

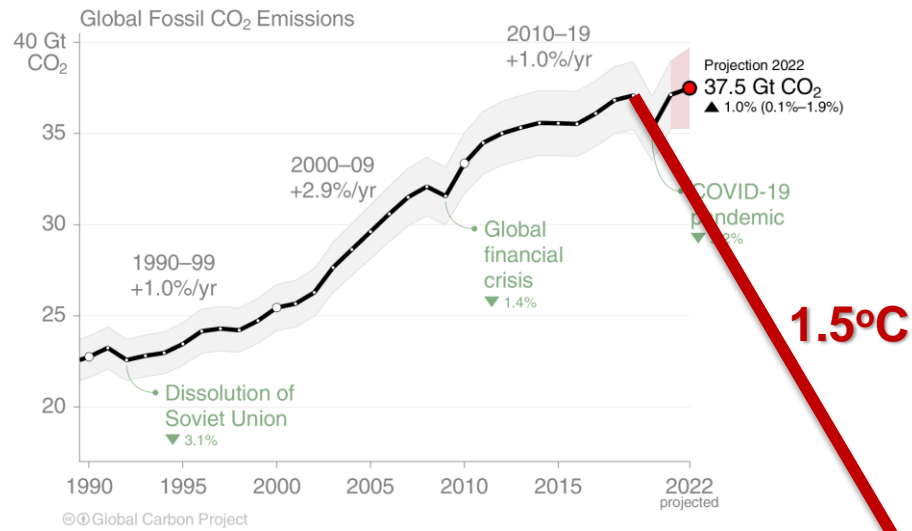
# Geological Net Zero

**Myles Allen**

Department of Physics, University of Oxford  
ECI, School of Geography and the Environment

**Oxford Net Zero**





## Learning from other wars





# The Paris Agreement, 2015

Nations U



United Nations

FCCC/CP/2015/L.9/Rev.1



Framework Convention on  
Climate Change

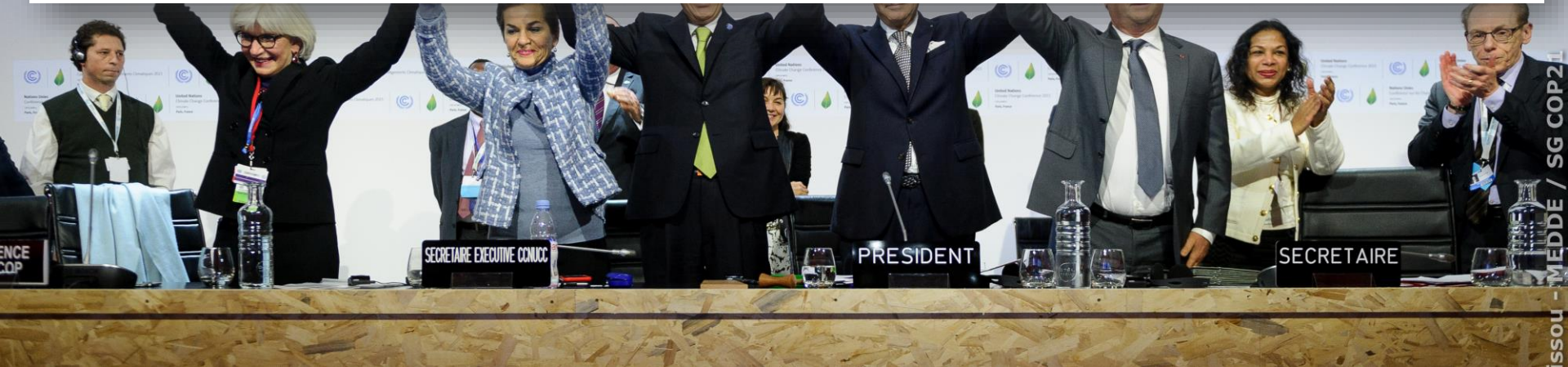
Distr.: Limited  
12 December 2015

Original: English

## Article 2

This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

- (a) Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;



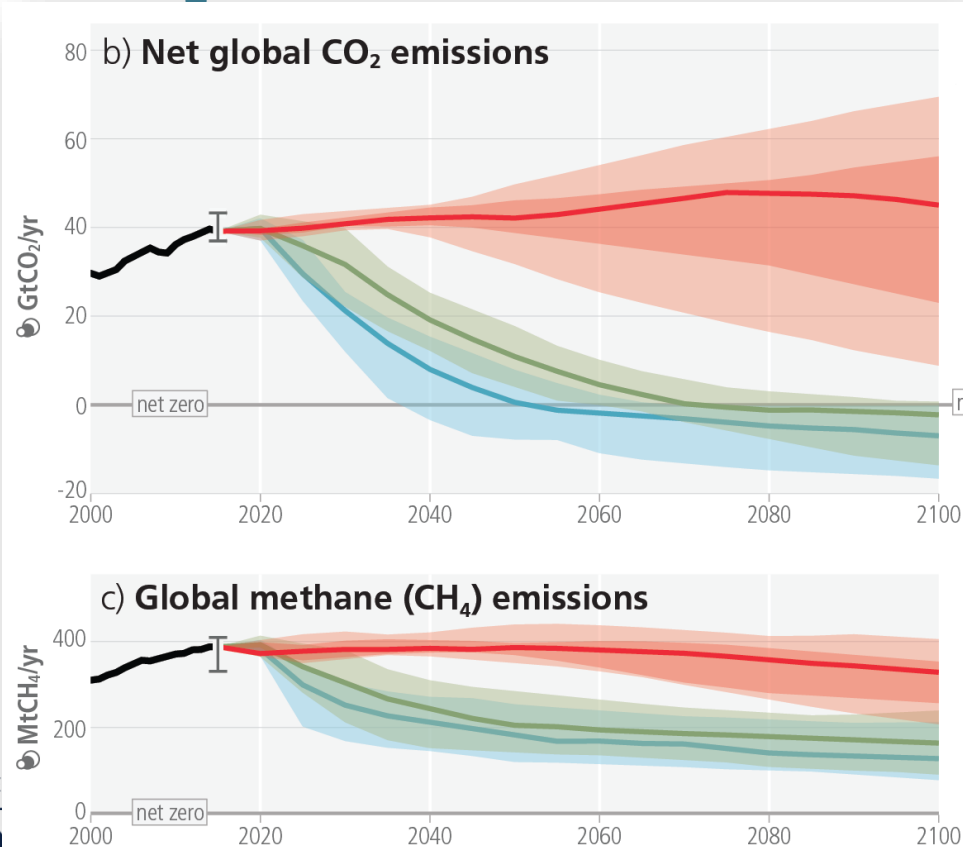
# The IPCC Special Report on 1.5°C, 2018



“Reaching and sustaining net-zero global human-induced CO<sub>2</sub> emissions and declining other emissions, mostly methane, would halt human-induced global warming on multi-decadal timescales (*high confidence*).”

# Halting warming requires (approximately) net zero global CO<sub>2</sub> emissions AND declining methane emissions

CO<sub>2</sub> emissions  
minus removals  
resulting directly  
from ongoing  
human activities



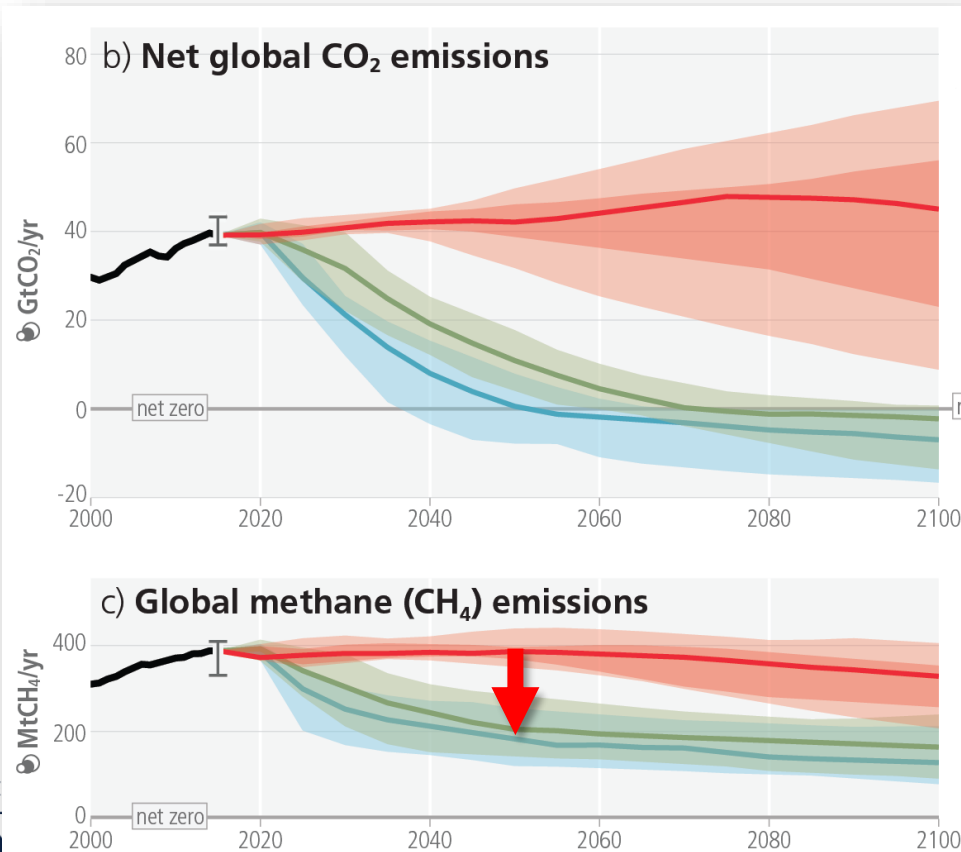
Key

- Implemented policies (median, with percentiles 25-75% and 5-95%)
- Limit warming to 2°C (>67%)
- Limit warming to 1.5°C (>50%) with no or limited overshoot
- Past emissions (2000–2015)

