, roughly **440 mya**, probably due to **global cooling**.

Second around **375 mya**, near close of **Devonian** era:
rapid spread of plant life on land reduced atmospheric CO_2 by photosynthesis–so again **cooling**.

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Fifth major extinction at **Cretaceous–Tertiary** (K/T) boundary, roughly **60 mya**: non-bird dinosaurs went extinct.

Decan Traps. Source: Wikipedia

Chicxulub impact crater near Yucatan peninsula, usually implicated, but also volcanism:
Decan Traps, **300,000** cubic kilometers of basalt.

All due to climate change cooling or heating.

Route map: Past, present and future of climate change

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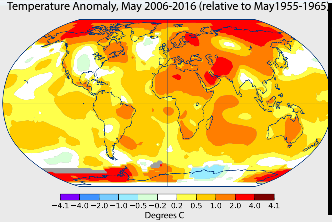

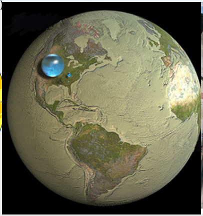

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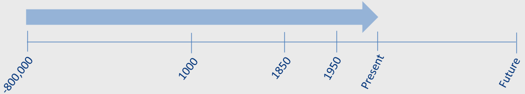

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Discovery of a ‘great ice age’ by Louis Agassiz (1840) based on movements of glaciers in his native Switzerland: explained previously puzzling features of Scottish landscape.

Archibald Geikie (1863) found plant fragments between layers of glacial deposits, so warm periods must have separated glacial.

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Croll’s research amplified by Milutin Milankovitch (1969) calculating solar radiation at different latitudes from interacting changes in eccentricity, obliquity and precession of the Earth.

Milankovitch also corrected Croll’s assumption that winter minimum temperatures mattered in starting ice ages to show that low summer maxima were more important.

The three main interacting orbital changes affecting incoming solar radiation (insolation) that could drive ice ages and inter-glacial periods are:

(a) eccentricity (*Ec*): 100,000 year periodicity from non-circularity of Earth's orbit round the Sun by gravitational influences of other solar system planets;

(b) obliquity (*Ob*): 41,000 year periodicity from changes in the tilt of the Earth's rotational axis relative to the ecliptic;

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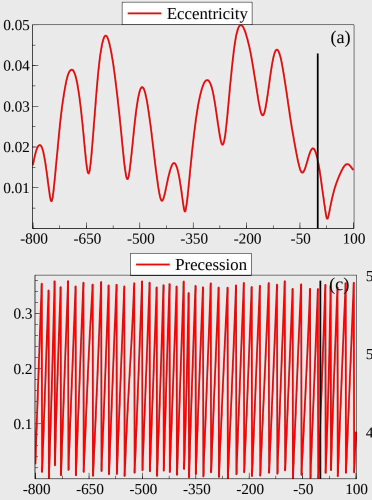
Measured at 1000-year intervals: in next Figures, X-axes labelled by time around present, from 800,000 years ago.
See Paillard, Labeyrie, and Yiou (1996).

Orbital drivers of Ice Ages and into the future



Ice-age orbital drivers: (a) eccentricity (*Ec*); (b) obliquity (*Ob*); (c) precession (*Pr*); (d) Summer-time insolation at 65° south (*St*).

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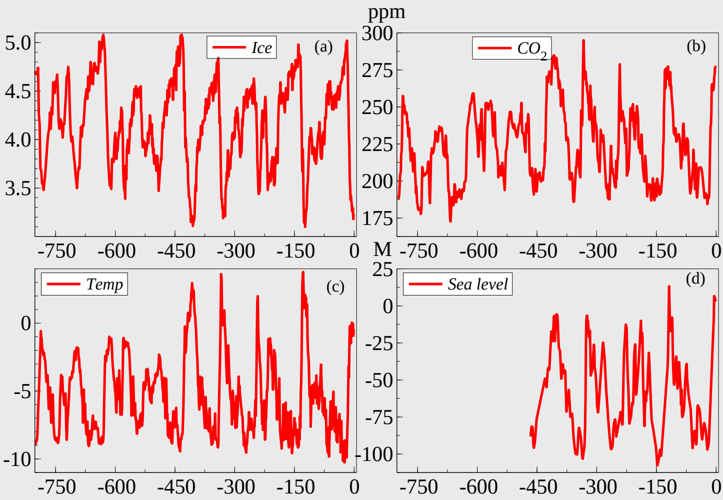
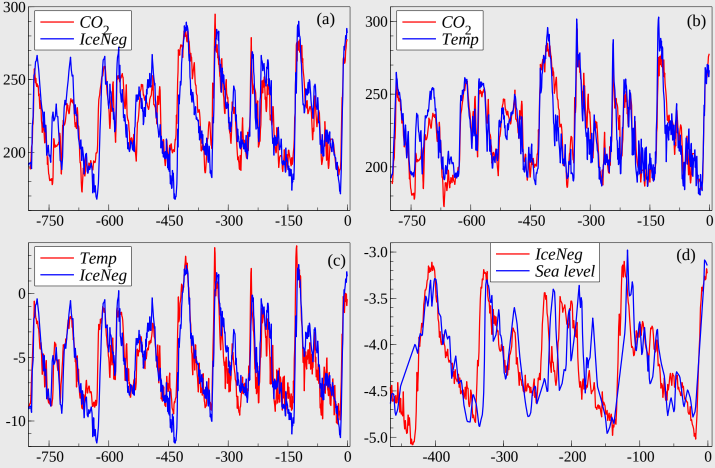


Large international collaboration for Ice-Age time series: (a) Ice volume (*Ice*); (b) atmospheric CO_2 in ppm (CO_2); (c) temperature (*Temp*); (d) shorter-sample sea level changes in meters.

Close relationships between the Ice Ages variables



(a) CO_2 and the **negative** of ice volume (*IceNeg*); (b) CO_2 and temperature; (c) temperature and *IceNeg*; (d) *IceNeg* and sea level.

If Ice Ages due to orbital variations, why should *CO_2* levels correlate so closely with *IceNeg*?
Is that what changes *Temp* & so *Ice*?

As oceans hold about 60 times more CO_2 than the atmosphere, deep oceans, especially Southern Ocean, act as carbon sinks during cold periods but release CO_2 as the planet warms, enhancing cooling and warming: see e.g., Jaccard *et al.* (2016).

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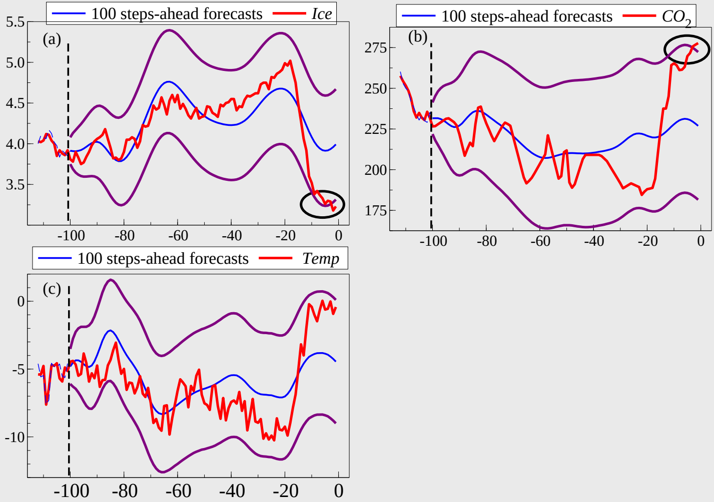
So orbital variations drive *Temp* which changes *Ice* volume and *CO_2* levels, that feedback to change *Temp*.

