Climate Change

Dyrehaugen Web Notebook

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Climate Change

1.1 Neo-liberal Climate Change

The neoliberal solution to climate change is to hope that somehow it will become profitable to save the planet. This will not work. (?)

Part I

Climate Models

2

Climate Models

Overview text on selected Climate Models

2.1 Mental Picture of Greenhouse Effect

Benestad

The popular picture of the greenhouse effect emphasises the radiation transfer but fails to explain the observed climate change.

The earth's climate is constrained by well-known and elementary physical principles, such as energy balance, flow, and conservation. Green- house gases affect the atmospheric optical depth for infrared radiation, and increased opacity implies higher altitude from which earth's equivalent bulk heat loss takes place. Such an increase is seen in the reanalyses, and the outgoing long- wave radiation has become more diffuse over time, consistent with an increased influence of greenhouse gases on the vertical energy flow from the surface to the top of the atmosphere. The reanalyses further imply increases in the overturning in the troposphere, consistent with a constant and continuous vertical energy flow. The increased overturning can explain a slowdown in the global warming, and the association between these aspects can be interpreted as an entanglement between the greenhouse effect and the hydrological cycle, where reduced energy transfer associated with increased opacity is compensated by tropospheric overturning activity.

Benestad (2017) (pdf)

2.2 DICE Climate Model

Independent of the normative assumptions of inequality aversion and time preferences, the Paris agreement constitutes the economically optimal policy pathway for the century. Authors claim they show this by incorporating a damage-cost curve reproducing the observed relation between temperature and economic growth into the integrated assessment model DICE.

Glanemann (2021) DICE Paris CBA (pdf)

2.2.1 The failure of Dice Economics

If there is one climate economist who is respected above all others, it's William Nordhaus of Yale, who won the Econ Nobel in 2018 "for integrating climate change into long-run macroeconomic analysis." The prize specifically cited Nordhaus' creation of an "integrated assessment model" for analyzing the costs of climate change. The most famous of these is the DICE Model, used by the Environmental Protection Agency.

But the DICE Model, or at least the version we've been using for years, is obviously bananas.

Noah Smith

For other economists look here

Catie Hausman Twitter Thread

2.3 EZ-Climate Model

Some text on EZClimate

2.4 FAIR Climate Model

The FAIR model satisfies all criteria set by the NAS for use in an SCC calculation. 22 Importantly, this model generates projections of future warming that are consistent with comprehensive, state- of-the-art models and it can be used to accurately characterize current best understanding of the uncertainty regarding the impact that an additional ton of CO 2 has on global mean surface temperature (GMST). Finally, FAIR is easily implemented and transparently documented, 23 and is already being used in updates of the SCC. 24

A key limitation of FAIR and other simple climate models is that they do not represent the change in global mean sea level rise (GMSL) due to a marginal change in emissions.

Carleton Greenstone (2021) Updating SCC (pdf)

FAIR

2.5 Global Calculator

Used by Kuhnhenn - STS - Heinrch Böll Stiftung

GlobalCalculator

Global Calculator Tool

2.6 Monash Climate Model

Some text on Monash Model

2.7 NorESM

Norwegian Earth System Model

About

A climate model solves mathematically formulated natural laws on a three-dimensional grid. The climate model divides the soil system into components (atmosphere, sea, sea ice, land with vegetation, etc.) that interact through transmission of energy, motion and moisture. When the climate model also includes advanced interactive atmosphere chemistry and biogeochemical cycles (such as the carbon cycle), it is called an earth system model.

The Norwegian Earth System Model NorESM has been developed since 2007 and has been an important tool for Norwegian climate researchers in the study of the past, present and future climate. NorESM has also contributed to climate simulation that has been used in research assessed in the IPCC's fifth main report.

INES

The project Infrastructure for Norwegian Earth System Modeling (INES) will support the further development of NorESM and help Norwegian scientists also gain access to a cutting-edge earth system model in the years to come. Technical support will be provided for the use of a more refined grid, the ability to respond to climate change up to 10 years in advance, the inclusion of new processes at high latitudes and the ability of long-term projection of sea level. Climate simulations with NorESM are made on some of the most powerful supercomputers in Norway, and INES will help these exotic computers to be exploited in the best possible way and that the large data sets produced are efficiently stored and used. The project will ensure that researchers can efficiently use the model tool, analyze results and make the results available.

2.7.1 CCSM4

UCAR NCAR

The University Corporation for Atmospheric Research (UCAR) is a US non-profit consortium of more than 100 colleges and universities providing research and training in the atmospheric and related sciences. UCAR manages the National Center for Atmospheric Research (NCAR) and provides additional services to strengthen and support research and education through its community programs. Its headquarters, in Boulder, Colorado, include NCAR's Mesa Laboratory. (Wikipedia)

CCSM

The Community Climate System Model (CCSM) is a coupled climate model for simulating Earth's climate system. CCSM consists of five geophysical models: atmosphere (atm), sea-ice (ice), land (lnd), ocean (ocn), and land-ice (glc), plus a coupler (cpl) that coordinates the models and passes information between them. Each model may have "active," "data," "dead," or "stub" component version allowing for a variety of "plug and play" combinations.

During the course of a CCSM run, the model components integrate forward in time, periodically stopping to exchange information with the coupler. The coupler meanwhile receives fields from the component models, computes, maps, and merges this information, then sends the fields back to the component models. The coupler brokers this sequence of communication interchanges and manages the overall time progression of the coupled system. A CCSM component set is comprised of six components: one component from each model (atm, lnd, ocn, ice, and glc) plus the coupler. Model components are written primarily in Fortran 90.

ccsm4

CESM

The Community Earth System Model (CESM) is a fully-coupled, global climate model that provides state-of-the-art computer simulations of the Earth's past, present, and future climate states.

CESM2 is the most current release and contains support for CMIP6 experiment configurations.

cesm models

Simpler Models

As part of CESM2.0, several dynamical core and aquaplanet configurations have been made available.

Simpler Models

2.7.2 NorESM Features

Despite the nationally coordinated effort, Norway has insufficient expertise and manpower to develop, test, verify and maintain a complete earth system model.

For this reason, NorESM is based on the Community Climate System Model version 4, CCSM4, operated at the National Center for Atmospheric Research on behalf of the Community Climate System Model (CCSM)/Community Earth System Model (CESM) project of the University Corporation for Atmospheric Research.

NorESM is, however, more than a model “dialect” of CCSM4. Notably, NorESM differs from CCSM4 in the following aspects: NorESM utilises an isopycnic coordinate ocean general circulation model developed in Bergen during the last decade originating from the Miami Isopycnic Coordinate Ocean Model (MICOM). The atmospheric module is modified with chemistry–aerosol–cloud–radiation interaction schemes developed for the Oslo version of the Community Atmosphere Model (CAM4-Oslo). Finally, the HAMburg Ocean Carbon Cycle (HAMOCC) model developed at the Max Planck Institute for Meteorology, Hamburg, adapted to an isopycnic ocean model framework, constitutes the core of the biogeochemical ocean module in NorESM. In this way NorESM adds to the much desired climate model diversity, and thus to the hierarchy of models participating in phase 5 of the Climate Model Intercomparison Project (CMIP5). In this and in an accompanying paper (Iversen et al., 2013), NorESM without biogeochemical cycling is presented. The reader is referred to Assmann et al. (2010) and Tjiputra et al. (2013) for a description of the biogeochemical ocean component and carbon cycle version of NorESM, respectively.

There are several overarching objectives underlying the development of NorESM. Western Scandinavia and the surrounding seas are located in the midst of the largest surface temperature anomaly on earth governed by anomalously large oceanic and atmospheric heat transports. Small changes to these transports may result in large and abrupt changes in the local climate. To better understand the variability and stability of the climate system, detailed studies of the formation, propagation and decay of thermal and (oceanic) fresh water anomalies are required.

NorESM is, as mentioned above, largely based on CCSM4. The main differences are the isopycnic coordinate ocean module in NorESM and that CAM4-Oslo substitutes CAM4 as the atmosphere module. The sea ice and land models in NorESM are basically the same as in CCSM4 and the Com- munity Earth System Model version 1 (CESM1), except that deposited soot and mineral dust aerosols on snow and sea ice are based on the aerosol calculations in CAM4-Oslo.

2.7.2.1 NorESM Aerosol Interactions

The aerosol module is extended from earlier versions that have been published, and includes life-cycling of sea salt, mineral dust, particulate sulphate, black carbon, and primary and secondary organics. The impacts of most of the numerous changes since previous versions are thoroughly explored by sensitivity experiments. The most important changes are: modified prognostic sea salt emissions; updated treatment of precipitation scavenging and gravitational settling;

inclu- sion of biogenic primary organics and methane sulphonic acid (MSA) from oceans; almost doubled production of land- based biogenic secondary organic aerosols (SOA); and in- creased ratio of organic matter to organic carbon (OM/OC) for biomass burning aerosols from 1.4 to 2.6. Compared with in situ measurements and remotely sensed data, the new treatments of sea salt and dust aerosols give smaller biases in near-surface mass concentrations and aerosol optical depth than in the earlier model version. The model biases for mass concentrations are approximately un- changed for sulphate and BC. The enhanced levels of mod- led OM yield improved overall statistics, even though OM is still underestimated in Europe and overestimated in North America. The global anthropogenic aerosol direct radiative forc- ing (DRF) at the top of the atmosphere has changed from a small positive value to −0.08 W m −2 in CAM4-Oslo. The sensitivity tests suggest that this change can be attributed to the new treatment of biomass burning aerosols and gravita- tional settling. Although it has not been a goal in this study, the new DRF estimate is closer both to the median model estimate from the AeroCom intercomparison and the best es- timate in IPCC AR4. Estimated DRF at the ground surface has increased by ca. 60 %, to −1.89 W m −2

The increased abundance of natural OM and the introduc- tion of a cloud droplet spectral dispersion formulation are the most important contributions to a considerably decreased es- timate of the indirect radiative forcing (IndRF). The IndRF is also found to be sensitive to assumptions about the coat- ing of insoluble aerosols by sulphate and OM. The IndRF of −1.2 W m −2 , which is closer to the IPCC AR4 estimates than the previous estimate of −1.9 W m −2 , has thus been obtained without imposing unrealistic artificial lower bounds on cloud droplet number concentrations.

NorESM

Bentsen (2013) NorESM - Part 1 (pdf)

Iversen (2013) NorESM - Part 2 (pdf)

Assmann (2010) Biogeochemical Ocean Component - Isopycnic (pdf)

Tjiputra (2010) Carbon Cycle Component (pdf)

Kirkevaag (2013) Aerosol-Climate Interactions (pdf)

Community Earth System Model CESM

3

Convection

Zhang

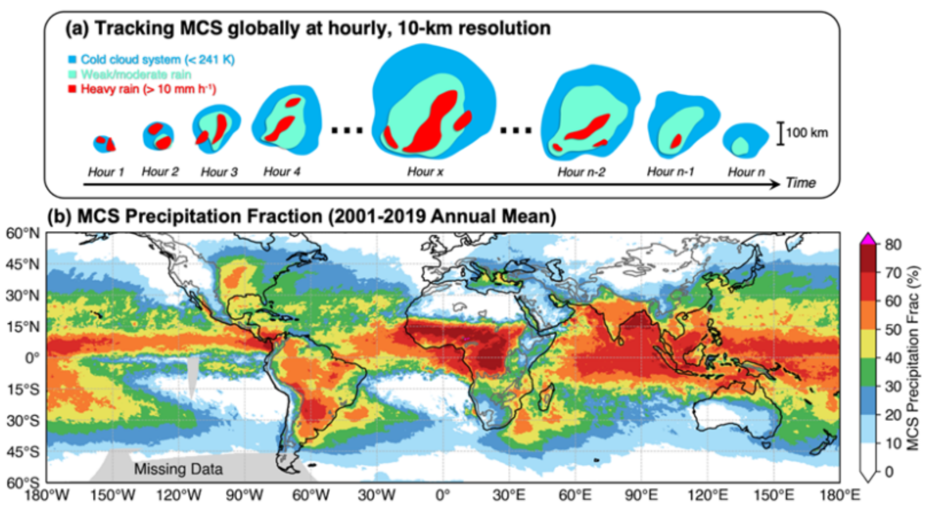


Figure: For the first time mesoscale convective systems (MCSs) in both the tropics and midlatitudes and all seasons can be tracked over many years by a new algorithm jointly using satellite observed cloud-top temperature and surface precipitation features at hourly and 10-km resolution globally (top panel). Results show that MCSs account for over 50% of the annual rainfall across the tropics *and many regions of the subtropics and midlatitudes (bottom panel).*

Mesoscale convective systems (MCSs) are a key component in the Earth's energy and hydrological cycles. They can grow to hundreds of kilometers in size, last for more than a day, and produce a majority of the annual rainfall in many regions of the world.

Past efforts to develop MCS databases have been limited to the tropics and used methodologies not well tested in the midlatitudes. Feng et al. [2021] developed a new methodology to track MCSs globally using high-resolution satellite observations of both cloud and precipitation. The new method significantly improves the detection of MCSs in the midlatitudes. This new storm tracking database is the first to cover both the tropics and midlatitudes for all seasons.

The study shows that MCSs account for over 50 per cent of the annual rainfall across the tropics and many regions of the subtropics and midlatitudes. Storms over land have more intense convection, while those over oceans produce heavier rainfall and last longer.

This global MCS database supports a broad range of research such as understanding the role of MCSs in global extreme rainfall and circulation, and evaluation of global weather and climate model simulations.

Zhang

Convective storms of mesoscale dimension are a key component in the Earth's energy and hydrological cycle. Mesoscale storms grow to hundreds of kilometers in size and can last for more than a day, and produce a majority of the annual rainfall in many regions of the world. Past studies of mesoscale storms have been limited to the tropics and used methodologies not well tested in the midlatitudes. Here, we develop a new methodology to track mesoscale storms globally using high-resolution satellite observations of both cloud and precipitation. The satellite-based storm tracking reproduces important storm statistics derived from ground-based radar observations. Our new method significantly improves the detection of mesoscale storms in the midlatitudes. This new storm tracking database is the first to cover both the tropics and midlatitudes for all seasons. Results show that mesoscale convective storms account for over 50% of annual rainfall across the tropics and many regions of the subtropics and midlatitudes. Storms over land have more intense convection, while those over ocean produce heavier rainfall and last longer. This global mesoscale storms tracking database supports a broad range of applications, such as understanding their role in global extreme rainfall and circulation and evaluation of global weather and climate model simulations.

Feng (2021) Mesoscale Convective System (pdf)

3.1 Goal Index

In economic modelling choice of goal index (utility) function matters. Daniel 2018[1] presents this figure:

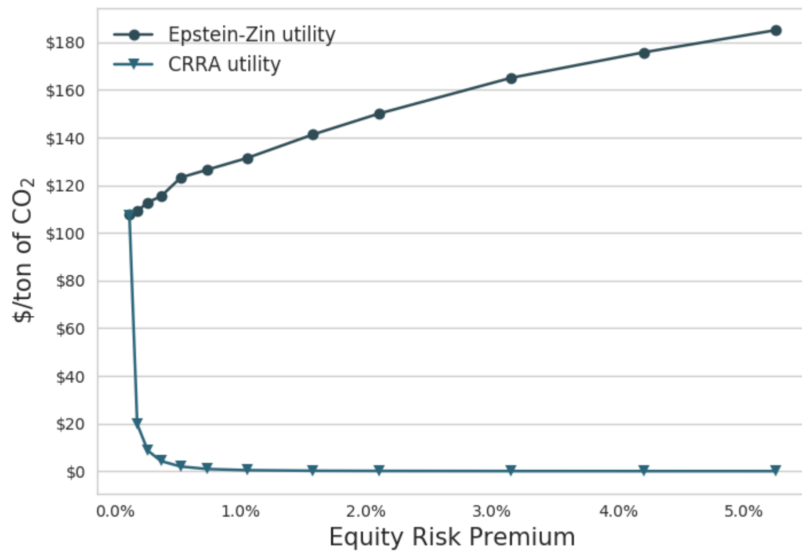


Fig. Optimal CO2-prices with increasing risk aversion for EZ vs CRRA utility specification. (From Daniel 2018)

As one of the co-authors explain: 'We where not able to get the Social Cost of Carbon (SCC) under $120'. That is for 'reasonable risk aversion', using EZ-utilities. The 'standard' specification - with CRRA - utilities ends up with SCC of $20 or below.

$$V_1 = A[\tilde{C\_}t, \mu_t(V\_t + 1)]$$

Specification of the Goal Index function may seem a trivial technical issue - no so! There exists a broad professional litterature and profound discussions on this matter - which might de difficult to dis-entangle.

Let us begin with Frank Ramsey's growth model from 1928, commonly known as the Ramsey-Cass-Koopmans model.

$F(K, L)$ is an aggregate production function with factors K (Capital) and L (Labour).

[1]See Links to references

3.2 Model Drift

Abstract Sausen

A method is proposed for removing the drift of coupled atmosphere-ocean models, which in the past has often hindered the application of coupled models in climate response and sensitivity experiments. The ocean-atmosphere flux fields exhibit inconsistencies when evaluated separately for the individual sub-systems in independent, uncoupled mode equilibrium climate computations. In order to balance these inconsistencies a constant ocean-atmosphere flux correction field is introduced in the boundary conditions coupling the two sub-systems together. The method ensures that the coupled model operates at the reference climate state for which the individual model subsystems were designed without affecting the dynamical response of the coupled system in climate variability experiments. The method is illustrated for a simple two component box model and an ocean general circulation model coupled to a two layer diagnostic atmospheric model.

Memo Barthel

The coupling of different climate sub-systems poses a number of technical problems. An obvious problem arising from the different time scales is the synchronization or matching of the numerical integration of subsys- tems characterized by widely differing time steps. A more subtle problem is

Model Drift When two general circulation models of the atmosphere and ocean are coupled together in a single model, it is generally found that the cou- pled system gradually drifts into a new climate equilibrium state which is far removed from the observed climate. The coupled model climate equilibrium may be so unrealistic (for example, with respect to sea ice extent, or the oceanic equatorial current system) that climate response or sensitivity experiments relative to this state be- come meaningless. This occurs regularly even when the individual models have been carefully tested in detailed numerical experiments in the decoupled mode and have been shown to yield satisfactory simulations of the climate of the sepa- rate ocean or atmosphere sub-systems. The drift of the coupled model is clearly a sign that something is amiss with the models. However, we suggest that it is not necessary to wait with climate response and sensitivity experiments with coupled models unit all causes of model drift have been properly identified and removed. Model drift is, in fact, an extremely sensitive indi- cator of model imperfections. The fact that the equilibrium climate into which a coupled model drifts is unacceptably far removed from the real climate does not necessarily imply that the model dynamics are too unrealistic for the model to be applied for climate response and sensitivity ex- periments. One should therefore devise methods for separating the drift problem from the basically independent problem of determining the change of the simulated climate induced by a change in boundary conditions a n d / o r external forcing (climate response), and from the question of the ef- fect of changes in the physical or numerical for- mulation of the model (model sensitivity).

Flux Correction The separation of the mean climate simulation from the climate response or sensitiv- ity problem can be achieved for coupled models rather simply by an alternative technique, the flux correction method. The errors that result in a drift of the coupled model are compensated in this method by constant correction terms in the flux expressions by which the separate sub-system models are cou- pled together. The correction terms have no in- fluence on the dynamics of the system in climate response or sensitivity experiments, but ensure that the "working point" of the model lies close to the climate state for which the individual models were originally tuned. The basic principle of the flux correction method is to couple the atmosphere and the ocean in such a manner that in the unperturbed case each sub- system simulates its own mean climate in the same manner as in the uncoupled mode, but re- sponds fully interactively to the other sub-system in climate response or sensitivity experiments.

Sausen (1988) Coupled Ocean-Atmosphere Model Drift Flux Correction (pdf)

3.3 Spatial Shock

3.3.1 Coastal Flooding

Desmet

Just moving to higher grounds

Nobel Prize winner William Nordhaus has called climate change "the ultimate challenge for economics."

Economists increasingly have been trying to understand how rising tides and global temperatures will impact resource allocation around the globe, as well as the potential policy tools that can help curb damage to our natural world.

SMU professor Klaus Desmet says that a lot of those analyses are missing a critical factor: migration.

Desmet coauthored a paper in the American Economic JournalEvaluating the Economic Cost of Coastal Flooding (paywall): Macroeconomics that examines how economic output will be affected over the next 200 years as humans move away from coastal areas threatened by rising sea levels. Although losses in vulnerable Southeast Asian cities such as Bangkok and Shanghai will still be very significant, their research shows that overall GDP declines are substantially less than predicted by models that don't account for spatial shifts in economic activity.

> Climate change is to a large extent a spatial shock.
>
> Migration as one of the key responses to climate change.

What we find in our model is that at a global level, flooding decreases real GDP by about 0.1 percent by the year 2200. If we were to completely ignore the dynamic spatial response of the economy, if we were to have everyone stay put in the face of rising seas, then the loss would actually increase to 4.5 percent. So, that difference between 0.1 and 4.5 percent underscores the first-order importance of taking into account moving, migration, and the spatial dynamic response of the economy to rising sea levels.

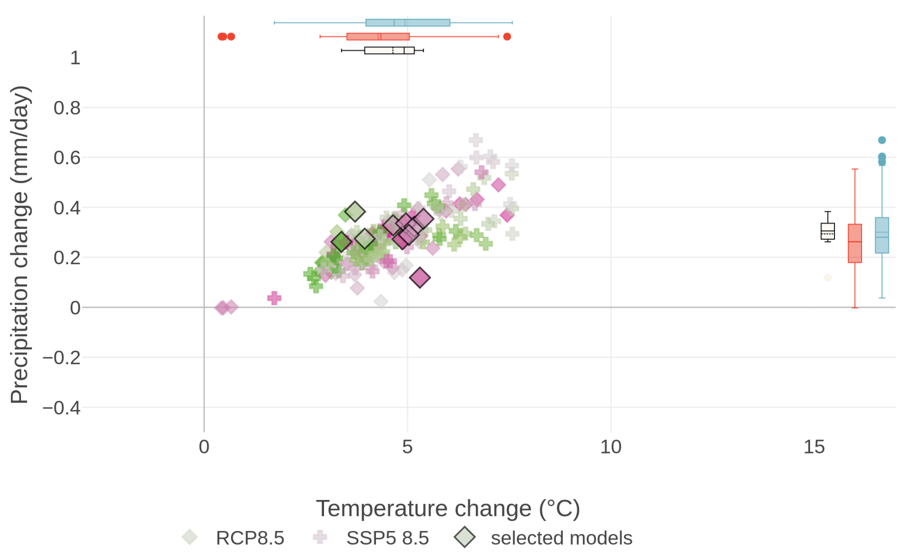
We develop a high resolution dynamic model of the world economy. This model splits up the world into 64,800 1° by 1° grid cells, which are linked to each other through trade and migration. We feed into this model high-quality projections of both global and local sea level rise over the next 200 years. . . . When we run our model forward, we can then assess what the economic effect will be of having these pieces of land lost for production.

We find large losses in coastal areas of south and east Asia, with countries such as Vietnam, Thailand, and Bangladesh losing up to 10 percent of real GDP in present discounted value terms over the next 200 years. Other areas that will also suffer disproportionately include coastal Northwest Europe, [and] some areas on the US East Coast and Gulf Coast. By contrast, the Pacific Coast of the Americas is much less affected and, in fact, most of the coastal areas of Africa are also a lot less affected.

Desmet

3.4 Model-evaluation

GCMeval: a tool for climate model ensemble evaluation



The global climate models indicate quite a range of future outcomes in terms of precipitation and temperature. To account for that, regional scenarios need to use fairly large multi-model ensembles.

GCM-eval

3.4.1 Measuering Forcings

Earth is on a budget – an energy budget. Our planet is constantly trying to balance the flow of energy in and out of Earth's system. But human activities are throwing that off balance, causing our planet to warm in response.

Adding more components that absorb radiation – like greenhouse gases – or removing those that reflect it – like aerosols – throws off Earth's energy balance, and causes more energy to be absorbed by Earth instead of escaping into space. This is called a radiative forcing, and it's the dominant way human activities are affecting the climate.

limate modelling predicts that human activities are causing the release of greenhouse gases and aerosols that are affecting Earth's energy budget. Now, a NASA study has confirmed these predictions with direct observations for the first time: radiative forcings are increasing due to human actions, affecting the planet's energy balance and ultimately causing climate change. The paper was published online March 25, 2021, in the journal Geophysical Research Letters.

NASA's Clouds and the Earth's Radiant Energy System (CERES) project studies the flow of radiation at the top of Earth's atmosphere. A series of CERES instruments have continuously flown on satellites since 1997. Each measures how much energy enters Earth's system and how much leaves, giving the overall net change in radiation. That data, in combination with other data sources such as ocean heat measurements, shows that there's an energy imbalance on our planet. But it doesn't tell us what factors are causing changes in the energy balance.

This study used a new technique to parse out how much of the total energy change is caused by humans. The researchers calculated how much of the imbalance was caused by fluctuations in factors that are often naturally occurring, such as water vapor, clouds, temperature and surface albedo (essentially the brightness or reflectivity of Earth's surface). The researchers calculated the energy change caused by each of these natural factors, then subtracted the values from the total. The portion leftover is the radiative forcing.

The team found that human activities have caused the radiative forcing on Earth to increase by about 0.5 Watts per square meter from 2003 to 2018. The increase is mostly from greenhouse gases emissions from things like power generation, transport and industrial manufacturing. Reduced reflective aerosols are also contributing to the imbalance.

NASA Goddard Direct Observations of Forcings

4

Climate Change Indicators

EPA partners with more than 50 data contributors from various government agencies, academic institutions, and other U.S and international organizations to compile a key set of indicators related to the causes and effects of climate change.

EPA Indicators EPA Indicators FAQ

EPA's climate change indicators are grouped into six categories:

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[Greenhouse Gases](https://www.epa.gov/climate-indicators/greenhouse-gases)
[Weather and Climate](https://www.epa.gov/climate-indicators/weather-climate)
[Oceans](https://www.epa.gov/climate-indicators/oceans)
[Snow and Ice](https://www.epa.gov/climate-indicators/snow-ice)
[Health and Society](https://www.epa.gov/climate-indicators/health-society)
[Ecosystems](https://www.epa.gov/climate-indicators/ecosystems)
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5

IPCC

5.1 Shared Socioeconomic Pathways

The RCPs set pathways for greenhouse gas concentrations and, effectively, the amount of warming that could occur by the end of the century. Whereas the SSPs set the stage on which reductions in emissions will – or will not – be achieved.

The new SSPs offer five pathways that the world could take. Compared to previous scenarios, these offer a broader view of a "business as usual" world without future climate policy, with global warming in 2100 ranging from a low of 3.1C to a high of 5.1C above pre-industrial levels.

While the RCPs were finished in time to be used in the IPCC Fifth Assessment Report, developing the more complex SSPs has been a much longer and more involved process. The SSPs were initially published in 2016, but are only now just starting to be used in the next round of climate modelling – known as the Coupled Model Intercomparison Project version 6, or CMIP6 – in preparation for the IPCC's sixth assessment report.

The SSPs are based on five narratives describing broad socioeconomic trends that could shape future society. These are intended to span the range of plausible futures.

They include: a world of sustainability-focused growth and equality (SSP1); a "middle of the road" world where trends broadly follow their historical patterns (SSP2); a fragmented world of "resurgent nationalism" (SSP3); a world of ever-increasing inequality (SSP4); and a world of rapid and unconstrained growth in economic output and energy use (SSP5).

SSP1 Sustainability – Taking the Green Road (Low challenges to mitigation and adaptation) The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and the emphasis on economic growth shifts toward a broader emphasis on human well-being. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Consumption is oriented toward low material growth and lower resource and energy intensity.

SSP2 Middle of the Road (Medium challenges to mitigation and adaptation) The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly and challenges to reducing vulnerability to societal and environmental changes remain.

SSP3 Regional Rivalry – A Rocky Road (High challenges to mitigation and adaptation) A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. Policies shift over time to become increasingly oriented toward national and regional security issues. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialized and high in developing countries. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions.

SSP4 Inequality – A Road Divided (Low challenges to mitigation, high challenges to adaptation) Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor intensive, low-tech economy. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. The globally connected energy sector diversifies, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas.

SSP5 Fossil-fueled Development – Taking the Highway (High challenges to mitigation, low challenges to adaptation) This world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy, while global population peaks and declines in the 21st century. Local environmental problems like air pollution are successfully managed. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary.

The SSPs were designed to reflect worlds in which mitigation and adaptation challenges vary from low to very high. While the baseline SSP scenarios assume an absence of climate policy, researchers also wanted to look at how the underlying socioeconomic conditions would affect the implementation of climate policy.

For example, SSP1 features low challenges to mitigation and adaptation due to its rapid technological development, relative global equality of income and focus on environmental sustainability. SSP4, on the other hand, features similarly low challenges to mitigation due to its rapid technological development, but high challenges to climate adaptation due to persistent inequality and poverty in many parts of the world.

The main differences between SSPs come from their assumptions on global population growth, access to education, urbanisation, economic growth, resources availability, technology developments and drivers of demand, such as lifestyle changes.

All scenarios in the SSP database that keep warming below 2C incorporate some bioenergy with carbon capture and storage (BECCS).

Hausfather (2018) SSP

Part II

Measurements

6

Attribution

For too long, weather's randomness has kept events such as these from being blamed squarely on climate change. Reporters in the late 1990s and early 2000s would ask climate scientists about climate change's role in a weather-related disaster. All we could say was that we'd expect to see more of these events. Now, we can specify increased chances for specific events. This extends to forecasts: we can identify the places that are more likely to see wildfires, mudslides and fish die-offs. Such calculations dent both climate denial and a false sense of security. They take away the argument that 'extreme weather happens anyway, so we don't need to worry about it'. Extreme weather happens — and these metrics pinpoint what is becoming more likely, by how much and why.

Betts (2021) Nature

Ametsoc (2021) Explaining Extreme Weather (pdf)

6.1 Map of Attribution Studies

Known as "extreme event attribution", the field has gained momentum, not only in the science world, but also in the media and public imagination. These studies have the power to link the seemingly abstract concept of climate change with personal and tangible experiences of the weather.

Scientists have published more than 300 peer-reviewed studies looking at weather extremes around the world, from wildfires in Alaska (pdf) and hurricanes in the Caribbean to flooding in France and heatwaves in China. The result is mounting evidence that human activity is raising the risk of some types of extreme weather, especially those linked to heat.

To track how the evidence on this fast-moving topic is stacking up, Carbon Brief has mapped – to the best of our knowledge – every extreme-weather attribution study published to date.

The map above shows 355 extreme weather events and trends across the globe for which scientists have carried out attribution studies.

Carbon BriefMap

6.2 Bottom Trawling CO2 release

Time Magzine: How Industrial Fishing Creates More CO2 Emissions Than Air Travel

Bottom trawling is responsible for one gigaton of carbon emissions a year—a higher annual total than (pre-pandemic) aviation emissions. Not only does the practice contribute to climate change, it is extremely damaging to ocean biodiversity—the "equivalent of ploughing an old-growth forest into the ground, over and over and over again until there is nothing left"

Bottom trawling is also one of the least cost effective methods of fishing. Most locations have been trawled so many times, there is little left worth catching. Without government subsidies, no one would be making a penny.

Refuting a long-held view that ocean protection harms fisheries, the study found that well placed marine protected areas (MPAs) that ban fishing would actually boost the production of marine life by functioning as fish nurseries and biodiversity generators capable of seeding stocks elsewhere.

Sala

Marine sediments are the largest pool of organic carbon on the planet and a crucial reservoir for long-term storage29. If left undisturbed, organic carbon stored in marine sediments can remain there for millen-nia30. However, disturbance of these carbon stores can re-mineralize sed-imentary carbon to CO2, which is likely to increase ocean acidification, reduce the buffering capacity of the ocean and potentially add to the build-up of atmospheric CO2

Using satellite-inferred information on fishing activity by industrial trawlers and dredgers between 2016 and 2019, aggregated at a reso-lution of 1 km2, we estimate that 4.9 million km2 or 1.3% of the global ocean is trawled each year. This disturbance to the seafloor results in an estimated 1.47 Pg of aqueous CO2 emissions, owing to increased carbon metabolism in the sediment in the first year after trawling. If trawling continues in subsequent years, emissions decline as sediment carbon stocks become exhausted. However, after 9 years of continuous trawling, emissions stabilize at around 40% of the first year's emissions, or around 0.58 Pg CO2 (Supplementary Fig. 35). If the intensity and footprint of trawling remains constant, we estimate that sediment carbon emissions will continue at approximately 0.58 Pg CO2 for up to around 400 years of trawling, after which all of the sediments in the top metre are depleted. Although 1.47 Pg CO2 represents only 0.02% of total marine sedimentary carbon, it is equivalent to 15–20% of the atmospheric CO2 absorbed by the ocean each year32,33, and is compara-ble to estimates of carbon loss in terrestrial soils caused by farming34. Although an unknown fraction of the aqueous CO2 is emitted to the atmosphere, the increase in CO2 in the water column and sediment pore waters can have far-reaching and complex effects on marine carbon cycling, primary productivity and biodiversity.