Source: IPCC



# Methane reductions would reduce global temperatures by 0.2-0.3°C



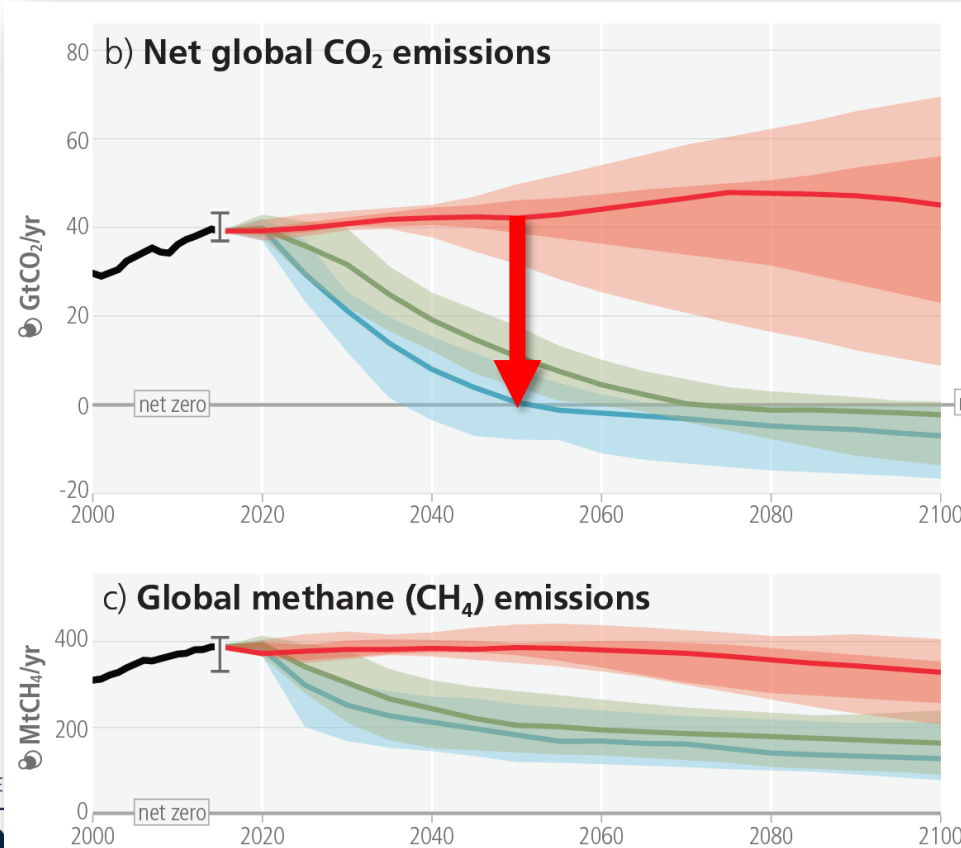
Key

- Implemented policies (median, with percentiles 25-75% and 5-95%)
- Limit warming to 2°C (>67%)
- Limit warming to 1.5°C (>50%) with no or limited overshoot
- Past emissions (2000–2015)

Source: IPCC



# Carbon dioxide reductions would reduce *rate* of global temperature increase by 0.2°C *per decade*



Key

- Implemented policies (median, with percentiles 25-75% and 5-95%)
- Limit warming to 2°C (>67%)
- Limit warming to 1.5°C (>50%) with no or limited overshoot
- Past emissions (2000–2015)

Source: IPCC





# So is it all sorted?

## Nations U

## Conférence sur les Changements Climatiques 2015

COP21/CMP11

## Paris France



United Nations



Framework Convention on  
Climate Change

FCCC/CP/2015/L.9/Rev.1

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Original: English

### Article 4

In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty.



# Some people would like to think so...



  
**10 DOWNING STREET**  
LONDON SW1A 2AA

12 June 2019

THE PRIME MINISTER

I profoundly believe that we share a moral duty to leave a better world for our children than the one we inherited.

So I have been proud to work with all of you – from across business and our whole society – to make rapid progress in moving towards a low-carbon economy. Together, through our actions, we have shown that we do not have to choose between lower emissions and higher economic growth. We can, and must, have both.

Through our Modern Industrial Strategy we are leading the world in the development, manufacture and use of low carbon technologies, creating thousands of new green jobs right across our economy.

We are acting faster than almost every other major developed economy by ending the sale of conventional new diesel and petrol cars and vans by 2040 through our Road to Zero strategy.

We secured more than half our electricity last year from low carbon sources and, just last month, we set a new record for the number of days we have gone without burning any coal. But if we are to do everything possible to mitigate the damaging effects of climate change, we all agree that we must now go further and faster still.

- 2 -

But it can only be delivered by a coalition forged across the breadth of our society. So I want to thank each and every one of you who has written to me to express your support for this landmark proposal.

Of course, it will rightly be for my successor to work with you in building on the policies and progress that we have made in order to seize the full economic potential of a competitive and climate-neutral economy. He or she will also need your help in continuing our international leadership, not least to encourage other nations to join us in setting this highest level of ambition.

But I believe we must start by legislating for this net zero commitment in our own Parliament. And I will be proud to make doing so one of my final acts as Prime Minister.

*Yours sincerely*  


Ending our contribution to global warming by 2050 can be the defining decision of this generation in fulfilling our responsibility to the next.



# Tracking progress to Net Zero



## GLOBAL NET ZERO COVERAGE



Country-level coverage only. We do not include sub-national net zero targets in countries without a target.

## NET ZERO NUMBERS

Countries	Regions
133	143
Cities	Companies
252	923

Out of 198 countries, 709 regions, 1,186 cities and 1,986 companies.



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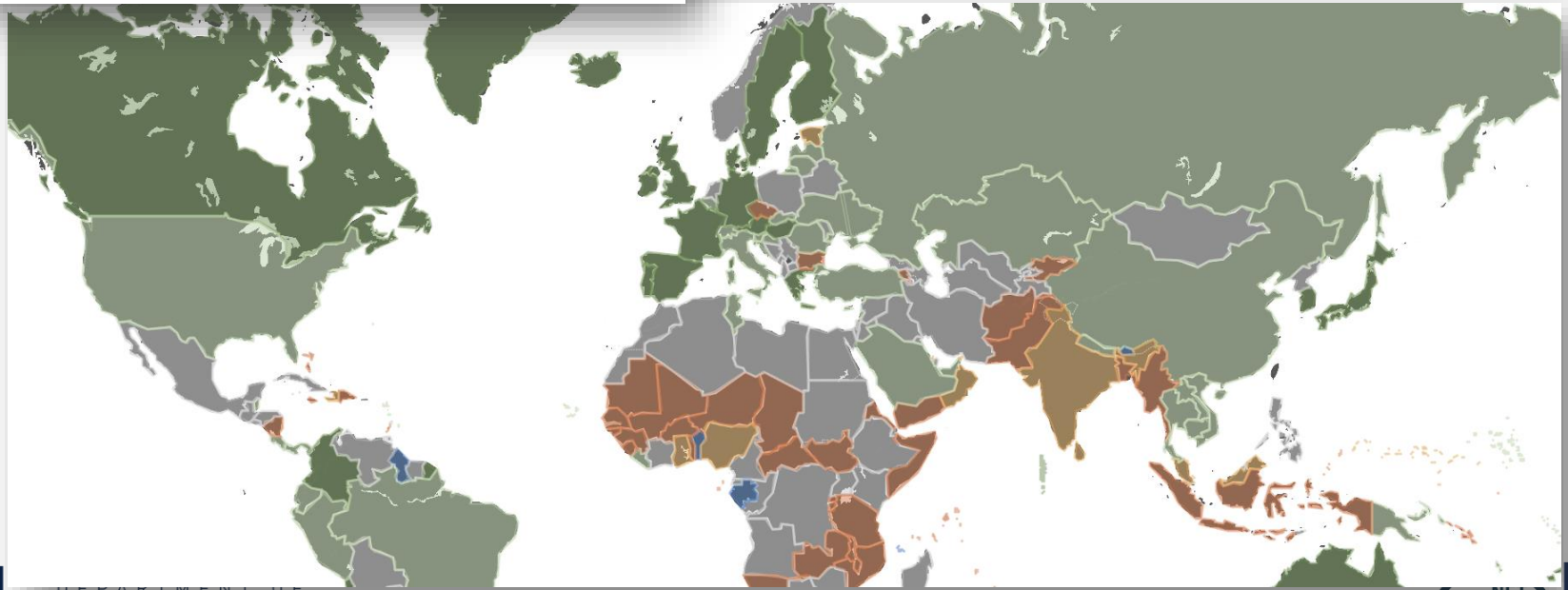
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<https://zerotracker.net>