To resolve, Castle and Hendry (2020) modelled *Ice*, *CO_2* and *Temp* jointly as functions of the orbital variables for data up to 100,000 years ago and forecast the remainder.

A hundred steps-ahead forecasts with error bands



(a) for *Ice*; (b) for CO_2; (c) for *Temp*: **ellipses show 'something happened' near modern times**.

Could reflect slowly growing divergence that might derive from the increasing influence of humanity envisaged by Ruddiman (2005) who suggests humanity began to influence climate 10,000 years ago when domesticating animals and starting farming.

From presence of proto-weeds that need ground disturbance to grow in new areas, Snir *et al.* (2015) provide evidence of origins of cultivation long before Neolithic farming, dating such events to around 23,000 years ago.

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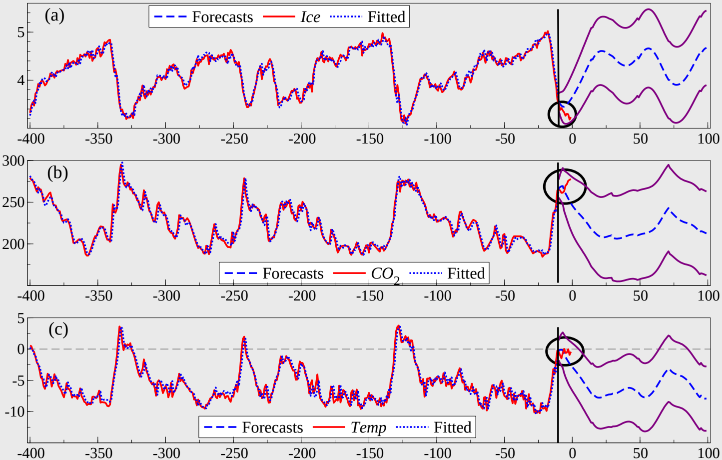
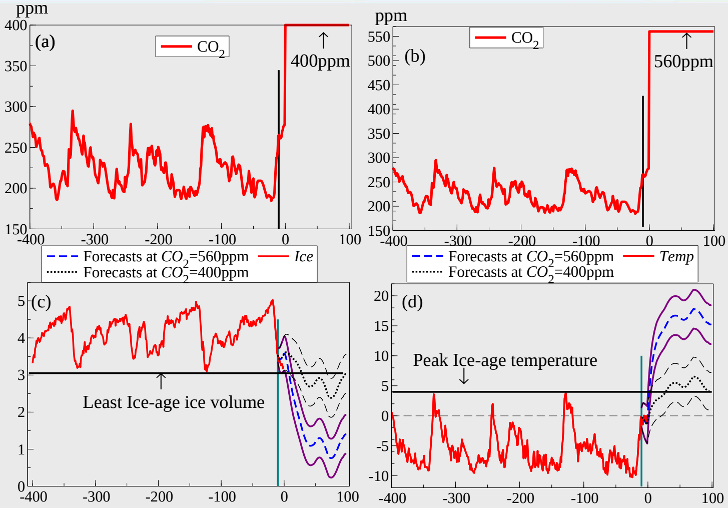
Earth's orbital path is known far into the future, so can calculate scenarios for atmospheric CO_2 in alternative futures: no human intervention, or continued anthropogenic emissions keeping CO_2 at 400ppm (approximately where we are now) or even 560ppm (roughly Representative Concentration Pathway, RCP8.5).
Start forecasts 10,000 years ago.

110 steps-ahead forecasts from model, no human impact



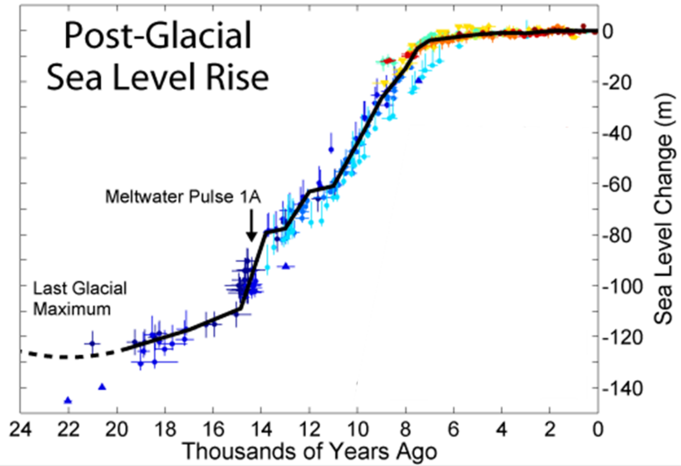
(a) for *Ice*; (b) for CO_2; (c) for *Temp*. **These long-run forecasts give a path well within the range of past data, matching relatively quiescent orbitals. But ellipses show outcomes already differ.**

Scenarios for anthropogenic CO_2 in two possible futures



(a) & (b) $CO_2 = 400$ppm and 560ppm; 110 steps-ahead conditional forecasts with error bands for (c) *Ice* and (d) *Temp*. **At 560ppm face a near ice-free planet, and global temperatures around 6°C higher.**

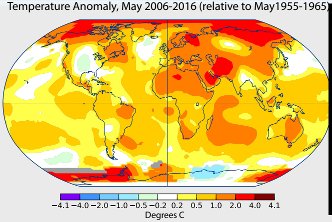
Post glacial sea-level rise

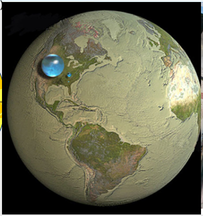


Sea level has increased dramatically since the end of the last ice age: roughly 120 meters. Source

http://www.climateplus.info/2015/07/08/scoping-long-term-sea-level-rise/

Route map: Past, present and future of climate change





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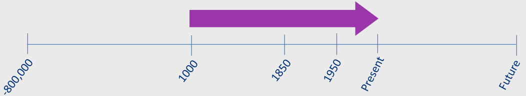

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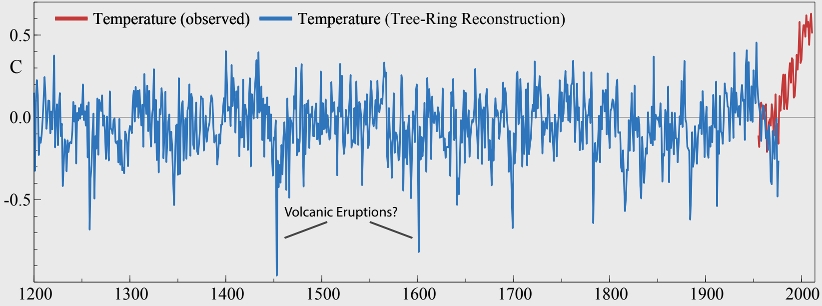
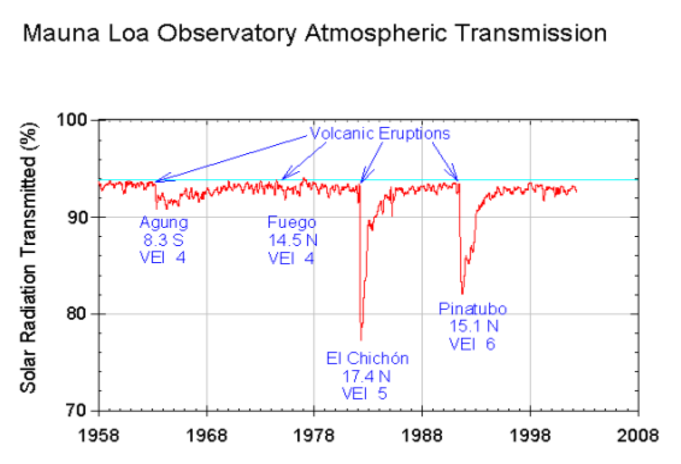
- Uncertainty around the timing and magnitude of eruptions
- but can correct tree-ring based temperature records if we can detect their impacts
- so distinguish temperature reductions due to eruptions from natural and human-induced variation.



