Understanding and Preventing Climate Breakdown

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27th November, 2021
Outline

Part I: The Bigger Picture
Part II: Climate Impacts Today & Tomorrow

Part III: Why Have We Failed So Far?
Part IV: What Can We Do Today?

Part V: Climate Action with En-ROADS
Part I: The Bigger Picture
Burke et al. (2018); Brannen (2021); United Nations (2021)
Changes in global surface temperature relative to 1850-1900

(a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and observed (1850-2020)

- Warming is unprecedented in more than 2000 years
- Warmest multi-century period in more than 100,000 years

(b) Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (both 1850-2020)

Temperature in °C
Socio-economic trends

- Population
- Real GDP
- Foreign direct investment
- Urban population
- Primary energy use
- Fertilizer consumption
- Large dams
- Water use
- Paper production
- Transportation
- Telecommunications
- International tourism

Steffen et al. (2015)
Breaking Boundaries
Rockström COP26

Rockström et al. (2009a, b); Steffen et al. (2015)
Raworth (2017)
Part II: Climate Impacts
Today & Tomorrow
Seville, Spain
August 2021: A billboard shows 47°C (117°F)

Badghis, Afghanistan
September 2021: A farmer holds a handful of failed wheat from his crop

Crop Failures

Extreme Heat
Heat

CMIP6 - Mean temperature (T) Change deg C - Warming 2°C SSP2-4.5 (rel. to 1850-1900) - Annual (34 models)

Byrne (2020)
McSweeney (2019)
The Netherlands

Already +2.1 °C in 2020

Heading for around +4.3 °C in 2100
China

Already +1.9 °C in 2020

Heading for around +5.0 °C in 2100
Brazil

Already **+1.6 °C** in 2020

Heading for around **+3.9 °C** in 2100
Increasing trends in regional heatwaves

S. E. Perkins-Kirkpatrick & S. C. Lewis

Nature Communications 11, Article number: 3357 (2020) | Cite this article

21k Accesses | 54 Citations | 1095 Altmetric | Metrics

Abstract

Heatwaves have increased in intensity, frequency and duration, with these trends projected to worsen under enhanced global warming. Understanding the critical implications for the biophysical and human system requires a comprehensive assessment of regional observed changes. Metrics employed, underpinning datasets, and time periods differ. Berkeley Earth temperature dataset and key heatwave metrics are reviewed. A trend analysis of regional and global observed heatwave trends is presented. In almost all regions, heatwave characteristics are different now compared to 1950s, and due to the high influence of variability we recommend a reassessment over multiple decades. Our results provide an updated view on heatwave trends, on spatial and temporal scales necessary for adaptation and mitigation planning.

The burden of heat-related mortality attributable to recent human-induced climate change

A. M. Vicedo-Cabrera, N. Scovronick, & A. Gasparrini

Nature Climate Change 11, 492–500 (2021) | Cite this article

10k Accesses | 2 Citations | 5519 Altmetric | Metrics

Abstract

Climate change affects human health; however, there have been no large-scale, systematic efforts to quantify the heat-related human health impacts that have already occurred due to climate change. Here, we use empirical data from 732 locations in 43 countries to estimate the mortality burdens associated with the additional heat exposure that has resulted from recent human-induced warming, during the period 1991–2018. Across all study countries, we find that 37.0% (range 20.5–76.3%) of warm-season heat-related deaths can be attributed to anthropogenic climate change and that increased mortality is evident on every continent. Burdens varied geographically but were of the order of dozens to hundreds of deaths per year in many locations. Our findings support the urgent need for more ambitious mitigation and adaptation strategies to minimize the public health impacts of climate change.
Hausfather (2018); Evans & Hausfather (2018)
Extreme Heat - Current Trajectory

Number of people impacted by major heatwaves each year

- 10,000
- 9,000
- 8,000
- 7,000
- 6,000
- 5,000
- 4,000
- 3,000
- 2,000
- 1,000
- 0

Millions of people per year

- 2010
- 2020
- 2030
- 2040
- 2050
- 2060
- 2070
- 2080
- 2090
- 2100

Shaded area represents the lower and upper estimates of the given impact. Solid line represents the central estimate.

Quiggin et al. (2021) Arnell et al. (2019)
Extreme Heat - Current Trajectory

Regional impacts, 2040: proportion of population experiencing major heatwaves each year
(Major heatwaves are comparable to the most extreme historic heatwaves)

By 2050, **more than 70 per cent of people in every region** will experience heatwaves each year.

Urban areas will suffer the greatest challenges of workability and survivability.

Quiggin et al. (2021) Arnell et al. (2019)
The emergence of heat and humidity too severe for human tolerance

Colin Raymond\textsuperscript{1,2*}, Tom Matthews\textsuperscript{3}, Radley M. Horton\textsuperscript{2,4}

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.

Projections of tropical heat stress constrained by atmospheric dynamics

Yi Zhang\textsuperscript{1,2+}, Isaac Held\textsuperscript{1} and Stephan Fueglistaler\textsuperscript{1,2}

Extreme heat under global warming is a concerning issue for the growing tropical population. However, model projections of extreme temperatures, a widely used metric for extreme heat, are uncertain on regional scales. In addition, humidity needs to be taken into account to estimate the health impact of extreme heat. Here we show that an integrated temperature-humidity metric for the health impact of heat, namely, the extreme wet-bulb temperature (TW), is controlled by established atmospheric dynamics and thus can be robustly projected on regional scales. For each 1°C of tropical mean warming, global climate models project extreme TW (the annual maximum of daily mean or 3-hourly values) to increase roughly uniformly between 20° S and 20° N latitude by about 1°C. This projection is consistent with theoretical expectation based on tropical atmospheric dynamics, and observations over the past 40 years, which gives confidence to the model projection. For a 1.5°C warmer world, the probable (66% confidence interval) increase of regional extreme TW is projected to be 1.33-1.49°C, whereas the uncertainty of projected extreme temperatures is 3.7 times as large. These results suggest that limiting global warming to 1.5°C will prevent most of the tropics from reaching a TW of 35°C, the limit of human adaptation.
One billion face heat-stress risk from 2°C rise

Author: Grahame Madge
00:01 (UTC) on Tue 9 Nov 2021

Areas where TW > 32°C for > 10 days per year at 4°C warming
Canadian inferno: northern heat exceeds worst-case climate models

Scientists fear heat domes in North America and Siberia indicate a new dimension to the global crisis

Jonathan Watts
@jonathanwatts
Fri 2 Jul 2021 16.28 BST

“[T]here is something else going on with this heatwave, and indeed, with many of the very persistent weather extremes we’ve seen in recent years in the US, Europe, Asia and elsewhere, where the models aren’t quite capturing the impact of climate change.”

- Michael Mann

“The recent extreme weather anomalies were not represented in global computer models that are used to project how the world might change with more emissions.”

- Johan Rockström

Source
Mann Podcast
Fisher et al. (2021)
McSweeney (2019)
Climate change prediction: Erring on the side of least drama?

Keynyn Brysse a,*, Naomi Oreskes b, Jessica O'Reilly c, Michael Oppenheimer d

a Program in Science, Technology and Society, Office of Interdisciplinary Studies, University of Alberta, Canada
b History and Science Studies, University of California, San Diego, United States
c Department of Sociology, College of St. Benedict/St. John's University, United States
d Department of Geosciences and Woodrow Wilson School of Public and International Affairs, Princeton University, United States

ABSTRACT

Over the past two decades, skeptics of the reality and significance of anthropogenic climate change have frequently accused climate scientists of “alarmism”: of over-interpreting or overreacting to evidence of human impacts on the climate system. However, the available evidence suggests that scientists have in fact been conservative in their projections of the impacts of climate change. In particular, we discuss recent studies showing that at least some of the key attributes of global warming from increased atmospheric greenhouse gases have been under-predicted, particularly in IPCC assessments of the physical science, by Working Group I. We also note the less frequent manifestation of over-prediction of key characteristics of climate in such assessments. We suggest, therefore, that scientists are biased not toward alarmism but rather the reverse: toward cautious estimates, where we define caution as erring on the side of less rather than more alarming predictions. We call this tendency “errning on the side of least drama (ESLD).” We explore some cases of ESLD at work, including predictions of Arctic ozone depletion and the possible disintegration of the West Antarctic ice sheet, and suggest some possible causes of this directional bias, including adherence to the scientific norms of restraint, objectivity, skepticism, rationality, dispassion, and moderation. We conclude with suggestions for further work to identify and explore ESLD.