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# Tracking progress to Net Zero



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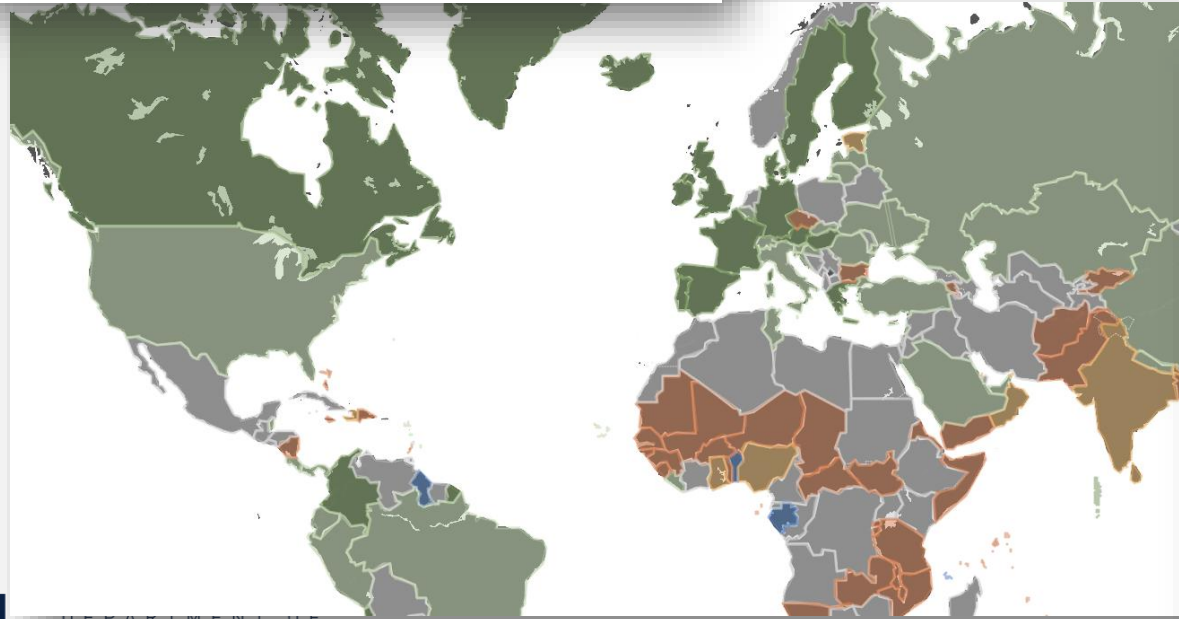
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<https://zerotracker.net>



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# Tracking progress to Net Zero



United Kingdom — 2050

IN LAW

Detailed plan?



Reporting mechanism?



International offset credits?



Greenhouse gas coverage?



FIND OUT MORE



Last updated: 07 Dec 2022



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<https://zerotracker.net>



# Tracking progress to Net Zero



"Gabon pins its hopes for increasing production on offshore exploration efforts."

<https://zerotracker.net>

Gabon — 2050

ACHIEVED (SELF-DECLARED)

Detailed plan?



Reporting mechanism?



International offset credits?



Greenhouse gas coverage?



FIND OUT MORE



Last updated: 21 Feb 2023



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# Climate policy before net zero



## Article 2

### OBJECTIVE

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.



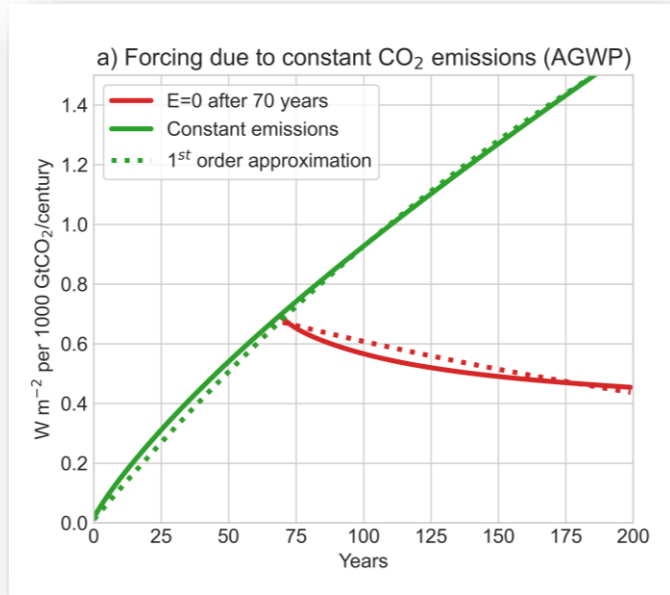
# What changed in 2009?



- Two coordinated papers, Allen et al & Meinshausen et al, making the point that peak warming was determined by cumulative emissions of  $\text{CO}_2$ , so to stop global warming we had to reduce global emissions to net zero.

# What's the science?

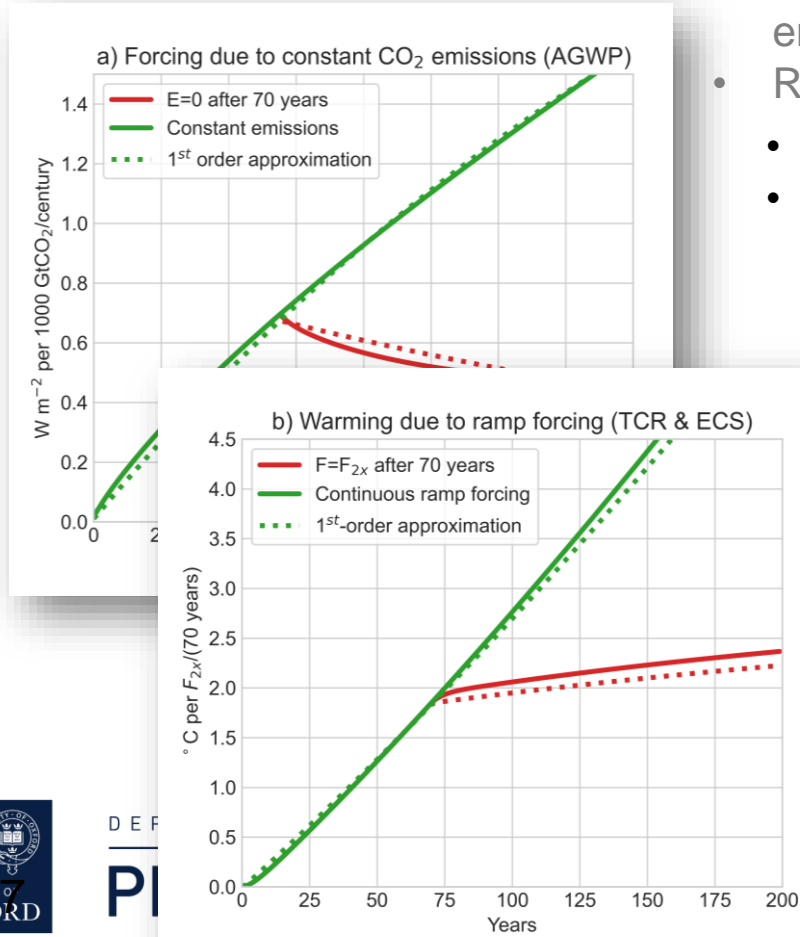
- Green: impact of constant CO<sub>2</sub> emissions on global energy budget (radiative forcing) – curves down
- Red: zero emissions from year 70 – declines





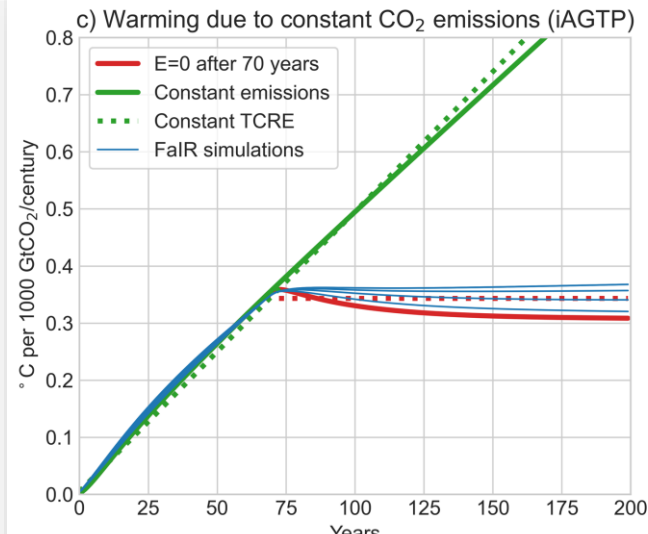
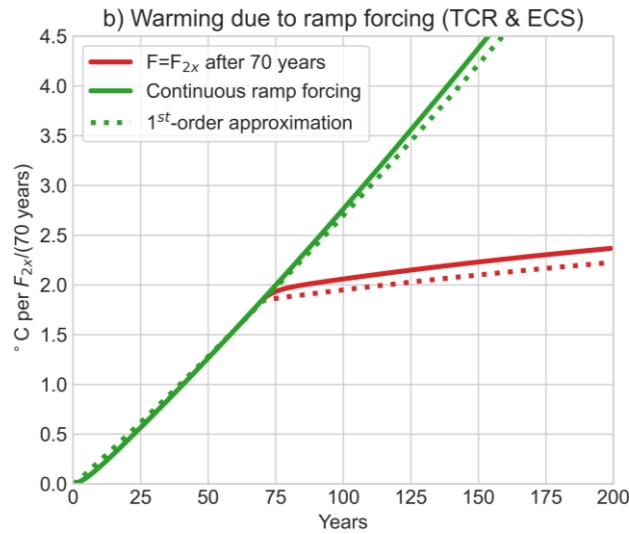
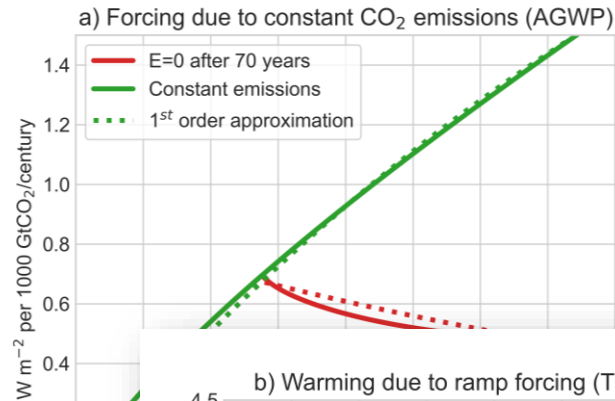
# What's the science?