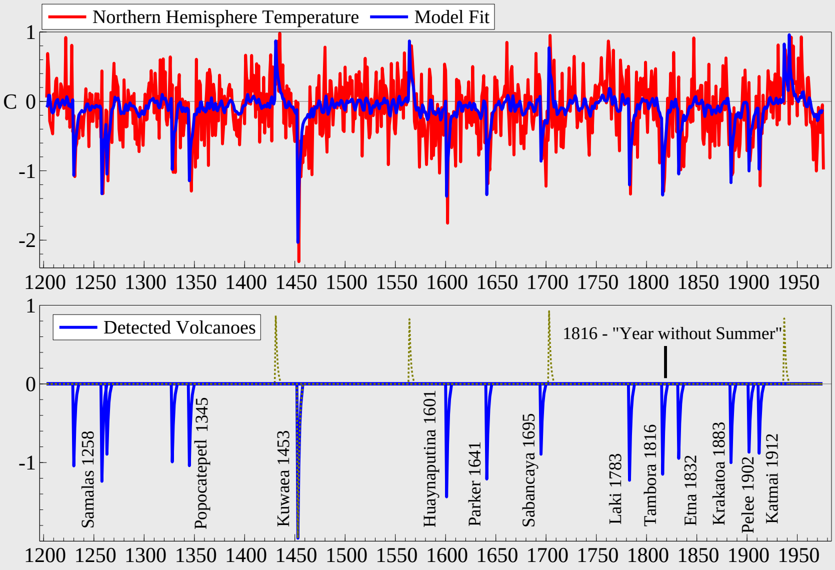
Research with Felix Pretis, Lea Schneider and Jason Smerdon, (2016)

Emissions block solar radiation which reduces temperatures (closer tree rings), but emissions gradually removed from atmosphere. ‘Shape’ of that response is relatively standard.



Design indicators from physical-theory shape of ν.

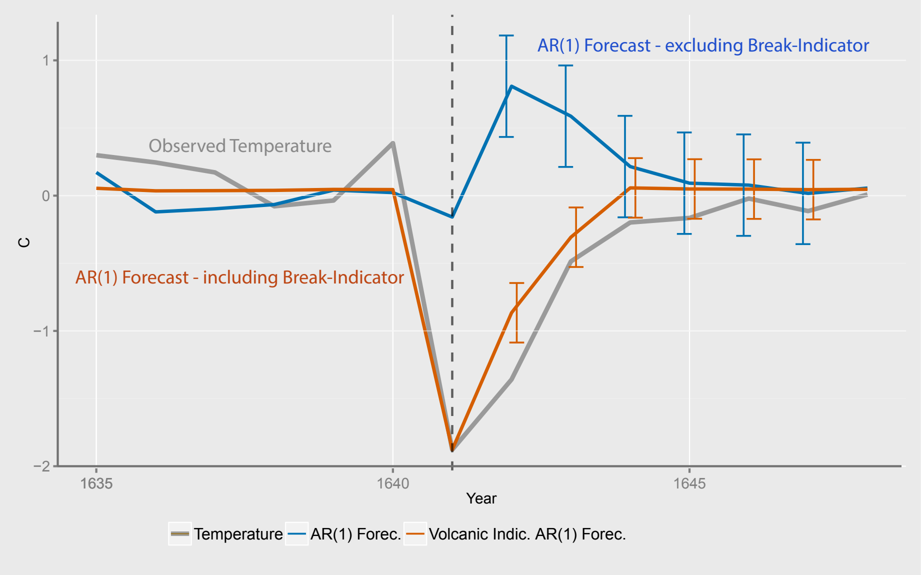
Detecting volcanic impacts on temperature reconstructions: 1200–2000 using our machine learning software



Top Panel–model fit; lower Panel–volcanoes detected

Forecasting temperature recovery immediately after eruptions

Example eruption: 1641 Parker (Philippines)



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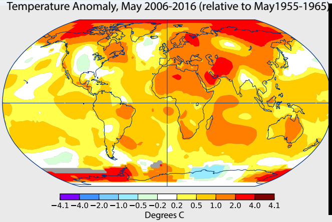

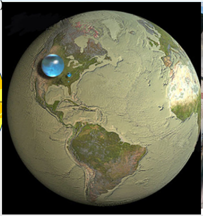

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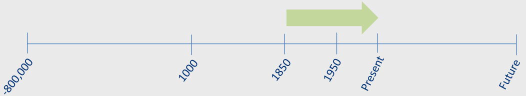


(6) **Present: modelling the costs of mis-forecasting hurricanes**

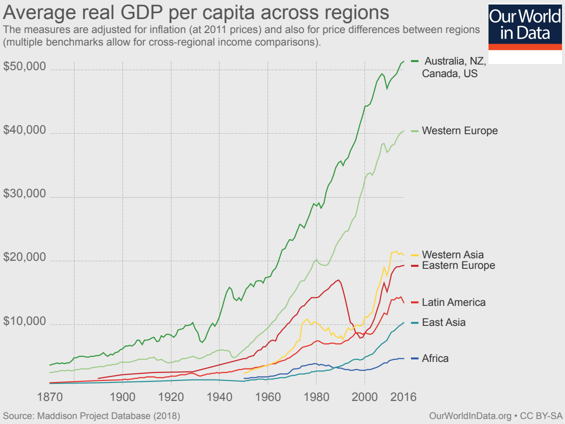
(7) **Future: COP21–impacts of 1.5° versus 2° & sea-level rise**

(8) **Conclusions: what can be done?**

Industrial Revolution began in the UK in the mid-18th Century

Startling consequences 250 years later:

real income levels are **7–10 fold higher per capita**,
many killer diseases tamed, & longevity roughly doubled.
Industrial Revolution led to vast benefit for humanity.



Unintended cost of major increase in atmospheric CO_2 and hence in the planet's temperature.

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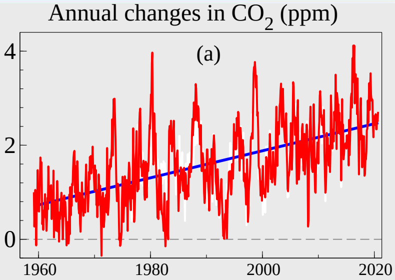

Atmospheric CO_2 increases still increasing–despite CoP21

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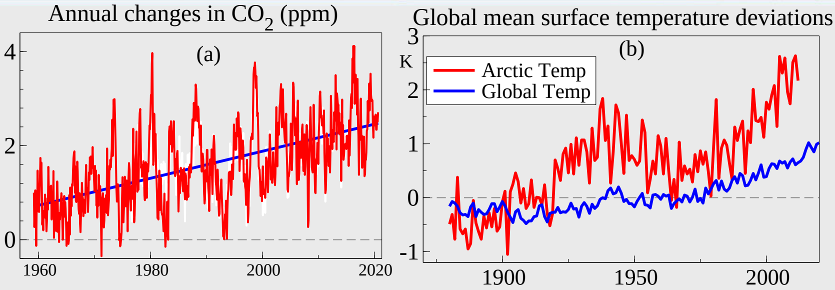