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Seville, Spain
August 2021: A billboard shows 47°C (117°F)

Badghis, Afghanistan
September 2021: A farmer holds a handful of failed wheat from his crop

Crop Failures

Source
C. Global land use in circa 2015
The bar chart depicts shares of different uses of the global, ice-free land area. Bars are ordered along a gradient of decreasing land-use intensity from left to right.

Global ice-free land surface 100% (130 Mkm²)

- 1% (1 - 1%): Infrastructure
- 12% (12 - 14%): Irrigated cropland
- 37% (30 - 47%): Intensive pasture
- 22% (16 - 23%): Plantation forests
- 28% (24 - 31%): Unforested ecosystems with minimal human use

- Non-irrigated cropland 10%
- Used savannas and shrublands 16%
- Extensive pasture 19%
- Forests managed for timber and other uses 20%
- Forests (intact or primary) with minimal human use 9%
- Other land (barren, rock) 12%
Share of land area used for agriculture, 2018

The share of land area used for agriculture, measured as a percentage of total land area. Agricultural land refers to the share of land area that is arable, under permanent crops, and under permanent pastures.

Source: Food and Agriculture Organization of the United Nations (via World Bank)
OurWorldInData.org/yields-and-land-use-in-agriculture/ • CC BY
Severe drought devastates Washington state's wheat crop

A drought in eastern Washington state that is the worst since 1977 has devastated what is normally the fourth largest U.S. wheat crop

By NICHOLAS K. GERANIOS Associated Press
11 August 2021, 20:46 • 4 min read

'Worst year I've ever witnessed': Drought withers Western Canada's spring wheat

'Some are harvesting about 25 per cent of what they would typically expect. The conditions are terrible

Laura Brehaut
Aug 19, 2021 • August 19, 2021 • 8 minute read • 72 Comments

News | Climate Change

Mexico water supply buckles on worsening drought, crops at risk

Weather forecasts warn of high temperatures portending crop damage and water supply shortages.

| 2 Jul 2021
Record-breaking drought in Chile offers bountiful proof of climate change

- Science Minister Andres Couve said the steady decline in the country's water reserves because of climate change was now a 'national priority'.
- 'The weather events are happening with a frequency and intensity that makes it very easy for people to see', he said.

Brazil, Besieged by Covid, Now Faces a Severe Drought

Brazilians are paying more for electricity, dealing with the possibility of water rationing and expecting a destructive fire season in the Amazon in the worst dry spell in at least 90 years.

Record Droughts Plague Latin America

By Chase Harrison and Katie Hopkins

Abnormally dry conditions in Argentina, Brazil, Mexico, and Paraguay threaten water reserves and economic recovery.
Jordan facing ‘one of the most severe’ droughts in its history

Experts say Jordan is now in the grip of one of the most severe droughts in its history, but many warn the worst is yet to come.

6 May 2021

Iran buying record volume of wheat after worst drought in 50 years – sources

‘The challenge for us now is drought, not war’: livelihoods of millions of Afghans at risk

Tue 21 Sep 2021 10.36 BST
At least 1m people facing starvation as Madagascar’s drought worsens

People eating termites and clay as UN says acute malnutrition has almost doubled this year in south

Mon 10 May 2021 06.00 BST

Drought puts 2.1 million Kenyans at risk of starvation

National disaster declared as crops fail after poor rains and locusts, while ethnic conflicts add to crisis

Wed 15 Sep 2021 07.00 BST

Angola: Millions facing hunger, as thousands flee their homes as drought ravages the south of Angola

July 22, 2021 2:00 am
Agriculture - Current Trajectory

Proportion of global cropland exposed to severe drought of three months or more, each year.

Shaded area represents the lower and upper estimates of the given impact. Solid line represents the central estimate.

Quiggin et al. (2021) Arnell et al. (2019)
Agriculture - Current Trajectory

Regional impacts, 2050: proportion of cropland exposed to severe drought each year
(Severe drought is equivalent to that experienced in Central Europe in 2018)

Farmers in the worst-affected areas (including the critical breadbasket regions of southern Russia and the US) are likely to experience severe agricultural drought impacting 40 per cent or more of their cropland area every year during the 2050s.

During the 2040s there is a 50% chance of synchronous crop failure

Quiggin et al. (2021)
Arnell et al. (2019)
Seville, Spain
August 2021: A billboard shows 47°C (117°F)

Badghis, Afghanistan
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Extreme Heat

Crop Failures

Source
Nine climate “tipping points” where rising global temperatures could push parts of the Earth system into irreversible change.
Past abrupt changes, tipping points and cascading impacts in the Earth system

The geological record shows that abrupt changes in the Earth system can occur on timescales short enough to challenge the capacity of human societies to adapt to environmental pressures. In many cases, abrupt changes arise from slow changes in one component of the Earth system that eventually pass a critical threshold, or tipping point, after which impacts cascade through coupled climate-ecological-social systems. The chance of detecting abrupt changes and tipping points increases with the length of observations. The geological record provides the only long-term information we have on the conditions and processes that can drive physical, ecological and social systems into new states or organizational structures that may be irreversible within human time frames. Here, we use well-documented abrupt changes of the past 30 kyr to illustrate how their impacts cascade through the Earth system. We review useful indicators of upcoming abrupt changes, or early warning signals, and provide a perspective on the contributions of palaeoclimatic science to the understanding of abrupt changes in the Earth system.
Lenton et al. (2019)
Wunderling et al. (2021)
"I think we have more than a 5% chance of succeeding but it is definitely less than 50%, in my view. But what is the option? If we have a final chance to save our culture and our civilisation, I am just compelled to do it."

John Schellnhuber
Founding Director
Potsdam Institute for Climate Impact Research
“I think we have more than a 5% chance of succeeding but it is definitely less than 50%, in my view. But what is the option? If we have a final chance to save our culture and our civilisation, I am just compelled to do it.”

John Schellnhuber
Founding Director
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“I wish the Ring had never come to me. I wish none of this had happened.”
“So do all who live to see such times, but that is not for them to decide. All we have to decide is what to do with the time that is given to us.”
Pause
Part III:
Why Have We Failed So Far?
Stoddard et al. (2021)
GREENHOUSE GASES

- CO₂ from Burning Fossil Fuels (62%)
- Energy Related
- Materials Related
- Land Use Related

F-gases (2%)
N₂O from Agriculture, Industry (6%)
CH₄ from Agriculture, Industry (16%)
CO₂ from Deforestation, Land Use (11%)
CO₂ from Cement, Industrial Chemicals (3%)

Image: Jonathan Foley
Source: IPCC WG3

Copyright © 2021, Project Drawdown
Every tonne of CO₂ emissions adds to global warming

Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO₂ emissions (GtCO₂)

The near linear relationship between the cumulative CO₂ emissions and global warming for five illustrative scenarios until year 2050

Historical global warming

Cumulative CO₂ emissions since 1850

GtCO₂

IPCC AR6 WGI SPM

<table>
<thead>
<tr>
<th>Global warming between 1850–1900 and 2010–2019 (°C)</th>
<th>Historical cumulative CO₂ emissions from 1850 to 2019 (GtCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.07 (0.8–1.3; likely range)</td>
<td>2390 (± 240; likely range)</td>
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<tr>
<th>Approximate global warming relative to 1850–1900 until temperature limit (°C)*1</th>
<th>Additional global warming relative to 2010–2019 until temperature limit (°C)</th>
<th>Estimated remaining carbon budgets from the beginning of 2020 (GtCO₂)</th>
<th>Variations in reductions in non-CO₂ emissions*3</th>
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</thead>
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<tr>
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<td>Likelihood of limiting global warming to temperature limit*2</td>
<td>Higher or lower reductions in accompanying non-CO₂ emissions can increase or decrease the values on the left by 220 GtCO₂ or more</td>
</tr>
<tr>
<td>1.5</td>
<td>0.43</td>
<td>900 650 500 400 300</td>
<td></td>
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<tr>
<td>1.7</td>
<td>0.63</td>
<td>1450 1050 850 700 550</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>0.93</td>
<td>2300 1700 1350 1150 900</td>
<td></td>
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</tbody>
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*1 Allen et al (2009); Peters (2019)
Limiting warming to 1.5°C is increasingly difficult without large-scale negative emissions

Pathway to 1.5°C given cumulative emissions in 2000.