Time Magzine BBC Sala (2021) Protecting the global ocean for biodiversity, food and climate - Nature Share

6.3 Company Attribution

A 2017 report by the Carbon Disclosure Project showed that 100 companies have been responsible for 71 per cent of global emissions since 1988. In 2019, a similar study from the Climate Accountability Institute found that just 20 companies were responsible for 35 per cent of all energy-related carbon dioxide and methane worldwide since 1965.

Sultana

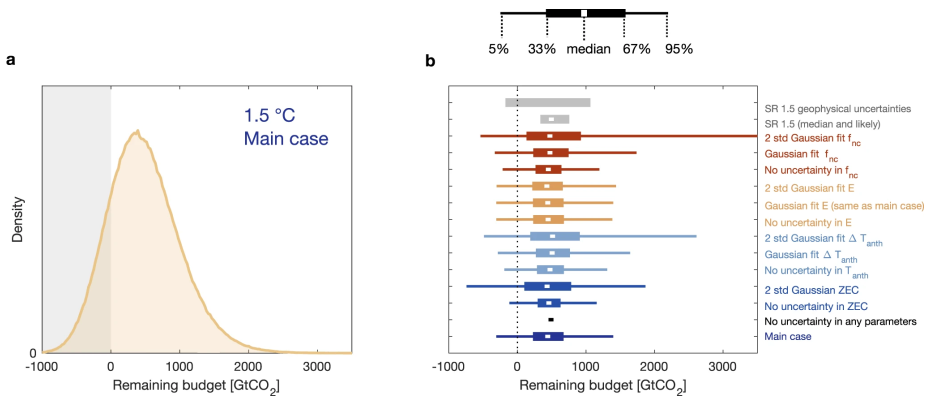
7

Carbon Budget

> The temperature response for a 1.5°C scenario has a huge uncertainty & this propagates to the uncertainty in the carbon budget. To say "the remaining carbon budget for 1.5°C is 440 GtCO " [add favorite number] is highly misleading Taking a narrow 67–33% range, the value is 230–670 GtCO , but full range (left) could be −1000 - 2000 GtCO ... (yes, could be negative or huge) (Glen Peters)

Memo Matthews:

The remaining carbon budget quantifies the future CO 2 emissions to limit global warming below a desired level. Carbon budgets are subject to uncertainty in the Transient Climate Response to Cumulative CO 2 Emissions (TCRE), as well as to non-CO 2 climate influences. We estimate a median TCRE of 0.44 °C and 5–95% range of 0.32–0.62 °C per 1000 GtCO 2 emitted. Considering only geophysical uncertainties, our median estimate of the 1.5 °C remaining carbon budget is 440 GtCO 2 from 2020 onwards, with a range of 230–670 GtCO 2 , (for a 67–33% chance of not exceeding the target). Additional socioeconomic uncertainty related to human decisions regarding future non-CO 2 emissions scenarios can further shift the median 1.5 °C remaining carbon budget by ±170 GtCO 2 .



Remaining carbon budgets (RCBs) represent the future cumulative CO 2 emissions that would be consistent with keeping global warming to a specified level. Despite being conceptually simple, RCBs have been defined and estimated in various ways and with many different underlying assumptions, resulting in a wide range of "best estimates" across different studies 2 . Moreover, most of these estimates of remaining budgets account for only a subset of the relevant uncertain processes and often omit the contribution of key uncertain processes (such as permafrost thaw or future scenario uncertainty, among others)

Median TCRE estimate is 0.44 °C per 1000 GtCO2 , with a 5–95% range of 0.32–0.62 °C per 1000 GtCO2

A stronger constraint on the left-hand side of the distribution (low TCRE values, with sharply increasing probability above 0.25 °C/ 1000 GtCO 2), while the right-hand side of this distribution has a wider tail. This right-skewed distribution shape of our observationally-constrained TCRE estimate is physically related to the possibility of a large negative aerosol forcing

Median RCB for 1.5 °C is 440 GtCO2 from 2020 onwards, representing a 50% chance of stabilising warming at or below 1.5 °C. The corresponding budget for a 67% chance of remaining below the target is 230 GtCO2 from the year 2020 onwards.

Matthews(2021) Carbon Budget Uncertainties (pdf)

7.1 Net-zero

Disaster looms if big finance is allowed to game the carbon offsetting markets to achieve 'net zero' emissions.

Net zero increasingly involves highly questionable carbon accounting. As a result, the new politics swirling around net zero targets is rapidly becoming a confusing and dangerous mix of pragmatism, self-delusion and weapons-grade greenwash.

The science of net zero is simple: every sector of every country in the world needs to be, on average, zero emissions. We know how to do this for electricity, cars, buildings and even a lot of heavy industry. But in certain areas, including air travel and some agricultural emissions, there is no prospect of getting to zero emissions in the near future. For these residual emissions, greenhouse gasses will need to be sucked out of the atmosphere at the same rate as they are added, so that, on average, there are net zero emissions.

The science of net zero is simple: every sector of every country in the world needs to be, on average, zero emissions. We know how to do this for electricity, cars, buildings and even a lot of heavy industry. But in certain areas, including air travel and some agricultural emissions, there is no prospect of getting to zero emissions in the near future. For these residual emissions, greenhouse gasses will need to be sucked out of the atmosphere at the same rate as they are added, so that, on average, there are net zero emissions.

Making this work requires carbon removal, also known as "negative emissions". This can be low-tech, like restoring forests, as this takes carbon out of the atmosphere and stores it in trees. Or it can be hi-tech, like using chemicals to strip carbon dioxide from the atmosphere and then pumping it deep underground into safe geological storage. In theory this is all fine, as pragmatically some carbon removal is needed to balance hard-to-reduce emissions: but negative emissions and offsetting alone are not a route to net zero.

In practice, by believing in the promise of these methods, we are too often deceiving ourselves, in three major ways. The first is an unrealistic overreliance on carbon removal to preserve the status quo. Critically, there is far too little land to plant enough trees to counter today's emissions, and large-scale hi-tech methods do not yet exist. The second deception is in offsetting against notional emissions trajectories instead of removing carbon from the atmosphere.Offsetting needs to be used to remove carbon dioxide from the atmosphere to counter difficult-to-remove emissions, and not just be an enabler of business-as-nearly-usual. The third deception comes from not getting what you think you're paying for in the self-regulated global carbon market. The commercial carbon offset concept relies on "additionality" – that money paid then reduces emissions or captures carbon that would not otherwise have happened. The offsets market is awash with old legacy carbon credits where that assumption is violated.

If such deceptions remain, disaster looms. Big finance, led by Carney, is planning to massively expand carbon markets. Conceivably, new carbon-based financial products could boom, with little impact on emissions. Just like the sub-prime crisis, few will understand what they bought, and another globe-spanning crash could sweep the world, compounding economic and climate crises causing mass suffering, as we realise again that the Earth owes us nothing. Nature doesn't do bailouts.

Lewis (Guardian)

8

Climate Sensitivity

8.1 Climate Feedbacks

Abstract Heinze Earth system models (ESMs) are key tools for providing climate projections under different sce- narios of human-induced forcing. ESMs include a large number of additional processes and feedbacks such as biogeochemical cycles that traditional physical climate models do not consider. Yet, some processes such as cloud dynamics and ecosystem functional response still have fairly high uncertainties. In this article, we present an overview of climate feedbacks for Earth system components currently included in state-of-the-art ESMs and discuss the challenges to evaluate and quantify them. Uncertainties in feedback quantification arise from the in- terdependencies of biogeochemical matter fluxes and physical properties, the spatial and temporal heterogeneity of processes, and the lack of long-term continuous observational data to constrain them. We present an outlook for promising approaches that can help to quantify and to constrain the large number of feedbacks in ESMs in the future. The target group for this article includes generalists with a background in natural sciences and an interest in climate change as well as experts working in interdisciplinary climate research (researchers, lecturers, and students). This study updates and significantly expands upon the last comprehensive overview of climate feedbacks in ESMs, which was produced 15 years ago (NRC, 2003).

Heinze (2019) Climate Feedbacks (pdf)

8.2 ECS - Equilibrium Climate Sensitivity

ECS

Climate sensitivity is defined as the equilibrium change in global and annual mean surface air temperature, ΔT, due to an increment in downward radiative flux, ΔR_f , that would result from sustained doubling of atmospheric CO_2 over its preindustrial value (2 x CO_2).

Studies based, on observations, energy balance models, temperature reconstructions, and global climate models (GCMs) have found that the probability density distribution of ΔT is peaked in the range 2.0°C ΔT 4.5°C, with a long tail of small but finite probabilities of very large temperature increases.

An important parameter in climate science is the equilibrium or long-run response in the global mean surface temperature to a doubling of atmospheric carbon dioxide.

In the climate science community, this is called the equilibrium climate sensitivity ECS. With reference to climate models, this is calculated as the increase in average surface temperature with a doubled CO2 concentration relative to a path with the pre-industrial CO2 concentration. This parameter also plays a key role in the geophysical components in the IAMs.

Given the importance of the ECS in climate science, there is an extensive literature estimating probability density functions. These pdfs are generally based on climate models, the instrumental records over the last century or so, paleoclimatic data such as estimated temperature and radiative forcings over ice-age intervals, and the results of volcanic eruptions. Much of the literature estimates a probability density function using a single line of evidence, but a few papers synthesize different studies or different kinds of evidence.

The IPCC Fifth Assessment report (AR5) reviewed the literature quantifying uncertainty in the ECS and highlighted five recent papers using multiple lines of evidence (IPCC, 2014). Each paper used a Bayesian approach to update a prior distribution based on previous evidence (the prior evidence usually drawn from instrumental records or a climate model) to calculate the posterior probability density function.

Gilligham (2015) Modelling Uncertainty (pdf)

8.2.1 Roe and Baker Distribution

Abstract

Uncertainties in projections of future climate change have not lessened substantially in past decades. Both models and observations yield broad probability distributions for long-term increases in global mean temperature expected from the doubling of atmospheric carbon dioxide, with small but finite probabilities of very large increases. We show that the shape of these probability distributions is an inevitable and general consequence of the nature of the climate system, and we derive a simple analytic form for the shape that fits recent published distributions very well. We show that the breadth of the distribution and, in particular, the probability of large temperature increases are relatively insensitive to decreases in uncertainties associated with the underlying climate processes.

Memo Roe and Baker

What determines the distribution shape of ECS and in particular, the high ΔT tail? To what extent we can decrease the distribution width?

Climate consists of a set of highly coupled, tightly interacting physical processes. Understanding these physical processes is a massive task that will always be subject to uncertainty. How do the uncertainties in the physical processes translate into an uncertainty in climate sensitivity?

Explanations for the range of predictions of DT, summarized in (14), have focused on (i) uncertainties in our understanding of the individual physical processes (in particular, those associated with clouds), (ii) complex interactions among the individual processes, and (iii) the chaotic, turbulent nature of the climate system, which may give rise to thresholds, bifurcations, and other discontinuities, and which remains poorly understood on a theoretical level. We show here that the explanation is far more fundamental than any of these.

We use the framework of feedback analysis to examine the relationship between the uncertainties in the individual physical processes and the ensuing shape of the probability distribution of ΔT. Because we are considering an equilibrium temperature rise, we consider only time-independent processes.

Roe and Baker (2007) Climate Sensitivity (pdf)

Memo Hannart

RB addressed these questions using rather simple theoretical considerations and reached the conclusion that reducing uncertainties on climate feedbacks and underlying climate processes will not yield a large reduction in the envelope of climate sensitivity. In this letter, we revisit the premises of this conclusion. We show that it results from a mathematical artifact caused by a peculiar definition of uncertainty used by these authors.

Reducing inter-model spread on feedbacks does in fact induce a reduction of uncertainty on climate sensitivity, almost proportionally. Therefore, following Roe and Baker assumptions, climate sensitivity is actually not so unpredictable.

The main originality of RB07 approach consists in analyzing explicitly the way uncertainties on f, due to a limited understanding of their underlying physical processes, prop- agates into uncertainties on ΔT: assuming f is a random variable with mean f and standard deviation σ_f , RB07 uses this simple probabilistic model to highlight several fundamental properties of uncertainty propagation from feedbacks to climate sensitivity. The most prominent conclusion of this analysis is that reducing uncertainties on f does not yield a large reduction in the uncertainty of ΔT, and thus that improvements in the understanding of physical processes will not yield large reductions in the envelope of future climate projections. We show that this conclusion is a mathematical artifact with no connection whatsoever to climate.

RB07 uses the feedback analysis framework. Denoting ΔT_0 the Planck temperature response to the radiative perturbation and f the feedback gain (RB07 refers to it as feedback factor), they obtain:

$$\Delta T = \frac{\Delta T_0}{1-f}$$

RB07 then assumes uncertainty on Planck response to be negligible so that the entire spread on ΔT results from the uncertainty on the global feedback gain f. To model this uncertainty, RB07 assumes that f follows a Gaussian distribution with mean $\overline{f}$, standard deviation σ_f and implicit truncation for $f > 1$. Then, they derive an exact expression of the distribution of ΔT. This simple probabilistic climatic model is used by RB07 to analyze the way uncertainties on f, due to a limited understanding of underlying physical processes, propagates into uncertainties on ΔT. Their analysis highlights two fundamental properties:

1. *Amplification*: The term in $\frac{1}{1-f}$ amplifies uncertainty on feedbacks, all the more intensely as f is close to (though lower than) one. Small uncertainties on feedbacks are thus converted in large uncertainties on the rise of temperature.

2. *Insensitivity*: reducing uncertainty on f has little effect in reducing uncertainty on ΔT, also stated as the breadth of the distribution of ΔT is relatively insensitive to decreases in σ_f.

We are puzzled by the second property, that is, the claimed insensitivity of uncertainty on ΔT to uncertainty on feedbacks. The reason why one may find this second assertion puzzling, is that it intuitively seems to contradict the first.

While the probability $P(\Delta T \in [4.5°C, 8°C])$ may be of interest practically, this metric is irrelevant to describe *the breadth of the distribution of climate sensitivity* which was RB07 explicit intent. To address this question, any measure of distribution spread chosen amongst those classically used in Descriptive Statistics is more appropriate.

(Hugo Mathjax don't render correctly here:?? OK in rpad !! OK in mathjax-test!!) With such measures when the spread of feedback parameter S_f decreases, the resulting spread of climate sensitivity $S_{\Delta T}$ values also decreases. Further the decrease is approximately linear for S_f small and tends to be steeper for larger values of S_f .

Hannart on RB (pdf)

Tol: RB-fitting Github

Memo Jules and James Roe and Baker have attempted to justify the pdfs that have been generated as not only reasonable, but inevitable on theoretical grounds

RB's basic point is that if "feedback" f is considered to be Gaussian, then sensitivity $= \lambda_0/(1-f)$ is going to be skewed, which seems fair enough.

Where I part company with them is when they claim that this gives rise to some fundamental and substantial difficulty in generating more precise estimates of climate sensitivity, and also that it explains the apparent lack of progress in improving on the long-standing 1979 Charney report estimate of 1.5-4.5C at only the "likely" level.

Stoat's complaints also seem pertinent: f cannot really be a true Gaussian, unless one is willing to seriously consider large negative sensitivity, and even though a Gaussian is a widespread and often reasonable distribution, it is hard to find any theoretical or practical basis for a Gaussian abruptly truncated at 1.

I can think of several alternative theories as to why the uncertainty in the IPCC estimate has not reduced. The probabilistic methods generally used to generate these long-tailed pdfs are essentially pathological in their use of a uniform prior (under the erroneous belief that this represents "ignorance"), together with only looking at one small subset of the pertinent data at a time, and therefore do not give results that can credibly represent the opinions of informed scientists.

There may also be the sociological effect of this range as some sort of anchoring device, which people are reluctant to change despite its rather shaky origins. Ramping up uncertainty (at least at the high end) is a handy lever for those who argue for strong mitigation, and it would also be naive to ignore the fact that scientists working in this area benefit from its prominence.

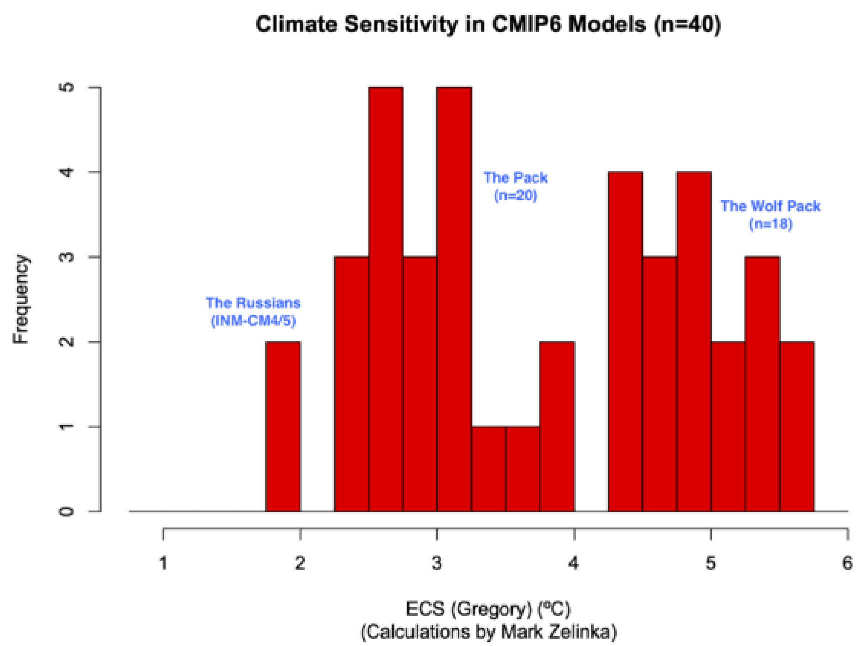
Jules and James: Comment on RB

Memo Gillingham

Note that the US government used a version of the Roe and Baker distribution calibrated to three constraints from the IPCC for its uncertainty estimates (IAWG, 2010). Specifically, the IAWG Report modified the original Roe and Baker distribution to assume that the median value is 3.0°C, the probability of being between 2 and 4.5°C is two-thirds, and there is no mass below zero or above 10°C. The modified Roe and Baker distribution has a higher mean ECS than any of the models (3.5°C) and a much higher dispersion (1.6°C as compared to 0.84°C from Olsen et al. 2012).

Gilligham (2015) Modelling Uncertainty (pdf)

8.2.2 GCM based Approach



Gavin (2019) RealClimate (Part 1)

Gavin (2020) RealClimate (Part 2)

8.2.3 GCM free Approach

Memo

- GCM free approach

The atmosphere is a complex system involving turbulent processes operating over a wide range of scales starting from millimeters at the Kolmogorov dissipation scale up to the size of the Earth, spanning over 10 orders of magni- tudes in space.

The dynamics are sensitive to initial conditions and there are deterministic predictability limits that are roughly equal to the eddy turn-over time (lifetime) of structures.

For planetary scale structures in the atmosphere, the overall deterministic prediction limit of about 10 days corresponds to the scaling transition timescale w from the weather regime to the macroweather regime.

The atmospheric components of GCMs exhibit the same weather-macroweather scaling transition as the atmosphere and similar predictability limits. Beyond this horizon, the internal variability has to be interpreted stochastically so that a single GCM run is only one realization of the random process; at these timescales, weather models effectively become stochastic macroweather generators. For projec- tions over multi-decadal timescales and beyond, multi-model ensembles (MME) that include several models are used. The mean of the MME is taken to obtain the deterministic forced component of temperature variability and average out the internal variability (Collins et al. 2013).

Emergent properties of the Earth's climate, i.e. proper- ties which are not specified a priori, are then inferred from GCM simulations.

The equilibrium climate sensitivity (ECS) is such a property; it refers to the expected temperature change after an infinitely long time following a doubling in carbon dioxide (CO 2) atmospheric concentration.

Another is the transient climate response (TCR), which is defined as the change in temperature after a gradual doubling of CO 2 atmospheric concentration over 70 years at a rate of 1% per year.

However, it is not clear whether such emer- gent properties from computational models can be taken as genuine features of the natural world.

The difficulty is that each GCM has its own climate ("structural uncertainty") and this leads to very large discrepancies in ECS and TCR between GCMs; this underscores the need for qualitatively different approaches which can narrow down the properties of the real climate directly from observations.

The ecological consequences of global warming could be dire; therefore, better constraining climate sensitivity is of utmost importance in order to meet the urgency of adjusting economical and environmental policies.

Multidecadal climate projections rely almost exclusively on deterministic global climate models (GCMs) in spite of the fact that there are still very large structural uncertainties between Coupled Model Intercomparison Project phase 5 (CMIP5) GCMs, i.e. each has its own climate, rather than the real world climate.

Climate skeptics have argued that IPCC projections are untrustworthy precisely because they are entirely GCM based. While this conclusion is unwarranted, it underscores the need for independent and qualitatively different approaches. It is therefore significant that the alternative GCM-free approach we present here yields comparable results albeit with smaller uncertainty.

According to our projections made to 2100, to avert a 1.5 K warming, future emissions will be required to undergo drastic cuts similar to RCP 2.6, for which we found a 46% probability to remain under the said limit; it is virtually certain that RCP 4.5 and RCP 8.5-like futures would overshoot.

Even a 2.0 K warming limit would surely be surpassed by 2100 under RCP 8.5 and probably also under RCP 4.5, with only a 6% chance of remaining under the limit. The safest option remains RCP 2.6 which we project to remain under 2.0

K with very high confidence. The question remains whether it is at all realistic given that it relies strongly on the massive deployment of speculative negative emission technologies.

On the other hand, our model has obvious limitations since it assumes a linear stationary relationship between forcing and temperature, neglecting nonlinear interac- tions which could arise as the system evolves, as it cur- rently warms.

In particular, so-called tipping points could be reached in the coming century which would lead to a breakdown of the linear model proposed. Such potential behaviours are of critical value for improving future projections, but they have not yet been observed with high confidence even in GCMs.

This underlines the need to exploit paleoclimate archives to achieve a better understanding of low-frequency natural variability, namely the transition scale from the macroweather regime to the climate regime.

In this study, we have assumed the increased variability in the climate regime to be strictly a result of forcing, but internal modes of variability could also have a significant contribution for longer timescales.

Climate News Network

Climate Sensitivity article (Climate Dynamics) (pdf)

8.3 Remote Sensing of Tipping Points

Many aspects of the climate are sensitive to small disrupting changes that could trigger an abrupt change in the system into a new stable state. Even at relatively low levels of global warming, systems that exhibit these instabilities could accelerate global warming through climate feedbacks or cause other cascading impacts. These ‘tipping elements’, or ‘large-scale discontinuities in the climate system’, as UNFCCC IPCC reports refer to them, have been assigned successively greater risk with each IPCC report since 2001.

Proximity to a tipping point may be indicated in remote sensing data by characteristic statistical changes. Early warning indicators can be developed using an increasing trend in the lag-1 autocorrelation when it is correlated with an increase in variance. Niklas Boers of the Potsdam Institute for Climate Impact Research highlighted recent work using these characteristic statistical changes to identify the reduction in a system’s resilience, and has developed early warning indicators for Arctic sea-ice extent, Greenland ice sheet, Atlantic Meridional Overturning Circulation, the Amazon rainforest and the South American Monsoon system. The technique has also been applied to aquatic ecosystems and marine anoxic events. Automatic detection of extreme events and abrupt shifts in climate datasets using edge detection algorithms.

futureearth

9

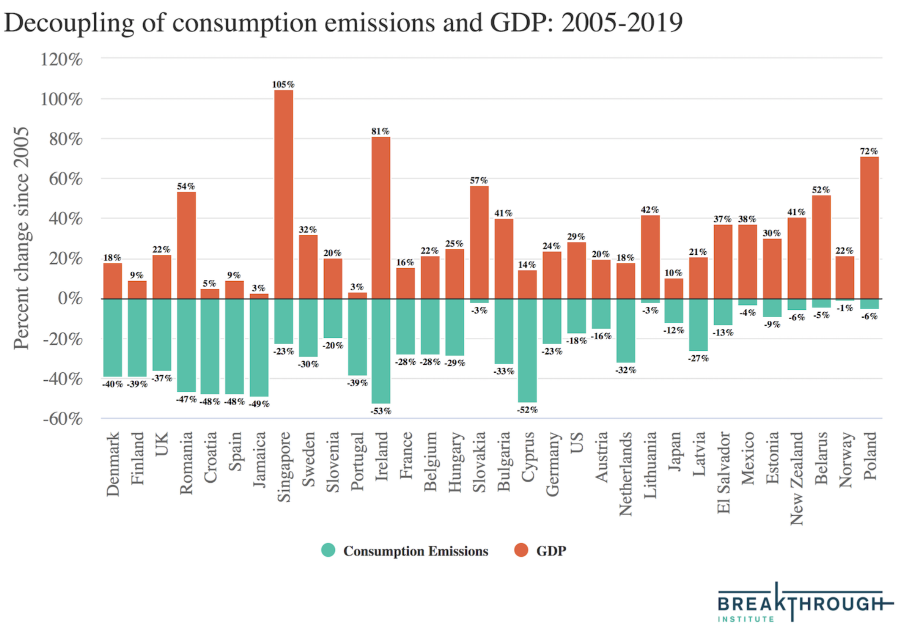
Decoupling

Hausfather

Absolute Decoupling of Economic Growth and Emissions in 32 Countries

Between 1990 and 2019, global emissions of CO2 increased by 56%. Historically, economic growth has been closely linked to increased energy consumption — and increased CO2 emissions in particular — leading some to argue that a more prosperous world is one that necessarily has more impacts on our natural environment and climate. There is a lively academic debate about our ability to "absolutely decouple" emissions and growth — that is, the extent to which the adoption of clean energy technology can allow emissions to decline while economic growth continues.

Over the past 15 years, however, something has begun to change. Rather than a 21st century dominated by coal that energy modelers foresaw, global coal use peaked in 2013 and is now in structural decline.



These 32 countries show that it is possible to have economic growth at the same time that CO2 emissions decline, even accounting for embodied emissions in goods imported from overseas. However, these are mostly relatively wealthy countries whose economies tend to be increasingly driven by lower-energy information technology and service sectors. We have relatively few examples of low- or middle-income countries with a focus on energy-intensive manufacturing experiencing absolute decoupling to date.

Absolute decoupling is possible. There is no physical law requiring economic growth — and broader increases in human wellbeing — to necessarily be linked to CO2 emissions. All of the services that we rely on today that emit fossil fuels — electricity, transportation, heating, food — can in principle be replaced by near-zero carbon alternatives, though these are more mature in some sectors (electricity, transportation, buildings) than in others (industrial processes, agriculture).

Hausfather

10

Paleoclimate

Earth's paleoclimate history provides guidance with a precision and reliability that climate models cannot match. Ice cores were usually the paleoclimate data source of choice for those scientists concerned about human-made climate change. That's understandable because ice cores provide precise data on atmospheric composition as well as climate change. However, ice cores cover only several hundred thousand years. That sounds like a long time, but Earth was mostly in ice ages during that time. The ice cores encompass several interglacial periods, but none of them were much warmer than our present global temperature. (James Hansen: Sophies Planet Ch.40)

10.1 Holocen Thermal Maxima

Abstract Bova

Proxy reconstructions from marine sediment cores indicate peak temperatures in the first half of the last and current interglacial periods (the thermal maxima of the Holocene epoch, 10,000 to 6,000 years ago, and the last interglacial period, 128,000 to 123,000 years ago) that arguably exceed modern warmth1,2,3. By contrast, climate models simulate monotonic warming throughout both periods4,5,6,7. This substantial model–data discrepancy undermines confidence in both proxy reconstructions and climate models, and inhibits a mechanistic understanding of recent climate change. Here we show that previous global reconstructions of temperature in the Holocene1,2,3 and the last interglacial period8 reflect the evolution of seasonal, rather than annual, temperatures and we develop a method of transforming them to mean annual temperatures. We further demonstrate that global mean annual sea surface temperatures have been steadily increasing since the start of the Holocene (about 12,000 years ago), first in response to retreating ice sheets (12 to 6.5 thousand years ago), and then as a result of rising greenhouse gas concentrations (0.25 ± 0.21 degrees Celsius over the past 6,500 years or so). However, mean annual temperatures during the last interglacial period were stable and warmer than estimates of temperatures during the Holocene, and we attribute this to the near-constant greenhouse gas levels and the reduced extent of ice sheets. We therefore argue that the climate of the Holocene differed from that of the last interglacial period in two ways: first, larger remnant glacial ice sheets acted to cool the early Holocene, and second, rising greenhouse gas levels in the late Holocene warmed the planet. Furthermore, our reconstructions demonstrate that the modern global temperature has exceeded annual levels over the past 12,000 years and probably approaches the warmth of the last interglacial period (128,000 to 115,000 years ago).

Bova (2021) Nature (Paywall)

11

Pattern Effect

Abtract

Our planet's energy balance is sensitive to spatial inhomogeneities in sea surface temperature and sea ice changes, but this is typically ignored in climate projections. Here, we show the energy budget during recent decades can be closed by combining changes in effective radiative forcing, linear radiative damping and this pattern effect. The pattern effect is of comparable magnitude but opposite sign to Earth's net energy imbalance in the 2000s, indicating its importance when predicting the future climate on the basis of observations. After the pattern effect is accounted for, the best-estimate value of committed global warming at present-day forcing rises from 1.31 K (0.99–2.33 K, 5th–95th percentile) to over 2 K, and committed warming in 2100 with constant long-lived forcing increases from 1.32 K (0.94–2.03 K) to over 1.5 K, although the magnitude is sensitive to sea surface temperature dataset. Further constraints on the pattern effect are needed to reduce climate projection uncertainty.

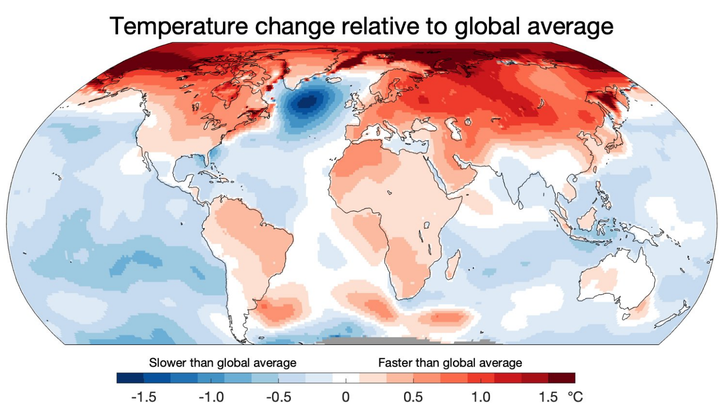
Nature article (paywall)

12

Temperature Measurements

Temperatures have increased over virtually the entire planet since the mid-19th century, but the warming rate has not been the same everywhere.

When looking at the changes relative to the global average, it is clear the Arctic and land areas are warming faster than the ocean.



Part III

Elements

13

Albedo

Some text on Albedo

14

Atmosphere

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- Emissions
    - CO2
    - Methane
    -
- Attributing Emissions
    - Norway's Responsibility
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14.1 Emissions

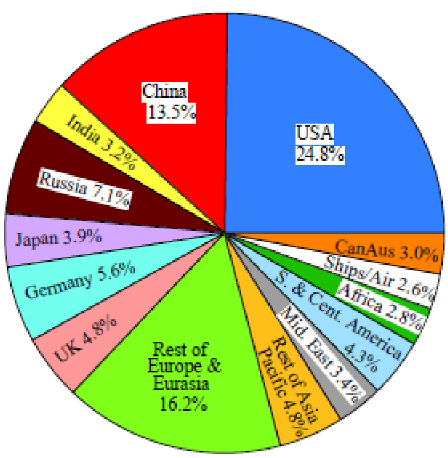
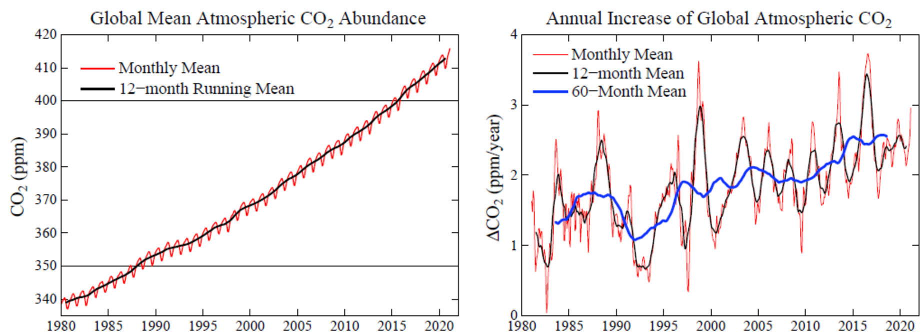


Fig: Cumulative Emissions 1751-2018 by Country/Region

The UK (like the US) is 5X more responsible for global warming than the average nation.