https://climate.nasa.gov/vital-signs/global-temperature/

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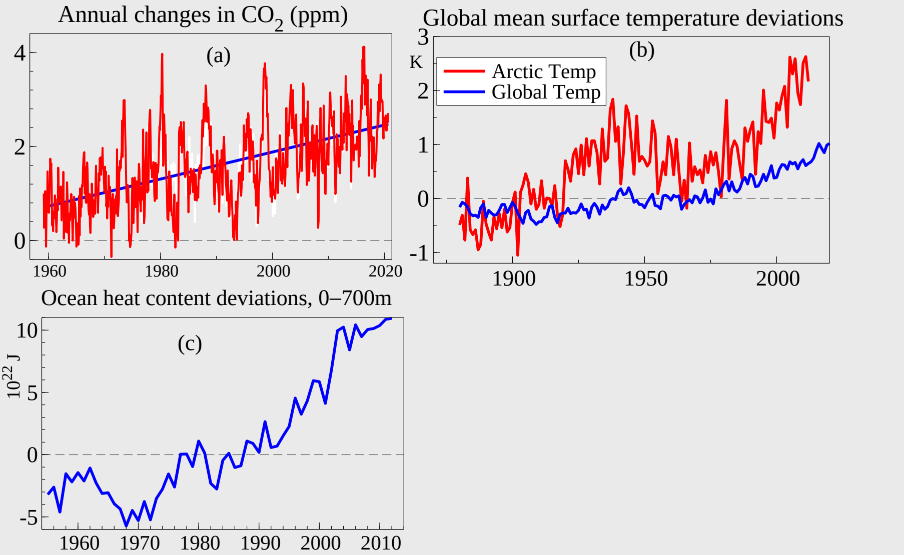

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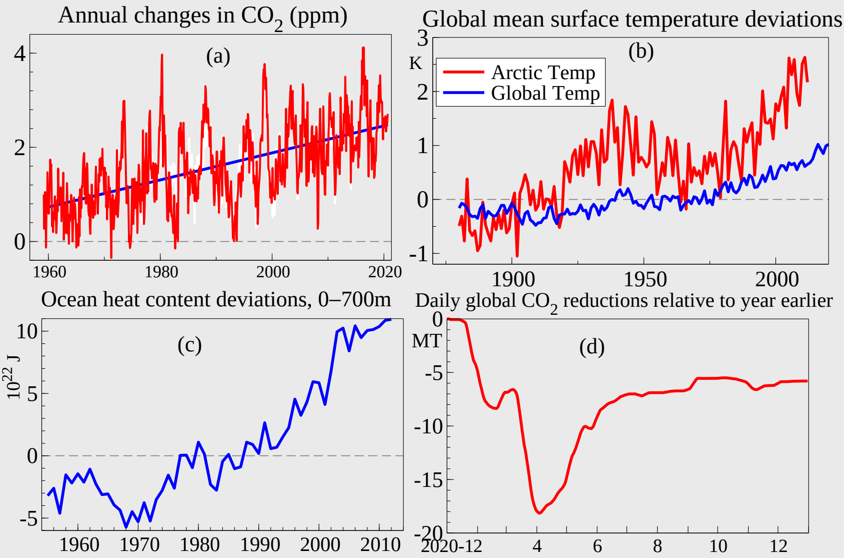
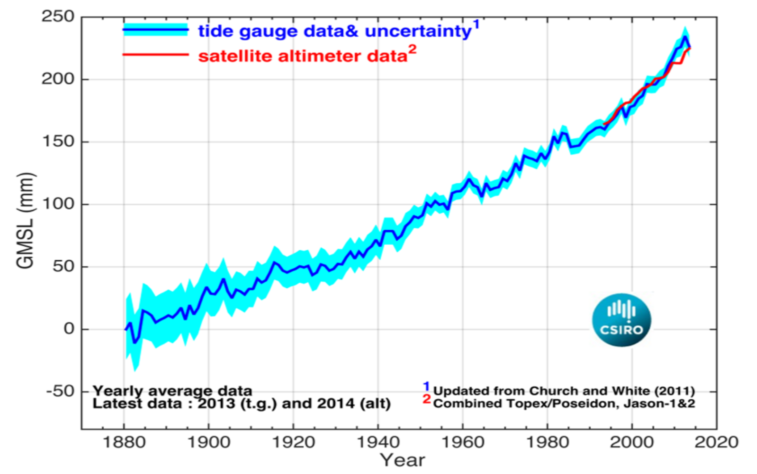


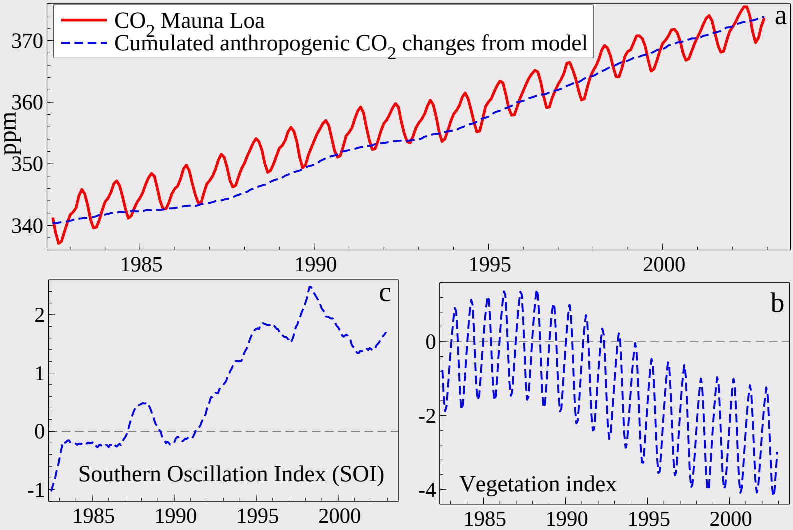
https://public.wmo.int/en/programmes/global-climate-observing-system/global-climate-indicators

Global sea-level rise since 1880



Rise of more than 20cm since 1880:
now 3.4mm p.a. versus 1.3mm p.a. 1850-1992

Cumulative sums of anthropogenic and natural CO_2 atmospheric contributions since 1982



a] Anthropogenic contributions to atmospheric CO_2; b] Vegetation contributions; c] SOI contributions (Hendry & Pretis, 2013).

Recent increases in atmospheric CO_2 levels are anthropogenic

Unintended cost of Industrial Revolution has been major increase in atmospheric CO_2.

Resulting climate change has potentially dangerous implications, highlighted by IPCC and many authors including Stern (2006).

Led to agreement in **Paris at COP21** to seek to limit temperature increases to less than **2**°C, and "to pursue efforts to limit it to **1.5**°C".

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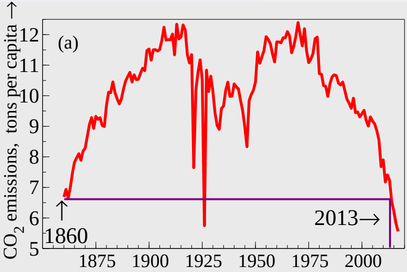
I will illustrate the current success of the UK's CO_2 emissions reduction from a model over 1860–2016 to **disentangle causes**, and the **role of policies** like the **UK's** *Climate Change Act* **of 2008.**
Now lowest per capita since 1860!

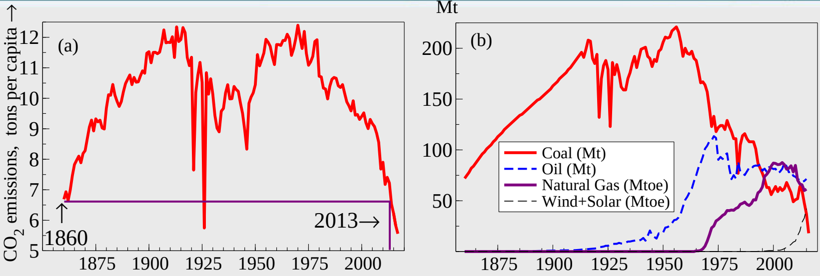
But much still to do.