- Green: impact of constant CO<sub>2</sub> emissions on global energy budget (radiative forcing) – curves down
- Red: zero emissions from year 70 – declines
  - Green: warming due to linear forcing – curves up
  - Red: Stable concentrations from year 70 – warms



# What's the science?

- Green: impact of constant CO<sub>2</sub> emissions on global energy budget (radiative forcing) – curves down
- Red: zero emissions from year 70 – declines
  - Green: warming due to linear forcing – curves up
  - Red: Stable concentrations from year 70 – warms
- Green: warming due to constant CO<sub>2</sub> emissions
- Red: zero emissions from year 70 – stable(ish)



# Drivers of carbon-dioxide-induced warming

$$\Delta T_{CO_2} = \kappa_E [E_{GEO} + E_{LUC}] + (\rho_F + \rho_E) C_E \Delta t$$

X X

Ongoing warming after CO<sub>2</sub>  
concentration stabilization

- Inputs (time- & policy-dependent):

$E_{GEO}$  = Net CO<sub>2</sub> emission rate from fossil fuels and industry

$E_{LUC}$  = Net CO<sub>2</sub> emission rate from direct land-use & nature-based solns.

$C_E$  = Cumulative CO<sub>2</sub> emissions since 1750 About 0.5°C per century for  
stabilization at 1.5-2°C

- Output:

$\Delta T_{CO_2}$  = CO<sub>2</sub>-induced warming over a multi-decade time-interval,  $\Delta t$

- Coefficients (approximately constant):

$\kappa_E$  = Transient Climate Response to Emissions, 0.45 °C per TtCO<sub>2</sub>

$\rho_F$  = Rate of Adjustment to Constant Forcing, 0.3% per year

$\rho_E$  = Rate of CO<sub>2</sub> forcing decline on zero emissions, 0.3% per year



# Drivers of carbon-dioxide-induced warming

$$\Delta T_{CO_2} = \kappa_E [(E_{GEO} + E_{LUC}) + (\rho_F - \rho_E) C_E] \Delta t$$

“Passive” CO<sub>2</sub> removal by  
biosphere and oceans

- Inputs (time- & policy-dependent):

$E_{GEO}$  = Net CO<sub>2</sub> emission rate from fossil fuels and industry

$E_{LUC}$  = Net CO<sub>2</sub> emission rate from direct land-use & nature-based solns.

$C_E$  = Cumulative CO<sub>2</sub> emissions since 1750 About -10 billion tonnes CO<sub>2</sub> per year at 1.5-2°C

- Output:

$\Delta T_{CO_2}$  = CO<sub>2</sub>-induced warming over a multi-decade time-interval,  $\Delta t$

- Coefficients (approximately constant):

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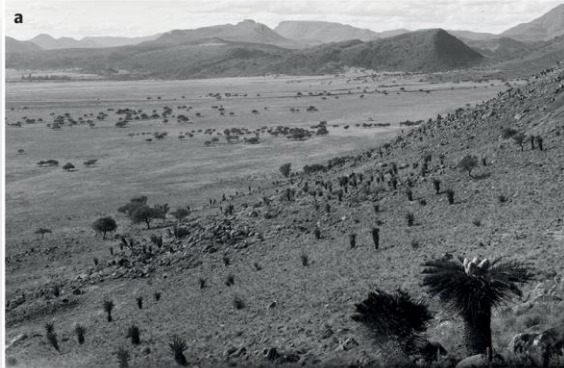
$\rho_E$  = Rate of CO<sub>2</sub> forcing decline on zero emissions, 0.3% per year





# Our biosphere is already responding to past emissions

1925



1993



2011



“CO<sub>2</sub> fertilization” in a relatively undisturbed African savannah

Midgeley & Bond, 2015



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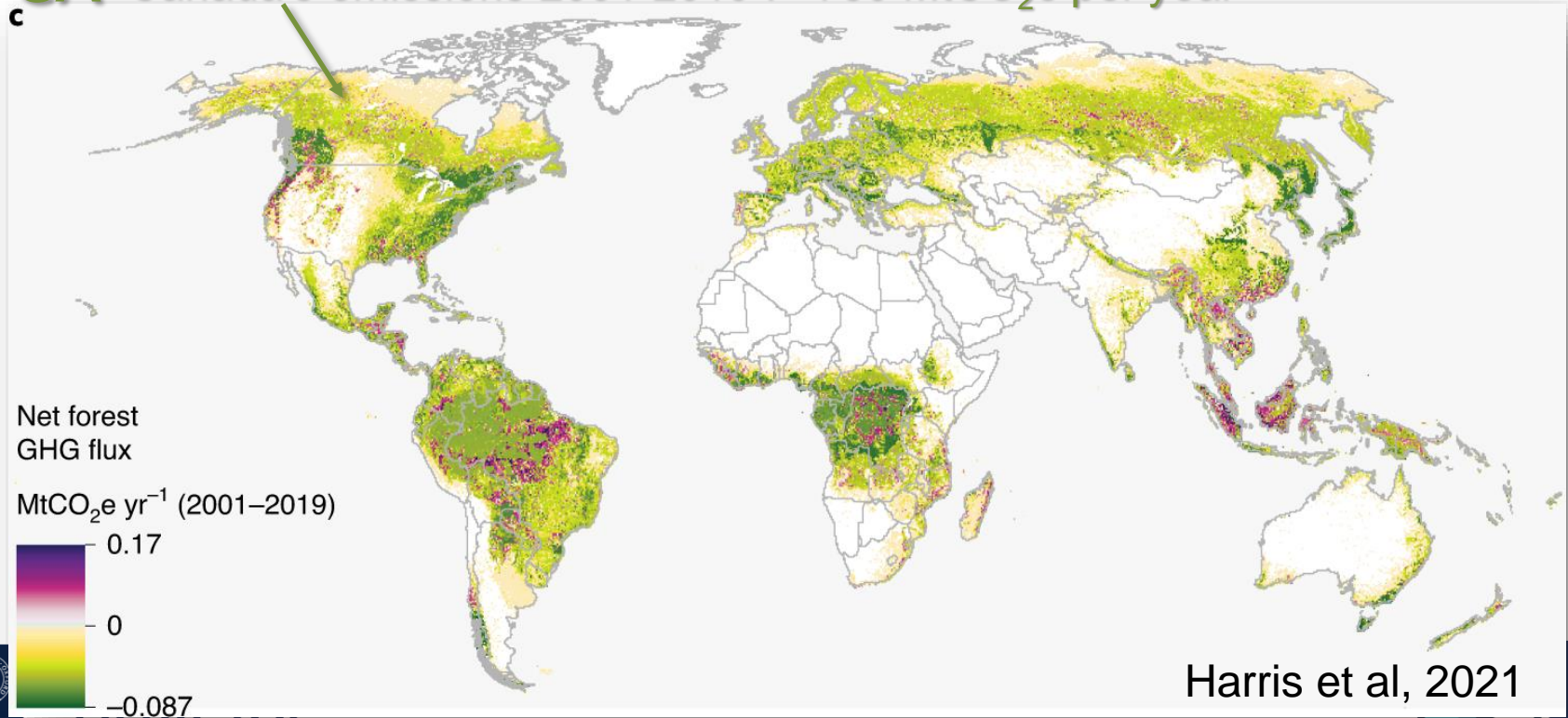


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# Who owns these “passive carbon sinks”?