14.1.1 CO2

James Hansen

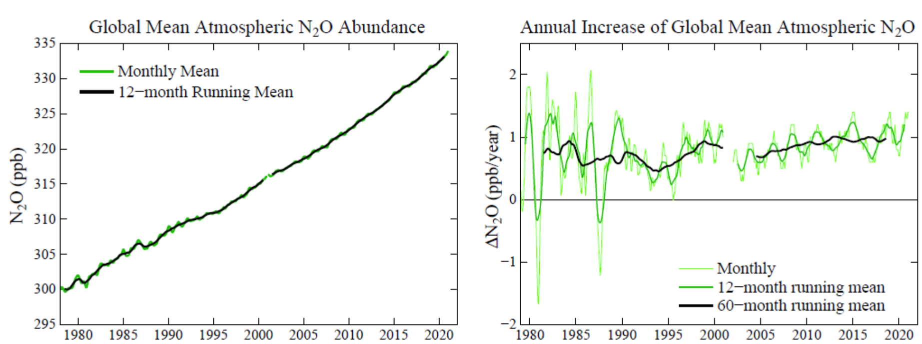


The CO2 growth rate (Fig. 5) is now a bit below the peaks that occur in conjunction with strong El Ninos. However, the CO2 growth rate is not declining. CO2 growth has not even slowed as a result of the reduced economic activity associated with Covid-19.

James Hansen 13 May 2021

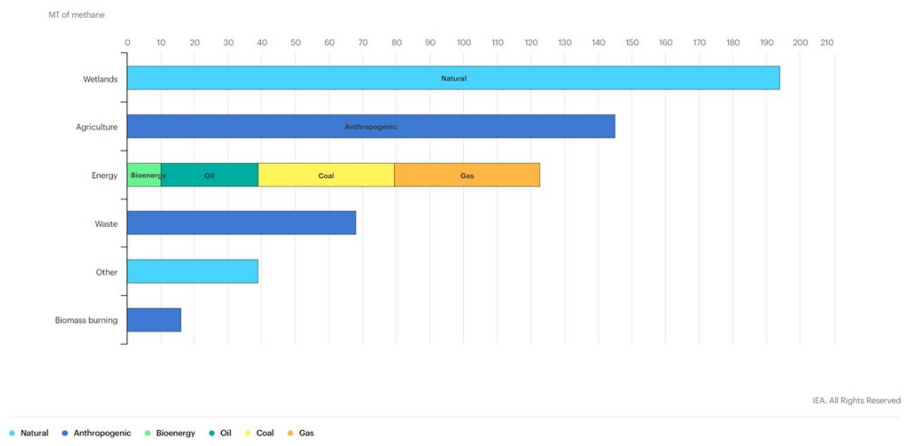
14.1.2 N2O

The growth rate of the third strongest greenhouse gas, N2O, does not provide any good news. Its growth rate continues to increase.



James Hansen 13 May 2021

14.1.3 Methane

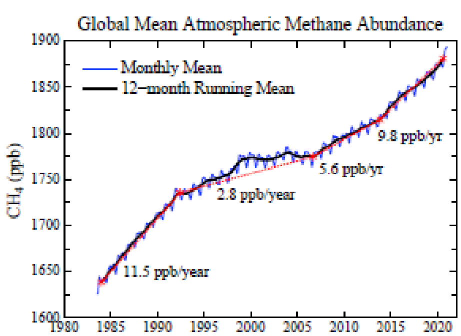


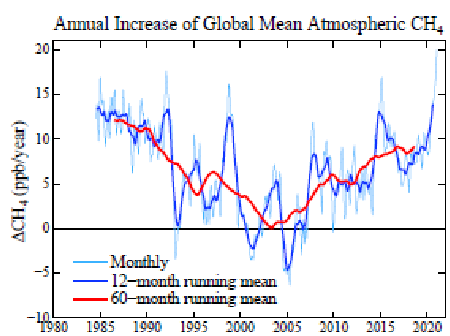
Methane, the largest component of natural gas, is sometimes called a "short-lived climate pollutant" because it remains in the atmosphere for far less time than carbon dioxide, which can remain in the atmosphere for hundreds of years. But methane is also a climate "super-pollutant," 86 times more potent than carbon dioxide at warming the atmosphere over a 20-year period.

Sources of methane include wetlands, rice paddies, livestock, biomass burning, organic waste decomposition and fossil fuel drilling and transport.

James Hansen

The methane (CH4) growth rate[3] is shocking. A CH4 increase causes tropospheric ozone (O3) and stratospheric water vapor (H2O) to also increase. Including these indirect effects, the climate forcing by observed CH4 growth is half as large as the climate forcing by CO2.





After CH4 nearly stabilized early this century, growth has returned and recently accelerated to its highest rate in the period of accurate global data, with increased growth at least in part as a result of "fracking" for gas and reliance on gas as the complement to intermittent renewable energies.

James Hansen 13 May 2021

14.1.3.1 Global Methane Assessment

The Global Methane Assessment shows that human-caused methane emissions can be reduced by up to 45 per cent this decade. Such reductions would avoid nearly 0.3°C of global warming by 2045 and would be consistent with keeping the Paris Climate Agreement's goal to limit global temperature rise to 1.5 degrees Celsius (1.5 ° C) within reach.

The assessment, for the first time, integrates the climate and air pollution costs and benefits from methane mitigation. Because methane is a key ingredient in the formation of ground-level ozone (smog), a powerful climate forcer and dangerous air pollutant, a 45 per cent reduction would prevent 260 000 premature deaths, 775 000 asthma-related hospital visits, 73 billion hours of lost labour from extreme heat, and 25 million tonnes of crop losses annually.

Global Methane Assessment Report

Inkl: Methane Far Worse

14.1.3.2 Cut Methane Now

Methane is the biggest and really the only lever we have to slow temperature rise during the next two decades.

Methane's potency and short atmospheric life make it a key greenhouse gas for policy makers to focus on as a way to combat global warming in the near term because the impact of those cuts will be felt almost immediately.

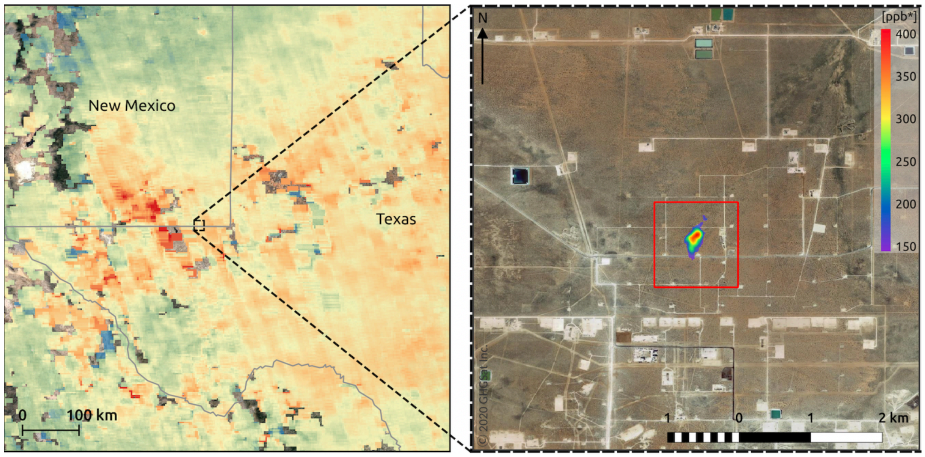
"If we cut methane emissions substantially during the 2020s, the abundance or concentration in the atmosphere will also drop rapidly during the 2020s," said Drew Shindell, an earth science professor at Duke University. "If we cut CO2 emissions, it takes a long time for actual concentrations to drop, and then longer for the climate to adjust."

Inside

14.1.3.3 Spotting Methane from Space

Methane is a key driver of climate change, with 80 times the global warming impact of carbon dioxide over a 20-year period. But methane only lingers in the atmosphere for about nine years, compared to a century for CO2.

That means reducing methane emissions from oil and gas wells and pipelines, livestock operations, landfills and other sources around the world will have an outsize impact on reducing global warming.



Two separate efforts to launch satellites that can scan the globe for methane emissions at a scope and level of detail not possible before, and to share their data with the public.

The first is MethaneSat, a subsidiary of the Environmental Defense Fund that is set to launch its satellite in 2022 and start delivering data in 2023. MethaneSat will be able to scan 200-kilometer-wide swaths of the earth with spectrometers that can detect methane at concentrations of 2 to 3 parts per billion, down to resolutions of about 100 meters by 400 meters. This will be the best performance of any satellite-based methane tracking technology yet launched.

In comparison, the Tropomi sensors on the European Space Agency's Copernicus Sentinel satellite can detect about 11 parts per billion at resolutions of 7 kilometers, and the sensors on satellites operated by Canadian-based company GHGSat can capture about 55 parts per billion, albeit at much tighter spatial dimensions, down to roughly 25 meters square.

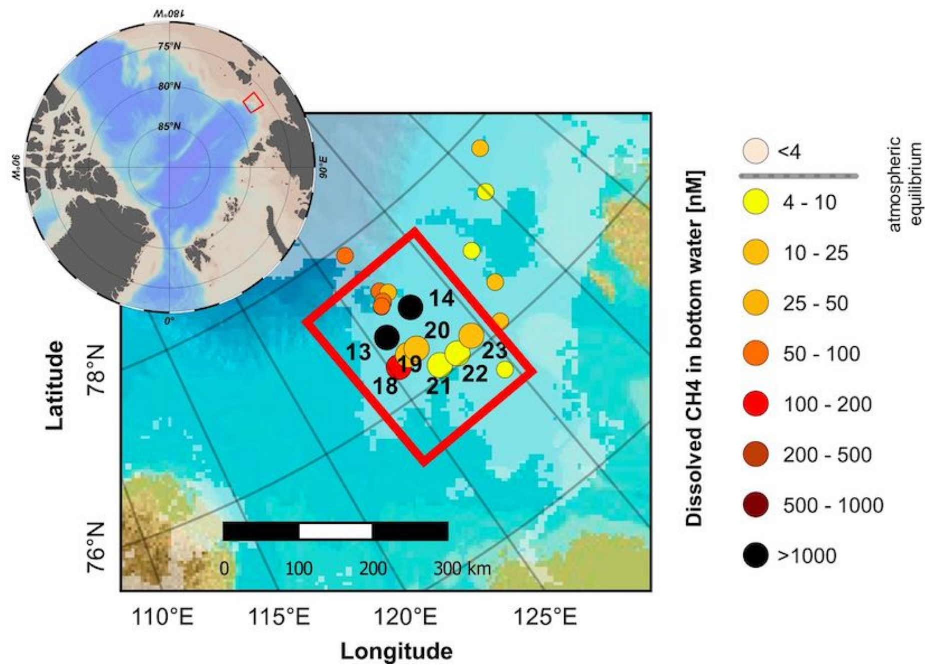
MethaneSat will be able to capture leaks as low as 5 kilograms per hour per square kilometer.

Newly released research finds that roughly half of global methane emissions can be cut over the next decade at no net cost. Of that low-cost reduction potential, 80 percent could come from the global oil and gas industries.

CanaryMedia

14.1.4 Methane Reservoir Laptev Sea

Methane bubbles regularly reach the surface of the Laptev Sea in the East Siberian Arctic Ocean (ESAO), each of them a small blow to our efforts to mitigate climate change. The source of the methane used to be a mystery, but a joint Swedish-Russian-U.S. investigation recently discovered that an ancient gas reservoir is responsible for the bubbly leaks.



Methane in the Laptev Sea is stored in reservoirs below the sea's submarine permafrost or in the form of methane hydrates—solid ice-like structures that trap the gas inside. It is also produced by microbes in the thawing permafrost itself. Not all of these sources are created equal: Whereas microbial methane is released in a slow, gradual process, disintegrating hydrates and reservoirs can lead to sudden, eruptive releases.

Methane is escaping as the Laptev's submarine permafrost is thawed by the relative warmth of overlying seawater. With an even stronger greenhouse effect than carbon dioxide, methane releases into the atmosphere could substantially amplify global warming.

The source of the methane was an old reservoir, deep below the permafrost. The big finding was that we really have something that's coming out from a deep pool. As the permafrost thaws, it opens up new pathways that allow methane to pass through. There is a risk that this methane release might increase, so it will eventually have a sizable effect on the climate.

It is quite plausible that there are other sources—the thawing permafrost or the hydrates that can be the major source of methane in other parts of this enormous system.

The permafrost is a closed lid over the seafloor that's keeping everything in place. And now we have holes in this lid.

Eos

14.2 Stratosphere shrinking

The thickness of the atmospheric layer has contracted by 400 metres since the 1980s, the researchers found, and will thin by about another kilometre by 2080 without major cuts in emissions. The changes have the potential to affect satellite operations, the GPS navigation system and radio communications.

The discovery is the latest to show the profound impact of humans on the planet. In April, scientists showed that the climate crisis had shifted the Earth's axis as the massive melting of glaciers redistributes weight around the globe.

The stratosphere extends from about 20km to 60km above the Earth's surface. Below is the troposphere, in which humans live, and here carbon dioxide heats and expands the air. This pushes up the lower boundary of the stratosphere. But, in addition, when CO2 enters the stratosphere it actually cools the air, causing it to contract.

Guardian

Pisoft Abstract

Rising emissions of anthropogenic greenhouse gases (GHG) have led to tropospheric warming and stratospheric cooling over recent decades. As a thermodynamic consequence, the troposphere has expanded and the rise of the tropopause, the boundary between the troposphere and stratosphere, has been suggested as one of the most robust fingerprints of anthropogenic climate change. Conversely, at altitudes above ~55 km (in the mesosphere and thermosphere) observational and modeling evidence indicates a downward shift of the height of pressure levels or decreasing density at fixed altitudes. The layer in between, the stratosphere, has not been studied extensively with respect to changes of its global structure. Here we show that this atmospheric layer has contracted substantially over the last decades, and that the main driver for this are increasing concentrations of GHG. Using data from coupled chemistry-climate models we show that this trend will continue and the mean climatological thickness of the stratosphere will decrease by 1.3 km following representative concentration pathway 6.0 by 2080. We also demonstrate that the stratospheric contraction is not only a response to cooling, as changes in both tropopause and stratopause pressure contribute. Moreover, its short emergence time (less than 15 years) makes it a novel and independent indicator of GHG induced climate change.

Pisoft

14.3 Attributing Emissions

14.3.1 Norway's Responsibility

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In real life responsibility is more than what is legally binding
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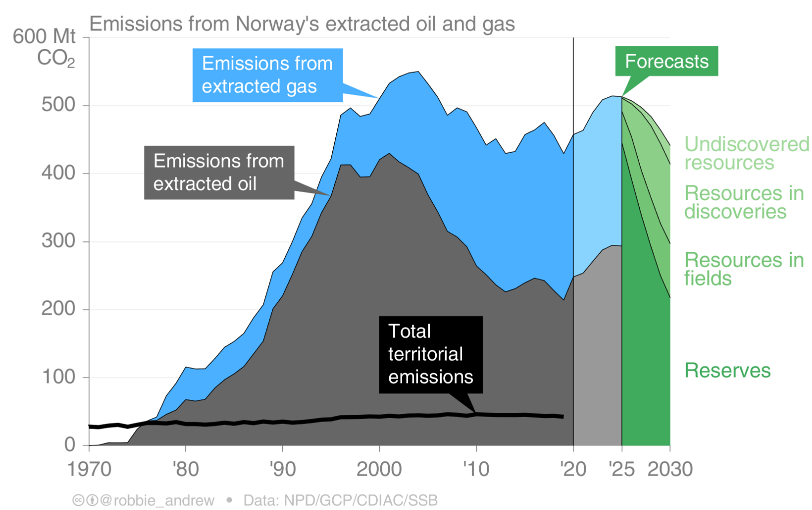
The emissions of CO2 that occur within Norway's territory are dwarfed by the emissions that result from combustion of all the oil and gas Norway produces. Because these fossil fuels are exported before being combusted, the emissions are allocated to the accounts of other countries. If Norway had generated electricity from the gas and then exported the electricity, for example, then emissions from that electricity generation would be allocated to Norway's accounts. There is therefore an element of artificiality associated with this allocation. It takes two to tango.

Norway's territorial emissions of CO2 were about 42 Mt in 2019, and over 1971–2019 totalled about 1.9 Gt. In comparison, emissions from Norwegian oil and gas since 1971 have been about 16 Gt. A similar amount (~15 Gt) will be emitted if all remaining Norwegian oil and gas resources are extracted from the continental shelf.

In 2019, emissions from Norwegian oil and gas amounted to 84 tonnes of CO2 for every person in Norway.



Norways Export Emissions (Robbie Andrew)

In Norwegian politics, there's been a very successful attempt to separate the discussion of oil policy from the discussion of climate policy. The two were never really tightly linked [in the country] until roughly the last decade, and this division has become increasingly difficult to maintain.

Norwegian politicians also haven't been alone in creating the conditions that made this division possible. They've been helped immensely by the international climate regime.

From the very beginning of international climate policy, there was this agreement that countries had to account for the emissions that they create when they burn fossil fuels. All the responsibility was placed on the demand side, not the supply side, which was very convenient for Norway.

Europe is the primary market for Norway's oil and gas. But determining the climate effects of Norwegian production is not straightforward. One study has estimated a clear climate benefit from reducing oil output, but the market is complex and the result really depends on your assumptions about how other actors will behave and how the market will evolve over time.

The big irony here is that Norway is a fairly large fossil-fuel producer, but we use relatively few fossil fuels directly in our energy use. Nearly all of our electricity has for a long time come from hydropower. In most years, we even export quite a lot of renewable electricity to our neighbors. The only place where fossil fuels are used to directly produce energy is to run the platforms offshore. They use gas to run the turbines to get the energy needed for oil and gas production.

The government's new climate plan, which was unveiled just a few days ago, does include a number of new and more aggressive measures to reduce Norway's domestic emissions. The proposal to increase the already quite high CO2 tax on offshore emissions came as something of a surprise, and it is likely to pass even if it is currently being challenged by the industry.

However, it is important to keep in mind that this proposal only targets the production-related emissions of Norwegian oil, not the level of oil that is being extracted and exported. As such, it is in line with the historical separation between climate and oil policymaking, which tends to focus only on emissions happening within Norway and exclude any concern for the climate impact of exported oil and gas.

The Norwegian paradox has worked out fairly well up until the last few years because there has been little focus on the production of fossil fuels, and because Norway is small enough to avoid the scrutiny that some larger nations face. But this is quickly changing, both in the domestic and international political discussion.

There is now a lot more focus on the supply side of fossil fuels than 10 years ago, with several countries like Denmark announcing an end to drilling and new research showing a mismatch between planned fossil-fuel production and ideas such as a "non-proliferation treaty" for fossil fuels being floated. The treaty would bring the world together in agreeing to end the use of fossil fuels much like the UN came together to curb the spread of nuclear weapons.

This will make it increasingly hard for Norway to hold on to a leadership claim as long as oil production keeps being expanded into new areas.

Norways Climate - Petroleum Dilemma (Bard Lahn)

14.3.2 Global North vs South Responsibility

The global North is responsible for 92% of total excess carbon dioxide emissions. Climate breakdown is colonial in character and ultimately requires an anti-colonial struggle in response. (Jason Hickel)

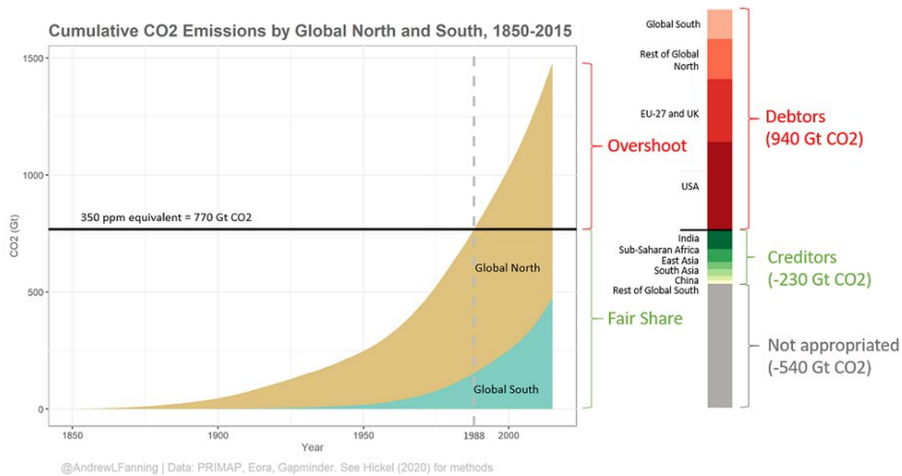


Figure 14.1: Fig. by **?**

15

Forests

15.1 Forests tipping: go from sink to source of CO_2 due to temperature increase.

New research shows that Earth's overheated climate will alter forests at a global scale even more fundamentally, by flipping a critical greenhouse gas switch in the next few decades. The study suggests that, by 2040, forests will take up only half as much carbon dioxide from the atmosphere as they do now, if global temperatures keep rising at the present pace.

Global warming has contributed to thinning canopies in European forests and to sudden die-offs of aspen trees in Colorado, as well as insect outbreaks that are killing trees around the world. In many places, forests are not growing back.

The data show a clear temperature limit, above which trees start to exhale more CO_2 than they can take in through photosynthesis. The findings mark a tipping point, of sorts, at which "the land system will act to accelerate climate change rather than slow it down,"

Trees From Sink to Source (InsideClimateNews)

At present, the land provides a "climate service" by absorbing around 30 per cent of the emissions caused by humans each year.

Unlike other tipping elements in the Earth system, the climate tipping point for the terrestrial biosphere could be exceptionally close – 20-30 years away – without action.

Plant respiration, the process by which plants produce energy for growth, causes CO_2 to be released into the atmosphere.

The 'buffer' or 'discount' against carbon emissions that we currently receive from the biosphere is more fragile than we previously realised.

Climate models are tools used by scientists to simulate how the world is likely to respond to greenhouse gas emissions.

However, it is worth noting that the global dataset used in the study uses "very few samples from tropical regions". This means that it is still not fully understood how tropical forests are responding to rising temperatures.

Independent

Memo Duffy

The temperature dependence of global photosynthesis and respiration determine land carbon sink strength. While the land sink currently mitigates ~30% of anthropogenic carbon emissions, it is unclear whether this ecosystem service will persist and what hard temperature limits, if any, regulate carbon uptake.

The mean temperature of the warmest quarter (3-month period) passed the thermal maximum for photosynthesis during the past decade. At higher temperatures, respiration rates continue to rise in contrast to sharply declining rates of photosynthesis.

Under business-as-usual emissions, this divergence elicits a near halving of the land sink strength by as early as 2040.

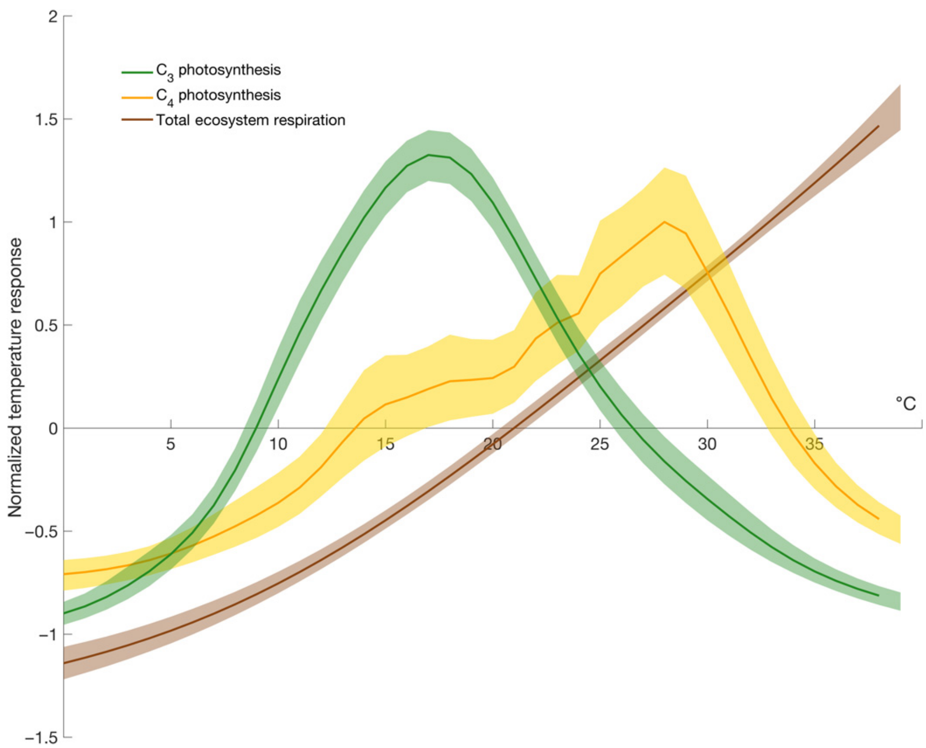
The difference between gross primary productivity and total ecosystem respiration (carbon uptake by vegetation minus carbon loss to the atmosphere) comprises the metabolic component of the land carbon sink [net ecosystem productivity (NEP)].

To date, land ecosystems provide a climate regulation service by absorbing ~30% of anthropogenic emissions annually. While temperature functions as a key driver of year-to-year changes in the land carbon sink, its temperature response is still poorly constrained at biome to global scales, making the carbon consequences of anticipated warming uncertain.

Like all biological processes, metabolic rates for photosynthesis and respiration are temperature dependent; they accelerate with in- creasing temperature, reach a maximum rate, and decline thereafter.

Highly divergent land carbon sink trajectories from Earth system models.

Continued future increases in sink strength due to the CO2 fertilization.

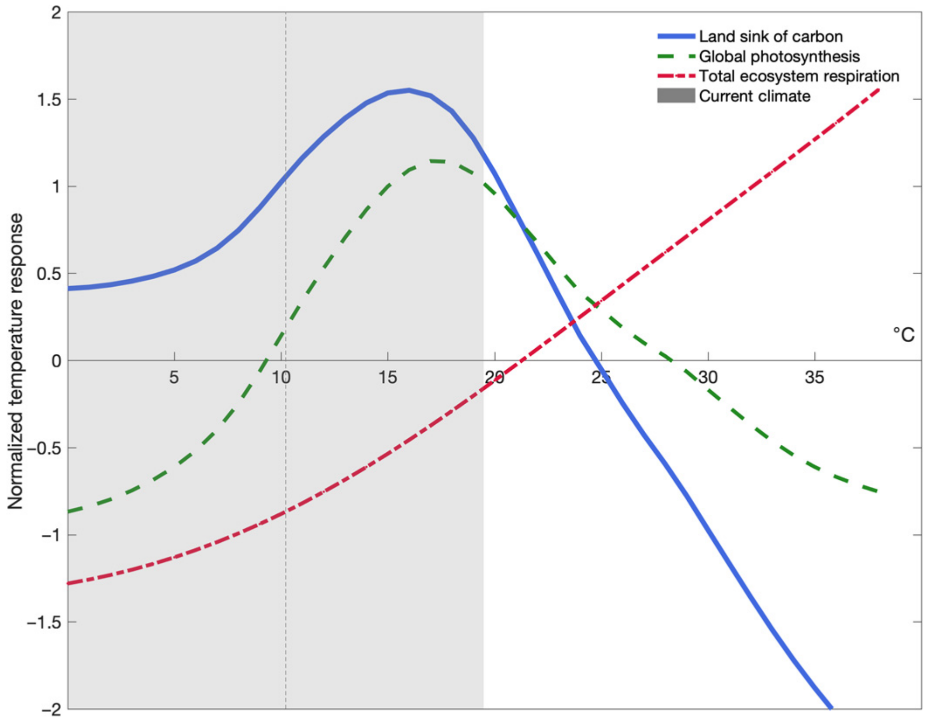


The temperature response of global photosynthesis shows distinct maxima at 18°C for C3 and 28°C for C4 plant systems. In contrast to photosynthesis, respiration rates increase across the range of ambient temperatures (up to 38°C), with no evidence of Tmax or rate decline. The thermal maxima of leaf and soil respiration reside at ~60°-70°C.

Responses diverge at temperatures above Tmax. The imbalance grows more pronounced as temperature increases.

Current climate mostly lies just below Tmax where slight increases in temperature act as climate fertilization of land carbon uptake. Under anticipated warming foreshadowed by historical temperature extremes and coincident land carbon loss—however, more and more time will be spent above Tmax. Past this threshold, the land carbon balance will first weaken and ultimately reverse sign from carbon sink to carbon source.

25°C constitutes a powerful tipping point for the land sink of carbon and a formidable positive climatic feedback,



Currently, less than 10% of the terrestrial biosphere experiences where land carbon uptake is degraded. For regions that do experience these temperatures, exposure is limited to 1 to 2 months or constitutes areas with sparse to no vegetation.

Under business-as-usual emissions, by 2100, up to half of the terrestrial biosphere could experience temperatures past the treshold.

The impact of elevated temperatures on the land sink is more than a function of cumulative area. Biomes that cycle 40 to 70% of all terrestrial carbon including the rainforests of the Amazon and Southeast Asia and the Taiga forests of Russia and Canada are some of the first to exceed biome-specific Tmax for half the year or more. This reduction in land sink strength is effectively front-loaded in that a 45% loss occurs by midcentury, with only an additional 5% loss by the end of the century. These estimates are conservative as they assume full recovery of vegetation after temperature stress and ignore patterns and lags in recovery.

In contrast to any CO2 fertilization effect, anticipated higher temperatures associated with elevated CO2 could degrade land carbon uptake. Failure to account for this results in a gross overestimation of climate change mitigation provided by terrestrial vegetation.

We are rapidly entering temperature regimes where biosphere productivity will precipitously decline and calls into question the future viability of the land sink.

Duffy(2021) Temperature tipping point of the terrestrial biosphere (pdf)

15.2 Plant and Cut - Forest CCS

Wood can also serve purely as a long-term carbon storage device. The key to locking away the carbon is to cut off the oxygen supply to microbes, thereby preventing decomposition.

Natural experiments show how this can be done. 19th-century lumberjacks in the US and Canada frequently stored logs on the surfaces of the Great Lakes or floated them down rivers, some of which ended up sinking along the way. These have remained in such good condition that a modern-day cottage industry has arisen to recover the logs and turn them into everything from hardwood floors to violins. New Zealand has a similar industry with logs that were fortuitously buried in swamps as long as 60,000 years ago.

Based on such examples, scholars have proposed chopping down trees or collecting fallen logs and intentionally stowing them away. That could mean sinking them to the bottom of lakes, interring them in abandoned mines or burying them in specially dug trenches. The idea hasn't gotten much traction yet, but in 2013, the Quebec Ministry of Agriculture, Fisheries and Food funded a pilot project to dig a trench and bury 35 metric tons of wood. The project came to about $29 per metric ton of CO2 sequestered, according to government scientist Ghislain Poisson, in line with a theoretical estimate of $10-$50.

That is cheaper than most high-tech forms of carbon capture and storage, which usually involve machines that filter carbon out of the air and pump it underground. Sequestering carbon at the typical power plant, where emissions are highly concentrated, runs to $30-$91 per metric ton of CO2, but in open air, which is the holy grail, costs theoretically range from $94-$232. To help this promising new technology get off the ground (or rather, into the ground), the federal government offers a tax credit of about $35 for every metric ton of CO2 removed in industrial carbon capture and storage. It's a policy that has enjoyed strong bipartisan support for over a decade.