UK CO_2 emissions and fossil fuels



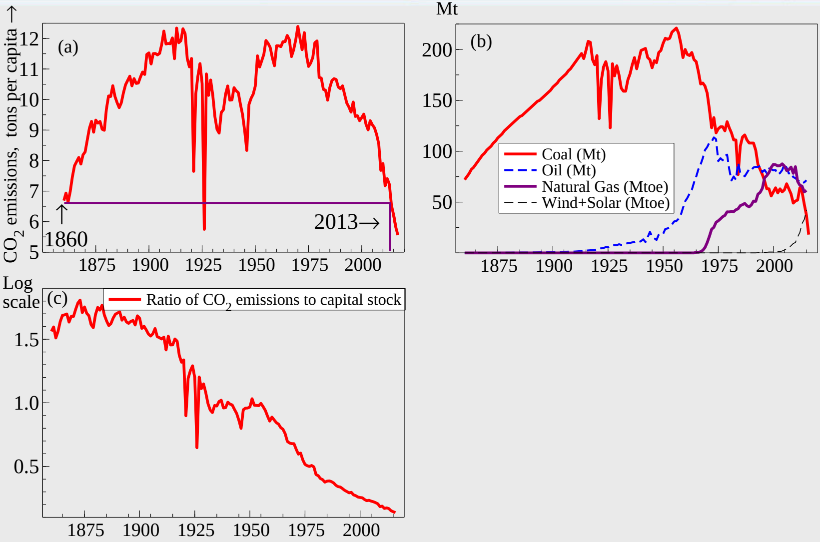
UK's CO_2 emissions per capita below 1860, yet real incomes have risen more than 7-fold.

UK CO_2 emissions and fossil fuels



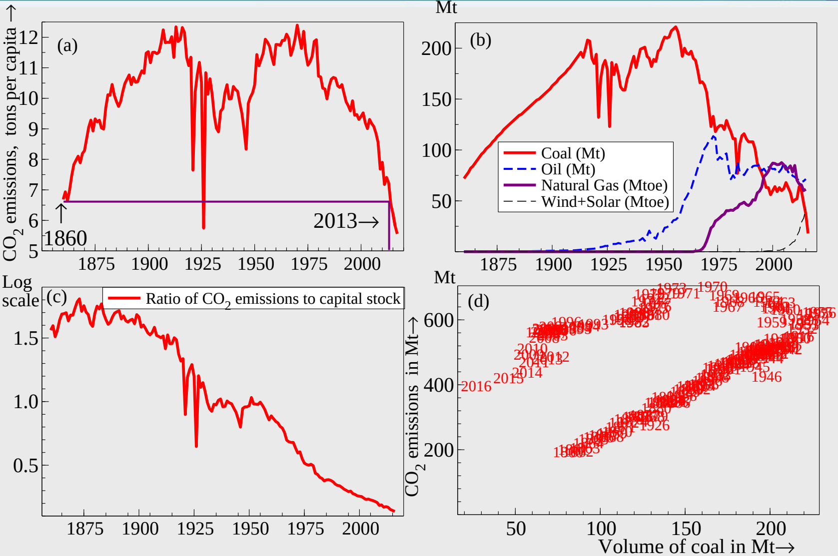
CO_2 emissions mainly driven by coal usage till mid-1950s then drop steadily, as does oil use after 1970s crises

UK CO_2 emissions and fossil fuels



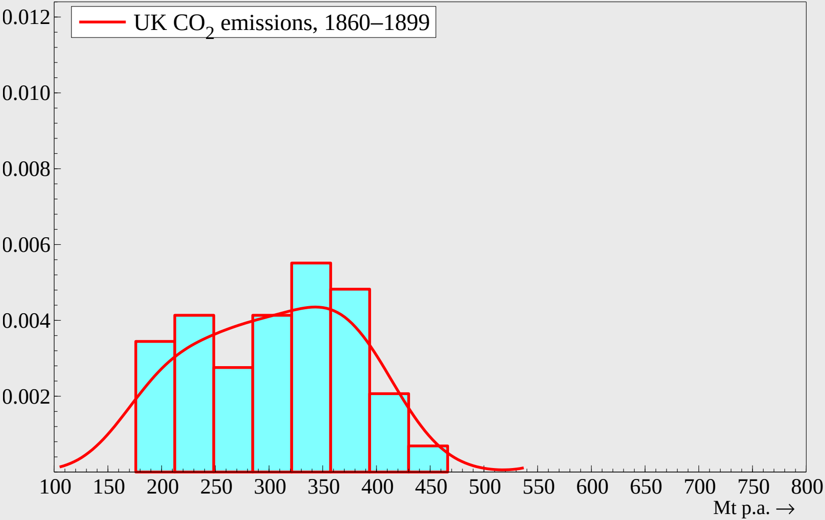
UK's CO_2 emissions have fallen by 92% relative to its capital stock from 1860

UK CO_2 emissions and fossil fuels



CO_2 emissions have no constant relations to individual fuel usages: all time series vary hugely

Distributional shifts of total UK CO_2 emissions in Mt p.a.



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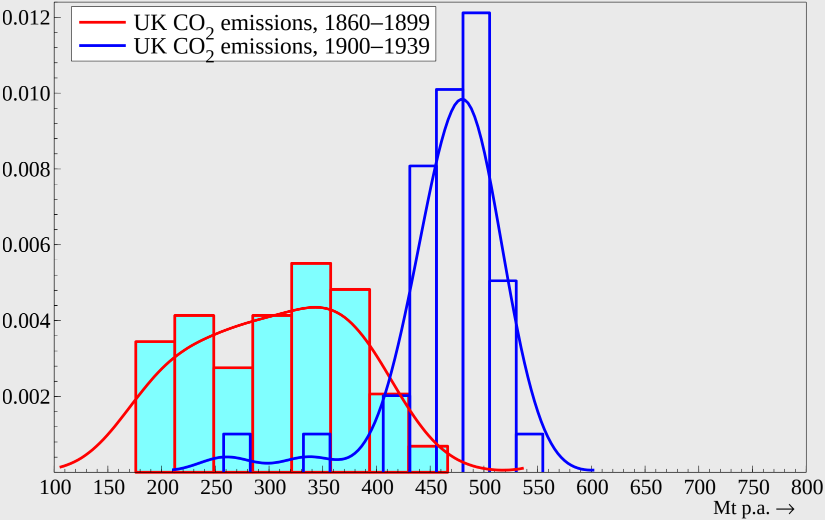

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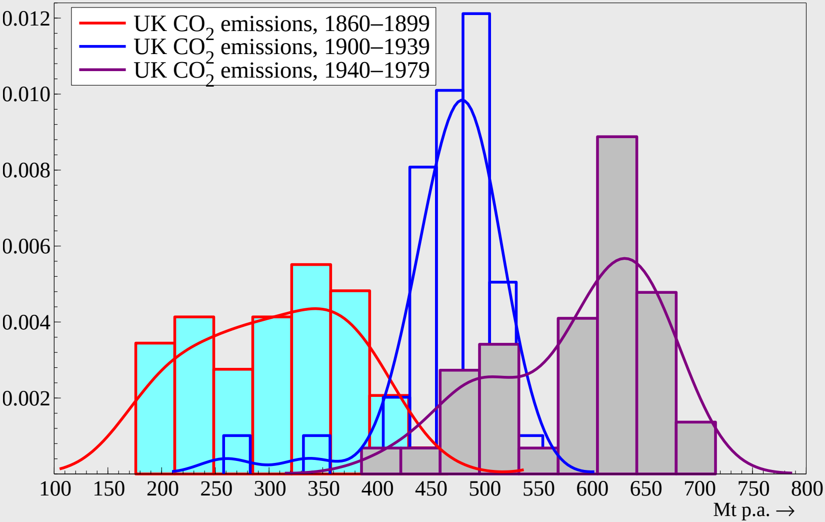