Canada's forest sink 2001-2019: -950 MtCO<sub>2</sub>e per year

CA Canada's emissions 2001-2019 : +730 MtCO<sub>2</sub>e per year



Harris et al, 2021



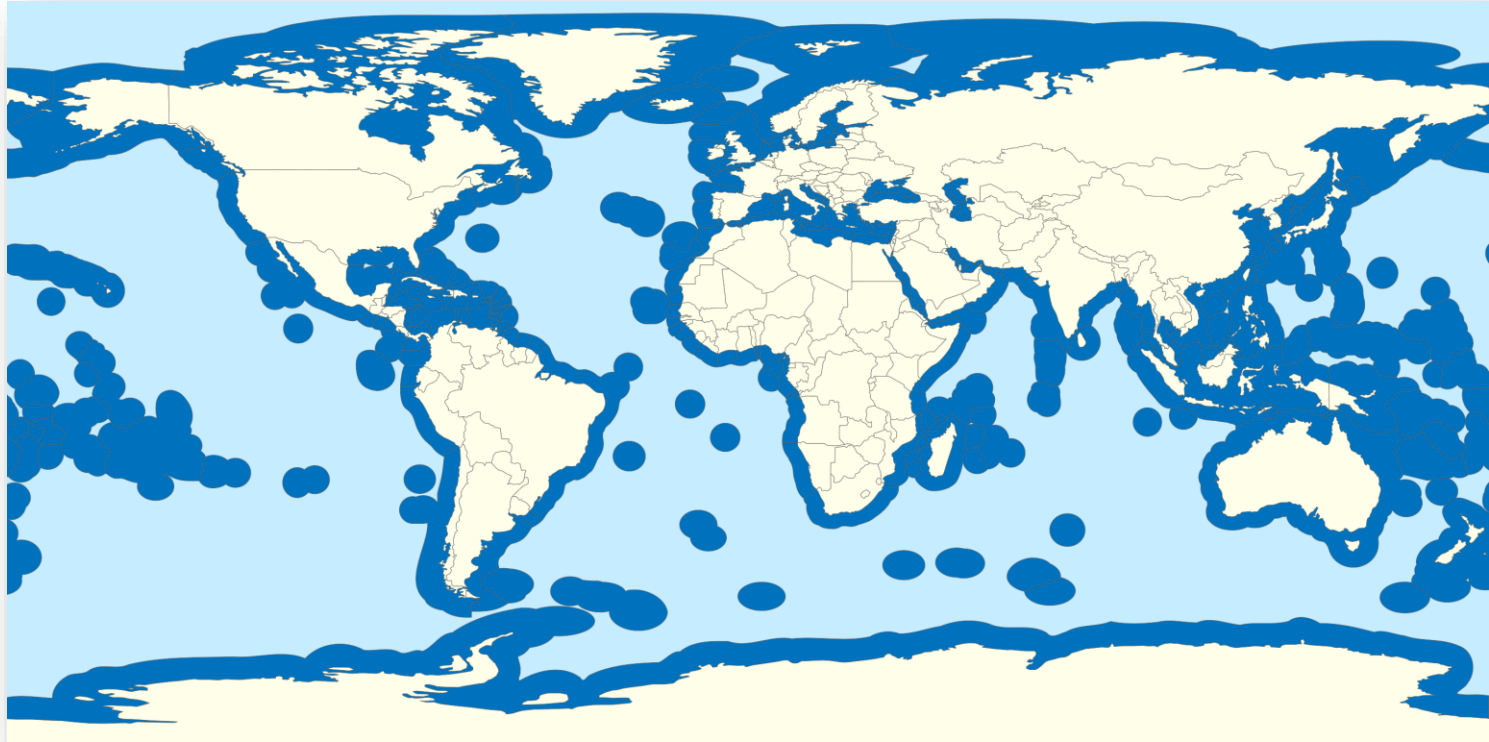


# The mistake...

- Back in 2009, we counted all carbon uptake in response to past emissions as “natural”.
- UNFCCC rules allow countries to count carbon uptake as a negative emission if it takes place on “managed land” (and sell it on).
- Suddenly, lots of land is managed.