Plant and Cut (CNN)

15.3 Deforestation Footprint

(see: env)

Hoang: Mapping Deforestation Footprint](https://www.nature.com/articles/s41559-021-01417-z)

16

Ice Sheet

16.1 Greenland

Abstract Noel

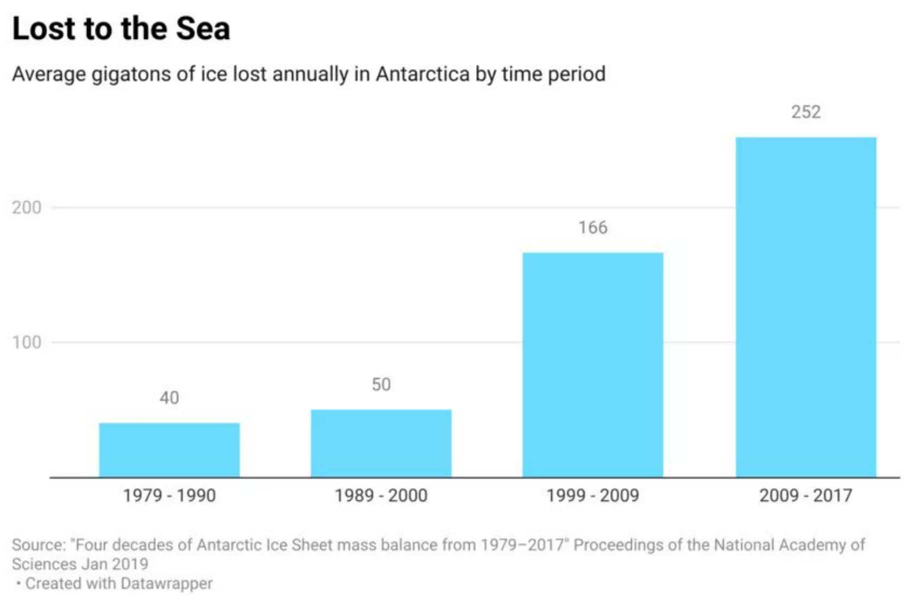
Under anticipated future warming, the Greenland ice sheet (GrIS) will pass a threshold when meltwater runoff exceeds the accumulation of snow, resulting in a negative surface mass balance (SMB < 0) and sustained mass loss.

Here we dynamically and statistically downscale the outputs of an Earth system model to 1 km resolution to infer that a Greenland near-surface atmospheric warming of 4.5 ± 0.3 °C—relative to pre-industrial—is required for GrIS SMB to become persistently negative.

Climate models from CMIP5 and CMIP6 translate this regional temperature change to a global warming threshold of 2.7 ± 0.2 °C. Under a high-end warming scenario, this threshold may be reached around 2055, while for a strong mitigation scenario it will likely not be passed. Depending on the emissions scenario taken, our method estimates a 6-13 cm sea level rise from GrIS SMB in the year 2100.

Noel (2021) Greenland Ice Sheet Loss (pdf)

16.2 Antarctica



16.2.1 Sea-level Rise from Antarctica

If it all melted, would raise global sea levels by 57 metres

DeConto Abstract

The Paris Agreement aims to limit global mean warming in the twenty-first century to less than 2 degrees Celsius above preindustrial levels, and to promote further efforts to limit warming to 1.5 degrees Celsius. The amount of greenhouse gas emissions in coming decades will be consequential for global mean sea level (GMSL) on century and longer timescales through a combination of ocean thermal expansion and loss of land ice. The Antarctic Ice Sheet (AIS) is Earth's largest land ice reservoir (equivalent to 57.9 metres of GMSL), and its ice loss is accelerating4. Extensive regions of the AIS are grounded below sea level and susceptible to dynamical instabilities5,6,7,8 that are capable of producing very rapid retreat. Yet the potential for the implementation of the Paris Agreement temperature targets to slow or stop the onset of these instabilities has not been directly tested with physics-based models. Here we use an observationally calibrated ice sheet–shelf model to show that with global warming limited to 2 degrees Celsius or less, Antarctic ice loss will continue at a pace similar to today's throughout the twenty-first century. However, scenarios more consistent with current policies (allowing 3 degrees Celsius of warming) give an abrupt jump in the pace of Antarctic ice loss after around 2060, contributing about 0.5 centimetres GMSL rise per year by 2100—an order of magnitude faster than today. More fossil-fuel-intensive scenarios result in even greater acceleration. Ice-sheet retreat initiated by the thinning and loss of buttressing ice shelves continues for centuries, regardless of bedrock and sea-level feedback mechanisms or geoengineered carbon dioxide reduction. These results demonstrate the possibility that rapid and unstoppable sea-level rise from Antarctica will be triggered if Paris Agreement targets are exceeded.

DeConto (2021) The Paris Climate Agreement and future sea-level rise from Antarctica (Nature Paywall)

Abrupt Jump in Ice Loss around 2060

The world faces a situation where there is an "abrupt jump" in the pace of Antarctic ice loss around 2060.

The oceans would have to cool back down before the ice sheet could heal, which would take a very long time. On a societal timescale it would essentially be a permanent change.

This tipping point for Antarctica could be triggered by a global temperature rise of 3C (5.4F) above the preindustrial era feasible by 2100 under governments' current policies.

These ice shelves won't be able to just grow back.

Antarctica is being winnowed away by a warming atmosphere as well as the heating oceans, with warming seawater entering crevasses and gnawing away at "pinning points" that hold enormous bodies of ice to submerged bedrock. A rapid acceleration of melting could cause a cascading effect where huge amounts of ice and water flow uninterrupted into the Southern Ocean. Once in motion, the impacts from such dramatic ice loss would unfurl over centuries.

Milman (Guardian)

17

Ocean

17.1 Sea Level Rise

In its most recent assessment, the Intergovernmental Panel on Climate Change said the sea level was unlikely to rise beyond 1.1 metre (3.6ft) by 2100.

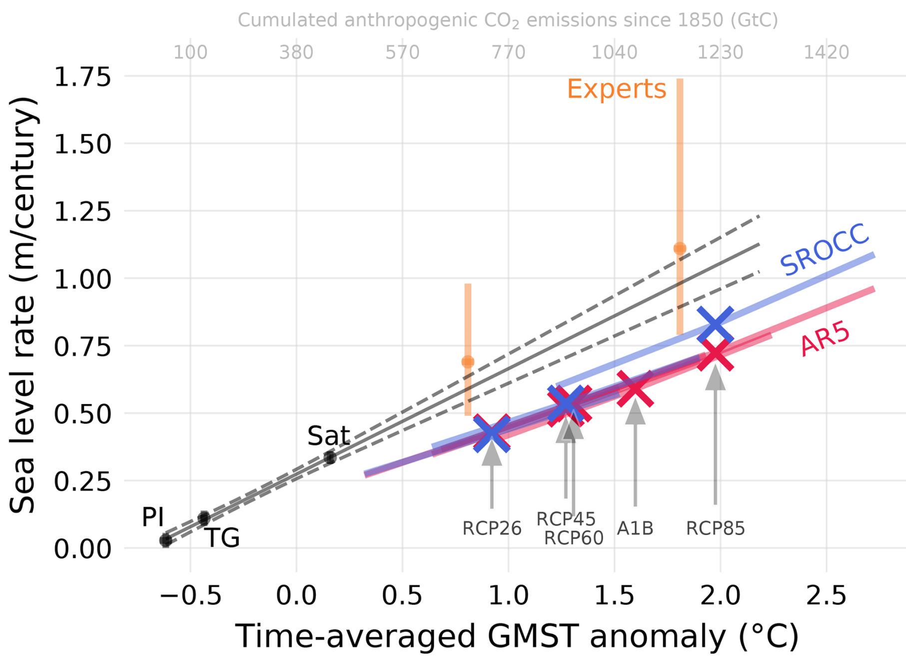
But climate researchers from the University of Copenhagen's Niels Bohr Institute believe levels could rise as much as 1.35 metres by 2100, under a worst-case warming scenario.

"The models used to base predictions of sea level rise on presently are not sensitive enough," he said. "To put it plainly, they don't hit the mark when we compare them to the rate of sea level rise we see when comparing future scenarios with observations going back in time."

Higher Sea Level Rise (Guardian)

17.1.1 TSLS Transient Sea Level Sensitivity

By analyzing the mean rate of change in sea level (not sea level itself), we identify a nearly linear rela- tionship with global mean surface temperature (and therefore accumulated carbon dioxide emissions) both in model projections and in observations on a century scale. This mo- tivates us to define the "transient sea level sensitivity" as the increase in the sea level rate associated with a given warm- ing in units of meters per century per kelvin. We find that future projections estimated on climate model responses fall below extrapolation based on recent observational records. This comparison suggests that the likely upper level of sea level projections in recent IPCC reports would be too low.



Sea level projections as assessed in AR5 and SROCC systematically fall below what would be expected from extrapolating observations to warmer conditions, as well as below the expert elicitation. Error bars show estimated likely ranges (17 %–83 %).

Grindsted (2021) Transient Sensitivity of Sea Level Rise (Ocean Science) (pdf)

17.2 AMOC - Gulf Stream

Weakest Gulf Stream in Millenium

The Atlantic Meridional Overturning Circulation (AMOC)—one of Earth's major ocean circulation systems—redistributes heat on our planet and has a major impact on climate. Here, we compare a variety of published proxy records to reconstruct the evolution of the AMOC since about ad 400. A fairly consistent picture of the AMOC emerges: after a long and relatively stable period, there was an initial weakening starting in the nineteenth century, followed by a second, more rapid, decline in the mid-twentieth century, leading to the weakest state of the AMOC occurring in recent decades.

Caesar (2021) AMOC Millenium Weakest (Nature Geoscience) [paywall!]

Rahmstorf - Twitter Thread

The Guardian

The Guardian (Commentary)

17.2.1 The Rise and Fall of AMOC

The AMO is simply an artifact of studies that misinterpret the time-varying pattern of human-caused climate change as a low-frequency oscillation

At times I feel like I created a monster when I gave a name to this putative climate oscillation in 2000. The concept of the AMO has since been misapplied and misrepresented to explain away just about every climate trend under the sun, often based on flawed statistical methods that don't properly distinguish a true climate oscillation from a time-varying trend: If you assume that all trends are a simple linear ramp, and call everything left-over an "oscillation", then the simple fact that global warming flattened out from the 1950s through the 1970s driven by the ramp-up in cooling sulphate aerosol pollution masquerades as an apparent "oscillation" on top of a simple linear trend. We've published a number of articles over the years (see e.g. here, here, here, here, here, and here) demonstrating that studies that use such an approach to define the AMO end up mis-attributing to a natural "oscillation" what is actually human-caused climate change. Such analyses have been used by some to dismiss, among other things, the impact climate change is having on increasingly active and destructive Atlantic hurricane seasons, attributing the increase in recent decades to a supposed upturn in the AMO.

RealClimate

17.2.2 Rethinking AMOC

Chafik

A weakened AMOC may have played a role in causing almost 600 years' worth of frigid winters in Europe and North America. This period, called the Little Ice Age, lasted roughly from 1300 until 1870 and came on the heels of the Medieval Warm Period (circa 950–1250), when temperatures in the Northern Hemisphere were unusually warm.

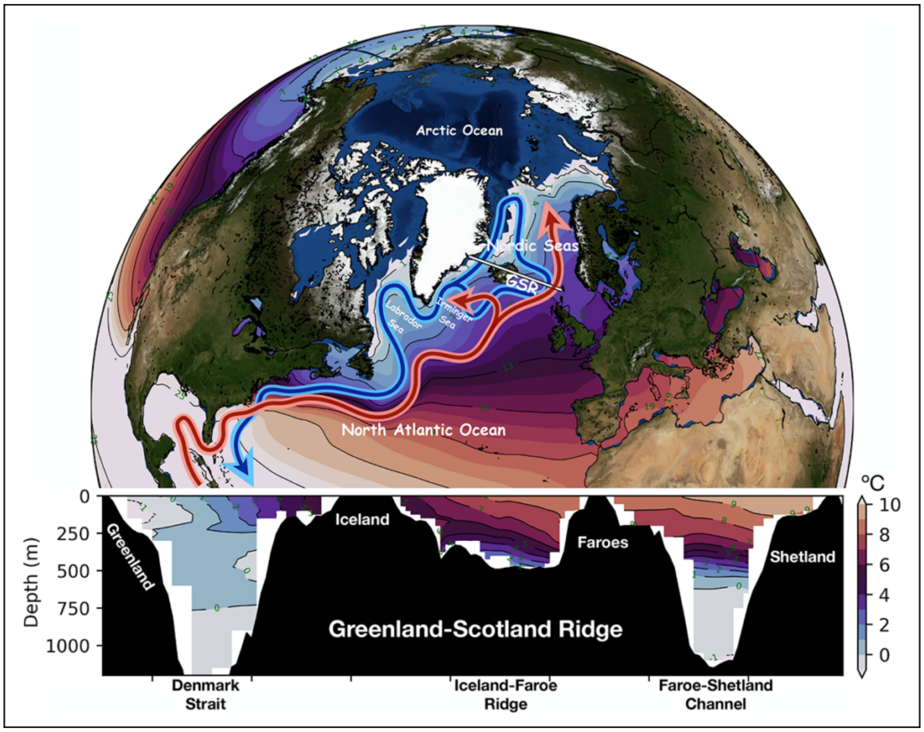


Figure: This simplified view (top) shows the surface flows (red arrows) and deep return flows (blue arrows) that make up the large-scale ocean circulation in the North Atlantic. Color bands on the ocean surface indicate average sea surface temperatures from 1900 to 2019 (data are from the Hadley Centre) and highlight the northward extent of warm waters to higher latitudes. The longitude-depth temperature distribution of the ocean (bottom; data are from the World Ocean Atlas 2018) across the Greenland-Scotland Ridge (GSR, white transect line in the top panel) is also shown. The exchange of waters across the GSR is driven by the rapid loss of heat to the atmosphere over the Nordic Seas. This heat loss causes the waters to sink and build a huge reservoir of cold, dense water that spills back into the deep North Atlantic across the GSR, completing the overturning process.

Nearly half of the AMOC's poleward flow of warm, salty waters enters the Nordic Seas—comprising the Greenland, Iceland, and Norwegian Seas. Here the water cools and pools north of the undersea Greenland-Scotland Ridge (GSR). A host of important questions remains about the dynamics of the ocean near the GSR and the effects of these dynamics on regulating climate.

The AMOC has two pathways of overturning circulation. One is open ocean convection in the Irminger and Labrador Seas that produces the upper layer of North Atlantic Deep Water (NADW). The second involves progressive cooling of warm, salty water from the Atlantic in the Nordic Seas. This cooling results in dense water spilling over the GSR back into the North Atlantic—mainly through two passages, the Denmark Strait between Greenland and Iceland and the Faroe Bank Channel south of the Faroes—and forming a lower layer of NADW.

Both regions depend upon heat loss to produce water of greater density, but it appears that huge heat losses from the Nordic Seas and the concomitant production and pooling of very dense water behind the GSR are fundamental to maintaining a mild climate in northern Europe. This heat loss produces a healthy supply of NADW that spills back into the global abyss and enables warm, salty water to feed the Nordic Seas.

Evidence of strong variability in Nordic Seas inflow on multidecadal timescales. The volume of and heat transported in this poleward flow, as measured at the GSR, are strongly coupled to the Atlantic multidecadal variability (AMV), which describes natural patterns of sea surface temperature variability in the North Atlantic that influence climate globally

The AMV affects Nordic Seas inflow because deep convection in the northeast Atlantic translates the surface temperature variations down into the upper layers of the ocean, and these variations shape the ocean's dynamic height field.

The inflow of warm water to the Nordic Seas has been quite stable over the past century since the start of modern oceanography.

Nordic Seas overturning circulation has been stable over the past 100 years. This stability is surprising given the extraordinary warming presently underway in the Nordic Seas and Arctic Ocean. The continued stability of this vital ocean circulation system is not guaranteed in the future. It is also unclear how future change may manifest or which early-warning indicators should be relied upon to forecast change.

The recent discovery of an unknown route by which cold water courses its way through the Norwegian Sea. We identified that this new route directs cold deep flows north of the Faroe Islands to the Norwegian slope before turning them south through the Faroe-Shetland Channel and into the deep North Atlantic.

Which route water takes north of the GSR and how much is funneled each way depend on the prevailing winds.

Under weak westerly wind conditions in the Nordic Seas, the densest water that feeds the Faroe Bank Channel comes primarily from north of Iceland. During strong westerly wind conditions, however, more water seems to originate from along the Jan Mayen Ridge, which is located farther north of Iceland and more in the middle of the Nordic Seas. This wind dependence is curious, considering the strong control that bathymetry can exert on the circulation.

Deep rapid flow, or deep jet, called the Faroe-Shetland Channel Jet. Remarkably, this jet flows south along the eastern slope of the channel rather than along the western side as has long been assumed. The deep jet is found to be the main current branch in terms of transport that delivers the densest water to the North Atlantic Ocean via the Faroe Bank Channel. This surprising finding countered past observations and thinking.

We do not yet have a firm grasp of the deep circulation of the Nordic Seas and how it varies over time.

All available observational evidence so far indicates that there is no long-term trend in the Nordic Seas meridional overturning circulation to date.

The degree to which fresh water from the Arctic and Greenland Sea can mix with and dilute warm, saline water from the Atlantic. Such dilution could suppress deep temperature- and density-driven convection, thus weakening or shutting down the overturning in the Nordic Seas and, by extension, the deepest component of the AMOC.

However, most scientists no longer think such a shutdown scenario is likely because observations to date indicate that Arctic and Greenland waters tend to remain trapped around and south of Greenland rather than mixing and diluting the Atlantic water flowing north in the Nordic Seas

Nonetheless, there is broad agreement that the climatic consequences of a potential shutdown of this vital ocean circulation are so enormous that they obligate us to improve our understanding of the Nordic Seas.

Chafik (2021) Rethinking Oceanic Overturning in Nordic Seas

18

Permafrost

Some text on Permafrost

19

Soil

Guardian

The storage potential of one of the Earth's biggest carbon sinks – soils – may have been overestimated, research shows. This could mean ecosystems on land soaking up less of humanity's emissions than expected, and more rapid global heating.

The study, based on over 100 experiments, found the opposite. When plant growth increases, soil carbon does not. The finding is significant because the amount of organic carbon stored in soils is about three times that in living plants and double that in the atmosphere. Soils can also store carbon for centuries, whereas plants and trees rot quickly after they die.

When rising CO2 increases plant growth, there is a decrease in soil carbon storage. If soils do absorb less in future, "the speed of global warming could be higher"

Soils, plants and trees are important for carbon levels, but ending the burning of fossil fuels is essential. To stop global warming, we need to stop emissions, because ecosystems only take up a fraction of all the CO2 emissions.

The researchers found that in grasslands, elevated CO2 led to 9% plant growth – less than forests – but soil carbon rose by 8%. Terrier said there has been a lot of discussion about tree planting as a way to tackle the climate crisis. "What I found very concerning in that debate is that people were suggesting planting trees in natural grasslands, savannah, and tundra," he said. "I think that would be a terrible mistake because, as our results imply, there is a very large potential to increase soil carbon storage in grasslands."

Given that the land absorbs 30% of the carbon emitted from fossil fuels and deforestation, understanding if that will change in the future matters. Change would be determined by the balance between rising CO2 boosting plant growth and the negative effects of climate change itself, including drought, heatwaves and fires. The evidence to date suggests the biggest change will be the negative effects of global heating on ecosystems

Guardian

Part IV

Policy

20

Adaptation

Climate Services may help build *resilience*

Climate Services

Norsk KlimaServiceSenter

20.1 Lagging mitigation, lagging adaptation

Given the current uncertainties around efforts to limit climate change, the world must plan for, finance and implement climate change adaption measures appropriate for the full range of global temperature increases or face serious costs, losses and damages.

Adaptation – reducing countries' and communities' vulnerability to climate change by increasing their ability to absorb impacts and remain resilient – is a key pillar of the Paris Agreement. The Agreement requires all of its signatories to plan and implement adaptation measures through national adaptation plans, studies, monitoring of climate change effects and investment in a green future.

The Gap Report finds that such action is lagging far behind where it should be. It finds that while nations have advanced in planning and implementation, huge gaps remain, particularly in finance for developing countries and bringing adaptation projects to the stage where they bring real reductions in climate risks.

The Green Climate Fund (GCF) has allocated 40 per cent of its total portfolio to adaptation and is increasingly crowding-in private sector investment. Another important development is the increasing momentum to ensure a sustainable financial system.

New tools such as sustainability investment criteria, climate-related disclosure principles and mainstreaming of climate-related risks into investment decisions can stimulate investments in climate resilience and direct finance away from investments that increase vulnerability.

Nature-based solutions (NbS), one of the most cost-effective ways in the adaptation portfolio, has a potential to make a big contribution to climate change adaptation, but there are few tangible plans and limited financing available for them. NbS are mainly used to address coastal hazards, intense precipitation, heat and drought.

UNEP Adaptation Report 2020

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Carbon Pricing

21.1 Policy Sequencing

Meckling

Many economists have long held that carbon pricing—either through a carbon tax or cap-and-trade—is the most cost-effective way to decarbonize energy systems, along with subsidies for basic research and development. Meanwhile, green innovation and industrial policies aimed at fostering low-carbon energy technologies have proliferated widely. Most of these predate direct carbon pricing. Low-carbon leaders such as California and the European Union (EU) have followed a distinct policy sequence that helps overcome some of the political challenges facing low-carbon policy by building economic interest groups in support of decarbonization and reducing the cost of technologies required for emissions reductions. However, while politically effective, this policy pathway faces significant challenges to environmental and cost effectiveness, including excess rent capture and lock-in. Here we discuss options for addressing these challenges under political constraints. As countries move toward deeper emissions cuts, combining and sequencing policies will prove critical to avoid environmental, economic, and political dead-ends in decarbonizing energy systems.

The EU offers a prime example of this policy sequence. The EU adopted rules on promoting renewable energies in 2001, after eight member states had already implemented renewable-energy sup-port schemes. This occurred in the context of the liberalization of electricity markets across Europe. The EU followed up with indus-trial policy for renewable fuels in the transport sector in 2003. In a second phase, the EU adopted carbon pricing in 2003, which entered into force in 2005. In a third phase, the EU's decarbonization efforts led to a ratcheting up of all measures in the 2020 Climate and Energy Package of 2009, the 2030 Climate and Energy Package of 2014, and the recent EU winter package of 2016. California followed a path similar to that of the EU11. China is on its way to replicate the policy path of climate leaders: in the mid-2000s, it adopted supply-side industrial policy to develop clean-energy industries, followed by feed-in tariffs that fostered domestic demand for renewable energy, leading to a domestic carbon pricing system in the energy sector to be implemented in 2017

Careful policy sequencing can help facilitate the progressive decarbonization of energy systems under political constraints, as California and the EU demonstrate. An excessive focus on the need for efficient pricing alone often ignores these constraints. A better integration of economic and political perspectives should help point the way forward on low-carbon policymaking

Wagner (Blog) Meckling (Nature)(web-pdf)

21.2 Limited Impact on Emissions

Green -Abstract

Carbon pricing has been hailed as an essential component of any sensible climate policy. Internalize the externalities, the logic goes, and polluters will change their behavior. The theory is elegant, but has carbon pricing worked in practice? Despite a voluminous literature on the topic, there are surprisingly few works that conduct an ex-post analysis, examining how carbon pricing has actually performed. This paper provides a meta-review of ex-post quantitative evaluations of carbon pricing policies around the world since 1990. Four findings stand out. First, though carbon pricing has dominated many political discussions of climate change, only 37 studies assess the actual effects of the policy on emissions reductions, and the vast majority of these are focused on Europe. Second, the majority of studies suggest that the aggregate reductions from carbon pricing on emissions are limited – generally between 0% and 2% per year. However, there is considerable variation across sectors. Third, in general, carbon taxes perform better than emissions trading schemes (ETSs). Finally, studies of the EU-ETS, the oldest emissions trading scheme, indicate limited average annual reductions – ranging from 0% to 1.5% per annum. For comparison, the IPCC states that emissions must fall by 45% below 2010 levels by 2030 in order to limit warming to 1.5 degrees Celsius – the goal set by the Paris Agreement (IPCC 2018). Overall, the evidence indicates that carbon pricing has a limited impact on emissions.

”Green -Memo*

Carbon taxes place a surcharge on fuel or energy use. In emissions trading schemes, the government sets a ceiling or cap on the total amount of allowed emissions. Allowances are distributed to those firms regulated by the scheme, either free of charge or by auction. Each firm then has the right to emit up to its share of allowances. They may also trade allowances with each other to meet their individual emission allocations. Those who emit more than their allowance can purchase more; those that emit less can sell their excess supply, or bank it for future use. an Carbon taxes and ETSs differ in a number of respects. First, carbon taxes provide certainty of cost: the price is set by the government. Yet there is no limit on emissions, provided that regulated entities are willing and able to pay the tax. By contrast, ETSs provide certainty of quantity: the cap, set by the government, constitutes the upper limit on emissions. The cost will vary, depending on the scarcity (or oversupply) of allowances, and other design features. In practice, the distinction between the two policies is sometimes blurred (Hepburn, 2006). For example, an ETS might have a floor price; this guaranteed price makes it resemble a tax.

First, the mismatch between the incremental effects of carbon pricing and the demand for rapid decarbonization cannot be understated. The IPCC states that emissions must fall by 45% below 2010 levels by 2030 in order to limit warming to 1.5 degrees Celsius – the goal set by the Paris Agreement (IPCC 2018). The Low Carbon Economy Index estimates that this translates to an annual emissions reduction of 11.3% by the "average" G20 nation (PwC 2019). Yet GHG emissions have risen an average of 1.5% per year in the last decade (UN Environment 2019, p. iv). It is important to understand the extent to which one of the most widely-used climate policies contributes to this goal.

Second, there is little evidence to suggest that carbon pricing promotes decarbonization The most common outcome is fuel-switching and efficiency improvements. Unlike policies which create pathways to decarbonization – such as binding renewable portfolio standards, feed in tariffs or investment in R&D – carbon pricing addresses emissions (flow), rather than overall concentrations of greenhouse gases (stock).

The real work of emission control is done through regulatory instruments. Within the EU, where nations are also part of the EU-ETS, nations without a carbon tax reduced emissions more quickly than those with a carbon tax.

It is astonishing how little hard evidence there is on the actual performance of carbon pricing policies using ex-post data. Tthe overall effect on reductions for both types of policy is quite small, generally between 0-2% per annum. Norway, Sweden and Denmark were early adopters, implementing some of the first carbon taxes in 1991-92. EU-ETS was the first compulsory emissions trading scheme, beginning in 2005.

The single study of California cap and trade scheme estimates that between 24%-43% of emissions from electricity generation were shifted out of state to avoid carbon pricing regulations.

The drivers of these modest reductions are incremental solutions: fuel switching, enhanced efficiency, and reduced consumption of fuels. These actions, though useful on the margins, fall well short of the societal transformations identified needed.

A common rejoinder is that carbon prices simply aren't high enough to generate substantial emissions reductions. Indeed, low prices are pervasive; the vast majority of carbon prices are well below even the most conservative estimates of the “social cost of carbon” (SCC).

Given the prevalence of low prices, it is particularly important to consider the few jurisdictions with carbon prices at or near the SCC. Sweden has the highest carbon price in the world. Studies range in their reduction estimates from 0%-17% per year, with the upward bound being an outlier among all 37 studies. In 2019, Finnish taxes on transport fuels were at $68 per ton, and $58 per ton for all other fossil fuels. Emissions reductions there are estimated to be between 0%-1.7% The other two jurisdictions with high carbon taxes are Switzerland ($99 per ton in 2019) and Lichtenstein ($99 per ton in 2019 , No estimates of their effects on emissions).

It may be the case that pricing will work better after a certain threshold is surpassed. Indeed, Aydin and Esen find that energy taxes, including CO2 taxes, only reduce emissions after surpassing 2.2% of GDP (2018). Yet after nearly four decades of experience with carbon pricing, the empirical evidence to date suggests that low prices are a feature of this policy, rather than a bug. More worrisome is the fact that even those nations with high prices have relatively modest reductions.

A problem for carbon pricing concerns leakage, which occurs when economic activity subject to carbon pricing shifts to a jurisdiction without similar regulations. This problem is pervasive in environmental regulation, driven by variation in policy stringency. To the extent that leakage occurs, but is excluded from the studies examined here, emissions reductions may be overestimated.

Offsets can have two possible impacts on overall reductions. First, to the extent that offsets are not additional, their use will decrease the actual reductions achieved through a carbon pricing policy. To date, offsets have been an important component of most ETSs.

Green(2021) Carbon Pricing Ex-Post (pdf)

21.3 Carbon Price Norway

Norway has a carbon price covering ~80% of emissions, but it varies substantially by sector. The highest price is ~80€/tCO (domestic aviation) & agriculture is not taxed.

The average is ~60€/tCO , but Norwegian emissions are dropping very slowly.

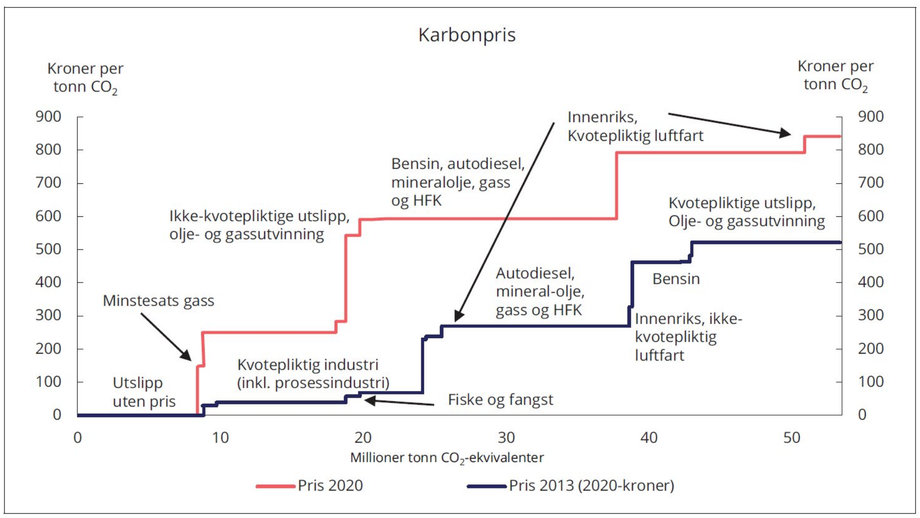

Figure 21.1: St.meld. 14 (2020-2021)

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Carbon Offsets

> There is no clear standard of what constitutes a carbon offset, and there is no global organization that defines offsets, sets criteria for them or verifies their validity.

Carbon offset schemes allow individuals and companies to invest in environmental projects around the world in order to balance out their own carbon footprints. The projects are usually based in developing countries and most commonly are designed to reduce future emissions. This might involve rolling out clean energy technologies or purchasing and ripping up carbon credits from an emissions trading scheme. Other schemes work by soaking up CO2 directly from the air through the planting of trees.

- Selling Indulgencies* George Monbiot famously compared carbon offsets with the ancient Catholic church's practice of selling indulgences: absolution from sins and reduced time in purgatory in return for financial donations to the church. Just as indulgences allowed the rich to feel better about sinful behaviour without actually changing their ways, carbon offsets allow us to buy complacency, political apathy and self-satisfaction.

Additionality the key issue for anyone who does want to offset is whether the scheme you're funding actually achieves the carbon savings promised. This boils down not just to the effectiveness of the project at soaking up CO2 or avoiding future emissions. Effectiveness is important but not enough. You also need to be sure that the carbon savings are additional to any savings which might have happened anyway. The problem is that it's almost impossible to prove additionality with absolute certainly, as no one can be sure what will happen in the future, or what would have happened if the project had never existed.

Partly because of the difficulty of ensuring additionality, many offset providers guarantee their emissions savings. This way, if the emissions savings don't come through or they turn out to be "non-additional", the provider promises to make up the loss via another project.

As the offset market grows, some offset companies have enough capital to invest in projects speculatively: they fund an offset project and then sell the carbon savings once the cuts have actually been made. This avoids the difficulty of predicting the future – and also avoids the claim that a carbon cut made some years in the future is worth less than a cut made now.

These kinds of guarantees and policies provide some reassurances, but do they mean anything in the real world? Without actually visiting the offset projects ourselves, how can individuals be sure that the projects are functioning as they should?

Even if offset projects do work as advertised, some environmentalists argue that they're still a bad idea. If we're to tackle climate change, they argue, the projects being rolled out by offset companies should be happening anyway, funded by governments around the world, while companies and individuals reduce their carbon footprints directly. Only in this way – by doing everything possible to make reductions everywhere, rather than polluting in one place and offsetting in another – does the world have a good chance of avoiding runaway climate change, such critics claim.

Market Standards To try and answer these questions, the voluntary offset market has developed various standards, which are a bit like the certification systems used for fairly traded or organic food. These include the Voluntary Gold Standard (VGS) and the Voluntary Carbon Standard (VCS). Offsets with these standards offer extra credibility, but that still doesn't make them watertight. Heather Rogers, author of Green Gone Wrong, visited a number of offset schemes in India and found all kinds of irregularities.