Pathway to 1.5°C given cumulative emissions in 2021.
Three Decades of Climate Mitigation: Why Haven't We Bent the Global Emissions Curve?

Annual Review of Environment and Resources
Vol. 46:653-689 (Volume publication date October 2021)
First published as a Review in Advance on June 29, 2021
https://doi.org/10.1146/annurev-environ-012220-011104

Isak Stoddard,1 Kevin Anderson,1,2 Stuart Capstick,3 Wim Carton,4 Joanna Depledge,5 Keri Facer,1,6 Clair Gough,2 Frederic Hache,7 Claire Hoolahan,2,3 Martin Hultman,8 Niclas Hällström,9 Sivan Kartha,10 Sonja Klinsky,11 Magdalena Kuchler,1 Eva Lövbrand,12 Naghmeh Nasiritousi,13,14 Peter Newell,15 Glen P. Peters,16 Youba Sokona,17 Andy Stirling,18 Matthew Stilwell,19 Clive L. Spash,20 and Mariama Williams17

Davos Cluster
International Climate Governance
Vested Interests of the Fossil Fuel Industry
Geopolitics & Militarism

Enabler Cluster
Economics & Financialization
Mitigation Modelling
Energy Supply System

Ostrich Cluster
Inequity
High-Carbon Lifestyles
Social Imaginaries
Three Decades of Climate Mitigation: Why Haven't We Bent the Global Emissions Curve?

Isak Stoddard,¹ Kevin Anderson,¹,² Stuart Capstick,³ Wim Carton,⁴ Joanna Depledge,⁵ Keri Facer,¹,⁶ Clair Gough,² Frederic Hache,⁷ Claire Hoolohan,²,³ Martin Hultman,⁸ Niclas Hällström,⁹ Sivan Kartha,¹⁰ Sonja Klinsky,¹¹ Magdalena Kuchler,¹ Eva Lövbrand,¹² Naghmeh Nasiritousi,¹³,¹⁴ Peter Newell,¹⁵ Glen P. Peters,¹⁶ Youba Sokona,¹⁷ Andy Stirling,¹⁸ Matthew Stilwell,¹⁹ Clive L. Spash,²⁰ and Mariama Williams¹⁷

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**Ostrich Cluster**
- Inequity
- High-Carbon Lifestyles
- Social Imaginaries
Fossil Fuelled Lies

Society’s Understanding & Actions

Big Oil’s Understanding & Actions

Franta (2018a,b); Franta (2021a,b); Farrell (2016); Supran & Oreskes (2017,2021a,b); McKibben (2015); Bonneuil et al. (2021); Franta & Supran (2017)
## Fossil Fuelled Lies

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<td>• 2015: Paris Agreement</td>
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Fossil Fuelled Lies

Society’s Understanding & Actions

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• 1988: IPCC forms
• 1992: UNFCCC
• 1997: Kyoto Protocol signed
• 2015: Paris Agreement

Big Oil’s Understanding & Actions

• 1959: Edward Teller warns Big Oil
• 1965: President of API warns Big Oil
• 1979-83: Exxon internal research programme
• 1980: API argues for tripling coal
• 1987: IPIECA Strategy meeting
  Emphasise uncertainties
  Stress the cost of action
  Focus on policies that do not threaten fossil fuels
  Insist on ‘detection before action’
• 1989-2002: Global Climate Coalition
• 2000-now: Greenwashing

Franta (2018a,b); Franta (2021a,b); Farrell (2016); Supran & Oreskes (2017,2021a,b);
McKibben (2015); Bonneuil et al. (2021); Franta & Supran (2017)
Three Decades of Climate Mitigation: Why Haven't We Bent the Global Emissions Curve?

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Hausfather (2018); Evans & Hausfather (2018)
How do Integrated Assessment Models work?

- GDP
- Population
- Policies
- Other assumptions
- Economy
- Energy system
- Land system
- Climate
- Economic Outcomes
- Emissions
- Energy pathways
- Land use

Hausfather (2018); Evans & Hausfather (2018); Pindyck (2013); Farmer et al. (2015); Creutzig et al. (2017); Anderson & Jewell (2019); Hickel et al. (2021)
Integrated Assessment Models

• Based on neoclassical economics
  • Rational agents, full information
  • Markets work, no wasted investments, no unemployment
  • Reduction in economic activity by definition a cost
  • Economic growth can be decoupled from emissions (“green growth”)

• Discount rate
  • Weigh near-time costs more heavily than those in the future
  • Action today is more costly than action tomorrow

• Under-predicted the fall in the cost of renewables
  • Overstated the cost of rapid decarbonisation

• Focus on market-based solutions (e.g., carbon price)
• Focus on technological innovation such as large-scale negative emissions technology

Hausfather (2018); Evans & Hausfather (2018); Pindyck (2013); Farmer et al. (2015); Creutzig et al. (2017); Anderson & Jewell (2019); Hickel et al. (2021)
No quick fixes

Modelers generally report net carbon emissions, unintentionally hiding the scale of negative emissions. Separating out the positive CO₂ emissions from fossil fuel combustion, industry, and land-use change reveals the scale of negative CO₂ emissions in the model scenarios (16). INDCs, Intended Nationally Determined Contributions.

![Graph showing global CO₂ emissions from 1980 to 2100, with a focus on emission pledges and realized emissions.](image)

“Negative-emission technologies are not an insurance policy, but rather an unjust and high-stakes gamble.”

- Anderson & Peters (2016)

Hickman (2016)
Sen & Dabi (2021)
Carbon Brief

Land used exclusively for removal* could compete with food production

- Land for carbon removal: 1.62bn ha
- Cropland worldwide: 1.5bn ha

*Afforestation, reforestation and BECCS
ECONOMICS

Unraveling the claims for (and against) green growth
Can the global economy grow indefinitely, decoupled from Earth's limitations?

By Tim Jackson¹ and Peter A. Victor²

Comment | Published: 04 August 2021

Urgent need for post-growth climate mitigation scenarios

Jason Hickel, Paul Brockway, Giorgos Kallis, Lorenz KeyBer, Manfred Lenzen, Aljoša Slameršak, Julia Steinberger & Diana Ţurgh-Vorsatz

Nature Energy 6, 766-768 (2021) | Cite this article

2218 Accesses | 1476 Altmetric | Metrics

ABSTRACT
The notion of green growth has emerged as a dominant policy response to climate change and ecological breakdown. Green growth theory asserts that continued economic expansion is compatible with our planet's ecology, as technological change and substitution will allow us to absolutely decouple GDP growth from resource use and carbon emissions. This claim is now assumed in national and international policy, including in the Sustainable Development Goals. But empirical evidence on resource use and carbon emissions does not support green growth theory. Examining relevant studies on historical trends and model-based projections, we find that: (1) there is no empirical evidence that absolute decoupling from resource use can be achieved on a global scale against a background of continued economic growth, and (2) absolute decoupling from carbon emissions is highly unlikely to be achieved at a rate rapid enough to prevent global warming over 1.5°C or 2°C, even under optimistic policy conditions. We conclude that green growth is likely to be a misguided objective, and that policymakers need to look toward alternative strategies.

KEYWORDS
Sustainable development; ecological economics; green growth; degrowth; decoupling

Wiedmann et al. (2020); Haberl et al. (2020); Jackson & Victor (2019); Hickel & Kallis (2019); Hickel et al. (2021); Hickel & Hallegatte (2021)
Climate Change Policy: What Do the Models Tell Us?

Robert S. Pindyck

Abstract

Very little. A plethora of integrated assessment models (IAMs) have been constructed and used to estimate the social cost of carbon (SCC) and evaluate alternative abatement policies. These models have crucial flaws that make them close to useless as tools for policy analysis: certain inputs (e.g., the discount rate) are arbitrary, but have huge effects on the SCC; estimates the models produce; the models' descriptions of the impact of climate change are completely ad hoc, with no theoretical or empirical foundation; and the models can tell us nothing about the most important driver of the SCC, the possibility of a catastrophic climate outcome. IAM-based analyses of climate policy create a perception of knowledge and precision, but that perception is illusory and misleading.