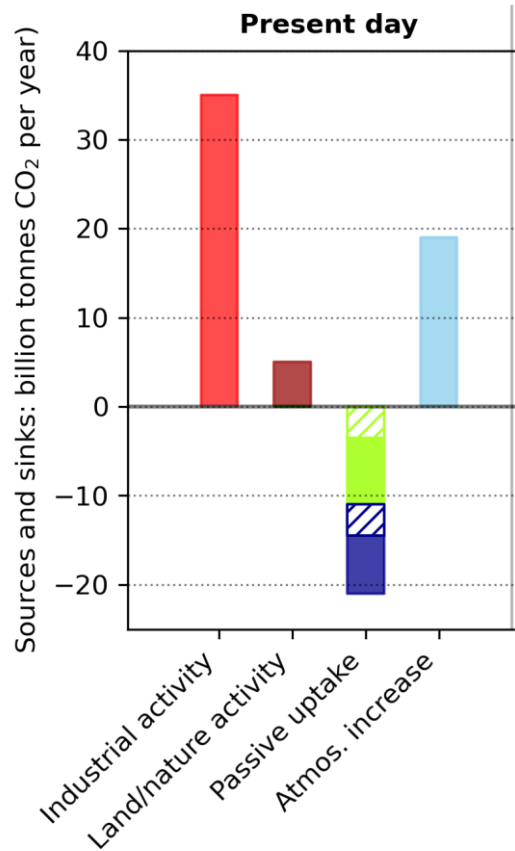


# And “managed oceans”?





# How the flows of carbon dioxide add up



**Fossil fuels and industrial activity**

**Direct land-use & agriculture**

**Atmospheric increase**

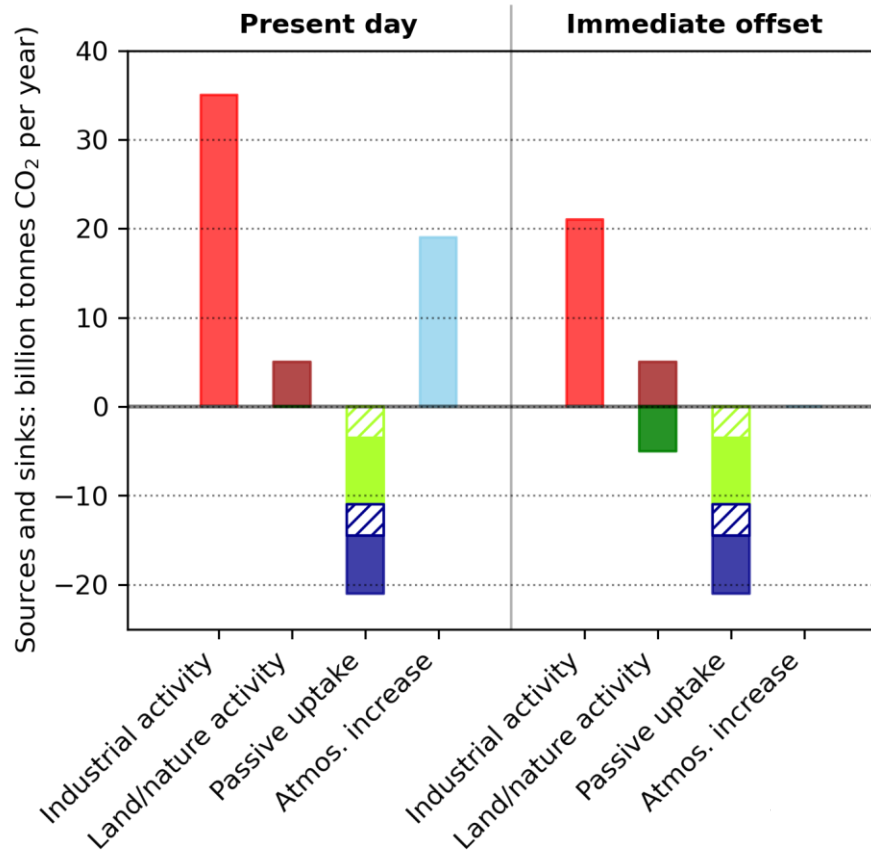
**Passive uptake by the biosphere**

**Passive uptake by the oceans**

**Hatching indicates uptake due to historical cumulative emissions**



# Immediate net zero maxing out UNFCCC rules



**Fossil fuels and industrial activity**

**Direct land-use & agriculture**

**Nature-based solutions**

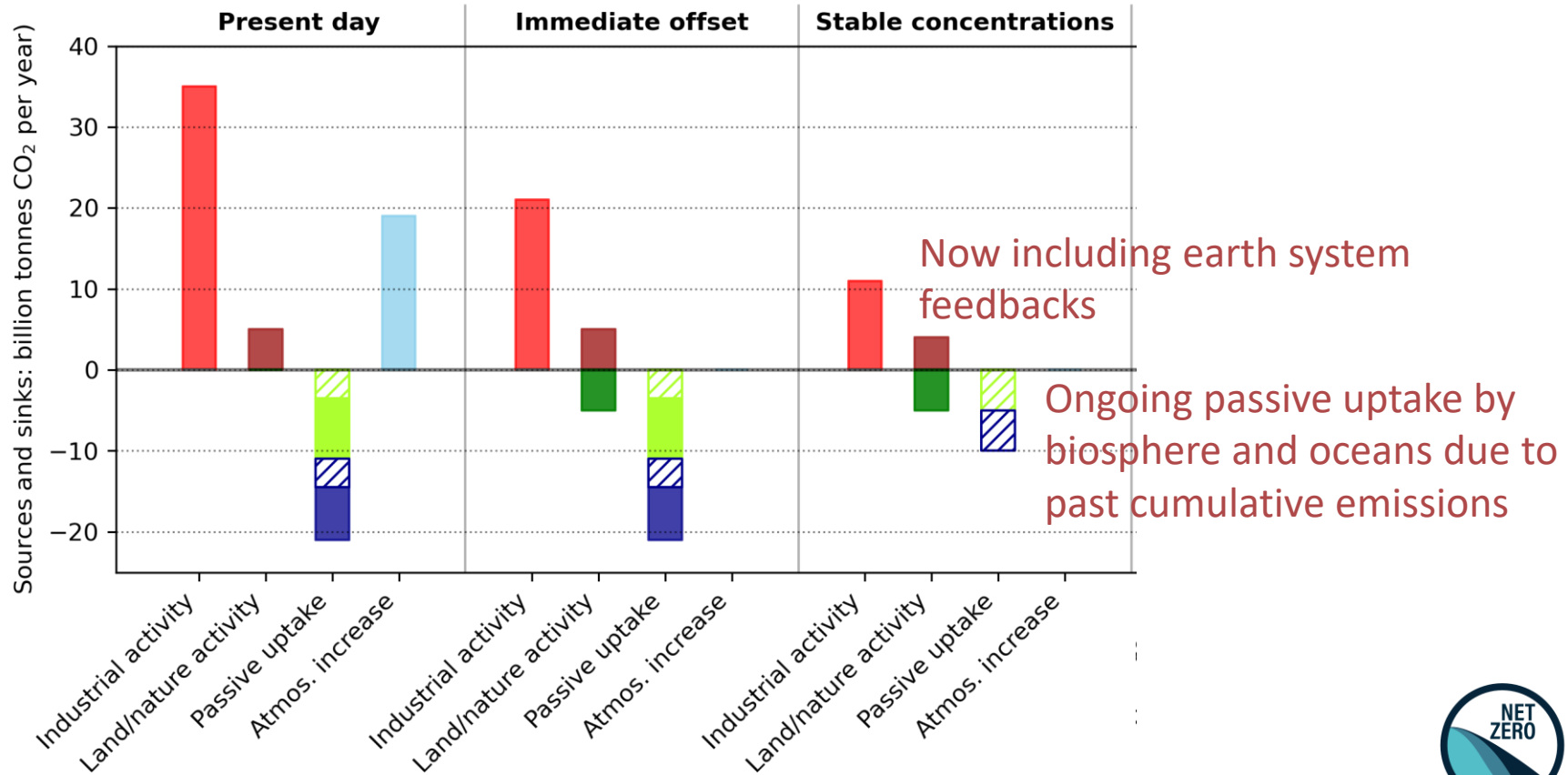
**Passive uptake by the biosphere**

**Passive uptake by the oceans**

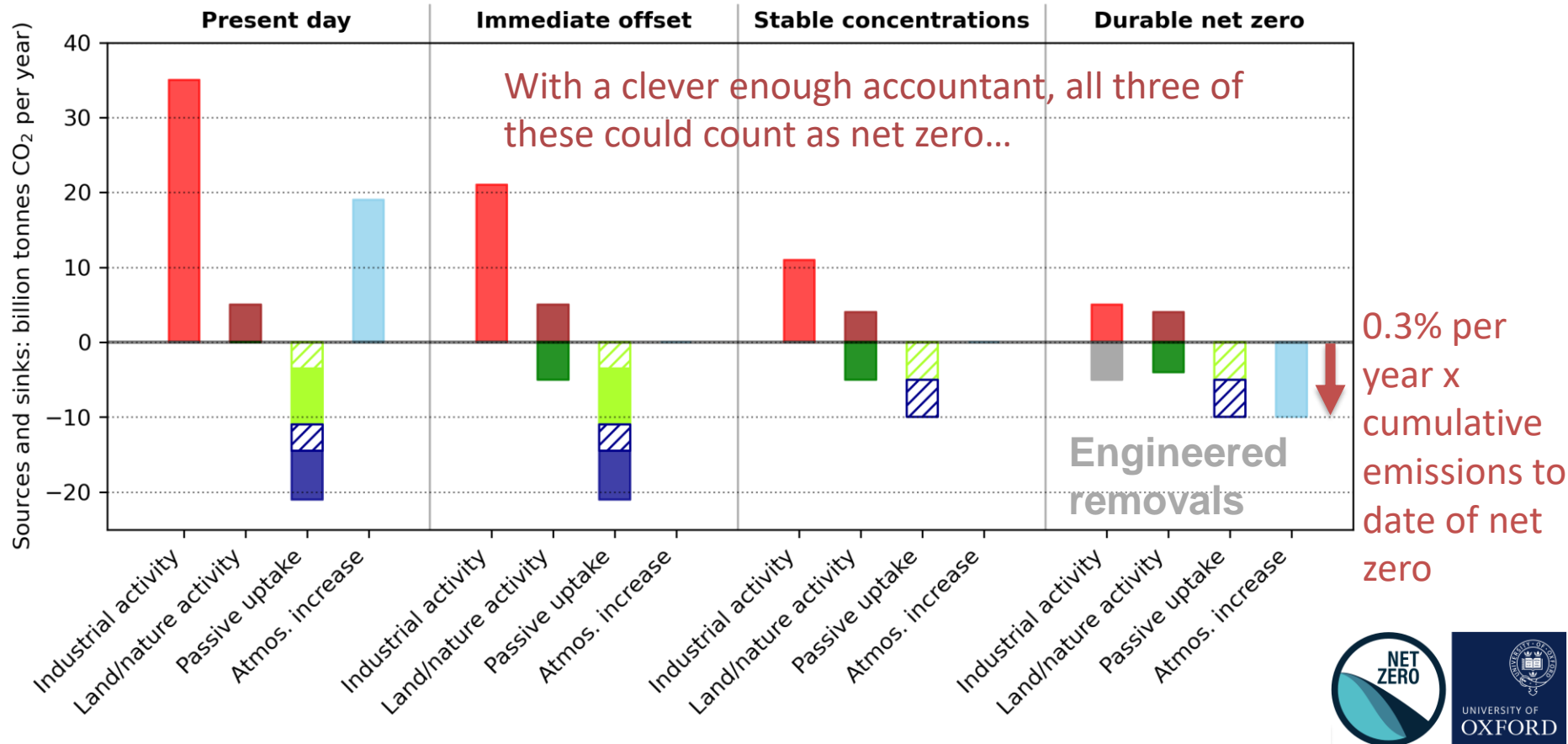
**Hatching indicates uptake due to historical cumulative emissions**



# What it takes to stabilize atmospheric CO<sub>2</sub> concentrations



# What it takes to stop global warming



What happens when you forget to specify the question



Net Zero

~~42~~

“The Answer to the Ultimate Question  
of Life, the Universe, and Everything”