Offset Price Many people are confused by the low prices of carbon offsets. If it's so bad for the environment to fly, can a few pounds really be enough to counteract the impact? The answer is that, at present, there are all kinds of ways to reduce emissions very inexpensively. After all, a single low-energy lightbulb, available for just £1 or so, can over the space of six years save 250kg of CO_2 – equivalent to a short flight. That's not to say that offsetting is necessarily valid, or that plugging in a low-energy lightbulb makes up for flying. The point is simply that the world is full of inexpensive ways to reduce emissions. In theory, if enough people started offsetting, or if governments started acting seriously to tackle global warming, then the price of offsets would gradually rise, as the low-hanging fruit of emissions savings – the easiest and cheapest "quick wins" – would get used up.

Another frequent point of confusion about the cost of offsetting is that different offset companies quote different prices for offsetting the same activity. There are two reasons for this. First, there are various ways of estimating the precise impact on climate change of certain types of activity – including flying, which affects global temperature in various different ways. Second, different types of offset project will inevitably have different costs – especially given that projects may be chosen not just for the $CO2$ impacts but for their broader social benefits.

Duncan Clark (Guardian 2011): Complete Guide to Carbon Offsetting

Offsetting carbon reductions do nothing to eliminate emissions, and they delay tough choices

While net-zero goals are based on climate science, they allow governments and corporations responsible for emissions to delay tough decisions, rely on new and unproven technology, have no clear standards to account for the amount of carbon that goes into and comes out of the atmosphere, lack an international governing body to apply any such standards, and do not address the root cause of climate change by lowering fossil fuel use directly.

"Net-zero by 2050 is a meaningless target," DiPerna said. "If you look at the arc of decision-making, if you look at the arc of an executive's career, if you look at the arc of a presidential administration, you got four, three, two, five years to execute your power," she said. "You can promise anything for three decades, but it's what can you do within the arc of your control that's important".

It's a relatively expensive way to reduce emissions. Reducing the emissions before they go into the atmosphere tends to be much cheaper than removing them afterward.

Hulac (2021) Off-put by Offsets

22.1 Market Upscaling

Carney presented plans at the virtual Davos meeting of global business and political leaders on Wednesday evening for vast increases in the number of carbon offsets sold, aiming to expand the market from about $300m at present to between $50bn and $100bn a year.

He told the conference that he "categorically rejected" criticism that offsets were greenwash. Companies buying offsets in the market would be subject to scrutiny, and must have clear plans to reach net zero, "not something written on the back of a napkin", he said, but would need offsets to fulfil their plans.

"This is bringing those companies into a formal system," he said. "This is about maximising the use of a very limited [global] carbon budget. This is complementary [to companies taking action to reduce their own emissions] and is one piece of the puzzle. We do need this market."

The leaders of two UK environmental charities have written to Mark Carney, the UN climate envoy and former governor of the Bank of England, to raise concerns over the blueprint for carbon offsetting that could result in billions of new carbon credits being sold around the world.

Campaigners say system risks becoming greenwashing exercise unless loopholes closed.

The markets are used as a cover by companies that wish to give the appearance of working towards net zero emissions but prefer buying cheap credits to the more difficult task of cutting their emissio

This initiative risks setting a terrible example ahead of the critical carbon market negotiations at the global climate summit in Glasgow later this year. [It] seems to have ignored past failures of offsetting schemes to guarantee emission cuts. At the same time, it assumes that the natural world has unlimited potential to absorb climate-wrecking emissions. It fails to acknowledge that the most important thing companies must do is to reduce their own emissions and use of fossil fuels.

Carney's scheme will serve as a giant get-out-of-jail-free card for polluting companies.

There is a danger that it becomes a large international greenwashing exercise, creating a market with low standards but high PR value,

Guardian on Carney Offsets

> If you scale a bad thing, it doesn't matter how big you make it, it's still bad.

As Mark Carney presented the world's top political and business leaders with a blueprint to scale up the voluntary carbon market on Wednesday, campaigners warned key criteria to improve environmental integrity were missing.

With carbon neutrality pledges becoming the benchmark for climate ambition, businesses around the world are looking to offset the emissions they cannot cut and for cheaper ways to meet their climate goals.

Its report identified ways to bring coherence to what is currently a fragmented market. But it said little on how to ensure projects financed through the market deliver genuinely additional emissions reductions.

An open letter to Carney signed by 47 researchers, academics and campaigners ahead of the launch accused the initiative of trying to "minimise the cost of compliance for private corporations" at the cost of environmental integrity.

An independent process driven by civil society should define what constitute a quality offset to avoid the private sector self-regulating.

Sequestrating carbon in ecosystems should not replace real emissions cuts. We need to sequester past emissions that are already in the atmosphere whereas offsetting by definition is about future emissions. The whole point of an offset is that an entity keeps emitting. There is a striking lack of binding and credible measures to actually prioritise emissions reductions.

The biodiversity co-benefits that result from the voluntary carbon market are "a strong assumption" with no evidence.

It's important not to forget the huge flows of finance currently facilitating the drivers of biodiversity loss - warning against the market being perceived as an adequate substitute to conservation.

ClimateChangeNews

Memo TSVCM Report

Chaired by Bill Winters, group chief executive of Standard Chartered, and sponsored by the Institute of International Finance (IIF), the taskforce includes some of the world's most polluting companies: airline easyJet, plane manufacturer Boeing, oil giants BP, Shell and Total, and steel producer Tata Steel. No green groups are represented among its members.

The need for climate action, and tools to mobilize finance for the low-carbon and resilient transition, grows more urgent by the day. To achieve the Paris goals to limit global warming to 1.5 degrees Celsius, the global community needs to reach net-zero emissions by no later than 2050. This will require a whole-economy transition—every company, every bank, every insurer and investor will have to adjust their business models, develop credible plans for the transition, and implement them.

Many companies, especially in hard-to- abate sectors, will need to offset emissions as they achieve their decarbonization goals, creating a surge in demand for credible offsets.

To facilitate this global decarbonization there is a need for a large, transparent, verifiable and robust voluntary carbon market, one that promotes genuine action of high environmental integrity.

Along with the carbon avoided, reduced, or removed, the scaling up of markets has the further potential to help support financial flows to the Global South, as activities and projects in these countries can provide a cost- effective source of these carbon-emission reductions. Voluntary carbon markets can also play a critical role in scaling down cost curves for emerging climate technologies, bringing these technologies to market earlier, and allowing them to be used in direct decarbonization efforts.

The Taskforce has found six key areas where efforts are required to achieve a large, transparent, verifiable, and robust voluntary carbon market; these themes are establishing core carbon principles, core carbon reference contracts, infrastructure, offset legitimacy, market integrity, and demand signaling.

!! Direct emissions reductions by corporates must be the priority, with appropriate offsetting playing an important complementary role to accelerate climate mitigation action.

Taskforce on Scaling Voluntary Carbon Markets (pdf)

23

CSS - Carbon Capture and Storage

Tyndall Report:

CCS, as the technology is known, is designed to strip out carbon dioxide from the exhaust gases of industrial processes. These include gas- and coal-fired electricity generating plants, steel-making, and industries including the conversion of natural gas to hydrogen, so that the gas can then be re-classified as a clean fuel.

The CO2 that is removed is converted into a liquid and pumped underground into geological formations that can be sealed for generations to prevent the carbon escaping back into the atmosphere.

It is a complex and expensive process, and many of the schemes proposed in the 1990s have been abandoned as too expensive or too technically difficult.

Currently (2020) there are only 26 CCS plants operating globally, capturing about 0.1% of the annual global emissions from fossil fuels.

Ironically, 81% of the carbon captured to date has been used to extract more oil from existing wells by pumping the captured carbon into the ground to force more oil out. This means that captured carbon is being used to extract oil that would otherwise have had to be left in the ground.

CCS features prominently in many energy and climate change scenarios, and in strategies for meeting climate change mitigation targets.

It is the cumulative emissions from each year between now and 2030 that will determine whether we are to achieve the Paris 1.5°C goal. With carbon budgets increasingly constrained we cannot expect CSS to make a meaningful contribution to 2030 climate targets.

23.0.1 CSS will not work as planned and is a dangerous distraction

Instead of financing a technology they can neither develop in time nor make to work as claimed, governments should concentrate on scaling up proven technologies like renewable energies and energy efficiency.

The technology has not lived up to expectations. Instead of capturing up to 95% of the carbon from any industrial process, rates have been as low as 65% when they begin and have only gradually improved.

CCS won't work (ClimateNewsNetwork)

Global operational CCS capacity is currently 39MtCO2 per year, this is about 0.1% of annual global emissions from fossil fuels.

There are just 26 operational CCS plants in the world, with 81% of carbon captured to date used to extract more oil via the process of Enhanced Oil Recovery [EOR], and at this stage CCS planned deployment remains dominated by EOR. Financing of these CCS projects has relied on the increased revenue from EOR,

CCS is not capable of operating with zero emissions. Many projections assume a capture rate for CCS of 95%, however, capture rates at that level are unproven in practice.

Current capacity in the energy sector is just 2.4 MtCO 2 a year. This compares to the International Energy Agency's (IEA) estimate of 310 MtCO 2 a year in the energy sector by 2030, an increase of 129 times from today.

Reliance on CCS is not a solution to the climate emergency.

Tyndall Centre Report (pdf Summary) (pdf Report)

But the industry do not agree:

When CCS was first touted, it was seen as a way of cleaning up electricity generated by fossil fuels, in particular those burning coal. But now it is clear it can play a key role in cleaning up other industries.

The opposition to CCS technology from some campaigners seems driven by a hatred of fossil fuel companies that is preventing a level-headed understanding of how we can stop climate change.

Industry Response to Tyndall Report

23.1 CSS and DAC cause more Damage than Good

Spending money on carbon capture and storage or use (CCS/U) and synthetic direct air capture and storage and use (SDACCS/U) increases carbon dioxide equivalent (CO2e) emissions, air pollution, and costs relative to spending the same money on clean, renewable electricity replacing fossil or biofuel combustion.

The low net capture rates are due to uncaptured combustion emissions from natural gas used to power the equipment, uncaptured upstream emissions, and, in the case of CCU, uncaptured coal combustion emissions. Moreover, the CCU and SDACCU plants both increase air pollution and total social costs relative to no capture. Using wind to power the equipment reduces CO2e relative to using natural gas but still allows air pollution emissions to continue and increases the total social cost relative to no carbon capture. Conversely, using wind to displace coal without capturing carbon reduces CO2e, air pollution, and total social cost substantially. Further, using wind to displace coal reduces more CO2e than using the same wind to power the capture equipment. As such, spending money on wind powering carbon capture always increases CO2e compared with spending on the same wind replacing fossil fuels or biofuels. In sum, CCU and SDACCU increase or hold constant air pollution health damage and reduce little carbon before even considering sequestration or use leakages of carbon back to the air. Spending on capture rather than wind replacing either fossil fuels or bioenergy always increases CO2e, air pollution, and total social cost substantially. No improvement in CCU or SDACCU equipment can change this conclusion while fossil power plant emissions exist, since carbon capture always incurs an equipment cost never incurred by wind, and carbon capture never reduces, instead mostly increases, air pollution and fuel mining, which wind eliminates. Once fossil power plant emissions end, CCU (for industry) and SDACCU social costs need to be evaluated against the social costs of natural reforestation and reducing nonenergy halogen, nitrous oxide, methane, and biomass burning emissions.

Jakobsen (2019)

23.2 BECCS

BECCS, rapidly emerged as the new saviour technology. By burning “replaceable” biomass such as wood, crops, and agricultural waste instead of coal in power stations, and then capturing the carbon dioxide from the power station chimney and storing it underground, BECCS could produce electricity at the same time as removing carbon dioxide from the atmosphere. That’s because as biomass such as trees grow, they suck in carbon dioxide from the atmosphere. By planting trees and other bioenergy crops and storing carbon dioxide released when they are burnt, more carbon could be removed from the atmosphere.

BECCS, just like all the previous solutions, was too good to be true.

Across the scenarios produced by the Intergovernmental Panel on Climate Change (IPCC) with a 66% or better chance of limiting temperature increase to 1.5°C, BECCS would need to remove 12 billion tonnes of carbon dioxide each year. BECCS at this scale would require massive planting schemes for trees and bioenergy crops.

The Earth certainly needs more trees. Humanity has cut down some three trillion since we first started farming some 13,000 years ago. But rather than allow ecosystems to recover from human impacts and forests to regrow, BECCS generally refers to dedicated industrial-scale plantations regularly harvested for bioenergy rather than carbon stored away in forest trunks, roots and soils.

Currently, the two most efficient biofuels are sugarcane for bioethanol and palm oil for biodiesel – both grown in the tropics. Endless rows of such fast growing monoculture trees or other bioenergy crops harvested at frequent intervals devastate biodiversity.

It has been estimated that BECCS would demand between 0.4 and 1.2 billion hectares of land. That's 25% to 80% of all the land currently under cultivation. How will that be achieved at the same time as feeding 8-10 billion people around the middle of the century or without destroying native vegetation and biodiversity?

Growing billions of trees would consume vast amounts of water – in some places where people are already thirsty. Increasing forest cover in higher latitudes can have an overall warming effect because replacing grassland or fields with forests means the land surface becomes darker. This darker land absorbs more energy from the Sun and so temperatures rise. Focusing on developing vast plantations in poorer tropical nations comes with real risks of people being driven off their lands.

And it is often forgotten that trees and the land in general already soak up and store away vast amounts of carbon through what is called the natural terrestrial carbon sink. Interfering with it could both disrupt the sink and lead to double accounting.

Dyke

Youtube: BECCS Explainer

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SAI Stratospheric Aerosol Injection

Pain-killer - no solution

I often compare SAI to painkillers, opioids, which treat symptoms but don't solve underlying problems – and their use can delay much needed action on a solution. This corresponds to my largest concern about the risks of SAI research: the moral hazard. This is the idea that humanity will relax its already feeble efforts on mitigation because of the hope of a 'painkiller'. Also similar to painkillers, there is the danger of addiction to SAI, in which continued use requires higher and higher doses as no action on emissions is taken. Just like sudden withdrawal of opioids can be disastrous, so could sudden cessation of SAI – creating a 'termination shock', as the full force of underlying climate change came to bear over the 2-3 year lifetime of stratospheric aerosol.

SAI has not been researched nearly enough to even consider anything close to deployment and research is slow. There are essentially no existing governance processes specific to small-scale outdoor experiments on SAI.

As the principal investigator of the Stratospheric Controlled Perturbation Experiment (SCoPEx) – a proposed experiment that would be the first to inject particles into the stratosphere, but which would begin outdoor testing without particle injection – I share concerns about SAI research.

What is known, and not known, about stratospheric aerosol injection (SAI)?

SAI is the idea of introducing particles into the stratosphere, which would scatter sunlight to space and cool the Earth's surface. Our prediction is that they would stay there for 2-3 years before returning to ground.

Current computer-based models make injecting particles into the atmosphere look good – I fear too good. Some simulations have suggested that combining SAI with emissions cuts could reduce many global climate impacts, such as extreme temperatures, droughts, and tropical storm intensity.

SAI could perhaps be used to slow down the rate of climate change (a rapid rate of change could make it impossible for humanity and ecosystems to adapt), while the slower acting – but more important – emission reductions, and very likely carbon dioxide removal, are taking place.

Yet, there are also tremendous uncertainties and potential risks around SAI. For example, sulfate aerosol, a commonly modelled aerosol due to its natural stratospheric occurrence, destroys the stratospheric ozone layer and heats up the stratosphere, changing atmospheric circulation.

We do not understand stratosphere circulation well enough, and so we cannot know the implications of messing with it without research.

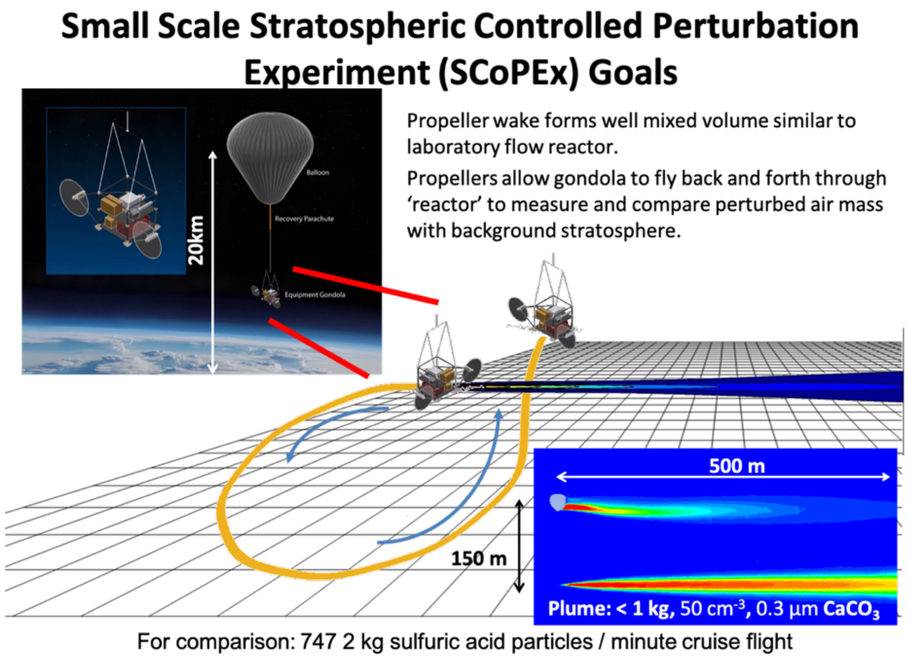
SCoPex

If we receive permission, our Stratospheric Controlled Perturbation Experiment (SCoPEx) would launch a large research balloon from Esrange Space Center in Kiruna, Sweden. It would rise to approximately 20 kilometers, where we would test its navigation, communication, and instrumentation under extreme stratospheric conditions.

Later, if approved by the independent Advisory Committee, follow-up experiments would release about 2 kilograms of calcium carbonate particles over an area roughly 1 kilometer long and 100 meters wide. (SCoPEx proposes to study calcium carbonate as early indoor research suggests it may cause lower ozone destruction and significantly less stratospheric heating than sulfate.)

The balloon would then turn around to measure whether the particle sizes, locally reflected sunlight, and chemical impact on ozone match our models.

These results and meteorological measurements would then be integrated into global climate models, improving their ability to predict the effectiveness and risks of stratospheric geoengineering.


Small Scale Stratospheric Controlled Perturbation Experiment (SCoPEx) Goals
Propeller wake forms well mixed volume similar to laboratory flow reactor.
Propellers allow gondola to fly back and forth through 'reactor' to measure and compare perturbed air mass with background stratosphere.
Balloon
Recovery Parachute
Equipment Gondola
20km
500 m
150 m
Plume: < 1 kg, 50 cm^{-3}, 0.3 µm $CaCO_3$
For comparison: 747 2 kg sulfuric acid particles / minute cruise flight

Keutsch

25

Cap and Trade

26

Fee and dividend

We agreed on the merits of fee-and-dividend, because it is more efficacious than cap-and-trade and easier to make near-global. Also, it would be popular because it helps address a growing wealth disparity that exists in many nations. We even talked about writing a joint paper on fee-and-dividend to help decisionmakers understand its merits.

[James Hansen: Sophie's Planet Ch.47]

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SAI Stratospheric Aerosol Injection

As the mirage of each magical technical solution disappears, another equally unworkable alternative pops up to take its place. The next is already on the horizon – and it's even more ghastly. Once we realise net zero will not happen in time or even at all, geoengineering – the deliberate and large scale intervention in the Earth's climate system – will probably be invoked as the solution to limit temperature increases.

Dyke

Pain-killer - no solution

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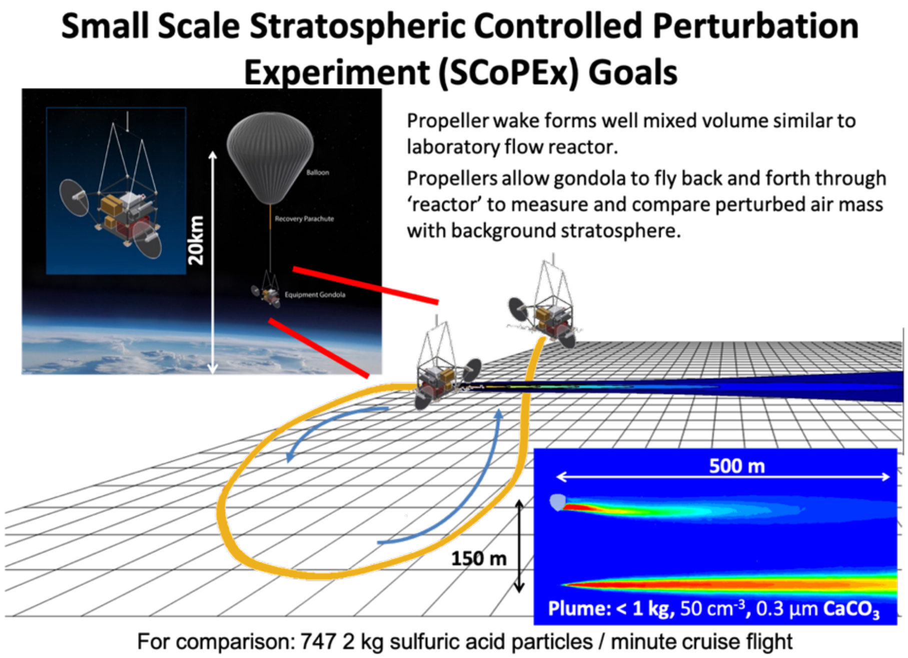
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For comparison: 747 2 kg sulfuric acid particles / minute cruise flight

Keutsch

28

SCC - Social Costs of Carbon

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The most important number you have never heard of
    Greenstone Testimony
    Greenstone Estimating SCC
    Greenstone Updating SCC
Current prices far below SCC
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SCC: The straw that stirs the drink

The dollar value that future populations and governments around the world would be willing to pay to avoid experiencing climate change.

> If you could see dimly into the future—which you can!—and calculate in dollars the benefits of actions preventing utter destruction and chaos, what would you call this price? You might call it "the alpha price," the price of having a safe future.

The social cost of carbon alpha price is a regulatory tool (yawn) that addresses an important disparity, which is the difference between market prices for fossil fuels and the value of the damage they inflict on the world. By calculating the alpha price… and using it as a "benefit" in cost-benefit analyses, government can make sure that they truly understand the costs and benefits of new policies. They ensure that demonstrably incorrect market prices for fossil fuels are not obscuring the real benefits of action. t's a complicated thing, calculating the alpha price, which brings us to the question of how bureaucratic inertia and professional conventions perpetuate thinking we don't need anymore. Hold your breath, we're free-diving now deep into the bowels of regulatory bureaucracy. Which brings us to the punchline: Is there a better way to bring about a net-zero, safe future without even relying on an alpha price? Is applying a cost-benefit analysis to climate change itself a part of the bureaucratic and professional conventions that are holding back climate progress? Maybe! That's why(I think!) **?** et al have given us Near-Term to Net-Zero and (I think) why **?** et al have given us declining CO2 price paths. (Eric Roston, twitter thread).

28.1 The most important number you have never heard of

28.1.1 Greenstone Testimony

- The social cost of carbon (SCC) is the cost to society of polluting an additional ton of CO2. The SCC enables regulators to account for potential benefits to society through lower carbon emissions and also points towards the optimal price on carbon required to address excess greenhouse gas emissions. The US government SCC was approximately $50 per ton of CO2 as of 2016, using a discount rate of 3%.

Since its inception, the SCC has been used in roughly 150 federal regulations that cover energy efficiency, forest conservation, fuel-economy standards, and emissions performance standards. Indeed, in many cases the SCC was instrumental in passing these regulations, offering relevant agencies a reliable, transparent tool to calculate the full benefits the new rules would offer to society. All told, a recent paper calculated, federal regulations written to include the SCC in the US have more than $1 trillion of benefits.

When one considers the possibility of larger-than- expected temperature changes for a given change in emissions, sea level rise in short time periods, physical "tipping points", and human responses like mass migration, then the case for a low discount rate appears strong.

The broader point is that global interest rates have declined since the SCC was set and, even setting aside the risk characteristics of payoffs from climate mitigation investments, there is a solid case that the discount rates currently used to calculate the SCC may be too high.

When the US accounts for the full global benefits of reducing our emissions, this incentivizes reciprocal climate policies in other countries, like China and India, that reduces their emissions which benefits the US.

The use of a SCC that only considers domestic benefits is very likely to deprive the United States of emissions reductions in the United States that would protect us from more virulent climate change

Climate Impact Lab (CIL) aims to produce the world's first empirically derived estimate of the social cost of carbon

CIL's core findings to date have been in the mortality sector. Climate change has a demonstrable impact on mortality rates, as extreme temperatures, both hot and cold, affect health outcomes such as heat stroke and cardiovascular disease. Using data from forty countries and statistical methods to account for the benefits and costs of adaptation, we estimate the full mortality risk due to climate change to be an additional 85 deaths per 100,000 in 2100. This increase in the global mortality rate is more than the mortality rate associated with all infectious diseases in 2018.

The elevated mortality risk equates to a monetary cost of $23.6 per metric ton of carbon emitted today when using the same assumptions that underlie the Obama SCC calculation. In other words, we estimate the partial social cost of carbon, accounting for costs to human mortality alone, to be at least $23.6 per ton.

The Obama administration's estimate of the SCC assumed that society is risk neutral, that is, we are not willing to pay a premium to avoid uncertainty. If the more realistic assumption that society is risk averse were introduced, then the estimated SCC would be higher, likely substantially so, than the $50 per metric ton of CO 2 discussed in the previous section. Similarly, there is a good case for scaling the damages from the CIL's research upwards to reflect the risk aversion that characterizes individuals' choices in their own lives.

While Accra, Ghana will see an increase in the full mortality risk of 160 per 100,000 due to climate change in 2100, Oslo, Norway will experience a decline in the full mortality risk of 230 per 100,000 due to warmer winters. Climate change will leave some regions as winners and others as losers both around the globe and within the United States.

Climate impacts vary considerably across locations. While northern latitudes will experience net savings due to reduced heating needs, increased cooling demand will lead to large increases in many areas of the tropics.

Within the United States, I find that rural areas will be hard-hit. My co-author and I estimate that with a high emissions scenario 18 , rising temperatures will reduce 2050 corn acreage by 94% and soybean acreage by 98% when compared to levels in 2002. The lost corn and soybean production will not be replaced by increased production of any crop currently grown in the US: as returns to agriculture decline in connection with climate change, farmers will seek to shift land use toward different crops and non-agricultural options. It will effectively bring an end to the more than 150-year tradition of farming as we know it in the US corn-belt that encompasses great swatches of Iowa, Nebraska, and Illinois.

The uneven distribution of climate damages means that the very mitigation of climate change is a pursuit of environmental justice.

Michael Greenstone testimony (pdf)

28.1.2 Greenstone Estimating SCC (MIT CEEPR WP 2011-006):*

For 2010, the central value of the SCC is $21 per ton of CO 2 emissions and sensitivity analyses are to be conducted at $5, $35, and $65 (2007$). This paper summarizes the methodology and process used to develop the SCC values.

The 2009-2010 interagency process that developed these SCC values was the first U.S. federal government effort to promote consistency in the way that agencies calculate the social benefits of reducing CO 2 emissions in regulatory impact analyses. 4 Prior to 2008, reductions in CO 2 emissions were not valued in federal benefit–cost analyses.

IAMs

Analysts face a number of significant challenges when attempting to quantify the economic impacts of CO 2 emissions. In particular, analysts must make assumptions about four main steps of the estimation process: (1) the future emissions of greenhouse gases; (2) the effects of past and future emissions on the climate system; (3) the impact of changes in climate on the physical and biological environment; and, (4) the translation of these environmental impacts into economic damages. Integrated assessment models (IAMs) have been developed to combine these steps into a single modeling framework; the word "integrated" refers to the fact that they integrate knowledge from science and economics. However, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems.

The IAMs translate emissions into changes in atmospheric greenhouse gas concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages.

The emissions projections used in the models are based on specified socio- economic (GDP and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

(DICE-PAGE-FUND differences discussed in paper omitted here)

Overall, the power of the IAMs is that they offer guidance to the incredibly complex question of what an extra ton of greenhouse damages will do to human wellbeing. This is no small task and this is what makes them so appealing. However, the results are highly dependent on a series of assumptions that cannot easily be verified.

On Discount Rates:

Historically Observed Interest Rates

Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and (pure rate of time preference). 18 These are then combined with g (growth rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $+ \cdot g$.

Most papers in the climate change literature adopt values for in the range of 0.5 to 3, although not all authors articulate whether their choice is based on prescriptive or descriptive reasoning. 19 Dasgupta (2008) argues that should be greater than 1 and may be as high as 3, since equal to 1 suggests savings rates that do not conform to observed behavior. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $= 0$ would unjustly discriminate against future generations (e.g., Arrow et al. 1996, Stern et al. 2006). However, even in an inter-generational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a of zero avoids giving preferential treatment to one generation over another. The choice of has also been posed as an ethical choice linked to the value of an additional dollar in poorer countries compared to wealthier ones. Stern et al. (2006) applies this perspective through his choice of $= 0.1$ percent per year $= 1$, yielding an annual discount rate of 1.4 percent when combined with the growth rate. Recently, Stern (2008) revisited the values used in Stern et al. (2006), stating that there is a case to be made for raising due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with $= 1$).

If there is a persistent element to the uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower discount rates tend to dominate over the very long term

Updating 2021 - $125 - Abstract

This paper outlines a two-step process to return the United States government's Social Cost of Carbon (SCC) to the frontier of economics and climate science. The first step is to implement the original 2009-2010 Inter-agency Working Group (IWG) framework using a discount rate of 2%. This can be done immediately and will result in an SCC for 2020 of $125. The second step is to reconvene a new IWG tasked with comprehensively updating the SCC over the course of several months that would involve the integration of multiple recent advances in economics and science. We detail these advances here and provide recommendations on their integration into a new SCC estimation framework.

Michael Greenstone (2011) Estimatiung SCC (pdf)

28.1.3 Greenstone: Updating SCC

In many respects, the SCC is the "straw that stirs the drink" for most domestic climate policies, determining in some cases whether or not regulatory action can proceed.

A defining feature of the best new (after 2010) research is that it relies on large-scale data sets, rather than assumptions that are often unverifiable.

New estimates for two of three recently studied SCC sectors (mortality and agriculture) indicate substantially larger damages from CO 2 , suggesting that the SCC, as settled in 2013, is too low. Climate change is projected to disproportionately harm today's poorest populations, exacerbating concerns about environmental justice.

The Biden administration can initiate the first step immediately and simply involves implementing the IWG's approach again with a discount rate of no higher than 2 percent, which reflects profound changes in international capital markets that make the current values difficult to justify. At a discount rate of 2% the SCC in 2020 is $125.

There are seven "ingredients" necessary to construct the SCC. The first four are often referred to as "modules" :

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1. A socioeconomic and emissions trajectory, which predicts how the global
economy and CO 2 emissions will grow in the future;
2. A climate module, which measures the effect of emissions on the climate;
3. A damages module, which translates changes in climate to economic
damages; and
4. A discounting module, which calculates the present value of future
damages.
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In addition, there are three cross-cutting modeling decisions that affect the entire process:

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1. Whether to include global or instead only domestic climate damages;
2. How to value uncertainty; and
3. How to treat equity.
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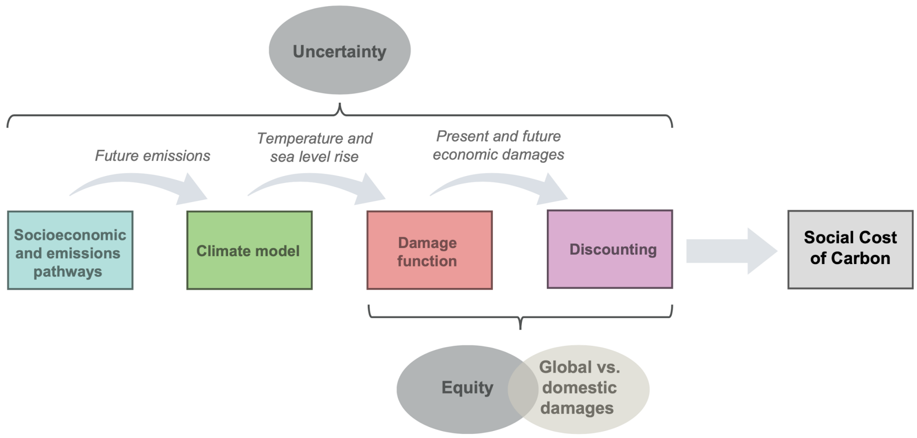


DICE, FUND, and PAGE substantially underestimate the speed of temperature increase, relative to climate models that satisfy the NAS criteria for meeting scientific standards (Figure 4). 17 For example, higher atmospheric CO 2 concentrations cause the oceans to warm and acidify, which makes them less effective at removing CO 2 from the atmosphere. The consequence is a positive feedback loop that accelerates warming. 18 However, this dynamic is missing from both the DICE and PAGE climate modules. The delayed projection of warming in the IAMs' climate models means that resulting estimates of the SCC are likely to be too low. The delay pushes warming further into the future, which is discounted more heavily.