The appallingly bad neoclassical economics of climate change

Steve Keen

Institute for Strategy, Resilience and Security, University College London, London, UK

ABSTRACT

Forecasts by economists of the economic damage from climate change have been notably sanguine, compared to warnings by scientists about damage to the biosphere. This is because economists made their own predictions of damages, using three spurious methods: assuming that about 90% of GDP will be unaffected by climate change, because it happens indoors; using the relationship between temperature and GDP today as a proxy for the impact of global warming over time; and using surveys that diluted extreme warnings from scientists with optimistic expectations from economists. Nordhaus has misrepresented the scientific literature to justify the using a smooth function to describe the damage to GDP from climate change. Correcting for these errors makes it feasible that the economic damages from climate change are at least an order of magnitude worse than forecast by economists, and may be so great as to threaten the survival of human civilization.

Keen (2020)
Pindyck (2013)
Evans, Pidcock, & Yeo (2017)
Three Decades of Climate Mitigation: Why Haven't We Bent the Global Emissions Curve?

Annual Review of Environment and Resources
Vol. 46:653-689 (Volume publication date October 2021)
First published as a Review in Advance on June 29, 2021
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Isak Stoddard,1 Kevin Anderson,1,2 Stuart Capstick,3 Wim Carton,4 Joanna Depledge,5 Keri Facer,1,6 Clair Gough,2 Frederic Hache,7 Claire Hoolohan,2,3 Martin Hultman,8 Niclas Hållström,9 Sivan Kartha,10 Sonja Klinsky,11 Magdalena Kuchler,1 Eva Lövbrand,12 Naghmeh Nasirousi,13,14 Peter Newell,15 Glen P. Peters,16 Youba Sokona,17 Andy Stirling,18 Matthew Stilwell,19 Clive L. Spash,20 and Mariama Williams17

Davos Cluster

International Climate Governance

Vested Interests of the Fossil Fuel Industry

Geopolitics & Militarism

Enabler Cluster

Economics & Financialization

Mitigation Modelling

Energy Supply System

Ostrich Cluster

Inequity

High-Carbon Lifestyles

Social Imaginaries
Carbon Inequality

Top 1%: > 94,000 € / year
Top 10%: > 32,800 € / year
Billionaire Emissions

Estimates of wealth are based on Feb. 15 data, according to Forbes, except for Sheldon Adelson, who died in January.

Shift the focus from the super-poor to the super-rich

Ilona M. Otto, Kyoung Mi Kim, Nika Dubrovsky & Wolfgang Lucht

Nature Climate Change 9, 82–84 (2019) | Cite this article

4864 Accesses | 28 Citations | 1921 Altmetric | Metrics

Scientists’ warning on affluence

Thomas Wiedmann, Manfred Lenzen, Lorenz T. Keyßer & Julia K. Steinberger

Nature Communications 11, Article number: 3107 (2020) | Cite this article

171k Accesses | 107 Citations | 4550 Altmetric | Metrics

The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions

Kristian S. Nielsen, Kimberly A. Nicholas, Felix Creutzig, Thomas Dietz & Paul C. Stern

Nature Energy 6, 1011–1016 (2021) | Cite this article

12k Accesses | 671 Altmetric | Metrics

Otto et al. (2019); Wiedmann et al. (2020); Nielsen et al. (2021)
Responsibility for climate breakdown

USA (40%)

EU-28 (29%)

Rest of Europe (13%)

Rest of Global North (10%)

Global South (8%)

Hickel (2020)

Anderson et al. (2020)
Mittal & Bassey Event
Climate Reparations
Learning From Ladakh

In-depth Q&A: What is ‘climate justice’?
Three Decades of Climate Mitigation: Why Haven't We Bent the Global Emissions Curve?

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- Geopolitics & Militarism

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"I’ve been there all along, and it had taken me too long to figure out what was happening. I wrote the first book about [climate change] and I kept writing more books, articles, and having symposiums on the theory that if we kept piling up enough data and reason eventually the powers that be would get to work — why wouldn’t they?

- Bill McKibben
"I’ve been there all along, and it had taken me too long to figure out what was happening. I wrote the first book about [climate change] and I kept writing more books, articles, and having symposiums on the theory that if we kept piling up enough data and reason eventually the powers that be would get to work — why wouldn’t they?

I thought that we were in an argument. And it took me too long to figure out that we won the argument, but that that didn’t mean anything. We won the argument — the science was entirely robust and clear. We were just losing the fight.

- Bill McKibben
"I’ve been there all along, and it had taken me too long to figure out what was happening. I wrote the first book about [climate change] and I kept writing more books, articles, and having symposiums on the theory that if we kept piling up enough data and reason eventually the powers that be would get to work — why wouldn’t they?

I thought that we were in an argument. And it took me too long to figure out that we won the argument, but that that didn’t mean anything. We won the argument — the science was entirely robust and clear. We were just losing the fight.

**Because the fight wasn’t about data and reason, the fight was about money and power, which is what fights are always about.**”

- Bill McKibben
Pause
Part IV:
What Can We Do Today?
It’s easy to feel pessimistic about the climate. But we’ve got two big things on our side

*Bill McKibben*
The price of electricity from new power plants are expressed in "levelized costs of energy" (LCOE). LCOE captures the cost of building the power plant itself as well as the ongoing costs for fuel and operating the power plant over its lifetime.

The price of electricity from solar declined by 89% in these 10 years.

The price of onshore wind electricity declined by 70% in these 10 years.

How to waste over half a trillion dollars

The economic implications of deflationary renewable energy for coal power investments

The sky’s the limit

Solar and wind energy potential is 100 times as much as global energy demand

Report I; Report II
Campanale Interview
Way et al. (2021); Roser (2020)

Ahead of next week’s United Nations climate summit, the focus is on one crucial question: How many degrees hotter will the Earth get?

Pre-Paris policies
+4.2°C to 3.6°C projected warming above preindustrial levels by 2100

In 2014, before the Paris climate agreement, the world was on track to heat up nearly 4 degrees Celsius (7.2 degrees Fahrenheit) by the end of the century, an outcome widely seen as catastrophic.

Current policies
+3.1°C to 2.7°C

Today, thanks to rapid growth in clean energy, humanity is on pace for roughly 3 degrees Celsius of warming by 2100 — a better result, but still devastating.

1.5°C-compatible
less than +1.5°C

Yet scientists and world leaders increasingly say even that much warming is too risky. To hold global temperature rise to a safer limit of 1.5 degrees Celsius, far more drastic action is needed.

Pledges
+2.4°C to 2.1°C

Many countries have vowed to slash emissions even faster. If nations follow through, the world could potentially limit total warming to around 2 to 2.4 degrees Celsius by 2100.

Source: Climate Action Tracker | Note: The graphic does not include Climate Action Tracker’s “optimistic net-zero targets” pathway.
The group based its 1.5°C-compatible pathway on scenarios from IPCC’s Special Report on Global Warming of 1.5°C.  Nadia Popovich and Bill Marsh/The New York Times
Nielsen et al. (2021a, b, c, d)
Carbon Footprint Reduction

• Stop or lower air travel

• Stop driving petrol cars

• Reduce your meat consumption, especially beef

• Talk about it!

An Audacious Toolkit: Actions Against Climate Breakdown (Part 3: I is for Individual)

Your Personal Action Guide for the Environment

Solving our biggest environmental problems will require huge changes in policy and business practice. But it turns out that our personal actions can help too, if we focus on the right things. Here are some places to start.