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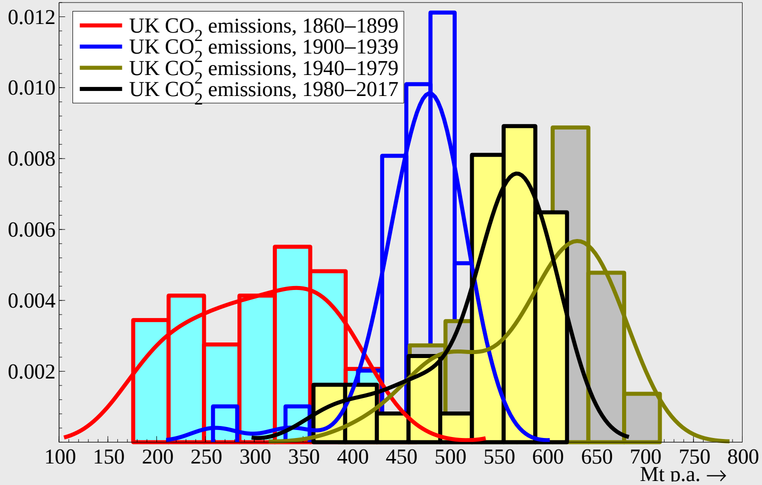


Model the evolving dynamic relation of UK's CO_2 emissions by coal, oil, GDP and capital, allowing for shifts in the relationship.

Detecting step shifts similar to detecting volcanic eruptions.

***Retained only if model otherwise does not fit the data*.**

Detecting step shifts similar to detecting volcanic eruptions.

Retained only if model otherwise does not fit the data.

Found **3** large step shifts **clearly identified with major events**:

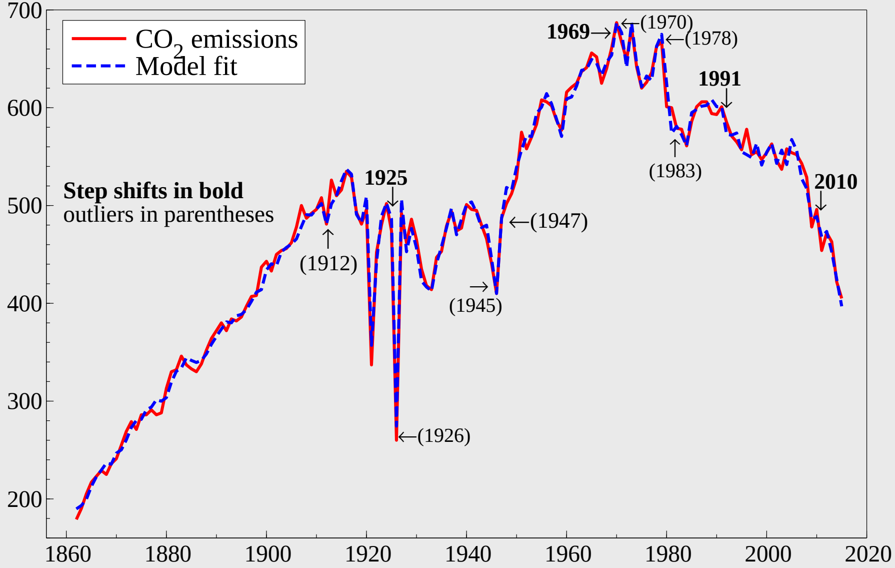
1926 was **Act of Parliament** creating UK's nationwide electricity grid.

1969 saw start of **conversion** from coal gas to natural gas.

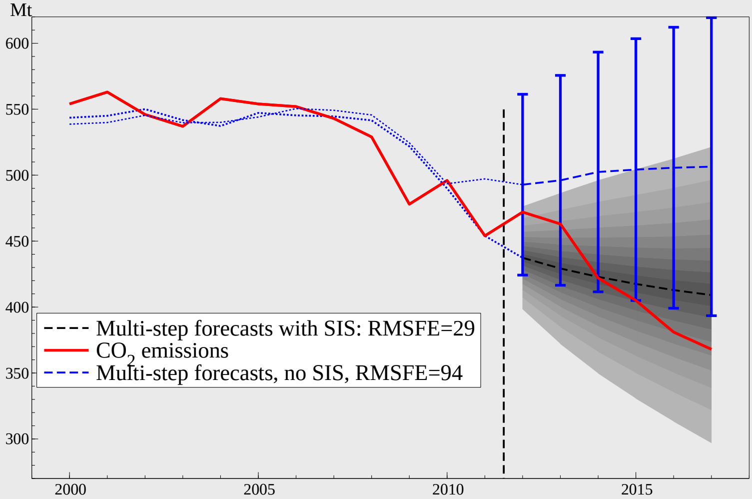
2010 follows implementation of the **Climate Change Act** of 2008.

We did not impose that policy had an effect–the data tell us it did.

Outcomes of modelling the UK's total CO_2 emissions

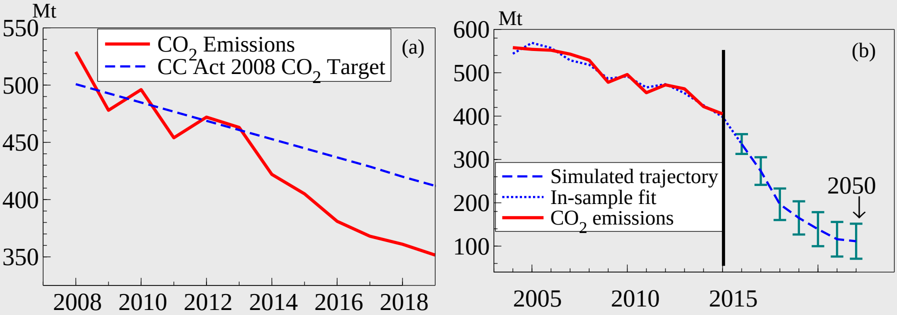


Actual and fitted values of model for UK CO_2 emissions.

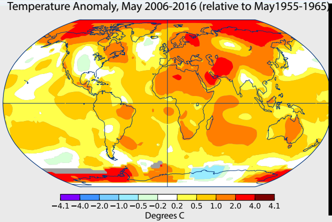


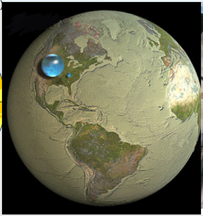
Outcomes and h-step point and interval forecasts shown as bars and fans with & without step indicators (SIS). RMSFE is root mean-square forecast error in Mt.

(a) 5-year targets and outcomes for CO_2.
(b) reductions in CO_2 emissions from model simulation: no coal, 75% reductions in oil & gas; 50% from agriculture, construction and waste, compressed to 5-year intervals after 2015.



Achieving net zero emissions will need both sequestration and even extraction of CO_2 from the atmosphere.





(1) **Can humanity really change the climate? Yes.**

(2) **Distant past: 500 million years of mass extinctions**

(3) **Last 800,000 years: Ice ages, atmospheric CO_2 & sea-level**

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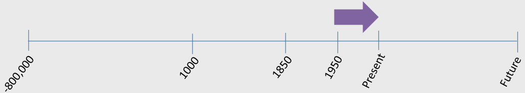
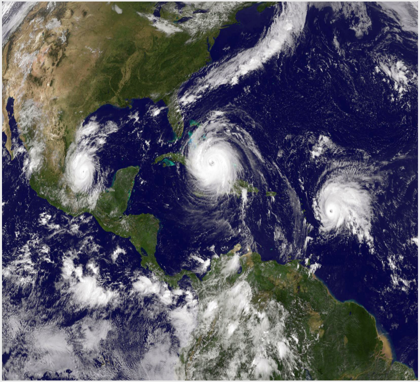


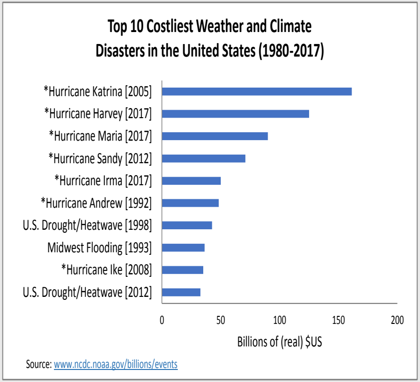
(7) **Future: COP21–impacts of 1.5° versus 2° & sea-level rise**

(8) **Conclusions: what can be done?**

Hurricanes: frequently occurring, destructive natural events

4 of top 5 costliest US disasters from this decade's hurricanes.