A simple Earth system model that can conduct uncertainty analysis while also matching predictions from these more complex models is necessary. (FAIR)

A key limitation of FAIR and other simple climate models is that they do not represent the change in global mean sea level rise (GMSL) due to a marginal change in emissions. However, statistical methods can be used in combination with long historical records of both temperature and sea level to build a semi-empirical model of the relationship between GMSL and GMST. 25 Such models are readily available 26 and can enable the inclusion of marginal damages due both to warming and to projected changes in sea level. An important potential caveat is that available semi-empirical models of GMSL, in addition to more complex bottom-up models, may underestimate future sea level rise due to their inability to capture plausible future dynamics that are not observed in the historical record (e.g., ice cliff collapse).

At least two problems have plagued the IAM damage functions. First, they are primarily derived from ad-hoc assumptions and simplified relationships, not large-scale empirical evidence. Further, the IAM damage functions have tended to treat the world as nearly homogeneous, dividing the globe into at most sixteen regions. This aggregation misses a great deal, especially because there are important nonlinearities in the relationship between temperature and human well-being that are obscured by substantial aggregation.

The damage functions from FUND, DICE, and PAGE used by the IWG do not meet this criterion. They are only loosely calibrated to empirical evidence and/or rely on outdated estimates that fail to isolate the role of changes in the climate from economic variables such as income and institutions. For example, the majority of the studies used in FUND's sector-specific damage functions were published prior to 2000, and all likely suffer from the influence of unobserved factors that are correlated with temperature. Similarly, early versions of DICE utilized a damage function that was only loosely tied to empirical literature (Diaz and Moore, 2017; Nordhaus, 2010), while the recent DICE update continues to rely on empirical papers that fail to identify plausibly causal effects (Nordhaus and Moffat, 2017).

Dramatic reductions in computing costs and increased data availability have enabled researchers to identify the effects of climate change on social and economic conditions at local scale across the globe. This body of work has uncovered that many socioeconomic outcomes display a strongly nonlinear relationship with climate variables.

The existing IAMs' damage functions fail to adequately characterize nonlinearities, to disaggregate local impacts around the world, or to include information from lower-income, hotter regions of the globe.

Overturned past findings that suggested that climate change would benefit agriculture, instead finding that it would cause substantial damage.

Along with a set of socioeconomic and emissions scenarios, discussed below, the climate and damages modules together translate a single additional ton of CO2 emissions into a trajectory of additional warming, and a stream of future damages. The final step in the SCC calculation is to express this stream of damages as a single present value, so that future costs and benefits can be directly compared to costs and benefits of actions taken today.

!! There are two reasons for "discounting the future," or more precisely for discounting future monetary amounts, whether benefits or costs. The first is that an additional dollar is worth more to a poor person than a wealthy one, which is referred to in technical terms as the declining marginal value of consumption. The relevance for the SCC is that damages from climate change that occur in the future will matter less to society than those that occur today, because societies will be wealthier. The second, which is debated more vigorously, is the pure rate of time preference: people value the future less than the present, regardless of income levels. While individuals may undervalue the future because of the possibility that they will no longer be alive, it is unclear how to apply such logic to society as a whole facing centuries of climate change. Perhaps the most compelling explanation for a nonzero pure rate of time preference is the possibility of a disaster (e.g., asteroids or nuclear war) that wipes out the population at some point in the future, thus removing the value of any events that happen afterwards.

!! U.S. government agencies have relied on the Office of Management and Budget's (OMB's) guidance to federal agencies on the development of regulatory analysis in Circular A-4, and used 3 percent and 7 percent discount rates in cost-benefit analysis. 61 These two values are justified based on observed market rates of return, which can be used to infer the discount rate for the SCC since any expenditures incurred today to mitigate CO 2 emissions must be financed just like any other investment. The 3 percent discount rate is a proxy for the real, after-tax riskless interest rate associated with U.S. government bonds and the 7 percent rate is intended to reflect real equity returns like those in the stock market. However, climate change involves intergenerational tradeoffs, raising difficult scientific, philosophical and legal questions regarding equity across long periods of time. There is no scientific consensus about the correct approach to discounting for the SCC.

The assumption that climate damages were projected to be uncorrelated with overall market returns (eliminating the 7 percent rate, derived from equity markets) and thus used insights from asset pricing theory that the riskless interest rate was appropriate.

The equilibrium real interest rate has declined substantially since the 1990s, suggesting a lower discount rate is justified. 65 Additionally, evidence from long-term real estate investments suggests that for climate mitigation, which has payoffs over very long periods of time, discount rates should be even lower than those used to discount costs and benefits of shorter-lived investments. 66 Overall, our judgement is that it is difficult to defend a 3 percent discount rate for climate investments and there is now a compelling case for a riskless discount rate of no higher than 2 percent.

!! There is also the possibility, however, that the riskless rate itself is not appropriate as the central discount rate due to the unique risk properties of climate change and uncertainty about future interest rates. Because discount rates reflect the returns to investments that mitigate climate change, Americans are best served by using an interest rate associated with investments that match the structure of payoffs from climate mitigation. Capital asset pricing models recommend low discount rates in scenarios where investments (in this case CO 2 mitigation) pay off in "bad" states of the world—that is, if climate damages are likely to coincide with a slowing overall economic growth rate that for example could be due "tipping points" or large-scale human responses to climate change, including mass migration. 68 If on the other hand climate damages act as tax on the economy (i.e., total damages are larger when the economy grows faster), then higher discount rates like the average return in equity markets would be merited.

Ramsey A second potential approach to deriving a discount rate is to explicitly account for future economic growth using the so-called Ramsey equation, 69 which is often referred to as the prescriptive approach. This approach has been recommended by the NAS as a "feasible and conceptually sound framework". Rather than rely on observed interest rates, it derives a discount rate from assumptions about three parameters: the pure rate of time preference, the growth rate of consumption, and a parameter capturing the decreasing marginal utility of consumption. Values for the first and third parameters have been estimated in a large literature, while the consumption growth rate will depend on the set of socioeconomic scenarios developed in the socioeconomic and emissions module described above. 70 The Ramsey approach has two key limitations. First, future economic growth is uncertain, while the Ramsey equation is deterministic. Second, climate damages are likely to be the highest in possible future scenarios where economic growth is the lowest. Both facts imply that climate mitigation policies act as a form of insurance for the future and imply a lower discount rate than is given by the Ramsey equation. Besides these limitations, some find it unappealing that the Ramsey approach requires several judgments by "experts" about the value of key parameters, rather than relying on observed market interest rates.

Socioeconomic and Emissions Module To calculate the SCC, it is necessary to compare a baseline trajectory of economic growth and CO 2 emissions to a trajectory in which one more ton of CO 2 is released. All else equal, a higher baseline CO 2 emissions trajectory will result in a greater SCC, because projected climate change damages are nonlinear; that is, an additional ton of CO 2 emissions is projected to cause more damages at higher atmospheric concentrations of CO 2 . Baseline economic growth affects the SCC in a variety of competing ways. Richer economies consume more energy and generate higher emissions, such that marginal tons do more damage and populations have higher willingness-to-pay to avoid climate change, which increases the SCC.

Uncertainty In the last decade, advances in computing have enabled probabilistic climate change projections that capture multiple measures of uncertainty about the magnitude of climate damages. Thus, for the first time, it is possible to characterize these uncertainties and to incorporate them into the calculation of the SCC. Accounting for this uncertainty when individuals are modeled as risk averse can substantially increase the SCC.

Equity An additional dollar is worth more to a poor person than a wealthy one. Applying this principle to the SCC would require "equity weighting". This logic would mean that damages occurring in poor countries are weighted more highly than damages in wealthy countries. The same logic that justifies discounting and the valuation of uncertainty over future states of the world implies that equity weights should be applied in any SCC calculation; declining marginal value of consumption is the fundamental economic concept behind all three concerns. Therefore, the most intellectually coherent approach to treating equity would be to calibrate equity weights from the large literature studying the marginal value of consumption, and to apply these weights at the spatial resolution of damages.

This pathway (C) is based on the recognition that a simple economic principle—declining marginal value of consumption—underlies the motivation for discounting as well as the valuation of both equity and uncertainty. 100 This principle is based on the straightforward observation that $100 is worth more to a person living in poverty than a wealthy person. In the climate setting, declining marginal value implies that one should attach a higher value to future and present impacts of climate change when they occur to populations experiencing lower incomes. It also means that when future incomes are uncertain, one has to account for the risk of severe damages occurring when average global income is very low, and thus when the value of an additional dollar is relatively high.

Therefore, an argument can be made for computing an SCC in which the damage function represents the difference in the "certainty-equivalent" value of consumption across all years, populations, and possible future states of the world with and without climate change. 102 In this approach, the valuation of climate damages is conducted from the perspective of a person who does not know their circumstances in advance, so they account for all potential income levels and degrees of climate risk they might face.

Under this approach, discounting, uncertainty valuation, and accounting for equity implications are all incorporated into the construction of a single, certainty-equivalent damage function.

Carleton Greenstone (2021) Updating SCC (pdf)

Climate Impact Lab

FAIR

28.2 Current Prices far below SCC

The vast majority of carbon prices are well below even the most conservative estimates of the "social cost of carbon" (SCC). The SCC internalizes the environmental and health effects of greenhouse gas emissions. A recent study surveyed environmental experts on their estimation of SCC, which ranged between $80 and $300 per ton (Pindyck, 2019). Another study estimates a global median price of $417, with substantial national level variation (Ricke et al., 2018) A more conservative estimate puts the SCC between $50-$100 by 2030 (Carbon Pricing Leadership Commission, 2017). Even compared to the most conservative estimates of the SCC, carbon pricing falls short. The most recent World Bank survey of carbon pricing shows that half of the 61 carbon pricing policies around the globe have a price lower than $10. The IMF estimates that the average global price for carbon is $2/ton (Parry, 2019).

Green(2021) Carbon Pricing Ex-Post (pdf)

28.3 Stern Stiglitz Alternative Approach

A Catalogue of all that is wrong with IAMs

Abstract

Designing policy for climate change requires analyses which integrate the interrelationship between the economy and environment, including: the immense risks and impacts on distribution across and within generations; the many failures, limitations or absences of key markets; and the limitations on government, both in offsetting these failures and distributional impacts. Much of the standard economic modelling, including Integrated Assessment Models, does not embody key aspects of these essentials. We identify fundamental flaws in both the descriptive and normative methodologies commonly used to assess climate policy, showing systematic biases, with costs of climate action overestimated and benefits underestimated. We provide an alternative methodology by which the social cost of carbon may be calculated, one which embraces the essential elements we have identified.

Memo

Ambition

The idea of integrating economics and the environment makes eminent sense, but the devil is in the details. The fact that the overwhelming consensus in the international community, including the scientific community, differs so markedly from the results of the IAMs raises a key question: is it sloppy thinking, perhaps an excess of compassion for the species that may be extinguished as climate change proceeds apace to the 3.5 to 4 degree "recommended" by the IAMs, that has led the international community to irrationally embrace a goal involving excessive costs from the perspective of a hard-headed analysis of society welfare maximization; or is it that the IAMs have left something—or many things— out of their analysis? Or is their whole conceptual apparatus so deeply flawed as to give us little guidance either for the calculation of SCC or the level of climate change that should be acceptable? The objective of this paper is to answer that question, and in doing so, to formulate another approach, which better reflects the risks, the distributive effects, and the market failures that are integral to the analysis of climate change.

Varia

Capital markets do not represent moral valuations across individuals.

The key assumption within IAMs, showing how they all, on damages, on technology, on values and preferences, in the treatment of risk, distribution, and other market failures, tilt conclusions away from strong action on climate change and towards a low social cost of carbon.

Conclusion

The paper provides a path towards the reconciliation between the perspectives of the broader scientific community, which has pushed for urgent and strong action (IPCC, 2018; Ripple et al., 2020) and a part of the economics community, using particular versions of Integrated Assessment Models, who have been skeptical of the need for such urgent action and have not only been tolerant of, but urged the acceptance, of higher levels of climate change. The intuitions of the scientific community may well be right: the simplistic models of the economists have simply not captured essential aspects of the societal decision problem, and when they do so, the disparities in perspectives may be closed, if not eliminated.

Stern Stiglitz NBER (pdf)

28.3.1 Stern Stiglitz Carbon Pricing Commission

The Commission's objective is to identify indicative corridors of carbon prices that can be used to guide the design of carbon-pricing instruments and other climate policies, regulations, and measures to incentivize bold climate action and stimulate learning and innovation to deliver on the ambition of the Paris Agreement and support the achievement of the Sustainable Development Goals.

The purpose of this Commission is to explore explicit carbon-pricing options and levels that would induce the change in behaviors— particularly in those driving the investments in infrastructure, technology, and equipment—needed to deliver on the temperature objective of the Paris Agreement,** in a way that fosters economic growth** and development, as expressed in the Sustainable Development Goals (SDGs)

'Climate Policy Packages'

Relatively high prices today may be more effective in driving the needed changes and may not require large future increases, but they may also impose higher, short-term adjustment costs.

Stern Stiglitz (2017) Commision Report (pdf)

29

Geoengineering

29.1 Solar Geoengineering

NAS Recommendations

The US should establish a multimillion-dollar research programme on solar geoengineering, according to the country's national science academy.

It recommends funding of $100m (£73m) to $200m over five years to better understand the feasibility of interventions to dim the sun, the risk of harmful unintended consequences and how such technology could be governed in an ethical way.

The National Academies of Sciences (NAS) said cutting fossil fuel emissions remained the most urgent and important action to tackle the climate crisis. But it said the worryingly slow progress on climate action meant all options needed to be understood.

Outdoor experiments should be allowed only if they provide critical knowledge that cannot be obtained by other means, said the report, and the research programme "should not be designed to advance future deployment of these interventions".

Proponents of geoengineering argue that impacts of global heating could be so great that every option to limit these must be explored. Opponents argue that such research increases the risk that such technologies could be deployed, perhaps by rogue states, instead of cutting emissions. Critics also warn that solar geoengineering could cause damage such as crop failures, and would need to be maintained to avoid a sudden hike in temperature, unless carbon emissions fall rapidly.

"Solar geoengineering is an extremely risky and intrinsically unjust technological proposal that doesn't address any of the causes of climate change," said Silvia

Ribeiro, Latin America director for the ETC campaign group. “The report asking for more research into a technology we don’t want is essentially flawed.”

The Guardian NAS Solar geoengineering Recommendations (pdf)

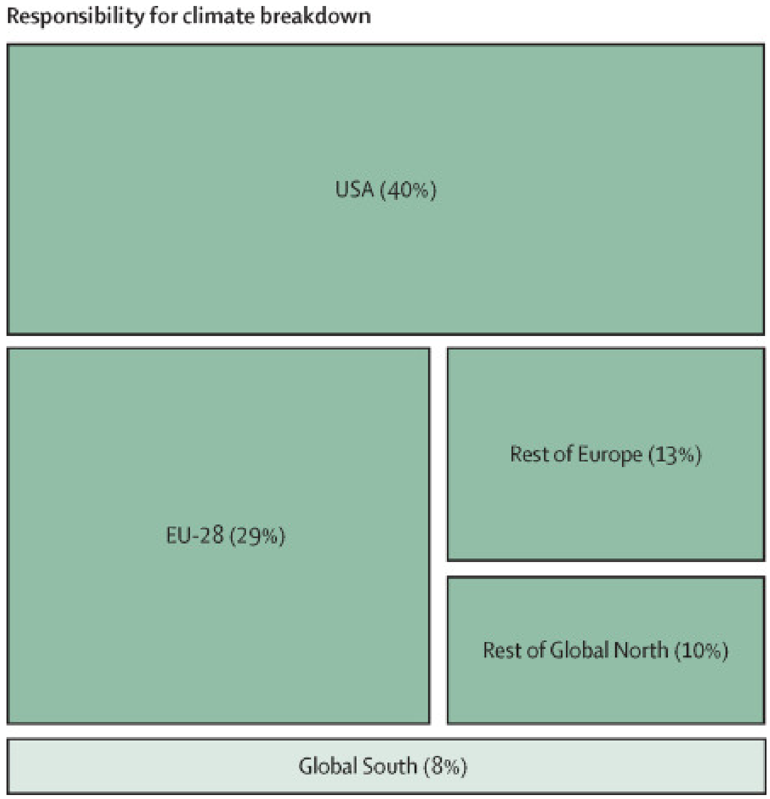
30

Fair Shares

This analysis proposes a novel method for quantifying national responsibility for damages related to climate change by looking at national contributions to cumulative CO_2 emissions in excess of the planetary boundary of 350 ppm atmospheric CO_2 concentration. This approach is rooted in the principle of equal per capita access to atmospheric commons.

For this analysis, national fair shares of a safe global carbon budget consistent with the planetary boundary of 350 ppm were derived. These fair shares were then subtracted from countries' actual historical emissions (territorial emissions from 1850 to 1969, and consumption-based emissions from 1970 to 2015) to determine the extent to which each country has overshot or undershot its fair share. Through this approach, each country's share of responsibility for global emissions in excess of the planetary boundary was calculated.

As of 2015, the USA was responsible for 40% of excess global CO_2 emissions. The European Union (EU-28) was responsible for 29%. The G8 nations (the USA, EU-28, Russia, Japan, and Canada) were together responsible for 85%. Countries classified by the UN Framework Convention on Climate Change as Annex I nations (ie, most industrialised countries) were responsible for 90% of excess emissions. The Global North was responsible for 92%. By contrast, most countries in the Global South were within their boundary fair shares, including India and China (although China will overshoot soon).



These figures indicate that high-income countries have a greater degree of responsibility for climate damages than previous methods have implied. These results offer a just framework for attributing national responsibility for excess emissions, and a guide for determining national liability for damages related to climate change, consistent with the principles of planetary boundaries and equal access to atmospheric commons.

Hickel (2021) The Lancet Planetary Health (pdf)

Part V

Impacts

31

Impacts

Overview of Nature Communications on Climate Change Impacts:

Nature Communications

31.1 Draught

31.1.1 European Draught Extremes

The series of severe droughts and heatwaves in Europe since 2014 is the most extreme for more than 2,000 years, research suggests.

The study analysed tree rings dating as far back as the Roman empire to create the longest such record to date. The scientists said global heating was the most probable cause of the recent rise in extreme heat.

The study also found a gradual drying of the summer climate in central Europe over the last two millennia, before the recent surge. The scientists ruled out volcanic activity and solar cycles as causes of this long-term trend and think subtle changes in Earth's orbit are the cause.

The scientists said changes in the position of the jet stream and the circulation of air over the continent caused the droughts, and that climate change was probably the underlying driver.

Previous climate reconstructions from tree rings used width and wood density to determine temperature. The Büntgen-led study used measurements of carbon and oxygen isotopes to show how much water was available to the trees, giving a record of droughts. This showed that the high frequency of recent European droughts was unprecedented, even compared with severe historical droughts such as the Renaissance drought in the early 16th century.

The wood samples come from the Czech Republic and Bavaria in Germany, and represent climate conditions across central Europe. High temperatures were the main cause of recent droughts, and these have been seen across Europe.

Guardian

Abstract Büntgen

Europe's recent summer droughts have had devastating ecological and economic consequences, but the severity and cause of these extremes remain unclear. Here we present 27,080 annually resolved and absolutely dated measurements of tree-ring stable carbon and oxygen (13C and 18O) isotopes from 21 living and 126 relict oaks (Quercus spp.) used to reconstruct central European summer hydroclimate from 75 bce to 2018 ce. We find that the combined inverse 13C and 18O values correlate with the June–August Palmer Drought Severity Index from 1901–2018 at 0.73 ($P < 0.001$). Pluvials around 200, 720 and 1100 ce, and droughts around 40, 590, 950 and 1510 ce and in the twenty-first century, are superimposed on a multi-millennial drying trend. Our reconstruction demonstrates that the sequence of recent European summer droughts since 2015 ce is unprecedented in the past 2,110 years. This hydroclimatic anomaly is probably caused by anthropogenic warming and associated changes in the position of the summer jet stream.

Büntgen (2021) European drought extremes - Nature (Paywall)

31.2 Rainfall

31.2.1 Decreased Gloabel Precipitation Area

Benestad

The total area with 24 hrs precipitation has shrunk by 7% between 50°S–50°N over the period 1998–2016, according to the satellite-based Tropical Rain Measurement Mission data. A decrease in the daily precipitation area is an indication of profound changes in the hydrological cycle, where the global rate of precipitation is balanced by the global rate of evaporation. This decrease was accompanied by increases in total precipitation, evaporation, and wet-day mean precipitation. If these trends are real, then they suggest increased drought frequencies and more intense rainfall. A linear dependency was also found between the global mean temperature and the 50°S–50°N daily precipitation area with a slope value of -17×106km2/°C.

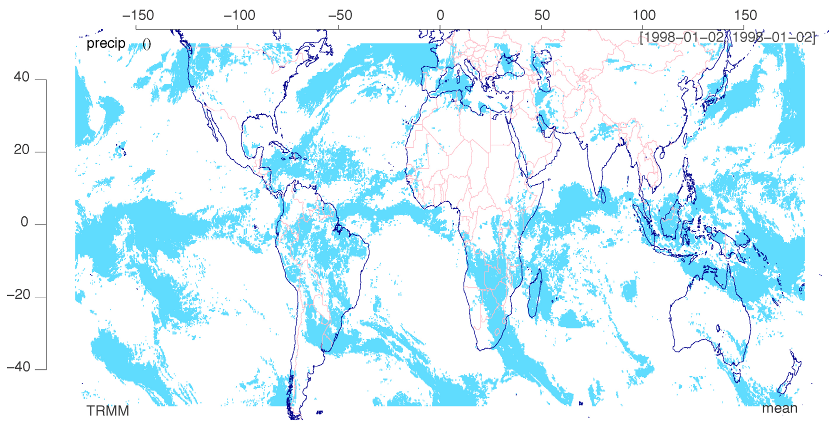


Figure: Global Rainfall Area on a random day.

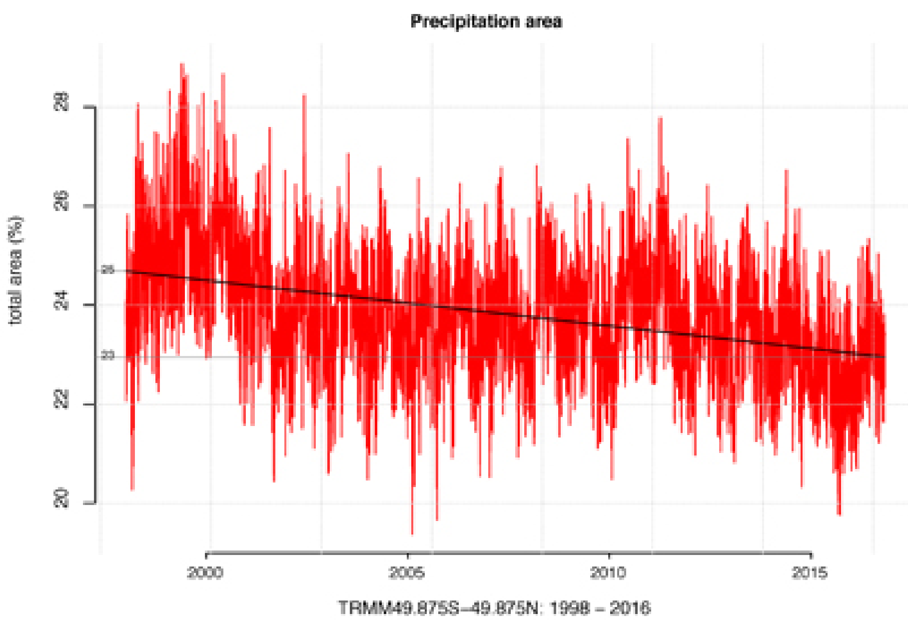


Figure: Time series of the rainfall area based on daily TRMM data expressed as the fraction of the total surface area between 50°S–50°N. A linear trend analysis indicates a change in the estimated rainfall area from 25% to 23% over the 1998–2016 period. The trend is statistically significant at the 1% level. (TRMM- Tropical Rainfall Measurement Mission).

The study of the precipitation area AP is both scientifically interesting and important in terms of our understanding of the hydrological cycle and climate change. A 7% decrease in AP over two decades is dramatic, especially if it reflects a real ongoing long-term change. The precipitation between 50°S–50°N dominates the water budget of the global hydrological cycle both because it represents 77% of the surface area and because the precipitation is most intense in the tropics (table 2). One plausible physical explanation for the observed decline may be that an increased rate of atmospheric overturning [7] may have resulted in more convection and precipitation from cumulonimbus type clouds rather than more spatially extensive stratonimbus clouds. Such changes will have consequences even if they only are due to slow natural variability.

A regression analysis suggested that the daily precipitation area diminishes with the global mean temperature, and used with global climate model simulations, crude projections for the future suggested a decrease in daily precipitation area by 28% by 2100. For monthly accumulated precipitation, however, the area appears to experience an increase over time, as the area of monthly precipitation is influenced by migratory phenomena and the area is estimated for amounts that are aggregated over longer time scales.

Benestad

31.2.2 Landslides

The global landslide hotspot is located in South Asia, driven by the summer (SW) monsoon. The monsoon drives a period of intense and prolonged rainfall in the period centred on June to September. Rainfall levels can be high – in some cases the highest in the world. The monsoon also drives convective activity that can cause cloudbursts. Together, these effects trigger large numbers of landslides, with catastrophic outcomes.

Thus, one of the key elements in the understanding of future landslide patterns is to understand the dynamics of the monsoon with climate change – i.e. under future warming. If the monsoon is likely to intensify then we might see more landslides through time. And of course vice versa. The pattern is not simple of course; the monsoon could weaken but rainfall intensity could increase. So understanding the dynamics of the monsoon is key.

A new open access paper has just been published in the journal Earth System Dynamics (Katzenberger et al. 2021) that examines the dynamics of the Indian monsoon under future warming scenarios. To do so it examines the 32 global climate models within the Coupled Model Intercomparison Project Phase 5 (CMIP5) under a range of emission scenarios.

The results are really interesting. As the authors put it:

All of these models show a substantial increase in June-to-September (JJAS) mean rainfall under unabated climate change (SSP5-8.5) and most do also for the other three Shared Socioeconomic Pathways analyzed (SSP1-2.6, SSP2-4.5, SSP3-7.0). Moreover, the simulation ensemble indicates a linear dependence of rainfall on global mean temperature with a high agreement between the models independent of the SSP if global warming is the dominant forcing of the monsoon dynamics as it is in the 21st century; the multi-model mean for JJAS projects an increase of 0.33 mm d−1 and 5.3 % per kelvin of global warming.

These are fascinating results. Under most likely scenarios for future warming the monsoon will strength, with more rainfall on average. In graphical form the figure below displays the outcomes:

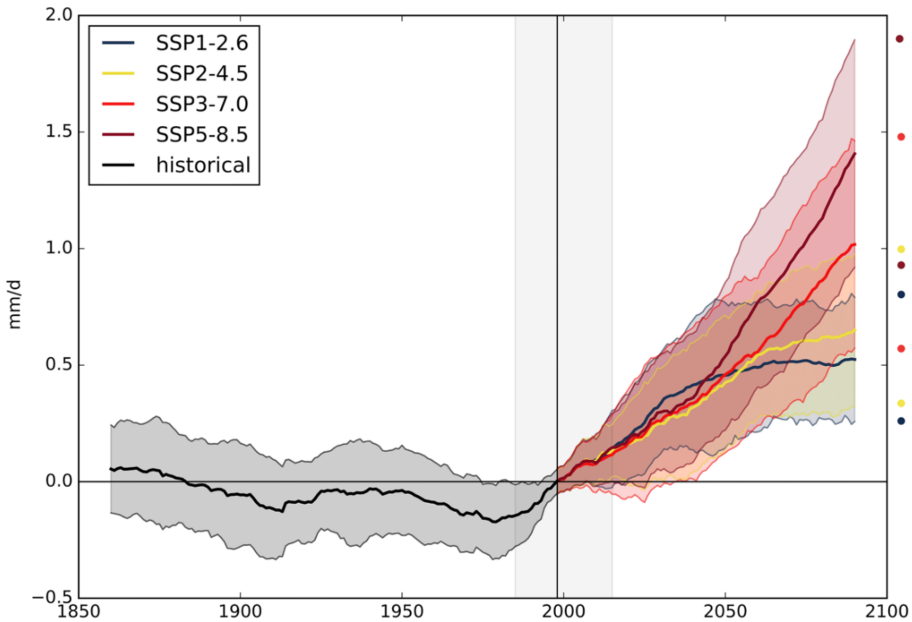


Figure: Multi-model mean of Indian summer monsoon rainfall (mm d−1) for the Indian summer monsoon for 1860–2090 relative to the mean (horizontal black line) in 1985–2015 (grey background) for the four scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5). The 20-year smoothed time series of one ensemble member per model was used to calculate the multi-model mean. Shading in the time series represents the range of mean plus/minus 1 standard deviation marked with circles on the right side of the figure. Image and caption (lightly edited) from Katzenberger et al. (2021).

nterestingly, the models project that both the west coast of India and the Himalaya region will show substantial increases in monsoon precipitation. These are the areas most affected by landslides. The models also suggest greater interannual variability, indicating that some years will be exceptionally wet.

Studies like this provide a general expectation for future behaviour. There will be nuances of course that require further investigation, such as the impacts on cloudburst rainfall and the interaction between the atmosphere and the topography. But in general terms, the models suggest that we might expect to see increased landslide activity driven by the summer monsoon with time. Coupled with the ongoing environmental degradation in the Himalayas, especially through haphazard road construction, the picture for future landslide impacts is poor. Strategies to adapt to future warming are urgently required.

Petley: Indian Monsoon

31.3 Water availability

Abstract Konapala

Accessibility of water resources for human consumption and ecosystems largely depends on the spatio-temporal distribution of both precipitation and evaporation. As a result, changes in characteristics of precipitation and evaporation due to human-caused climate change in the 21st century may result in changes in water availability (WA) that have implications for both humans and the biosphere. Previous studies have elucidated trends in precipitation in terms of both annual mean, seasonal variation, and the distribution of extreme events. Studies have also examined the corresponding changes in evaporation characteristics. Though the combined monthly distribution of precipitation and evaporation have widespread implications for regional hydrology, crop yield, and ecology, few studies have examined the concomitant changes in both annual mean and seasonal variation in these variables. Moreover, the existing global climate classifications that form the basis for WA studies rarely consider seasonal variation characteristics from a non-parametric standpoint, even though they vary in a complex manner across global land regions.

Konapala (2021) Water Availability (pdf)

31.3.1 Energy Crops takes away Water

Billions more people could have difficulty accessing water if the world opts for a massive expansion in growing energy crops to fight climate change, research has found.

The idea of growing crops and trees to absorb CO2 and capturing the carbon released when they are burned for energy is a central plank to most of the Intergovernmental Panel on Climate Change's scenarios for the negative emissions approaches needed to avoid the catastrophic impacts of more than 1.5°C of global warming.

But the technology, known as bioenergy with carbon capture and storage (BECCS), could prove a cure worse than the disease, at least when it comes to water stress.

Fabian Stenzel at the Potsdam Institute for Climate Impact Research in Germany and his colleagues project that the water needed to irrigate enough energy crops to stay under the 1.5°C limit would leave 4.58 billion people experiencing high water stress by 2100 – up from 2.28 billion today. That is 300 million more people than a scenario in which BECCS isn't used at scale and warming spirals to a devastating 3°C.

"I was a little bit shocked. The takeaway message is, so far, we haven't looked at side effects enough. To limit all the trade-offs that we might face in terms of climate change and climate change mitigation, it's really important to look at the holistic Earth system," says Stenzel.

New Scientist

Stenzel

Bioenergy with carbon capture and storage (BECCS) is considered an important negative emissions (NEs) technology, but might involve substantial irrigation on biomass plantations. Potential water stress resulting from the additional withdrawals warrants evaluation against the avoided climate change impact. Here we quantitatively assess potential side effects of BECCS with respect to water stress by disentangling the associated drivers (irrigated biomass plantations, climate, land use patterns) using comprehensive global model simulations. By considering a widespread use of irrigated biomass plantations, global warming by the end of the 21st century could be limited to 1.5 °C compared to a climate change scenario with 3 °C. However, our results suggest that both the global area and population living under severe water stress in the BECCS scenario would double compared to today and even exceed the impact of climate change. Such side effects of achieving substantial NEs would come as an extra pressure in an already water-stressed world and could only be avoided if sustainable water management were implemented globally.