Ivanova et al. (2020); Steinberger (2018); Foley (2020)
- Divestment (Personal & Organizational)
- Donations to environmental organizations
- Influence through position / status

Organize lectures / workshops
High-level interventions
(Reduce meat in cafeteria, at parties, disincentivize flights, etc.)
- Vote
- Talk about the climate crisis (urgency and agency)
- Contagion of low-carbon lifestyle (social norm shift)
• Vote
• Talk about the climate crisis (urgency and agency)
• Contagion of low-carbon lifestyle (social norm shift)

• Mobilize, mobilize, and mobilize

• Get together with other people and mobilize
• Vote
• Talk about the climate crisis (urgency and agency)
• Contagion of low-carbon lifestyle (social norm shift)

• Dedicate some time to change the world

Monbiot Podcast
Monbiot Interview
Stop Line 3 Documentary
Tipping positive change

Sensitive intervention points in the post-carbon transition
We must exploit socioeconomic tipping points and amplifiers

Social tipping dynamics for stabilizing Earth’s climate by 2050

Lenton (2019); Farmer et al. (2019); Otto et al. (2020); Hepburn et al. (2020); Winkelmann et al. (2020)
Government spending rose 10 fold from 1940 to 1945
National speed limit of 35 mph to conserve fuel, car sharing
Manufacturing of cars, construction of new homes banned
Rationing of gasoline, meat, butter, sugar etc.
Income taxes of up to 94%
“We need a billion climate activists.”

Strategy

- Peter Kalmus
We can despair and plunge into paralysis or we can become stubborn optimists with a fierce conviction that no matter how difficult, we must and we can rise to the challenge.

– Christiana Figueres
Pause
Part V: Climate Action with En-ROADS

Interactive Part
NOTES AND INSIGHTS

Climate interactive: the C-ROADS climate policy model

John Sterman, Thomas Fiddaman, Travis Franck, Andrew Jones, Stephanie McCauley, Philip Rice, Elizabeth Sawin and Lori Siegel

*Corresponding Author

Online Course

Appendix
Miscellaneous
Sustainability Resources
Fabian Dablander & Andrea Bacilieri

We recently started to curate a list of resources that we found useful and that we can recommend to others (including those outside the climate bubble). Note that the items are in no particular order, and that they need not necessarily express our views.

Online courses / Lecture series

- Mastering En-ROADS by Climate Interactive
- Climate Solutions 101 by Project Drawdown
- Oxford School of Climate Change
- Oxford Climate Society YouTube Channel
  - Especially the talks by Noam Chomsky as well as by Nimmo Bassey and Anuradha Mittal.

Books

- Thinking in Systems
- The Future We Choose
- The New Climate War
- Merchants of Doubt
- Doughnut Economics
- This Changes Everything
- Designing Regenerative Cultures
- Think Like a Commoner
- Less is More
- The Divide
- To Cook a Continent
- Revolutions That Made the Earth
- Earth System Science: A Very Short Introduction
- Climate Change: A Very Short Introduction
- This Is an Uprising
- How to Blow Up a Pipeline
- The Ministry for the Future
- The Great Derangement
- The Collapse of Western Civilization

Podcasts

- Drilled
- The Climate Pod
- Sustain Ability - The Potsdam Dialogues
- The Sustainability Agenda
  - Especially the episodes with Daniel Wahl, Rupert Read, Will Steffen, John Foley, Tim Lenton, Jason Hickel, Naomi Klein, Mark Campanale.

News / Newsletters

- Carbon Brief
- Mongabay
- Inside Climate News
- Bill McKibben's Newsletter [Superseded by his Substack]
- George Monbiot's weekly columns at The Guardian

Documentaries

- Breaking Boundaries
- David Attenborough: A Life on Our Planet
- Chasing Ice
- Chasing Coral
- Tomorrow
- How To Change the World
- The End of the Line
- Seaspiracy
- Cowspiracy
- Kiss the Ground
- The True Cost
- The End of Poverty?
- The Four Horsemen
- The Corporation
- Gasland
- The Prize: The Epic Quest for Oil, Money, and Power
- Ancient Futures: Learning from Ladakh
- LN3: Teachings of the Anishinaabe Resistance
Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling.

**Observed warming**
- a) Observed warming 2010-2019 relative to 1850-1900

**Contributions to warming based on two complementary approaches**
- b) Aggregated contributions to 2010-2019 warming relative to 1850-1900, assessed from attribution studies
- c) Contributions to 2010-2019 warming relative to 1850-1900, assessed from radiative forcing studies

- Total human influence
- Well-mixed greenhouse gases
- Other human drivers
- Solar and volcanic drivers
- Internal variability

**Mainly contribute to changes in non-\(\text{CO}_2\) greenhouse gases**
- Carbon dioxide
- Methane
- Nitrous oxide
- Halogenated gases
- Nitrogen oxides
- Volatile organic compounds and carbon monoxide
- Sulphur dioxide

**Mainly contribute to changes in anthropogenic aerosols**
- Organic carbon
- Ammonia
- Black carbon
- Land-use reflectance
- Aviation contrails

IPCC AR6 WGI SPM
GREENHOUSE GAS SOURCES

- Electricity Production: 25%
- Industry: 21%
- Food, Agriculture, Land Use: 24%
- Transportation: 14%
- Buildings: 6%
- Other: 10%
- Flaring/Fugitive: 6%
- Other Energy: 4%
- Buildings: Commercial/Other: 2%
- Buildings: Residential: 4%
- Transportation: Other: 2%
- Transportation: Flying: 2%
- Transportation: Road: 10%
- Industry: Waste: 3%
- Industry: Chemicals: 3%
- Industry: Cement: 3%
- Industry: Metals: 5%
- Industry: Other: 7%
- Electricity Used in Buildings: 12%
- Electricity Used in Industry: 11%
- Other Electricity Use: 2%
- Deforestation, Other Land Use: 9%
- Methane from Animals: 5%
- Methane from Rice: 1%
- Nitrous Oxide from Fertilizer, Manure: 4%
- Other Food, Agriculture, Land Use: 5%

Image: Jonathan Foley

Source: IPCC WG3 AR5

Copyright © 2021, Project Drawdown
a. Trends in global greenhouse gas emissions and the impact of alternative GWP metrics

b. Trends in global greenhouse gas emissions and their uncertainties
a. Trends in global and regional greenhouse gas emissions

b. Recent emission change by region vs. rates compatible with warming targets
*Emissions from fossil fuels and cement only (excluding international aviation and shipping). Note that emissions from agriculture, forestry, and other land use are not part of the data.*
The countries with the largest cumulative emissions 1850-2021

Billions of tonnes of CO2 from fossil fuels, cement, land use and forestry

United States
China
Russia
Brazil
Indonesia
Germany
India
United Kingdom
Japan
Canada
Ukraine
France
Australia
Argentina
Mexico
South Africa
Poland
Thailand
Italy
Iran

Evans (2021)
Fossil fuel CO2 emissions have risen dramatically since 1950

Until then, the largest source of CO2 was land use and forestry

Evans (2021)
Carbon inequality across EU member states

Gore & Alestig (2020)
Individualism
Individuals and consumers are ultimately responsible for taking actions to address climate change.

Whataboutism
Our carbon footprint is trivial compared to [...] Therefore it makes no sense for us to take action, at least until [...] does so.

The 'free rider' excuse
Reducing emissions is going to weaken us. Others have no real intention of reducing theirs and will take advantage of that.

Change is impossible
Any measure to reduce emissions effectively would run against current ways of life or human nature and is thus impossible to implement in a democratic society.

Doomism
Any mitigation actions we take are too little, too late. Catastrophic climate change is already locked-in. We should adapt, or accept our fate in the hands of God or nature.

Technological optimism
We should focus our efforts on current and future technologies, which will unlock great possibilities for addressing climate change.

All talk, little action
We are world leaders in addressing climate change. We have approved an ambitious target and have declared a climate emergency.

Fossil fuel solutionism
Fossil fuels are part of the solution. Our fuels are becoming more efficient and are the bridge towards a low-carbon future.

No sticks, just carrots
Society will only respond to supportive and voluntary policies, restrictive measures will fail and should be abandoned.

Someone else should take actions first: redirect responsibility

It's not possible to mitigate climate change: surrender

Disruptive change is not necessary: push non-transformative solutions

Change will be disruptive: emphasize the downsides

Appeal to well-being
Fossil fuels are required for development. Abandoning them will condemn the global poor to hardship and their right to modern livelihoods.

Appeal to social justice
Climate actions will generate large costs. Vulnerable members of our society will be burdened; hard-working people cannot enjoy their holidays.

Lamb, Mattioli, Levi et al. 2020
Discourses of Climate Delay
Global Sustainability
Limiting warming to 1.5°C is increasingly difficult without large-scale negative emissions.