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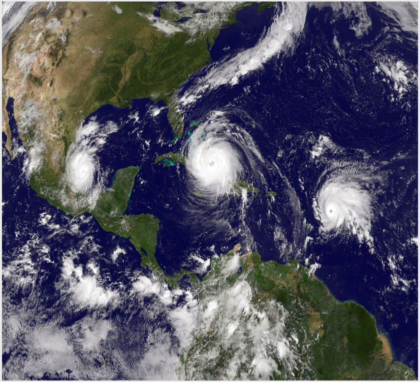
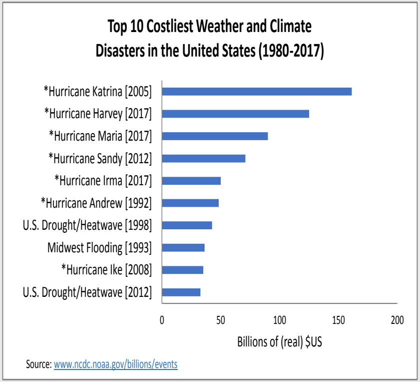




- Climate change can alter location, frequency, and intensity of such storms
- **Does forecast uncertainty impact hurricane damages?**

See Martinez (2020)

Must account for all influences on damages including adaptation efforts driven by beliefs

Embed forecast uncertainty in a general model of hurricane damages and use *Autometrics* automatic model selection:

Income

Population

Housing Units

Historical Frequency

Wind Speed/Pressure

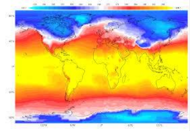
Max Storm Surge

Max Rainfall

Seasonal Cyclone Energy

Soil Moisture

Air Temperature



Forecast Uncertainty

Other

35
Additional
Variables

Embed forecast uncertainty in a general model of hurricane damages and use *Autometrics* automatic model selection:

Income

Population

Housing Units

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Min Pressure

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Max Rainfall

Seasonal Cyclone Energy

Soil Moisture

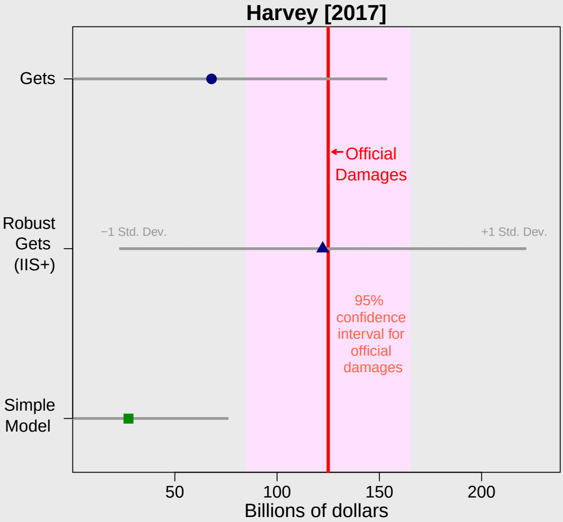
Air Temperature

Forecast Uncertainty

Other

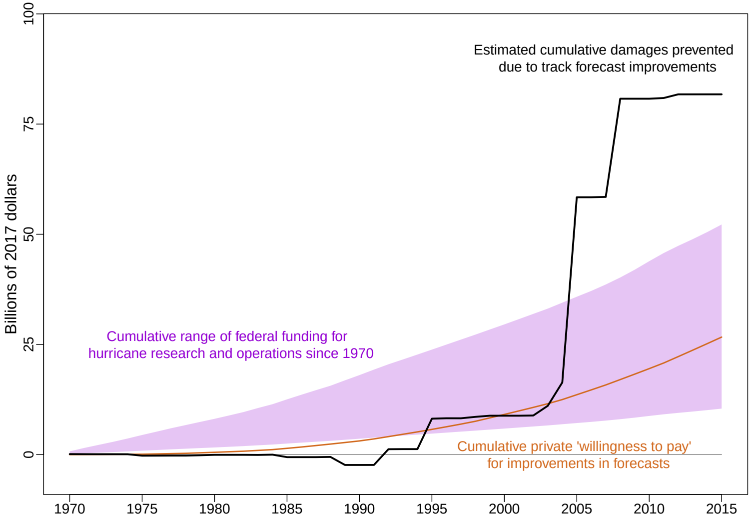
35 Additional Variables

Out of sample damage 'prediction'

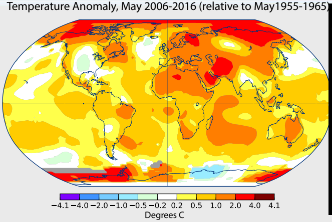


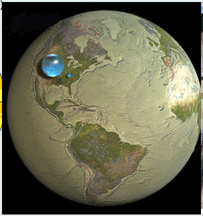
Green box shows calculation from simple damage model; pink shading likely range of damages; blue triangle is from our model with our uncertainty range.

Cumulative hurricane damages prevented by better forecasts



Route map: Past, present and future of climate change





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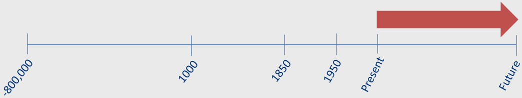
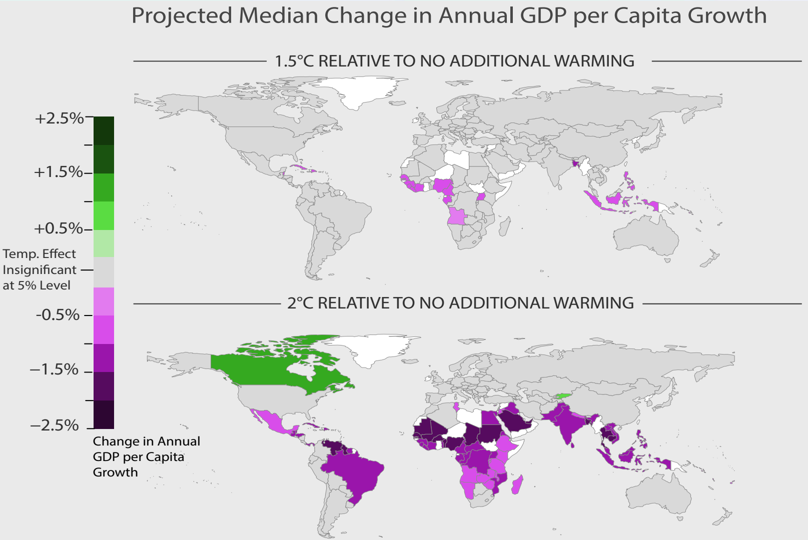
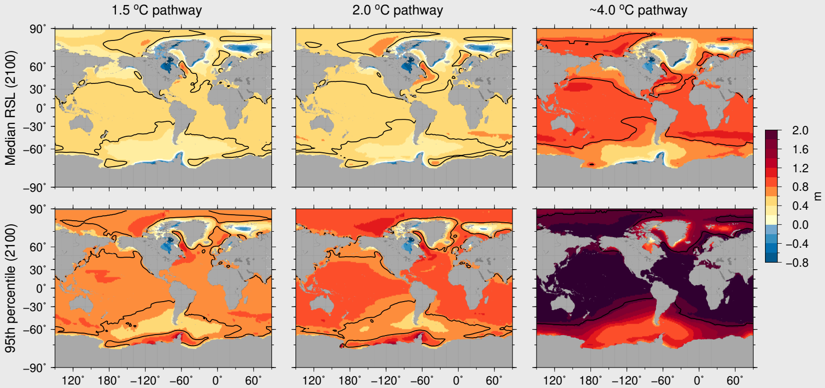


(8) Conclusions: what can be done?