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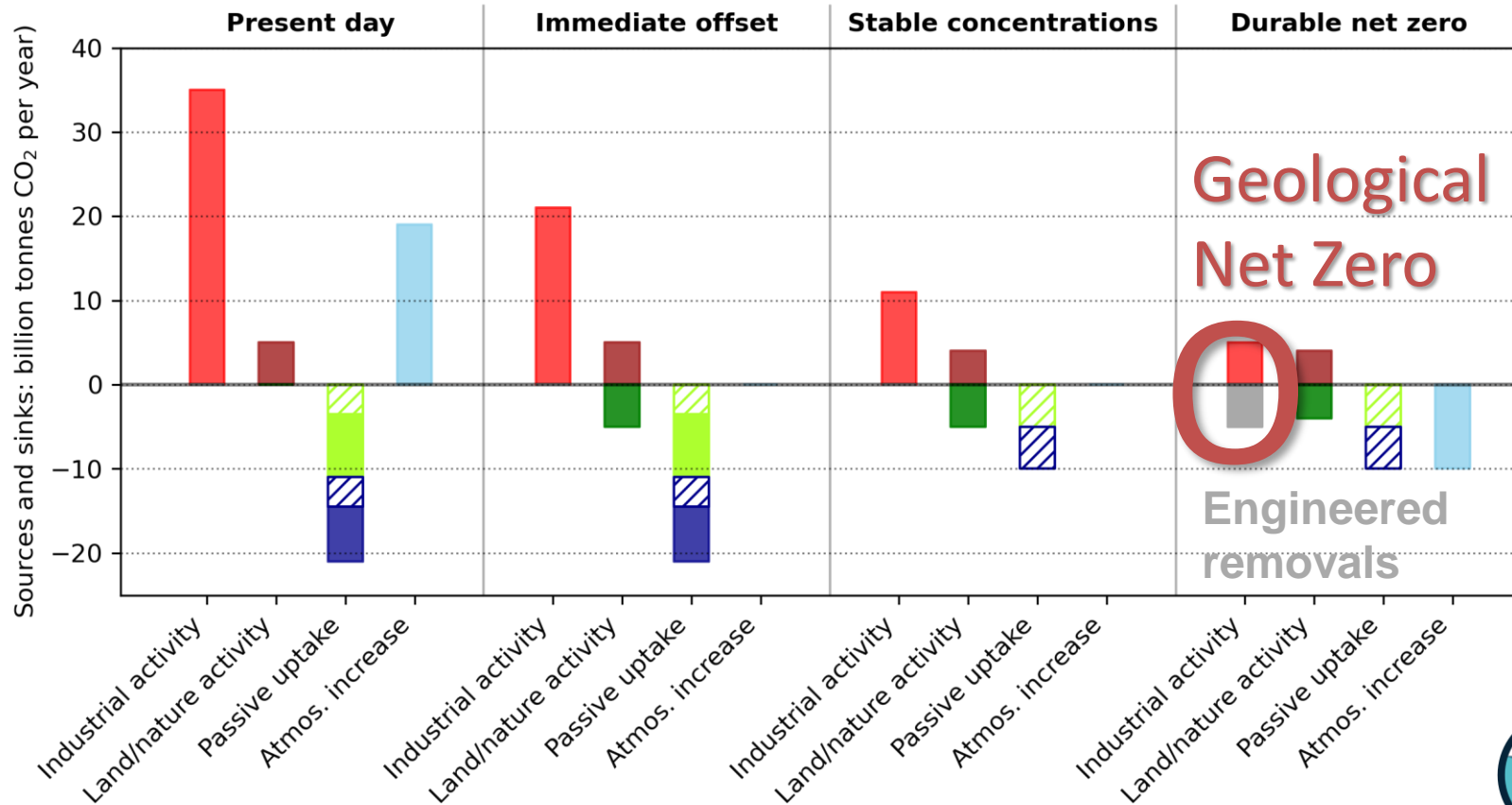
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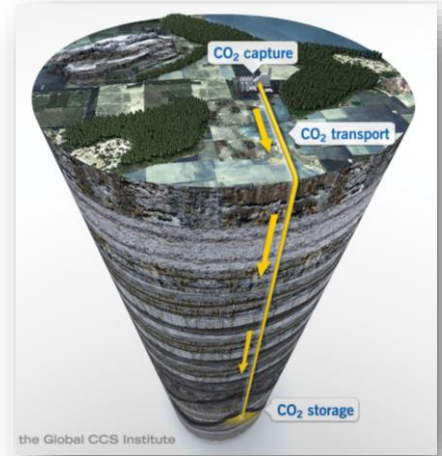
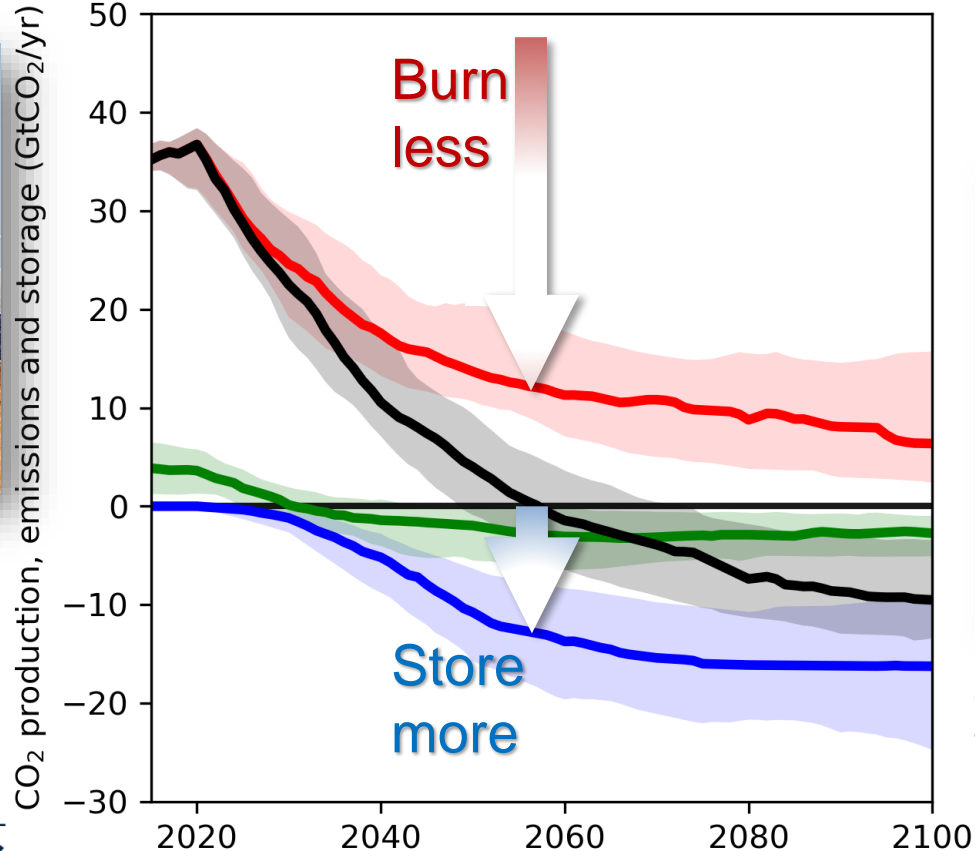
# What it takes to stop global warming



# What it takes to stop global warming



Industrial CO<sub>2</sub> production and storage in “technology neutral” 1.5°C scenarios