Pathway to 1.5°C given cumulative emissions in 2000.

Pathway to 1.5°C given cumulative emissions in 2021.
The later emissions peak the harder it is to limit warming below 2°C.
Year in which 1.5°C is exceeded in CMIP6 models

Based on both historical temperatures through 2020 and subsequent smoothed CMIP6 data

- SSP1-2.6: Exceedance year 2026 to 2057
- SSP2-4.5: Exceedance year 2026 to 2042
- SSP3-7.0: Exceedance year 2026 to 2038
- SSP5-8.5: Exceedance year 2026 to 2039

Hausfather (2020)
Year in which 2C is exceeded in CMIP6 models

Based on both historical temperatures through 2020 and subsequent smoothed CMIP6 data.

Hausfather (2020)
The World in Global Climate Models

Schematic for Global Atmospheric Model

Horizontal Grid (Latitude-Longitude)

Vertical Grid (Height or Pressure)

PERSPECTIVE

The scientific challenge of understanding and estimating climate change

Tim Palmer and Bjorn Stevens
See all authors and affiliations

PNAS December 3, 2019 116 (48) 24390-24395; first published December 2, 2019; https://doi.org/10.1073/pnas.1906661116

GLOBAL WARMING

Climate panel confronts implausibly hot models
Major IPCC report likely to curb near-term projections with measured warming trend

Voosen (2021)
Palmer & Stevens (2019)
Philip Stier Talk
McSweeney & Hausfather (2018)
Energy Supply
Global primary energy consumption by source


OurWorldInData.org/energy • CC BY

York & Bell (2019)
Wood sustainable 0
Natural gas 201
LPG 227
Gasoline 250
Kerosene 257
Crude oil 264
Diesel 267
Fuel oil 279
Hard coal 354
Lignite 364
Peat 382
Wood not sustainable 395

Source
On Biofuels
Fossil fuel industry gets subsidies of $11m a minute, IMF finds

Trillions of dollars a year are ‘adding fuel to the fire’ of the climate crisis, experts say

Fossil fuels benefitted from subsidies of $5.9 trillion in 2020

Explicit price subsidies and implicit environmental, health and tax subsidies ($ billion)

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Guardian graphic | Source: IMF
In the 5 years since the Paris Agreement, the world’s 60 biggest banks have financed fossil fuels to the tune of $3.8 trillion. Runaway funding for fossil fuel extraction and infrastructure fuels climate chaos and threatens the lives and livelihoods of millions.
US auctions off oil and gas drilling leases in Gulf of Mexico after climate talks

Biden administration launching auction of more than 80m acres for fossil fuel extraction that experts call 'incredibly reckless'

Emissions must fall 60% in 9 years & the IEA says zero new oil & gas projects for a hope of even 'net' zero. So it would be reasonable to assume laws are being passed to end exploration right? In fact, the world is on an oil & gas binge. A shocking, terrifying, revolutionary

Unextractable fossil fuels in a 1.5 °C world

Dan Welsby, James Price, Steve Pye & Paul Ekins

Nature 597, 230–234 (2021) | Cite this article

52k Accesses | 7 Citations | 4550 Altmetric | N
The price of electricity from new power plants

Electricity prices are expressed in ‘levelized costs of energy’ (LCOE). LCOE captures the cost of building the power plant itself as well as the ongoing costs for fuel and operating the power plant over its lifetime.

The price of electricity from **solar** declined by **89%** in these 10 years.

The price of onshore **wind** electricity declined by **70%** in these 10 years.

Way et al. (2021); Roser (2020)

Data: Lazard Levelized Cost of Energy Analysis, Version 13.0

OurWorldinData.org – Research and data to make progress against the world’s largest problems. Licensed under CC-BY
How to waste over half a trillion dollars

The economic implications of deflationary renewable energy for coal power investments

Key findings

- New investments in renewables are cheaper than new investments coal in all major markets today.
- Over half of coal plants operating today cost more to run than building new renewables.
- It could be cheaper to build renewables than run coal in all major markets by 2030.
- Governments and investors should cancel coal power projects or risk wasting over $600 bn in capital costs.

March 2020

Source: Report on Gas

Campanale Interview
1 Key findings

There is a huge new cheap energy resource available. With current technology and in a subset of available locations we can capture at least 6,700 PWh p.a. from solar and wind, which is more than 100 times global energy demand.

The opportunity has only just been unlocked. The collapse in renewable costs in the last three years means that half of this solar and wind technical potential now has economic potential, and by the end of the decade it will be over 90% of it.

Land is no constraint. The land required for solar panels alone to provide all global energy is 450,000 km², 0.3% of the global land area of 149 million km². That is less than the land required for fossil fuels today, which in the US alone is 126,000 km², 1.3% of the country.

People will take advantage of the cheap energy. Humans specialise in extracting cheap energy, and fast, as witnessed by the rapid development of shale gas. Now the opportunity has been unlocked, expect continued exponential growth of solar and wind deployment.

The tide is coming in fast. The technical and economic barriers have been crossed and the only impediment to change is political. Sector by sector and country by country the fossil fuel incumbency is being swamped by the rapidly rising tide of new energy technologies.

The fossil fuel era is over. The fossil fuel industry cannot compete with the technology learning curves of renewables, so demand will inevitably fall as solar and wind continue to grow. At the current 15-20% growth rates of solar and wind, fossil fuels will be pushed out of the electricity sector by the mid 2030s and out of total energy supply by 2050.

There are four key groups of countries. They range from those with superabundant renewables potential, more than 1,000 times their energy demand like Namibia, all the way down to those with stretched potential of less than 10 times their demand like South Korea.

Poor countries are the greatest beneficiaries. They have the largest ratio of solar and wind potential to energy demand, and stand to unlock huge domestic benefits. The continent of Africa for example is a renewables superpower, with 39% of global potential.

Germany is a special case. Germany has the third lowest solar and wind technical potential in the world relative to its energy demand. The troubles faced by Germany are therefore highly unusual, and if they can solve them then so can everyone else.

We enter a new era. The unlocking of energy reserves 100 times our current demand creates new possibilities for cheaper energy and more local jobs in a more equitable world with far less environmental stress.
Carbon Pricing

ENVIRONMENTAL RESEARCH LETTERS

TOPICAL REVIEW

Does carbon pricing reduce emissions? A review of ex-post analyses

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E-mail: JF.green@utoronto.ca

Keywords: carbon markets, carbon pricing, climate change, cap and trade, carbon tax

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 ETS, 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 °C—the goal set by the Paris Agreement (Intergovernmental Panel on Climate Change 2018). Overall, the evidence indicates that carbon pricing has a limited impact on emissions.

Green (2019, 2021)
Stokes & Mildenberger (2020)
Deforestation and Afforestation
Deforestation

What are the drivers of tropical deforestation?

Nearly all of global deforestation occurs in tropical and subtropical countries. 70% to 80% is driven by conversion of primary forest to agriculture or tree plantations. Shown is the breakdown of these drivers averaged over the years 2005 to 2013. Further observations since 2013 suggest that drivers have not changed substantially over this period.

- **African beef**: 215,000 ha per year, 4% of deforestation
- **Asian beef (excl. Indonesia)**: 70,000 ha, 1.4%
- **Latin American beef (excl. Brazil)**: 582,000 ha, 11%
- **Brazilian beef**: 1.2 million ha, 24%

41% of deforestation
2.1 million hectares per year
is driven by pasture expansion for beef

Nearly one-fifth (18.4%) of deforestation
950,000 hectares per year
is driven by cropland expansion for oilseeds.
This is dominated by soybean and palm oil.

13% of deforestation
680,000 hectares per year
is driven by expansion of tree plantations
into native forest for paper and wood.