Projected economic impacts of 1.5C versus 2C by 2100



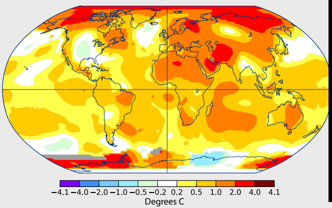
see Pretis, Schwarz, Tang, Haustein, and Allen in *Philosophical Transactions of the Royal Society* (2018), cited in IPCC report

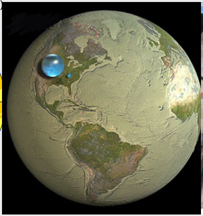


Research by Luke Jackson with others (2018), cited in IPCC Report.

Route map: Past, present and future of climate change

Temperature Anomaly, May 2006-2016 (relative to May1955-1965)





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Past mass extinctions due to climate change:

albeit 'natural' not anthropogenic—but now may be us.
Little time left to control emissions & keep under 1.5°C.

Atmosphere and oceans easily altered by human interventions by emitting excessive CO_2 and pollution.

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Forecasting from model of ice-age glaciation but with anthropogenic CO_2 showed near ice-free planet.

Past ice-free Arctic Ocean has led to tundra melting, which could release vast volumes of methane (see Vaks *et al.*, 2019).

Extreme weather: high 'wet bulb' heat dangerous to life;
more powerful cyclones; increased coastal & inland flooding;
longer droughts; worse wild fires; overly acid oceans.

Imperative to quickly get to net-zero emissions globally.
What can be done?

First decarbonize electricity generation: use **Earth** (**thermal**), **Air** (**wind**), **Fire** (**solar plus nuclear**) and **Water** (**hydro**). **Renewables can eliminate coal, oil & natural gas from electricity generation, but need massive increase & storage for still, cloudy periods, and to balance grid supply facing greater variability.**

Back up renewable electricity generation by safe small modular nuclear reactors (SMRs) based on well-developed nuclear engines in submarines.

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UK econometric model shows **climate policy has been effective: big reductions in CO_2 emissions at little aggregate cost by eliminating coal, improved capital-stock and renewable-electricity technologies, now fully competitive. But much more to do.**

Local losses were not addressed, and must be in future.

Technical issues to research: storage systems; SMRs use of transuranic waste & thorium.

Next, decarbonize ground transport–harder, but possible with electric vehicles, fuel cells & hydrogen drive-trains.

To sustain 100% renewables, research modular graphene-based carbon nanotube units (CNTs) to act as electrode supercapacitors for storing electricity & recharging batteries. Sandwich CNTs below a Faraday cage in a unit on vehicle's roof: increased distances yet rapid (dis)charging.

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If viable, offers sufficiently light electricity storage to advance developments in electric aircraft.

Ensure vehicles plugged into intelligent grid when not used: higher price to recharge if not. Vehicle-to-grid could provide low-cost investment electric storage system.

Technical issues to research: supercapacitors and batteries, plus intelligent infrastructure of charging-discharging points.

https://www.sciencedirect.com/topics/engineering/supercapacitor

Decarbonize households, construction and industry:

Replace household natural gas by green hydrogen, produced by methane pyrolosis + electrolysis produced when other electricity demands low. Store as liquid hydrogen.
Retrofit old buildings for improved insulation.
Install (hybrid) heat pumps, solar photovoltaics and evacuated tube solar collectors on roofs.
Net zero new buildings need lower GHG-intensive materials.

Liquid hydrogen could supply a high heat source for industry.
CCS and CO_2 extraction look essential, plus convert CO_2 to a useful fuel: https://www.sciencedaily.com/releases/2017/09/170918151710.htm

Technical issues to research: perovskite-based solar windows to generate electricity; efficient CCS; lower GHG refrigerants & building materials.

Fund research by prizes–successful historical route.

Essential to reduce CO_2 emissions from agriculture

Climate Econometrics

UNIVERSITY OF OXFORD

Down to Earth! Need a lower 'foodprint'

Reduce methane by

ruminant dietary changes (fumeric acid; *asparagopsis taxiformis*)
Human dietary changes to eating less mammal meat are feasible.

Reduce nitrous oxide by

mix artificial fertiliser with basalt dust, which also absorbs CO_2; cut cropland & environmental damage by better crop production efficiency, + vertical & underground farms.

Improve aquaculture production by

marine protection areas, and seaweed farming (kelp; seagrass); off-shore wind farms also act as marine reserves.

http://www.climateeconometrics.org/2020/09/21/decarbonising-agriculture/

Having invented the Industrial Revolution transforming world's wealth at the cost of climate change, UK is one of the first out, reducing its CO_2 emissions below the level first reached in 1894.

UK per capita CO_2 emissions:

below their level in 1860—when UK was 'workshop of the world'; yet real per capita incomes more than 7-fold higher.

UK's **33% emissions reductions** of **177** Mt since 2008 the more impressive given large global annual **increases** of more than **3**ppm pa.

Key policy implication is climate policy can be effective as a sensitive intervention point: big reductions in CO_2 emissions by eliminating coal, improved capital-stock and renewables.

Large emissions reductions have not involved major aggregate costs, but local losses not tackled.

Policy implications: creating virtuous circles and sensitive intervention points

Integrated GHG reduction strategy essential for net-zero target.

Replacing oil by renewables electricity entails huge expansion: hence vast storage requirement (so V2G & liquid hydrogen); balance supply and demand (hydrogen from ‘surplus’ electricity). By-product of methane pyrolosis is black carbon for graphene, lowering cost of CNTs.

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Increase taxes on oil as prices fall to maintain shift to all electric; border CO_2 import and deforestation taxes.

Research net CO_2 absorbers & efficient separation & collection of gasses. https://doi.org/10.1016/j.xcrp.2020.100210

‘Stranded assets’ could be a potential problem if legislation or improved standards impose lower CO_2 emissions targets and financial markets have not adjusted.

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Thank you

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Wind turbines and solar photovoltaics have fallen in cost and increased in efficiency so rapidly over last two decades that, for the UK at least, they offer low cost alternatives if carbon capture and storage (CCS) is enforced (MWh = megawatt hour).

Power generating technology costs £/MWh	2015	2025	2040
Solar Large-scale PV (Photovoltaic)	80	**44**	**33**
Wind Onshore	**62**	***46***	**44**
Wind Offshore	102	**57**	***40***
Biomass	87	87	98
Nuclear PWR (Pressurized Water Reactor)	93	93	93
Natural Gas Combined Cycle Gas Turbine	***66***	85	125
CCGT with CCS	110	85	82

Nuclear power guaranteed price of £92.50/MWh for Hinkley Point C in 2023.
Lowest cost in **bold**; next lowest in ***green italic***; **bold** if less than 2015.
Assumes increasing carbon taxes and falling CCS costs over time.

Source: *Electricity Generation Costs* 2020, UK Department for Business, Energy and Industrial Strategy (BEIS)