Stenzel in Nature (pdf)

31.4 Agricultural Productivity

Despite important agricultural advancements to feed the world in the last 60 years, a Cornell-led study shows that global farming productivity is 21% lower than it could have been without climate change. This is the equivalent of losing about seven years of farm productivity increases since the 1960s.

The future potential impacts of climate change on global crop production has been quantified in many scientific reports, but the historic influence of anthropogenic climate change on the agricultural sector had yet to be modeled.

The scientists and economists developed an all-encompassing econometric model linking year-to-year changes in weather and productivity measures with output from the latest climate models over six decades to quantify the effect of recent human-caused climate change on TFP.

The results show clearly that adaption efforts must look at the whole supply chain, including labor and livestock. Even as agriculture becomes more mechanized and sophisticated, the sensitivity to weather does not go away.

This study is a big leap beyond the traditional focus on a few major grain crops. By looking at the whole system – the animals, the workers, the specialty crops – we can see that the entire agricultural economy is quite sensitive to weather. It seems that in agriculture, practically everything gets harder when it's hotter.

Ortiz-Bobea Cornell News

Agricultural research has fostered productivity growth, but the historical influence of anthropogenic climate change (ACC) on that growth has not been quantified. We develop a robust econometric model of weather effects on global agricultural total factor productivity (TFP) and combine this model with counterfactual climate scenarios to evaluate impacts of past climate trends on TFP. Our baseline model indicates that ACC has reduced global agricultural TFP by about 21% since 1961, a slowdown that is equivalent to losing the last 7 years of productivity growth. The effect is substantially more severe (a reduction of ~26–34%) in warmer regions such as Africa and Latin America and the Caribbean. We also find that global agriculture has grown more vulnerable to ongoing climate change.

Nature (Paywall)

31.5 Human Health

31.5.1 Morbidity and Mortality

31.5.1.1 Humid Heat Bulbs

Abstract Raymond:

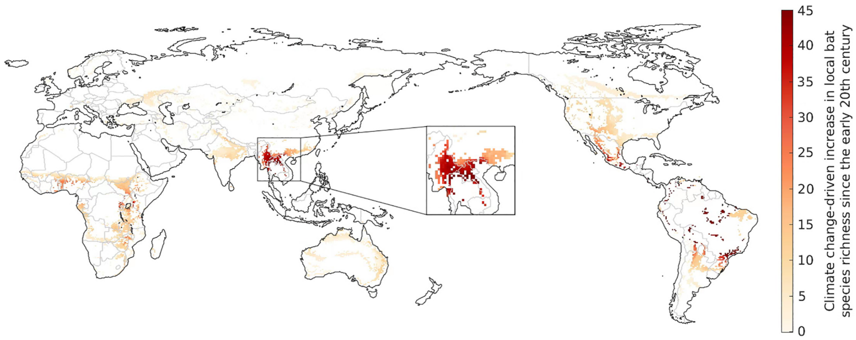
Humans' ability to efficiently shed heat has enabled us to range over every continent, but a wet-bulb temperature (TW) of 35°C marks our upper physiological limit, and much lower values have serious health and productivity impacts. Climate models project the first 35°C TW occurrences by the mid-21st century. However, a comprehensive evaluation of weather station data shows that some coastal subtropical locations have already reported a TW of 35°C and that extreme humid heat overall has more than doubled in frequency since 1979. Recent exceedances of 35°C in global maximum sea surface temperature provide further support for the validity of these dangerously high TW values. We find the most extreme humid heat is highly localized in both space and time and is correspondingly substantially underestimated in reanalysis products. Our findings thus underscore the serious challenge posed by humid heat that is more intense than previously reported and increasingly severe.

Raymond (2020)

31.5.2 COVID

Abstract Beyer

Bats are the likely zoonotic origin of several coronaviruses (CoVs) that infect humans, including SARS-CoV-1 and SARS-CoV-2, both of which have caused large-scale epidemics. The number of CoVs present in an area is strongly correlated with local bat species richness, which in turn is affected by climatic conditions that drive the geograph- ical distributions of species. Here we show that the southern Chinese Yunnan province and neighbouring regions in Myanmar and Laos form a global hotspot of climate change-driven increase in bat richness. This region coin- cides with the likely spatial origin of bat-borne ancestors of SARS-CoV-1 and SARS-CoV-2. Accounting for an es- timated increase in the order of 100 bat-borne CoVs across the region, climate change may have played a key role in the evolution or transmission of the two SARS CoVs.



Beyer (2021) Climate Change -> Bats -> Covid (pdf)

31.6 Metabolism

Global temperature rises threaten food chains and the survival of larger animals. Warmer conditions result in less efficient energy transfer, ultimately causing reductions in biomass.

Temperature rises due to the global climate crisis are putting growing pressure on food chains, ultimately threatening the survival of larger animals. New research examined the transfer of energy from tiny single celled organisms up to large mammals. 4C of warming reduced the energy transfer by up to 56 per cent - posing a grave risk to animals higher up the food chain.

Scientists from the University of Exeter and Queen Mary University of London measured the transfer of energy from phytoplankton - a kind of single-celled algae, to small animals which eat them - (zooplankton). Warmer conditions increase the “metabolic cost” of growth, meaning there was less efficient energy flow through the food chain, and consequently a reduction in overall biomass.

Phytoplankton and zooplankton are the foundation of food webs that support freshwater and marine ecosystems that humans depend on.

The study is the first direct evidence that the cost of growth increases in higher temperatures, limiting the transfer of energy up a food chain.

Independent

Abstract Barneche:

In natural ecosystems, the efficiency of energy transfer from resources to consumers determines the biomass structure of food webs. As a general rule, about 10% of the energy produced in one trophic level makes it up to the next. Recent theory suggests this energy transfer could be further constrained if rising temperatures increase metabolic growth costs, although experimental confirmation in whole ecosystems is lacking. We quantified nitrogen transfer efficiency (a proxy for overall energy transfer) in freshwater plankton in artificial ponds exposed to 7 years of experimental warming. We provide the first direct experimental evidence that, relative to ambient conditions, 4 °C of warming can decrease trophic transfer efficiency by up to 56%. In addition, both phytoplankton and zooplankton biomass were lower in the warmed ponds, indicating major shifts in energy uptake, transformation and transfer. These new findings reconcile observed warming-driven changes in individual-level growth costs and carbon-use efficiency across diverse taxa with increases in the ratio of total respiration to gross primary production at the ecosystem level. Our results imply that an increasing proportion of the carbon fixed by photosynthesis will be lost to the atmosphere as the planet warms, impairing energy flux through food chains, with negative implications for larger consumers and the functioning of entire ecosystems.

Barneche (2020) Warming impairs trophic transfer

Part VI

Actions

32

Action Strategy

Abstract Fazey

The most critical question for climate research is no longer about the problem, but about how to facilitate the transformative changes necessary to avoid catastrophic climate-induced change. Addressing this question, however, will require massive upscaling of research that can rapidly enhance learning about transformations. Ten essentials for guiding action-oriented transformation and energy research are therefore presented, framed in relation to second-order science. They include:

(1) Focus on transformations to low-carbon, resilient living; (2)Focus on solution processes;
(2) Focus on 'how to' practical knowledge;
(3) Approach research as occurring from within the system being intervened;
(4) Work with normative aspects;
(5) Seek to transcend current thinking;
(6) Take a multi-faceted approach to understand and shape change;
(7) Acknowledge the value of alternative roles of researchers;
(8) Encourage second-order experimentation; and
(9) Be reflexive.

Joint application of the essentials would create highly adaptive, reflexive, collaborative and impact-oriented research able to enhance capacity to respond to the climate challenge. At present, however, the practice of such approaches is limited and constrained by dominance of other approaches. For wider transformations to low carbon living and energy systems to occur, transformations will therefore also be needed in the way in which knowledge is produced and used.

Fazey: Ten Essentials for Action (pdf)

32.1 STS - Societal Transformation Scenario

Kuhnhenn: Beyond IPCC

To stop climate change, we have to limit global warming to 1.5°C. But can we still achieve this target? And if so, what pathways can society take in transiting towards a climate-just economy? One important yardstick emerging from it was the need for global emissions to reach net-zero by 2050, the Intergovernmental Panel on Climate Change (IPCC) says in his «Special Report on Global Warming to 1.5°C». One important problem with this and other scenarios is that virtually all rely on continued global economic growth.

The Heinrich-Böll-Stiftung and the Konzeptwerk Neue Ökonomie realised the importance of broadening the discussion's perspective and considering societal pathways that are currently not included in either the IPCC reports or the public debate. Together with researchers from engineering and the natural and social sciences, Heinrich Böll Foundation and Konzeptwerk Neue Ökonomie developed a «Societal Transformation Scenario» for this publication – a global climate mitigation scenario that explores the climate effects of limiting global production and consumptions and of envisioning a broader societal transformation to accompany these transformations to reach a good life for all.

The Societal Transformation Scenario (STS) is a climate mitigation scenario that distinguishes itself from the scenarios cited by the IPCC in that it assumes a socio-ecological transformation, leading to a better life while reducing consumption and production in the Global North.

The scenarios so far covered by the IPCC usually portray a world that sees no radical societal change, and has global GDP to rising until 2100 in all regions. Since economic growth is a major driver of greenhouse gas (GHG) emissions, these scenarios often rely on high-risk Carbon Dioxide Removal technologies and on a dangerous "overshoot" of the 1.5°C limit.

IPCC scenarios are very much shaped by what is currently often assumed to be economically and socially feasible, without considering new lines of societal change and progress.

The consequence of adhering to the growth paradigm is that mitigation scenarios have to rely on high- risk technologies such as geoengineering, CCS and nuclear energy to reach mitigation goals. In many cases, such scenarios even assume the temperature will «overshoot» the 1.5°C goal at least temporarily – with unknown consequence for humans and eco- systems and at the risk of hitting irreversible tipping points.

Being convinced that a sufficient decoupling of economic growth from GHG emissions is unlikely to happen in the future (see Section 1), we focus on reducing consumption and production in countries of the Global North as a way to reduce emissions.

A substantial reduction in consumption cannot result from a sum of individuals changing their behaviour; it has to be achieved by reshaping key infrastructures of socie- ties and by regulative frameworks, economic principles and incentive structures guiding behaviour within society. For different sectors (mobility, housing, food), we provide a first rough collection of instruments for achieving just those aims.

The STS instead envisages is a comprehensive socio-ecological transformation that involves radical redistribution of wealth and labour and a change of welfare systems, economic principles and lifestyles.

The STS excludes any mitigation options that lead to disproportionate environmental degradation and destruction, including nuclear energy 31 and so-called «negative emissions» technologies.

The STS is not primarily about producing and consuming less; it is about organising society differently.

The assumes a society that finds ways and instruments to prosper without an ever-increasing level of consumption and production, to prosper beyond growth, with redistribution of wealth and work as a fundamental building block.

The transformation is not envisaged as the result of some master plan that is implemented top-down; it is developed bottom-up.

Kuhnhenn (2020) Societal Transformation Strategy (pdf)

STS-FAQ

GlobalCalculator

Global Calculator Tool

32.2 Societal Impact (Lack of)

How to reshape research agendas for sustainability

Abstract Lahsen:

After decades of inadequate responses to scientists' warnings about global environmental threats, leading analysts of the science-policy interface are seeking an important shift of research focus. This switch is from continued modeling and diagnoses of biogeochemical conditions in favor of enhanced efforts to understand the many socio-political obstacles to achieving just transformations towards sustainability, and how to overcome them. We discuss why this shift continues to prove elusive. We argue that rarely analyzed mutually reinforcing power structures, interests, needs, and norms within the institutions of global environmental change science obstruct rethinking and reform. The blockage created by these countervailing forces are shielded from scrutiny and change through retreats behind shields of neutrality and objectivity, stoked and legitimated by fears of losing scientific authority. These responses are maladaptive, however, since transparency and reflexivity are essential for rethinking and reform, even in contexts marked by anti-environmentalism. We therefore urge greater openness, self-critique, and power-sharing across research communities, to create spaces and support for conversations, diverse knowledges, and decisions conducive to sustainability transformations.

Memo Lahsen:

Lock-in on biogeochemical climate science

…witnessed internal conversations about not 'overselling' policy-relevant science by mak- ing overly strong claims about its conclusiveness, reflecting attempts to reconcile continued science funding with policy relevance. Decades later, dia- gnoses of biogeochemical realities and uncertainty reduction remain the dominant center of global change research.

A study of the allocation of climate research funding by 333 funding sources in 37 countries found that 770% more funding went to natural science compared to social science, and that only 0.12% of funding went to social science focused on climate mitigation — that is, to prevention of climate change, as opposed to generally less transformative resilience and adaptation efforts.

Early career scientists, pushed for greater inclusion of social questions, including devel- opment and inequality challenges, and questioned decades-old prioritization of atmospheric and Earth system modeling and observation systems.

Starved of decisive funds and power, Future Earth was born weak, however, a shadow of what was intended.

The Belmont Forum has since joined forces with Future Earth in some endeavors, including a sub- program on transformations to sustainability. How- ever, it continues to direct its massive budget primar- ily towards diagnosing biogeochemical conditions and earth system modeling.

The shield of value neutrality allows incum- bent interests against institutional restructuring to present the lack of support of Future Earth as a defense of quality science.

The persistent underfunding contrasts the importance of these branches of research for understanding and foster- ing cultural orientations—including 'changes in the hearts and minds of the people' — conducive to transformations towards greater environmental sustainability and socio- economic solidarity and equity.

Lahsen (2021) Sustainability Transformation Obstruction (pdf)

33

Academic Failure

Steinberger

On climate change, the scientific community (by and large) has been criminally negligent when it comes to observing — and especially learning from — its own track record.

The physical science of climate change has been a resounding, phenomenal, triumphant success.

Science, as a whole body of institutions, people and knowledge, has failed on climate change. Spectacularly failed to curb or even slow down increases in greenhouse gas emissions.

Trying to exist outside history

The scientific endeavor, since at least Enlightenment & Newton, tries to see its contributions as existing outside history and culture. If something is scientifically true, it should be true before it was "discovered" and for all eternity after. This is a lovely idea in theory, but with devastating consequences. Because no matter the eternal truth of a scientific finding: its interpretation and translation into understanding and action relies upon the cultural and historical context surrounding its discovery.

The historical context of the late 20th century should have been taken much, much, much more seriously by scientific institutions and communities, because it included an ominous domination of neoclassical economic thinking in politics and culture, and a circumscribed, idealized role for scientists in public pronouncements and public life.

Partly as a result of descending from the Enlightenment, partly as a result of the structure of scientific institutions (universities, academies, national research centers), partly because this model worked relatively well for a long time without needing to be challenged, many scientific disciplines took on the idealized position of remote, neutral observers, staying well apart from the object of observation, emerging from their ivory towers to bestow impartial pronouncements on the busy world around.

Climate impacts will tear through social systems and disrupt them. Technological transitions will either happen (or not) depending on experimentation and adoption within social systems. An insistence on science as purely apolitical and technocratic thus leaves a blind spot the size of humanity in how climate impacts will affect us, and how we might respond and act proactively.

A final problem with the aspirations to being purely technocratic and apolitical advisors to power is that we have been generally averse to take our scientific findings directly to the people.

Julia Steinberger (2017) Postmortem

34

Climate Finance

34.1 Green Investing

Fancy

The market is the market

"The evidence on climate risk is compelling investors to reassess core assumptions about modern finance," the BlackRock chairman, Larry Fink, wrote in his highly influential annual letter to CEOs in 2020. "In the near future – and sooner than most anticipate – there will be a significant reallocation of capital."

But the climate crisis can never be solved by today's free markets - because the system is built to extract profits. Investors have a fiduciary duty to maximise returns to their clients and as long as there is money to be made in activities that contribute to global warming, no amount of rhetoric about the need for sustainable investing will change that. It's cheaper and easier to market yourself as green rather than do the long tail work of actually improving your sustainability profile. That's expensive and if there is no penalty from the government, in the form of a carbon tax or anything else, then this market failure is going to persist.

Moving money to green investments doesn't mean polluters will no longer find backers. The argument is similar to that of divestment, another strategy that doesn't work. If you sell your stock in a company that has a high emissions footprint, it doesn't matter. The company still exists, the only difference is that you don't own them. The company is going to keep on going the way they were and there are 20 hedge funds who will buy that stock overnight. The market is the market.

The public don't realizes we are not talking about stopping climate change. We are literally talking about selling assets so we don't get caught up in the damage when it hits.

BAU

Under the current system the costs are simply too high and the benefits of conducting business as usual are too great.

Government led

The overarching point is that real change has to be led by government, not Wall Street.

Fancy (2021) Green investing 'is definitely not going to work'

34.2 Sustainable Finance

> Basel rules limiting the ability of banks to provide long-term, non-recourse finance to clean energy projects. Solvency rules that prevented investors from funding infrastructure and public transport. Liquidity rules that made it impossible for pension funds and life insurers to back newer technologies. Definitions of fiduciary duties that stopped pension fund trustees from taking into account ESG considerations. Accounting regulations that failed to require disclosure of climate risks. Public investment funds forced by regulators to use ratings agencies that ignored climate change.

World Economic Forum published a version of the white paper at Davos in January 2013, kicking off a heated debate among delegates and at subsequent events.

In January 2014, The United Nations Environment Programme picked up the baton, launching an Inquiry into the Design of a Sustainable Financial System, which resulted in October 2015 in a major report entitled The Financial System We Need. Then, December 2015 saw the formation of the Task Force on Climate-related Financial Disclosures (TCFD), chaired by Mike Bloomberg (founder and majority owner of Bloomberg LP) at the request of the Financial Stability Board and its (then) chair Mark Carney (governor of the Bank of England at the time). TCFD has done much to raise awareness of climate change and the need for more climate-related disclosures in financial circles.

It is now hard to argue that the financial system is institutionally fossilist. Indeed, there is a lively debate going on about whether central banks should be promoting climate action – being 'institutionally anti-fossilist' – or not.

A veritable smorgasbord of organizations has sprung up in recent years, promoting sustainable finance from various angles. All of them, however, depend on methodologies that are at best not transparent, and at worst downright misleading.

No amount of investment in clean energy and transportation will get the world to net zero if the capital markets continue to invest at the same time in fossil fuel-based infrastructure. Investors must also stop funding fossil assets, and they may even have to walk away from assets before the end of their productive lives. How can the capital markets contribute to, rather than impede, such decisions?

It is not up to the financial system to protect the environment: that's the job of regulators in energy, transport, industry and so on. As soon as clean solutions made economic sense, the money would flow – but not before, because of their risks.

Central banks should stick to managing risks within the financial system posed by societal choices, not trying to manipulate the choices made by society.

Greenhouse Gas Protocol

The methodologies of the Greenhouse Gas Protocol. Originally developed 20 years ago by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), this is the rule-book defining Scope 1, Scope 2 and Scope 3 emissions.

A quick reminder: Scope 1 are emissions from your own burning of fossil fuels or emissions of other greenhouse gases; Scope 2 are emissions embodied in purchased energy services – electricity, steam, heating and cooling; and Scope 3 are emissions elsewhere in your value chain, either upstream or downstream.

Accounting for Scope 1 and Scope 2 is relatively straightforward. A utility's Scope 1 is a power user's Scope 2, so if you own shares in both, there is a double-count, but it is fairly easily removed. Scope 3, however, is a whole different ball game.

Scope 3

Take the example of a sustainability consultant taking a flight as part of a client engagement. The resulting emissions would count as Scope 1 for the airline, and Scope 3 for both the provider of jet fuel and the consultant's employer. They should also, however, be counted as Scope 3 by her client. And by the company which extracted the crude oil from which the jet fuel was produced. And by the owner of the refinery where it was refined. And the 'fixed base operator' who delivered the fuel to the plane. The same emissions should also be counted as Scope 3 by the owners of the departure and arrival airports, the leasing company that owns the plane, and the insurers of the oil production platform, the refinery, the airport and the aircraft – as well as the provider of the consultant's travel insurance. Then there are the companies providing the air traffic control system, components and subassemblies of the aircraft, aircraft maintenance, airport security and catering services.

A big asset owner or asset manager might conceivably hold shares in every one of these companies. Not only that, but in addition to equity, they might own some of each company's debt too, perhaps several issues of different maturities. And what about derivatives? If you buy a call option on a company's stock, are you responsible for some of its emissions? A credit default swap? If you borrow stock and sell it short? If you warehouse debt as collateral for a collateralized debt obligation?

How is any investor meant to keep up with this, not on an annual or quarterly basis, but as it changes by the millisecond?

f the goal is to get executives and investors to think about the carbon intensity of the value chain to which their organizations or portfolio companies belong, and to push them to work with other value chain players to reduce emissions, this approach is great. It is clearly working, and its promoters are to be lauded.

If, however, you want to find out how many tons of carbon dioxide companies in your investment portfolio are actually emitting, or if you want to differentiate between two possible funds on the basis of their impacts on the climate, or if you want to regulate your capital markets to ensure compatibility with the Paris Agreements – then Scope 3 is simply a mess.

EU Taxonomy

The European Union, meanwhile, is plumping for a completely different approach: the EU Taxonomy for Sustainable Activities, an attempt to define a master list to make it easy to see which companies are sustainable and, by extension, which investors are backing sustainable economic activity. As so often in sustainable finance, practice and theory diverge fast.

For the average EU business, the Taxonomy will entail a level of disclosure far beyond anything found in financial statements. Taken literally, it would reveal profitability by line item, investment plans for individual plants and future project launches. The more likely outcome is that an army of accountants and consultants will ensure that data are estimated and aggregated in such a way as to meet legal requirements while revealing little of value to competitors – or investors.

Disclosure will be little more than educated guesswork – and expensive guesswork, particularly for smaller players.

From January 2022, the EU expects asset managers to use the Taxonomy to disclose the sustainability of their investments and funds.

What is needed is a way of allocating responsibility to specific players in an economic activity, which will generally be the *first player in the supply chain* who could have avoided causing them, but did not do so.

That is my one-line summary of the conclusions reached by the Expert Group on Climate Obligations for Corporations, a collection of 68 eminent jurists and human rights experts who have produced the Principles on Climate Obligations for Corporations (pdf). In its 372 pages they attempt to establish – in the absence of explicit law or precedent – where companies' and investors' legal obligations with respect to climate change are likely to lie.

Differentiate between emissions that are avoidable and those that are excessive, and take into account which player actually has control over the decisions that drive emissions.

Demand Focus

holding everyone responsible for emissions means holding no one responsible, and blaming fossil fuel producers – however egregious their past misconduct – effectively means placing the onus for climate action on those with most to lose from accelerating it. Instead of demonizing the supply of fossil fuels, we need to focus primarily on choking off demand. By demanding action on climate while maintaining demand for the products that cause it, society is sending mixed signals.

Each ton of carbon extracted anywhere in the world should automatically be tracked through the point where it is burned to the product or service for which it is used.

Distributed Ledger

Distributed ledger technology could have been designed with a job like this in mind, as the OECD acknowledges in this white paper (pdf), particularly in the era of satellite technology, sensor networks, big data and machine learning. Knowing exactly what is emitted and who is responsible will be a game-changer.

The long-term shift of climate risk from fuzzy and voluntary ESG reports to quantified and regulated financial statements will mark a huge inflection point in the history of climate action.

Focusing responsibility for Scope 3 emissions on those who make the decisions that cause them, and ensuring that risks are quantified and included in financial reports, will do a huge amount to drive capital into decarbonizing the global economy.

None of the currently available carbon accounting methodologies focuses corporations unequivocally on the two goals: reducing controllable emissions and developing high-quality offsets capturing carbon and sequestering it permanently.

The world will never get to net zero if avoided emissions count.

Where developing world countries require incentives to avoid deforestation or leave fossil fuels in the ground, these must be provided by governments, not private players.

If we can accelerate these four trends – transparently allocating emissions to the organizations causing them; integrating climate risk into financial reporting; extending carbon pricing; and focusing on net zero – we can build a sustainable financial system. A future in which the health of the capital markets is not in opposition to the health of the planet.

Liebreich

34.3 Financial Stability

FED Note

Climate change-related financial risks pose both micro- and macroprudential concerns, but analysis and research is at an early stage. This Note describes an approach to understanding how risks arising from climate change may affect financial stability, and connects this discussion to the financial stability monitoring framework described in the Federal Reserve's Financial Stability Reports. That framework distinguishes between shocks to the financial system and economy, which are difficult to predict, and vulnerabilities, which are underlying features of an economic or financial system that can amplify the negative effects of shocks. We describe how climate-related risks may emerge both as shocks and as vulnerabilities that could amplify the effects of climate-change related shocks or other shocks.

This analysis offers a way to assess the financial stability impact of risks resulting from climate change as information on the nature, extent, and timing of those risks improves. Our approach to describing climate-related financial stability risks is complementary to, though both simpler and broader than, the existing international typology described in Carney (2015).

We offer three main conclusions. First, the Federal Reserve's financial stability monitoring framework is flexible enough to broadly incorporate many key elements of climate-related risks. Second, although we believe that climate change increases financial stability risks, more research and analysis is needed to incorporate these risks fully into financial stability monitoring, including substantial improvements in data and models. Third, domestic and international transparency efforts around climate-related financial exposures may help clarify the nature and scope of financial stability risks related to climate change.

In principle, quantifying climate-related risks should be similar to quantifying other financial stability risks. In practice, however, climate-related risks face several challenges to measurement beyond those associated with conventional financial system vulnerabilities and potential shocks, and which will require investment to address. These climate-related features impair not only estimation and modeling at the level of the overall economy, but also the analysis of region-, sector-, asset-, institution-, and investor-level exposures. Investment in data procurement, and careful analysis of climate-related data to describe specific economic and financial risks, is critical to addressing these challenges and producing high-quality research on climate-related outcomes.

A fundamental challenge relates to merging and cleaning climate-related data for use in economic models.24 Availability of sufficiently granular spatiotemporal and climate-related financial data is limited, including information on exposure to physical hazards or the emission levels of activities associated with particular investments or financial institutions. Investors or researchers hoping to assess the financial impacts of climate-related risks must often use proxies involving spatiotemporal weather data.

Models that seek to link climate directly to economic output involve a separate set of challenges. Climate models typically simulate the interaction of a wide range of variables over many decades. In addition, the effects of climate change on economic activity may involve heterogeneous local or regional effects. These factors introduce uncertainty into even short- and medium-term projections, making aggregate climate models an imprecise source of information for near-term economic estimates and risk assessment.

Deeper analysis of the specific channels by which climate-related risks create hidden vulnerabilities in the financial sector will be an especially important topic for exploration.

FED Note on Climate Risk and Financial Stability

To take action, central banks must decide on some strategic issues Central banks can formulate a clear strategic view on their tolerance of climate-related risks and decide how forward- looking they wish their frameworks to be.

Central banks need to form a clear opinion surrounding the appropriateness of various climate-related metrics in order to adjust their operational frameworks. At the current juncture, in the absence of reliable and commonly agreed ways of putting a price tag on climate-related risks, central banks wishing to act may have no choice but to consider using non-financial climate-related metrics as a pragmatic starting point. Central banks should develop policies to monitor and manage issues surrounding data quality and availability. The limited availability and accuracy of relevant data is currently constraining virtually all climate-related risk metrics.

NGFS Adapting Central Bank Operations to a hotter World (pdf)

34.3.1 Methods and Data

Battison

Climate change has been recently recognised as a new source of risk for the financial system. Over the last years, several central banks and financial supervisors have recommended that investors and financial institutions need to assess their exposure to climate-related financial risks. Central banks and financial supervisors have also started designing climate stress tests that can assess how vulnerable the financial system is to climate change. Nevertheless, the financial community falls short of methodologies that allow the successful analysis of the risks that climate change poses to the financial system.

Indeed, the characteristics of climate risks (i.e., deep uncertainty, non-linearity and endogeneity) challenge traditional approaches to macroeconomic and financial risk analysis.

Embedding climate change in macroeconomic and financial analysis using innovative perspectives is fundamental for a comprehensive understanding of risks and opportunities in the era of the climate crisis.

This Special Issue is devoted to the relation between climate risks and financial stability and represents the first comprehensive attempt to fill methodological gaps in this area and to shed light on the financial implications of climate change. It includes original contributions that use a range of methodologies such as network modelling, dynamic evolutionary macroeconomic modelling and financial econometrics to analyse climate-related financial risks and the implications of financial policies and instruments aiming at the low-carbon transition. The research insights of these contributions can inform the decisions of central banks and financial supervisors about the integration of climate change considerations into their policies and financial risk assessment.

Battison (2021) Climate Risk and Financial Stability (Paywall)

35

Legal Action

youth4climate The Case

35.1 Ecocide: Crime?

Ecocide is not yet illegal. International lawyers are working to codify it as a fifth crime but their campaign faces a long and uncertain road, riddled with thorny issues.

Pope Francis

Pope Francis, shepherd of 1.2 billion Catholics, has been among the most outspoken, calling out the wrongdoing with the full force of his office. He has advocated for the prosecution of corporations for ecocide, defining it as the damage or destruction of natural resources, flora and fauna or ecosystems. He has also suggested enumerating it as a sin in the Catechism of the Catholic Church, a reference text for teaching the doctrine of the faith.

President Emmanuel Macron of France, too, has been sharply vociferous. He has called the burning of the Amazon's rainforests an ecocide and blamed Brazilian President Jair Bolsonaro for reckless mismanagement of a planetary resource.

Indigenous leaders have gone further. They have formally requested the International Criminal Court to investigate Bolsonaro for crimes against humanity.

To prosecute and imprison political leaders and corporate executives for ecocidal actions, like Bolsonaro's, would require a parsing of legal boundaries and a recalibration of criminal accountability.

The moral power of advocates is increasing with the advance of environmental destruction. They already have much admissible evidence to make a case for placing limits on behaviors that make planetary matters worse.

Half a century after the problem was clearly identified, no one and no entity can yet be held responsible for climate change, the largest ecocide of all.

Sasson

Kutznet

The International Criminal Court, which was formally established in 2002 under a treaty called the Rome Statute to prosecute genocide, crimes against humanity, crimes of aggression and war crimes when its member countries, which currently number 123, fail to do so themselves.

Early drafts of the Rome Statute included the crime of environmental destruction, but it was removed after opposition from the United States, United Kingdom and the Netherlands, relegated instead to a wartime offense that has never been enforced.

As a result, international criminal law includes few guardrails to prevent peacetime environmental destruction.

"We currently cannot hold big corporations or big governments accountable for ecocide. So, what do you do? We name and shame, that's all we've got."

An ecocide crime would require International Criminal Court members to enact their own national ecocide laws, and failure to enforce those laws would enable the international court to step in.

Making ecocide a crime could help in weak states, where corporate polluters are sometimes more powerful than national governments.

While political leaders and warlords have been the usual targets of the court, an ecocide crime could place business executives on notice, too.

China, the United States, India and Russia—four of the world's top polluters—are not members of the International Criminal Court, but if a corporation based in one of those countries were to operate within a member state, as many of them do, their executives could fall under the court's jurisdiction.

The push to criminalize ecocide remained on the periphery until December 2019, when Vanuatu and the Maldives, two island nations threatened by rising seas and climate change-driven extreme weather, recommended that the court consider amending its statute to "criminalize acts that amount to ecocide."

After Vanuatu asked the International Criminal Court to consider criminalizing ecocide, Mehta's Stop Ecocide Foundation independently convened a panel of international legal experts, including Mackintosh of UCLA, to draft a clear definition of ecocide. They plan to publish their definition in June, at which point they hope at least one of the court's member nations will formally propose making ecocide the fifth international crime against peace.

Mehta has said the definition would likely require *"willful disregard"* for environmental destruction related to practices like widespread logging, drilling, mining and deep-sea trawling.

But climate change poses a greater challenge: Not only is it difficult to connect polluters to specific harms, he said, but there's also nothing illegal about extracting or burning fossil fuels.

"The situation we're dealing with is that the carbon system, which has fueled our economies since the Industrial Revolution, has not only been lawful, but it's been encouraged,"

Another point that the drafters will have to grapple with is whether the crime of ecocide should require prosecutors to prove that humans have been harmed. Mackintosh said that while this "human harm" threshold could prove appealing politically—the court's existing crimes all largely involve harm to humans—focusing ecocide only on the environment could make it easier for prosecutors to prove, especially when it comes to harms related to climate change, which are often incremental and indirect.