- **Indonesian oilseeds (mainly palm oil)** account for 6.4% of deforestation
- **Indonesian tree plantations** account for 4% of deforestation

Data source: Florence Pendrill et al. (2019). Deforestation displaced: trade in forest-risk commodities and the prospects for a global forest transition. OurWorldinData.org - Research and data to make progress against the world’s largest problems. Licensed under CC-BY by the author Hannah Ritchie.
If Tropical Deforestation were a Country, it Would Rank Third in CO₂e Emissions

Source: Seymour & Busch, 2016.
(1) Ecosystems, not tree planting campaigns, capture and store carbon
(2) Preventing ecosystem destruction is the most cost-effective natural climate solution
(3) Forests can regrow on deforested land without tree planting
(4) Tree plantations sequester less carbon, less securely, than naturally regenerated forests
(5) Tree plantations in grasslands, shrublands, and peatlands destroy biodiversity
(6) Trees can reduce water availability
(7) Trees can warm the atmosphere
(8) Perverse financial incentives lead to rushed planting and high tree mortality
(9) Tree planting threatens rural livelihoods
(10) Tree planting targets the Global South to capture emissions from the Global North

Fleischman et al. (2021); Jones (2021); Marshall (2020); Koberstein & Applegate (2019)
Technological Carbon Removal
Ten options for negative emissions technologies

1. **Direct air capture (DAC)**
   - Sucking carbon dioxide out of the air and either burying it underground or using it in chemical processes to make anything from plastic to fuel.

2. **Cloud treatment to increase alkalinity**
   - Adding alkali to clouds or the ocean to enhance the reaction that sees CO₂ dissolve in water, removing it from the air.

3. **Enhanced weathering**
   - Spreading pulverized rocks onto soils and/or the ocean to ramp up the natural rock weathering process that takes up CO₂ from the atmosphere and eventually sees it washed into the ocean as bicarbonate.

4. **Enhanced ocean productivity**
   - Adding iron or nitrogen to the ocean to increase the rate at which tiny microscopic plants photosynthesise, thus accelerating their take up of atmospheric CO₂.

5. **‘Blue carbon’ habitat restoration**
   - Conservation and restoration of degraded coastal and marine habitats, such as salt marshes, mangroves, and seagrass beds, so they continue to draw CO₂ out of the air.

6. **Afforestation and reforestation**
   - Planting trees where there were previously none (afforestation) or restoring areas where the trees have been cut down or degraded (reforestation).

7. **Bioenergy with carbon capture and storage (BECCS)**
   - Farming bioenergy crops, which extract CO₂ from the atmosphere as they grow, and then burning them for energy and sequestering the resulting emissions underground.

8. **Building with biomass**
   - Using plant-based materials in construction, storing carbon and preserving it for as long as the building remains standing.

9. **Biochar**
   - Burning biomass to create biochar and adding it to soils where it holds on to its carbon for hundreds or thousands of years.

10. **Soil carbon sequestration**
    - Using measures, such as modern farming methods, grassland restoration and creation of wetlands and ponds, to reverse past losses of soil carbon and sequester CO₂.
Transport
Lifecycle greenhouse gas emissions: conventional v Tesla (US battery)

Hausfather (2019)
Global carbon dioxide emissions from aviation

Aviation emissions include passenger air travel, freight and military operations. It does not include non-CO$_2$ climate forcings, or a multiplier for warming effects at altitude.

Aviation has quadrupled since 1966. It doubled since 1987. Since 2010, emissions have increased by 4-5% per year.

Aviation was responsible for 2% of CO$_2$ emissions in 1990, 2.3% in 2000, and 2.8% in 2018, which is 3% of all CO$_2$ emissions.

Source: Lee et al. (2020). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018; based on Sausen and Schumann (2000) & IEA.

Share of global emissions calculated based on total CO$_2$ data from the Global Carbon Project.

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Graver, Rutherford, & Zheng (2020)
Food
Supplementary Table 1. Contribution of top five production-based breadbaskets to global maize, rice, soybean, and wheat production based on 2013-2017 global crop production from the Food and Agricultural Organization. Europe includes all European countries except Russia.
Food: greenhouse gas emissions across the supply chain

Greenhouse gas emissions per kilogram of food product (kg CO₂-equivalents per kg product)

<table>
<thead>
<tr>
<th>Food Category</th>
<th>Emissions per Kilogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef (beef herd)</td>
<td>60</td>
</tr>
<tr>
<td>Lamb &amp; Mutton</td>
<td>24</td>
</tr>
<tr>
<td>Cheese</td>
<td>21</td>
</tr>
<tr>
<td>Pork (dairy herd)</td>
<td>19</td>
</tr>
<tr>
<td>Chocolate</td>
<td>17</td>
</tr>
<tr>
<td>Coffee</td>
<td>12</td>
</tr>
<tr>
<td>Prawns (farmed)</td>
<td>8</td>
</tr>
<tr>
<td>Palm Oil</td>
<td>7</td>
</tr>
<tr>
<td>Pig Meat</td>
<td>6</td>
</tr>
<tr>
<td>Poultry Meat</td>
<td>6</td>
</tr>
<tr>
<td>Olive Oil</td>
<td>5</td>
</tr>
<tr>
<td>Fish (farmed)</td>
<td>4.5</td>
</tr>
<tr>
<td>Eggs</td>
<td>3</td>
</tr>
<tr>
<td>Rice</td>
<td>3</td>
</tr>
<tr>
<td>Fish (wild catch)</td>
<td>3</td>
</tr>
<tr>
<td>Milk</td>
<td>3</td>
</tr>
<tr>
<td>Cane Sugar</td>
<td>2.5</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>2.5</td>
</tr>
<tr>
<td>Wheat &amp; Rye</td>
<td>1.4</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>1.4</td>
</tr>
<tr>
<td>Maize (Corn)</td>
<td>1.0</td>
</tr>
<tr>
<td>Cassava</td>
<td>1.0</td>
</tr>
<tr>
<td>Soynilk</td>
<td>0.9</td>
</tr>
<tr>
<td>Peas</td>
<td>0.9</td>
</tr>
<tr>
<td>Bananas</td>
<td>0.7</td>
</tr>
<tr>
<td>Root Vegetables</td>
<td>0.4</td>
</tr>
<tr>
<td>Apples</td>
<td>0.4</td>
</tr>
<tr>
<td>Citrus Fruit</td>
<td>0.3</td>
</tr>
<tr>
<td>Nuts</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Note: Greenhouse gas emissions are given as global average values based on data across 38,700 commercially viable farms in 119 countries. Data source: Poore and Nemecek (2018). Reducing food’s environmental impacts through producers and consumers. Science. Images sourced from the Noun Project. OurWorldinData.org – Research and data to make progress against the world’s largest problems. Licensed under CC-BY by the author Hannah Ritchie.
Food emissions could consume most of our 1.5°C or 2°C carbon budget

Shown are estimates of cumulative greenhouse gas emissions from food production from 2020 to 2100 based on population, dietary and agricultural trends in a business-as-usual scenario. This is shown relative to total cumulative emissions to keep global average temperature rise below 1.5°C or 2°C by 2100.

1356 billion tonnes (Gt) (between 2020 and 2100)

- **1.5°C budget (67% chance)**
  - 500 Gt from 2020 onwards
  - Even if we stop all emissions from non-food sectors (energy and industry) today, food emissions alone would take us well beyond 1.5°C by 2100.

- **1.5°C budget (50% chance)**
  - 705 Gt from 2020 onwards

- **2°C budget (67% chance)**
  - 1405 Gt from 2020 onwards

- **2°C budget (50% chance)**
  - 1816 Gt from 2020 onwards

To have a 67% chance of staying below 2°C we could emit only 49 billion tonnes of CO₂ from all non-food sectors.

This is equal to just over one year of current fossil fuel emissions (36 billion tonnes).

Note: This is measured in global warming potential (GWP) CO₂ warming-equivalents (CO₂-e).

Source: Michael Clark et al. (2020). Global food system emissions could preclude achieving the 1.5°C and 2°C climate change targets. Science.

OurWorldInData.org - Research and data to make progress against the world's largest problems.
How can we reduce global greenhouse gas emissions from food?

Shown are estimates of cumulative greenhouse gas emissions from food production from 2020 to 2100 under a business-as-usual scenario, and five interventions to reduce emissions. This is measured in global warming potential (GWP*) CO₂ warming-equivalents (CO₂-we).