If a nation agrees to introduce the ecocide proposal to the International Criminal Court for consideration, that is when even harder work will begin. Ratification is a multi-step process that ultimately requires support from either two-thirds or seven-eighths of the court's members, depending on the type of amendment introduced.

While no country has committed to formally proposing that the court adopt ecocide, the campaign is gaining traction, fueled by the youth-led climate movement and radical new groups like Extinction Rebellion.

In December, Belgian Foreign Minister Sophie Wilmès asked International Criminal Court member states to examine the possibility of adopting ecocide as a crime. A member of Belgium's Parliament has also proposed a bill to criminalize ecocide. And French lawmakers are working on legislation to make ecocide an offense punishable by fines and prison, though Stop Ecocide criticized the bill as "weak."

At least 10 countries have national ecocide laws already, including Vietnam, which enacted the law in 1990.

Separately, French lawyers in January filed a request with the International Criminal Court on behalf of Amazonian indigenous groups asking that the court investigate Brazil's Bolsonaro for crimes against humanity.

Mehta's campaign is also part of a wider effort by activists who have been looking to the courts to force more aggressive action on climate change.

As of July 1, 2020, at least 1,550 climate change cases have been filed in 38 countries, according to a U.N. report.

Kusnetz

35.2 German Constitutional Court

In an order published today, the First Senate of the Federal Constitutional Court held that the provisions of the Federal Climate Change Act of 12 December 2019 (Bundes-Klimaschutzgesetz – KSG) governing national climate targets and the annual emission amounts allowed until 2030 are incompatible with fundamental rights insofar as they lack sufficient specifications for further emission reductions from 2031 onwards. In all other respects, the constitutional complaints were rejected.

BVerfG

The judgment of 29 April 2021 quashing parts of the Climate Protection Act (CPA) has made history. Not only because the First Senate of the BVerfG put an end to deferring the reduction of greenhouse gasses to the future, or at least to the next government. But because this turn to the future came in the form of a turn to international law and institutions. It is precisely by relying on international law that the court overcomes the counter-majoritarian difficulty commonly tantalizing climate litigation and human rights law generally. The most astonishing fact is, however, that the court entirely avoids the tragic choice between supposedly undemocratic international commitments and the democratic legislature. I argue that it does so by approaching constitutional law in a decidedly postcolonial perspective.

[Goldman - Verfassingablog 30 april 2021](https://verfassungsblog.de/judges-for-future/

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Lobbying

Lobbying might be viewd as an 'anti-action' action

The oil industry knew at least 50 years ago that air pollution from burning fossil fuels posed serious risks to human health, only to spend decades aggressively lobbying against clean air regulations.

The industry was long aware that it created large amounts of air pollution, that pollutants could lodge deep in the lungs and be "real villains in health effects", and even that its own workers may be experiencing birth defects among their children.

These concerns did little to stop oil and gas companies, and their proxies, spreading doubt about the growing body of science linking the burning of fossil fuels to an array of health problems that kill millions of people around the world each year. Echoing the fossil-fuel industry's history of undermining of climate science, oil and gas interests released a torrent of material aimed at raising uncertainty over the harm caused by air pollution and used this to deter US lawmakers from placing further limits on pollutants.

Guardian

37

Net Zero

The predecessor to 'Net Zero' was and still is called 'offsetting'.

37.1 Net Zero Trap

Burn Now - Pay Later

The threats of climate change are the direct result of there being too much carbon dioxide in the atmosphere. So it follows that we must stop emitting more and even remove some of it. This idea is central to the world's current plan to avoid catastrophe. In fact, there are many suggestions as to how to actually do this, from mass tree planting, to high tech direct air capture devices that suck out carbon dioxide from the air.

The current consensus is that if we deploy these and other so-called "carbon dioxide removal" techniques at the same time as reducing our burning of fossil fuels, we can more rapidly halt global warming. Hopefully around the middle of this century we will achieve "net zero". This is the point at which any residual emissions of greenhouse gases are balanced by technologies removing them from the atmosphere.

This is a great idea, in principle. Unfortunately, in practice it helps perpetuate a belief in technological salvation and diminishes the sense of urgency surrounding the need to curb emissions now.

We have arrived at the painful realisation that the idea of net zero has licensed a recklessly cavalier "burn now, pay later" approach which has seen carbon emissions continue to soar. It has also hastened the destruction of the natural world by increasing deforestation today, and greatly increases the risk of further devastation in the future.

37.2 Net Negative

Overshoot

Given the dawning realisation of how difficult Paris would be in the light of ever rising emissions and limited potential of BECCS, a new buzzword emerged in policy circles: the “overshoot scenario”. Temperatures would be allowed to go beyond 1.5°C in the near term, but then be brought down with a range of carbon dioxide removal by the end of the century. This means that net zero actually means carbon negative. Within a few decades, we will need to transform our civilisation from one that currently pumps out 40 billion tons of carbon dioxide into the atmosphere each year, to one that produces a net removal of tens of billions.

37.3 Direct Air Capture

Direct air capture, now being touted by some as the most promising technology out there, has taken hold. It is generally more benign to ecosystems because it requires significantly less land to operate than BECCS, including the land needed to power them using wind or solar panels.

Unfortunately, it is widely believed that direct air capture, because of its exorbitant costs and energy demand, if it ever becomes feasible to be deployed at scale, will not be able to compete with BECCS with its voracious appetite for prime agricultural land.

Dyke

37.4 Net Zero Targeting

Navigating the nuances of net-zero targets analyses the momentum of targets for net-zero emissions across companies, cities and regions worldwide. We seek to unravel the net-zero targets to better enable the identification of truly ambitious actors and enhance support towards them. We offer recommendations for increasing target transparency with the aim of achieving greater accountability and ambition.

NewClimate Institute (2020) Net-Zero Targets Report (pdf)

37.5 Action Tracker

climateactiontracker

37.5.1 Net Negative

India

India does not have a target for when it will cut emissions and has been under diplomatic pressure ahead of the COP26 summit in Glasgow in November.

Instead it aims to reduce emissions intensity — or the amount of pollution relative to GDP — by 33 per cent by 2030, relative to 2005 levels. Emissions intensity targets do not guarantee reductions in absolute emissions.

India is expected to be among the world's biggest contributors to emissions growth in coming years because of its increasing energy needs, although its total emissions today are less than half of the US level.

Energy Minister Singh said: "I believe that it's important for all the developed countries to talk about, not net zero, but about removing more carbon from the atmosphere than they are adding — net negative is what they need to talk about."

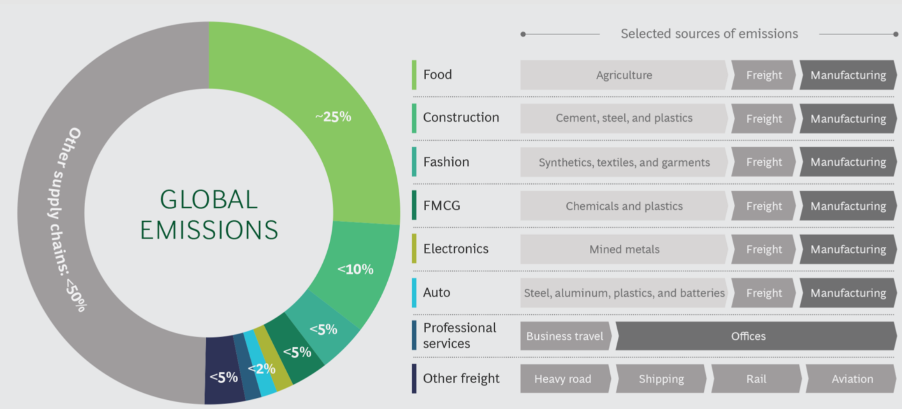
ft

37.6 Scope3 Value Chain Emissions

> Addressing scope 3 emissions is fundamental for companies to realize credible climate change commitments and is mandatory for all members of Race to Zero. It lets customer-facing sectors use their influence to speed and support rapid decarbonization throughout the economy.

In most supply chains, the costs of getting to net zero (the state in which as much carbon is absorbed as is released into the atmosphere) are surprisingly low.

EXHIBIT 1 | The Eight Supply Chains That Dominate Emissions



Source: BCG analysis.
Note: Only selected value chain steps are shown in chevrons. The width of a chevron does not reflect the proportion of CO_2 emissions.
FMCG = Fast-moving consumer goods.

Eight global supply chains account for more than 50% of annual greenhouse gas emissions. Only a small proportion of these emissions are produced during final manufacturing. Most are embedded in the supply chain—in base materials, agriculture, and the freight transport needed to move goods around the world.

For producers of many of these materials, as well as for freight transport players, ambitious decarbonization is extremely challenging. Many emission reduction measures are comparatively expensive. Supply chain partners often operate in markets that are commoditized, with slim margins and limited opportunities for differentiation. Across a whole value chain, however, emissions may be addressed more affordably. In most supply chains, there is the potential for substantially more efficiency and for much greater reuse of materials. In addition, a large share of emissions comes from traditional power, which can be replaced relatively cheaply with renewables.

As a result of this—and the fact that emission-intensive base materials account for only a small share of end consumer prices—decarbonization is much less expensive for companies at the end of any given value chain. In fact, in all the value chains we have analyzed, full decarbonization would lead to an increase of no more than 4% in end consumer prices.

So why is supply chain decarbonization not already commonplace? The answer is that it is challenging.

For one thing, most companies do not understand the extent or the nature of the problem. While a manufacturer can calculate the greenhouse gas emissions from its own operations with a relatively high degree of confidence, getting a view on scope 3 emissions is complex. The challenges are especially daunting for companies with tens of thousands of individual products and significant turnover in the supplier base. Some even struggle to understand who their suppliers are in the first place. It does not help that data-sharing on product emission footprints is still in its infancy.

BCG

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Outreach

Fossil fuel emissions from human activity are driving up Earth's temperature—yet something else is at work. The warming has set in motion nature's own feedback loops which are raising temperatures even higher. The urgent question is: Are we approaching a point of no return, leading to an uninhabitable Earth, or do we have the vision and will to slow, halt, and reverse them?

Feedbackloops 5 Videos

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Climate Politics

39.1 Asset Revaluation - Existential Politics

Colgan Abstract

Whereas scholars have typically modeled climate change as a global col- lective action challenge, we offer a dynamic theory of climate politics based on the present and future revaluation of assets. Climate politics can be understood as a contest between owners of assets that accelerate climate change, such as fossil fuel plants, and owners of assets vulnerable to climate change, such as coastal property. To date, obstruction by "climate-forcing" asset holders has been a large barrier to effect- ive climate policy. But as climate change and decarbonization policies proceed, holders of both climate-forcing and "climate-vulnerable" assets stand to lose some or even all of their assets' value over time, and with them, the basis of their political power. This dynamic contest between opposing interests is likely to intensify in many sites of polit- ical contestation, from the subnational to transnational levels. As it does so, climate politics will become increasingly existential, potentially reshaping political alignments within and across countries. Such shifts may further undermine the Liberal International Order (LIO); as countries develop pro-climate policies at different speeds and magni- tudes, they will have incentives to diverge from existing arrangements over trade and economic integration.

Colgan memo

For the last three decades, international relations (IR) theory has presented the politics of climate change as a collective action problem, relying on models of strategic interaction to explain the presence or absence of international cooperation. We suggest a different approach. We offer a dynamic theory of climate change politics based on the present and future revaluation of assets. We use "assets" as a broad category that includes all inputs to production and sources of material wealth: capital, labor, and natural endowments. We argue that climate change, along with decarbonization policies to mitigate it, will trigger a profound and uneven process of economic revaluation of these assets. That revaluation will ultimately render certain assets valueless, creating a stark distributional struggle, which we term "existential politics." Our aim is to develop a parsimonious political-economic model of the role of asset revaluation on climate politics. It serves as a materialist conceptual scaffolding upon which scholars can add ideational variables to explain climate politics.

The traditional thinking over- emphasizes free riding by viewing climate change as a static collective action problem among states. It underemphasizes distributional struggles, particularly those in domestic politics.

The politics of asset revaluation are central to understanding the interests and contestation around climate change.

CFA (Climate Forcing Assets) - CVA (Climate Vulnerable Assets)

We distinguish between two ideal-typical groups: holders of climate-forcing assets (CFAs) (for example, oil fields, beef farms) and holders of climate-vulnerable assets (CVAs) (for example, coastal property, fisheries). As climate change proceeds, and steps to address it unfold, they alter the value of these assets, and thus, over time, alter the balance of political power between their holders.

LIO Liberal International Order

Our theory of asset revaluation highlights a particular threat to the Liberal International Order (LIO) not commonly explored in the IR literature. The variation in climate and industrial policies across nations will affect the costs of exports and imports, incentivizing nations to place new restrictions on trade or other economic linkages. This threat is distinct from those commonly associated with climate change, such as increased risk of conflict, mass migration, or economic crises

We view current plans to introduce carbon border adjustment mechanisms, which would apply tariffs to certain goods from countries that do not have pro-climate pol- icies, as an early indicator of the tensions that we expect to grow between climate pol- itics and the LIO.

Our argument also challenges the implicit normative assumption underpinning much of this special issue: that the LIO as it has existed should be preserved.

The focus on climate multilateralism from the 1992 Rio Summit to the 2015 Paris Agreement has emphasized the collective action problem of mitigation. According to this view, free riding is the key political challenge. This account overlooks critical features of the problem. Many states are defying the static logic of collective action, and instead are choosing to enact pro-climate policies such as carbon pricing or regulations that restrict emissions.

The key driver of climate politics is domestic politics: politicians are responding to the demands of their constituents, many of whom want emissions reductions regardless of what other countries are doing.

We focus on how policy choices iteratively affect the size of economic interests that underpin domestic politics.

Climate change is a distributional problem unprecedented in scale, not only among states, but also within them.

Conventional bargaining models are useful in understanding the role of such obstruc- tionists, but the solutions they suggest have limited application to climate. Bargaining theory offers little insight on the conditions under which actors' preferences change, and how that affects political outcomes.

Unlike international trade, for example, reciprocity is not a key feature of a potential climate bargain because climate benefits accrue globally, not dyadically.

The *infeasibility of intergenerational distribution*: conventional bargaining theory has been less successful when applied to climate change.

The empirical results reflect these difficulties: whereas inter- national trade negotiators have overcome various bargaining problems, climate change negotiators have not had similar success.

Existential Politics

Existential politics often means that there is a contest over whose way of life gets to survive. Should we have Miami Beach and the Marshall Islands, or should we have coal miners, ExxonMobil, and Chevron?

This extreme form of distributional politics exists in other areas of international political economy (for example, a trade agree- ment or technological change can wipe out an uncompetitive industry), but we suggest that the scale of climate change will make existential politics the increasingly dominant lens through which to understand climate politics.

As distributional conflicts expand and intensify, climate politics will become existential. Different interests will not only fight over who gets what but also over whose way of life survives.

A greater number of actors will be directly, and sometimes gravely, affected by climate change. In turn, the gravity of these effects shifts the policy discussion from extract- ing concessions—an issue of distribution—to ensuring survival. The politics of mitigation thus seems primed to become increasingly existential.

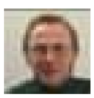
Colgan (2020) Asset Revaluation and the Existential Politics of Climate Change (pdf)

Part VII

Appendices

Appendix A

About



Dyre Haugen and *Dyrehaugen* is Webian for *Jon Martin* - self-owned Globian, Webian, Norwegian and Canarian with a background from industrial research policy, urban planning and economic development consulting on global, regional and urban scales. I am deeply concerned about the (insane) way humanity (i.e. capitalism) interfere with nature. In an effort to gain insights in how and why this happens stuff is collected from around the web and put together in a linked set of web-sites. The sites are operated as personal notebooks. However, these days things can be easily published to the benefit of others concerned with the same issues. But be aware - this is not polished for presentation or peer-reviewed for exactness. I offer you just to have a look at my 'work-desk' as it appears in the moment. Any comment or suggestion can be mailed to dyrehaugen@gmail.com You can follow me on twitter as @dyrehaugen. Thanks for visiting!

Appendix B

History

In Norwegian Allerede på 1950-tallet oppdaget en gruppe amerikanske forskere tegn på at menneskelig aktivitet kunne gjøre jorda varmere.

Prinsippene bak global oppvarming hadde da vært kjent siden slutten av 1800-tallet.

Det skulle likevel ta lang tid før temaet fikk stor oppmerksomhet her i landet.

I 1959 dukket for første gang ordet «drivhuseffekt» opp i en norsk avis. Men vi skal langt inn på 1980-tallet før den norske offentligheten fikk et forhold til det som senere blir omtalt som klimaendringer eller global oppvarming.

Klimaforskerne varslet ikke (Lars Sandved Dalen i Forskning.no)

Replikk til Dalen

Appendix C

Links

Current Dyrehaugen Sites:

- rcap - On Capitalism (loc)
- rclm - On Climate Change (loc)
- recs - On Economics (loc)
- rfin - On Finance (loc)
- rngy - On Energy (loc)
- renv - On Environment (loc)
- rsts - On Statistics (loc)
- rurb - On Urbanization (loc)
- rvar - On Varia (loc)
- rwsd - On Wisdom (loc)

Blogs:

- rde - Blog in English (loc)
- rdn - Blog in Norwegian (loc)

Discontinued:

- jdt - Collection (Jekyll) (loc)
- hdt - Collection (Hugo) (loc)

Not listed:

- (q:) dhe dhn jrw56
- (z:) rcsa rpad rstart

Appendix D

NEWS

D.1 210509 NDCs need 80% increase to 2°C

On current trends, the probability of staying below 2 °C of warming is only 5%

Liu (2021) Nature (pdf)

D.2 210508 Young Legal Action

The young people taking their countries to court over climate inaction

Children and young adults around the world are demanding action from governments on global heating and the ecological crisis,

Guardian

D.3 210424 Earth's Axis tilted by Melting Glaciers

Since the 1990s, the loss of hundreds of billions of tonnes of ice a year into the oceans resulting from the climate crisis has caused the poles to move in new directions.

The direction of polar drift shifted from southward to eastward in 1995 and that the average speed of drift from 1995 to 2020 was 17 times faster than from 1981 to 1995.

Since 1980, the position of the poles has moved about 4 metres in distance.

The accelerated decline [in water stored on land] resulting from glacial ice melting is the main driver of the rapid polar drift after the 1990s.

Guardian

D.4 210410 CO2 and Methane surged in 2020

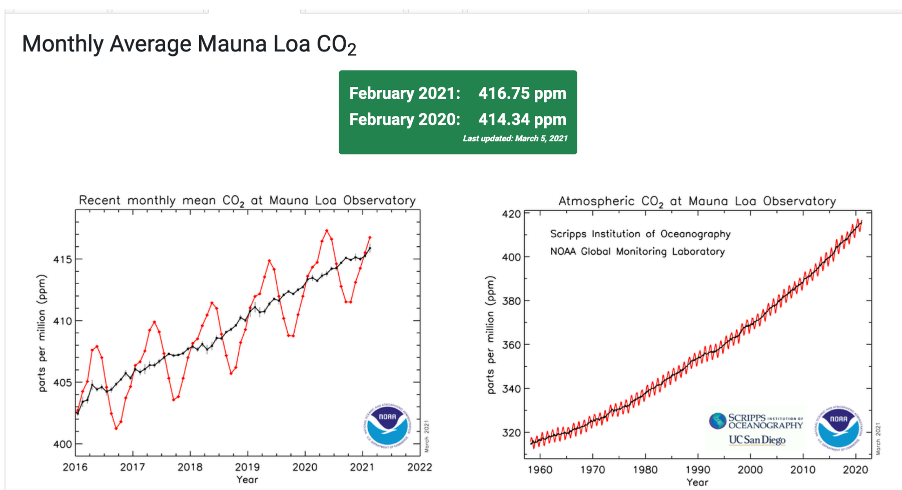
Levels of the two most important anthropogenic greenhouse gases, carbon dioxide and methane, continued their unrelenting rise in 2020 despite the economic slowdown caused by the coronavirus pandemic response.

CO2

The global surface average for carbon dioxide (CO2), calculated from measurements collected at NOAA's remote sampling locations, was 412.5 parts per million (ppm) in 2020, rising by 2.6 ppm during the year. The global rate of increase was the fifth-highest in NOAA's 63-year record, following 1987, 1998, 2015 and 2016. The annual mean at NOAA's Mauna Loa Observatory in Hawaii was 414.4 ppm during 2020.

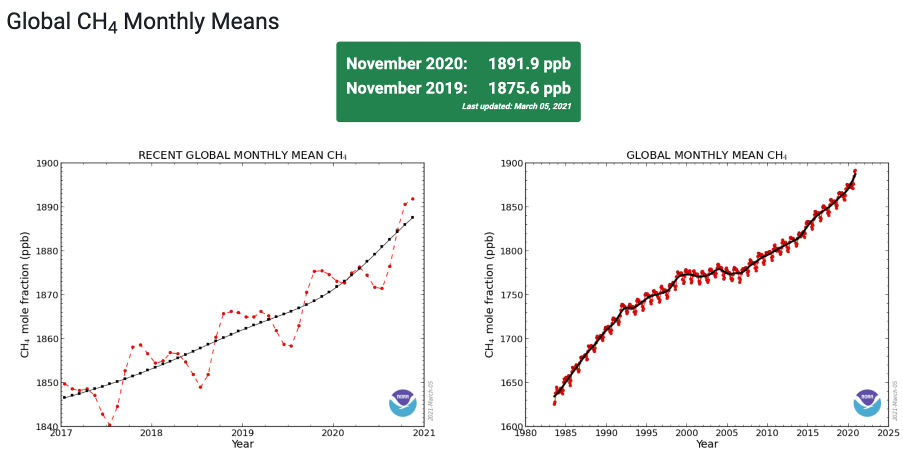
The economic recession was estimated to have reduced carbon emissions by about 7 percent during 2020. Without the economic slowdown, the 2020 increase would have been the highest on record, according to Pieter Tans, senior scientist at NOAA's Global Monitoring Laboratory. Since 2000, the global CO2 average has grown by 43.5 ppm, an increase of 12 percent.

The atmospheric burden of CO2 is now comparable to where it was during the Mid-Pliocene Warm Period around 3.6 million years ago, when concentrations of carbon dioxide ranged from about 380 to 450 parts per million. During that time sea level was about 78 feet higher than today, the average temperature was 7 degrees Fahrenheit higher than in pre-industrial times, and studies indicate large forests occupied areas of the Arctic that are now tundra.



Methane

Analysis of samples from 2020 also showed a significant jump in the atmospheric burden of methane, which is far less abundant but 28 times more potent than CO2 at trapping heat over a 100-year time frame. NOAA's preliminary analysis showed the annual increase in atmospheric methane for 2020 was 14.7 parts per billion (ppb), which is the largest annual increase recorded since systematic measurements began in 1983. The global average burden of methane for December 2020, the last month for which data has been analyzed, was 1892.3 ppb. That would represent an increase of about 119 ppb, or 6 percent, since 2000.



NOAA

D.5 210404 Gas Sustainability

**Scientifically Sustainable*

The European Commission is attempting to finish its sustainable finance taxonomy, a landmark regulation that from next year will define what can be labelled as a sustainable investment in the EU.

A leaked proposal for the rules, shared with EU states last week, would label as sustainable some gas plants that generate power and also provide heating or cooling. That came after the Commission's original proposal – which denied natural gas-fuelled power plants a green label, following the recommendation of the bloc's expert advisers – faced resistance from some EU countries.

Nine members of the expert group advising the European Union on its sustainable finance rules have threatened to step down if Brussels pushes ahead with plans that they say would discredit its efforts to fight climate change.

EU countries disagree on what role natural gas should play in meeting climate goals. Gas emits roughly half the CO2 of coal when burned in power plants, but gas infrastructure is associated with leaks of methane, a potent greenhouse gas.

“The concept of what is scientifically sustainable, that’s really not for politicians to decide,” said Andreas Hoepner, a professor at University College Dublin who signed the letter.

Reuters

D.6 210220 US SCC Update in Progress

In its 2013 revision of the SCC, the Obama IWG arrived at a central value of around US$50 per tonne of CO2 emitted in 2020 (all values expressed in today’s dollars). It also established a range for the SCC ($15–75) and presented an estimate at the 95th percentile ($150). The time is ripe for this update,

That IWG did a careful job, but devastating storms and wildfires are now more common, and costs are mounting. Advances in attribution science mean that researchers can now link many more extreme weather events directly to climate change, and new econometric techniques help to quantify the dollar impacts. The monetary losses exceed the predictions of early models. The same goes for sea-level rise and many other types of damage.

Plenty of scientific and economic judgements need to be made. These include how to deal with endemic uncertainties, including sudden and irreversible ‘tipping points’, such as ice-sheet collapses. Ethical questions must be considered, including the consequences for vulnerable communities and future generations.

Revising the SCC will take extensive research. A 2017 study by the US National Academies of Sciences, Engineering, and Medicine proposed building a new climate-economy model based on modules — separate components that handle climate change, socio-economic projections, damages, valuation and discounting

Other nations use widely different SCC values or overall approaches2. Germany’s 2020 guidance presented two values: €195 (US$235) and €680 ($820). Some countries instead establish a goal for emissions reductions (such as the United Kingdom’s 68% reduction by 2030 compared to 1990 levels) and then focus on minimizing the costs of achieving it, estimated at $20–100 per tonne of CO2. This is called a target-consistent approach.

Wagner (Nature)

D.7 210215 Focus on Steel, Meat and Cement

Bill Gates has written about Climate Change.

His assessment is that there is not the time, money or political will to reconfigure the energy sector in 10 years, and encouraging an impossible goal dooms the world to short-term measures that prove insufficient.

Crucially, people need to radically change how they produce the worst climate offenders: steel, meat and cement. Making steel and cement accounts for roughly 10% of all global emissions, and beef alone 4%.

Bill Gates

D.8 210127 10 New Insights in Climate Science 2020

Someof which are:

Earth's temperature response to doubling the levels of carbon dioxide in the atmosphere is now better understood. While previous IPCC assessments have used an estimated range of 1.5–4.5°C, recent research now suggests a narrower range of 2.3–4.5°C.

Emissions of greenhouse gases from permafrost will be larger than earlier projections because of abrupt thaw processes, which are not yet included in global climate models.

Global plant biomass uptake of carbon due to CO 2 fertilization may be limited in the future by nitrogen and phosphorus.

Rights-based litigation is emerging as a tool to address climate change.

Moving forward, the latest research calls for innovative, imaginative, and transformative approaches to building sustainable and resilient human societies. For instance, by strengthening global cooperative frameworks and building new governance arrangements that can include bottom-up community initiatives. In the short term, we have a one-off opportunity to get on the right path by directing post-pandemic recovery spending to green investments. If the focus is instead on economic growth, with sustainability as an afterthought, it would jeopardize our ability to deliver on the Paris Agreement. Alarmingly, governments do not yet seem to be seizing the opportunity to shift towards low-carbon, healthier, and more resilient societies.

futureearth (pdf)

D.9 210130 Adaptation Summit

Climate change adaptation seems to be a fairly new concept to many leaders. It were sometimes mix-ups with mitigation during the high-level talks. Mitigation and adaptation are both important and sometimes they overlap, so mix-ups are understandable. Climate adaptation involves many communities and disciplines (e.g. weather forecasting, climate services, regional climate modelling, “distillation“, disaster risk reduction).

Financing is clearly needed for climate change adaptation. To ensure progress and avoid lofty visions without results on the ground, there may also be a need for tangible results and to show examples and demonstrations. One specific type discussed at the summit was “Early warning systems” which play an important role.

But early warning systems, the way I understand them, don’t provide information about climate risks on longer timescales. Weather and climate – short and long timescales – are of course connected but nevertheless different

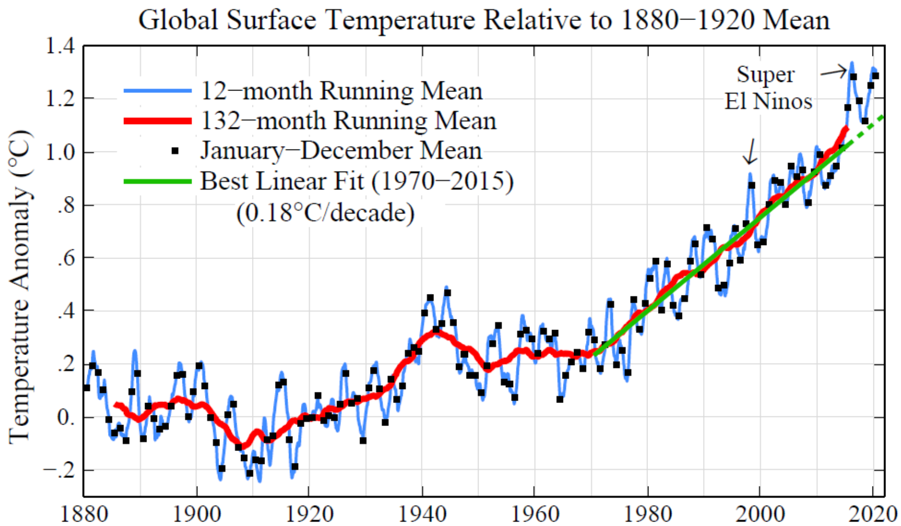
Rasmus (2021) Adaptation Summit

D.10 210118 Warming all anthropogenic

Parties to the Paris Agreement agreed to holding global average temperature increases “well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels”. Monitoring the contributions of human-induced climate forcings to warming so far is key to understanding progress towards these goals. Here we use climate model simulations from the Detection and Attribution Model Intercomparison Project, as well as regularized optimal fingerprinting, to show that *anthropogenic forcings caused 0.9 to 1.3 °C of warming in global mean near-surface air temperature in 2010–2019 relative to 1850–1900, compared with an observed warming of 1.1 °C.* Greenhouse gases and aerosols contributed changes of 1.2 to 1.9 °C and −0.7 to −0.1 °C, respectively, and *natural forcings contributed negligibly.* These results demonstrate the substantial human influence on climate so far and the urgency of action needed to meet the Paris Agreement goals.

Nature (paywall)

D.11 21014 Globale Temperature 1880-2020



The rate of global warming has accelerated in the past several years. The 2020 global temperature was +1.3°C (~2.3°F) warmer than in the 1880-1920 base period; global temperature in that base period is a reasonable estimate of 'pre-industrial' temperature. The six warmest years in the GISS record all occur in the past six years, and the 10 warmest years are all in the 21st century. Growth rates of the greenhouse gases driving global warming are increasing, not declining.

[GISSTEMP 2020 Update] (https://mailchi.mp/caa/global-temperature-in-2020?e=96d59a909f)

D.12 210104 Not so long lag?

> Until recently, Mann explained in The Guardian, scientists believed the climate system—a catch-all term for the interaction among the Earth's atmosphere, oceans, and other parts of the biosphere—carried a long lag effect. This lag effect was mainly a function of carbon dioxide remaining in the atmosphere and trapping heat for many decades after being emitted. So, even if humanity halted all CO2 emissions overnight, average global temperatures would continue to rise for 25 to 30 years, while also driving more intense heat waves, droughts, and other climate impacts. Halting emissions will take at least twenty years, under the best of circumstances, and so humanity was likely locked in to at least 50 more years of rising temperatures and impacts.
>
> Research over the past ten years, however, has revised this vision

> of the climate system. Scientists used to "treat carbon dioxide in the atmosphere as if it was a simple control knob that you turn up" and temperatures climb accordingly, "but in the real world we now know that's not what happens," Mann said. Instead, if humans "stop emitting carbon right now … the oceans start to take up carbon more rapidly." The actual lag effect between halting CO2 emissions and halting temperature rise, then, is not 25 to 30 years but, per Mann, "more like three to five years." (October 2020)

Guardian article

Covering Climate Now article

D.13 210102 Climate Finance Shadow Report 2020

Oxfam has released this report with subtitle *Asessing progress towards the $100 billion commitment* Progress is NOT in line with need or pledges.

> Climate change could undo decades of progress in development and dramatically increase global inequalities. There is an urgent need for climate finance to help countries cope and adapt. Over a decade ago, developed countries committed to mobilize $100bn per year by 2020 to support developing countries to adapt and reduce their emissions. The goal is a critical part of the Paris Agreement. As 2020 draws to a close, Oxfam's Climate Finance Shadow Report 2020 offers an assessment of progress towards the $100bn goal.
>
> Based on 2017–18 reported numbers, developed countries are likely to claim they are on track to meet the $100bn goal. And on their own terms, they may be. But how the goal is met is as important as whether it is met. The dubious veracity of reported numbers, the extent to which climate finance is increasing developing country indebtedness, and the enduring gap in support for adaptation, LDCs and SIDS, are grave concerns. Meeting the $100bn goal on these terms would be cause for concern, not celebration.

Oxfam Report (pdf)

Bibliography