<table>
<thead>
<tr>
<th>Interventions</th>
<th>Cumulative Emissions (Gt)</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business-As-Usual</td>
<td>1356</td>
<td></td>
</tr>
<tr>
<td><strong>Food emissions from 2020 to 2100 if we achieve one of the following...</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Yields</td>
<td>1162</td>
<td>14%</td>
</tr>
<tr>
<td>Half Food Waste</td>
<td>992</td>
<td>27%</td>
</tr>
<tr>
<td>Healthy Calories</td>
<td>946</td>
<td>30%</td>
</tr>
<tr>
<td>Best farm practices (lower emissions intensity)</td>
<td>817</td>
<td>40%</td>
</tr>
<tr>
<td>Plant-Rich Diet* (reduced meat, not vegan)</td>
<td>708</td>
<td>48%</td>
</tr>
<tr>
<td><strong>Food emissions from 2020 to 2100 if we achieve all of the above, partially (50%) or fully (100)</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial (50%)</td>
<td>506</td>
<td>63%</td>
</tr>
<tr>
<td>Fully (100%)</td>
<td>-7</td>
<td>101%</td>
</tr>
</tbody>
</table>

Under a business-as-usual scenario, food production will emit 1356 billion tonnes. Emissions from food alone will exceed our 1.5°C budget and most of our 2°C budget.

*Based on the EAT-Lancet Planetary Health diet which includes reduces but does not eliminate meat or dairy consumption.

Source: Michael Clark et al. (2020). Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. Science.

OurWorldinData.org – Research and data to make progress against the world’s largest problems.

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Economics
Figure SPM.8 | Climate change mitigation potentials classified in socio-behavioural, infrastructural, and technological options can reduce GHG emissions by 50-80% in end-use sectors by 2050. Drawing on the full potential requires changes in social norms, the provision in low-carbon infrastructures, and wide-range adoption of granular efficient end-use technologies. Electrification of transport, building and industry sector increases the demand on the electricity sector and associated indirect emissions, while demand side measures and load management compensate for this increased load. Based on review of studies estimating demand-side
Equitable Downscaling to Address the Climate Crisis with a focus on Europe

Policy Brief

Andrea Bacilieri, Fabian Dablander, Rayssa Ferrari, Sophie Reisinger, Federico Sibaja, Mara Strenger

Raworth (2017)
System Transformations
STATE OF CLIMATE ACTION 2021
Systems Transformations Required to Limit Global Warming to 1.5°C

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Exponential change possible

Exponential change possible

Exponential change unlikely

ON TRACK

STAGNANT

OFF TRACK

WRONG DIRECTION

WELL OFF TRACK

INSUFFICIENT DATA
Power

Increase the share of renewables in electricity generation to 55-90%

Lower the share of unabated coal in electricity generation to 0-2.5%

Reduce carbon intensity of electricity generation to 50-125 gCO₂/kWh
Transport

Increase the share of electric vehicles to 75-95% of total annual light duty vehicle sales.

Boost the share of battery and fuel cell electric vehicles to reach 75% of global annual bus sales by 2025.
Transport

Transport N/A
Expand the share of electric vehicles to account for 20-40% of total light duty vehicle fleet

Transport N/A
Raise zero-emissions fuel's share of international shipping fuel to 5%

Transport N/A
Increase the share of battery and fuel cell electric vehicles to 8% of global annual medium- to heavy-duty vehicle sales by 2025

Transport 12x
Raise the share of low-emissions fuels in the transport sector to 15%

Transport N/A
Increase sustainable aviation fuel's share of global aviation fuel supply to 10%
Transport

Transport N/A

Reduce the percentage of trips made by private light duty vehicles to between 4% and 14% below BAU levels

Transport Ins. data

Reduce the carbon intensity of land-based passenger transport to 35–60 gCO₂/pkm
Buildings

**Decrease the energy intensity of operations in key countries and regions by 20-30% in residential buildings and by 10-30% in commercial buildings, relative to 2015**

Indexed to 2015; 2015 = 100

- **70-90 Commercial**
- **70-80 Residential**

**Increase buildings’ retrofitting rate to 2.5-3.5% annually**

4%/yr

- **2.5-3.5%**

**Reduce the carbon intensity of operations in select regions by 45-65% in residential buildings and by 65-75% in commercial buildings, relative to 2015 (kgCO₂/m²)**

70 kgCO₂/m²

- **Commercial**: 60.7
- **Residential**: 29.8

**2010-2030**

15.2-21.2

10.4-16.4
Increase the share of electricity in the industry sector's final energy demand to 35%
Industry

**INDUSTRY**

Build and operate 20 low-carbon commercial steel facilities, with each producing at least 1 million tonnes annually

50 low carbon facilities

---

**INDUSTRY**

Boost green hydrogen production capacity to 0.23–3.5 Mt (25 GW cumulative electrolyzer capacity) by 2026

5 Mt

---

**HISTORICAL DATA**

2010 2019 2030

---

**2010 2018 2026**

---

0.01 0.23–3.5
Industry

Reduce carbon intensity of global cement production by 40%, relative to 2015

Reduce carbon intensity of global steel production by 25–30%, relative to 2015
Land Use & Coastal Zone Management

**LAND USE AND COASTAL ZONE MANAGEMENT**

Remove 3.0 GtCO₂ annually through reforestation

- 2010: 0.71 GtCO₂
- 2012: 3 GtCO₂
- 2030: 4.2x increase

**LAND USE AND COASTAL ZONE MANAGEMENT**

Restore 7 Mha of coastal wetlands, relative to 2018

- 2015-2016: 0.43 Mha (cumulative)
- 2030: 7 Mha
- 2.7x increase

**LAND USE AND COASTAL ZONE MANAGEMENT**

Reforest 259 Mha of land, relative to 2018

- 2000-2012: 80.6 Mha (cumulative)
- 2030: 259 Mha
- 3.2x increase
Land Use & Coastal Zone Management

Reduce the rate of deforestation by 70%, relative to 2018

HISTORICAL DATA

2010 2020 2030

12 Mha/yr

6.8 2
Land Use & Coastal Zone Management

Reduce degradation and destruction of peatlands by 70%, relative to 2018

- 1 Mha/yr in 2008
- 0.78 Mha in 2030
- 0.23 Mha/yr in 2030

Restore 22 Mha of peatlands, relative to 2018

- 30 Mha (cumulative) in 2015-2020
- 22 Mha in 2030

Reduce the conversion of coastal wetlands by 70%, relative to 2018

- 0.7 Mha/yr in 2005
- 0.63 Mha in 2030
- 0.19 Mha/yr in 2030
Agriculture

1. **AGRICULTURE 1.5x**
   - Reduce ruminant meat consumption in high-consuming regions to 79 kcal/capita/day by 2030.

2. **AGRICULTURE 1.9x**
   - Increase crop yields by 18%, relative to 2017.

3. **AGRICULTURE 1.6x**
   - Increase ruminant meat productivity per hectare by 27%, relative to 2017.
Agriculture

Reduce agricultural production emissions by 22%, relative to 2017

7 GtCO$_2$e/yr

HISTORICAL DATA

2010 2018 2030

5.3 → 4.2
Agriculture

**AGRICULTURE Ins. data**

Reduce share of food loss by 50%, relative to 2016

- 2010: 16%
- 2016: 14%
- 2030: 7%

**AGRICULTURE Ins. data**

Reduce per capita food waste by 50%, relative to 2019

- 2010: 140 kg/capita/yr
- 2019: 121 kg/capita/yr
- 2030: 60.5 kg/capita/yr
Technological Carbon Removal

Scale up technological carbon removal to 75 MtCO₂ annually
Finance

**Increase total climate finance flows to $5 trillion per year**

- **Historical Data:** $0.64
- **2010:** $6 Trillion US
- **2020:** $5
- **2030:** $5

**Raise public climate finance flows to at least $1.25 trillion per year**

- **Historical Data:** $0.30
- **2010:** $1.4 Trillion US
- **2020:** $1.25
- **2030:** $1.25

**Boost private climate finance flows to at least $3.75 trillion per year**

- **Historical Data:** $0.34
- **2010:** $4 Trillion US
- **2020:** $3.75
- **2030:** $3.75
Finance

Ensure that a carbon price of at least $135/tCO₂e covers the majority of the world’s GHG emissions.
Jurisdictions representing three-quarters of global emissions mandate TCFD-aligned climate risk reporting, and all of the world’s 2,000 largest public companies report on climate risk in line with TCFD recommendations.
Nielsen et al. (2021)
Thank You!