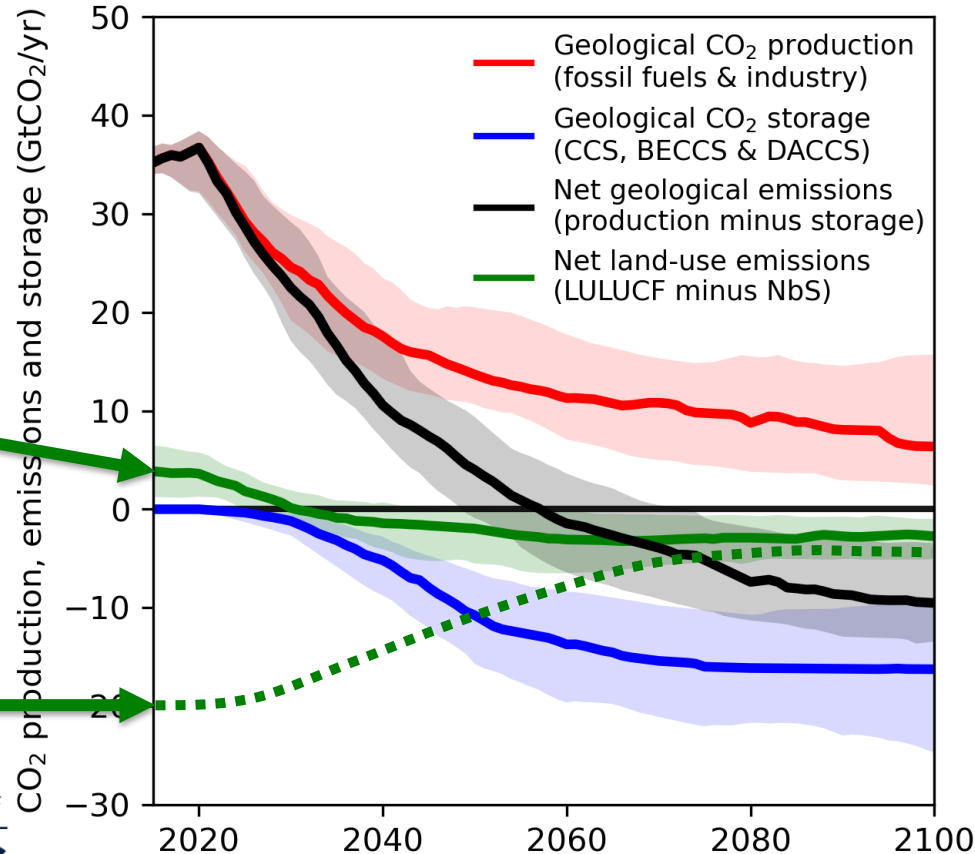


Jenkins et al (2023)  
from IPCC database

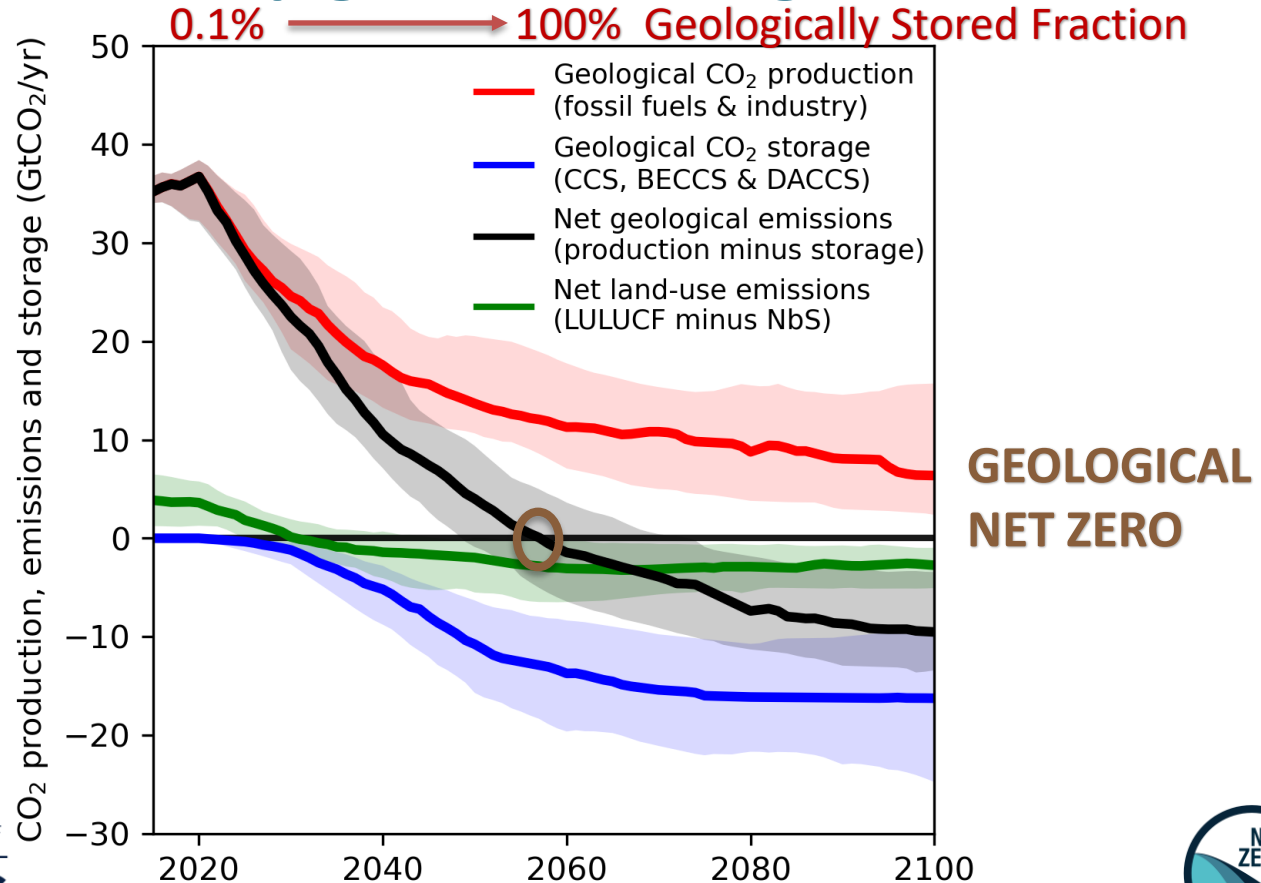
# What it takes to stop global warming

Contribution from  
reducing  
deforestation and  
Nature-based  
Solutions

“Natural” CO<sub>2</sub>  
uptake by oceans  
and biosphere due  
to past emissions



# What it takes to stop global warming







Where to stash your carbon...

Olivine, South Island



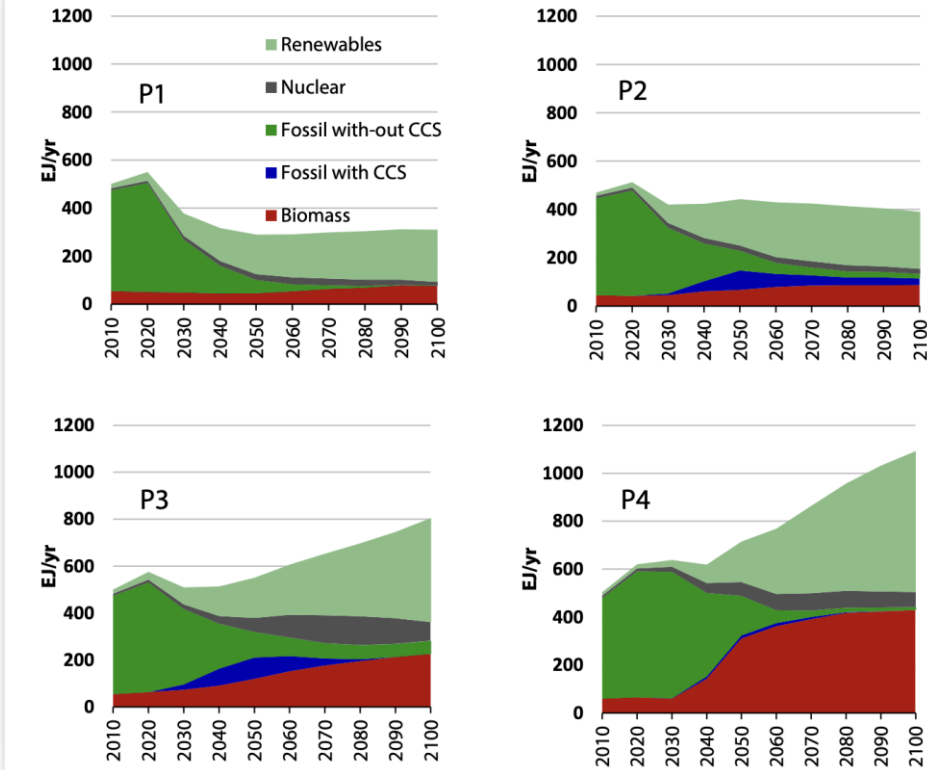
Carbon credits, Brazil, 2019

A photograph of a large fire burning in a field of dry grass. The fire is intense, with bright orange and yellow flames rising from the ground. The background is dark and smoky, suggesting a large-scale fire or controlled burn.



# We need to stop fossil fuels from causing global warming

Figure 3.3. Global primary energy in the four archetype 1.5°C scenarios set out by the IPCC



UK CCC  
2019 from  
IPCC  
database



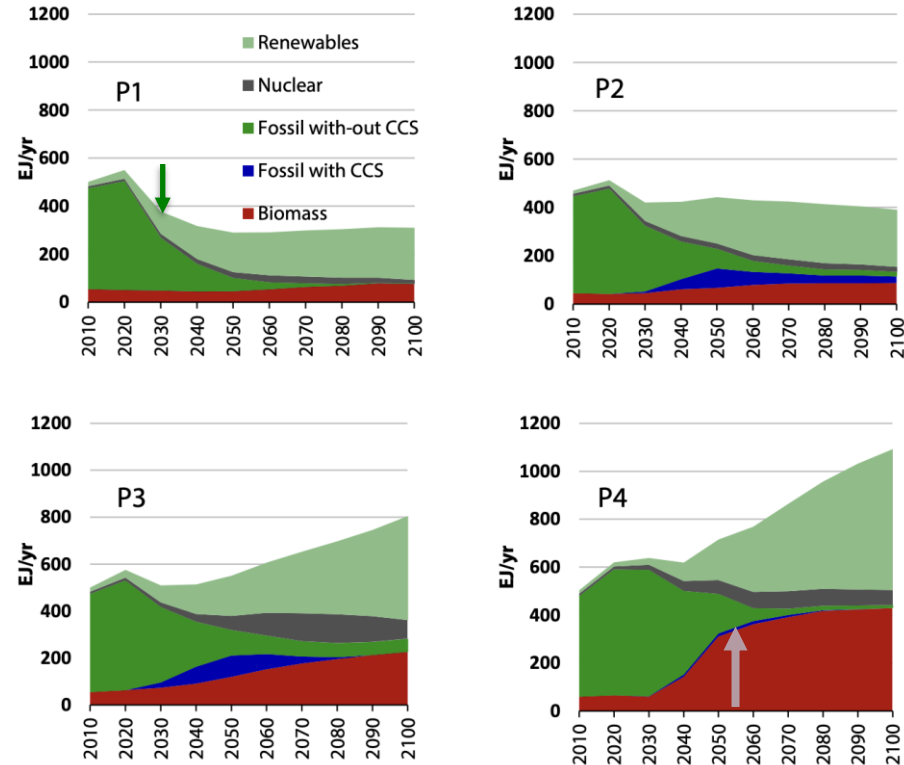
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# We need to stop fossil fuels from causing global warming – before the world stops using fossil fuels

“Fossil elimination”  
1.5°C scenarios  
require either...

Figure 3.3. Global primary energy in the four archetype 1.5°C scenarios set out by the IPCC



UK CCC  
2019 from  
IPCC  
database



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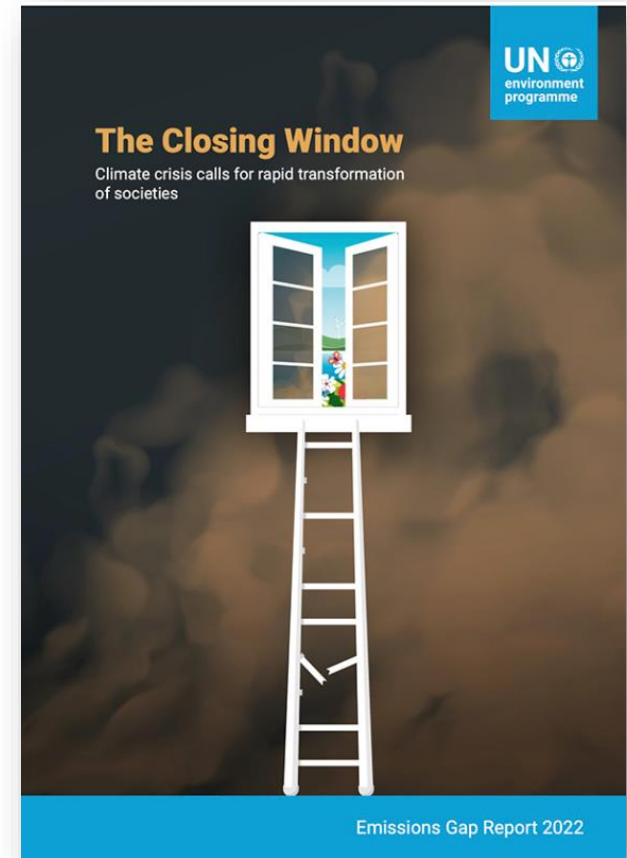


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# The case for Geological Net Zero

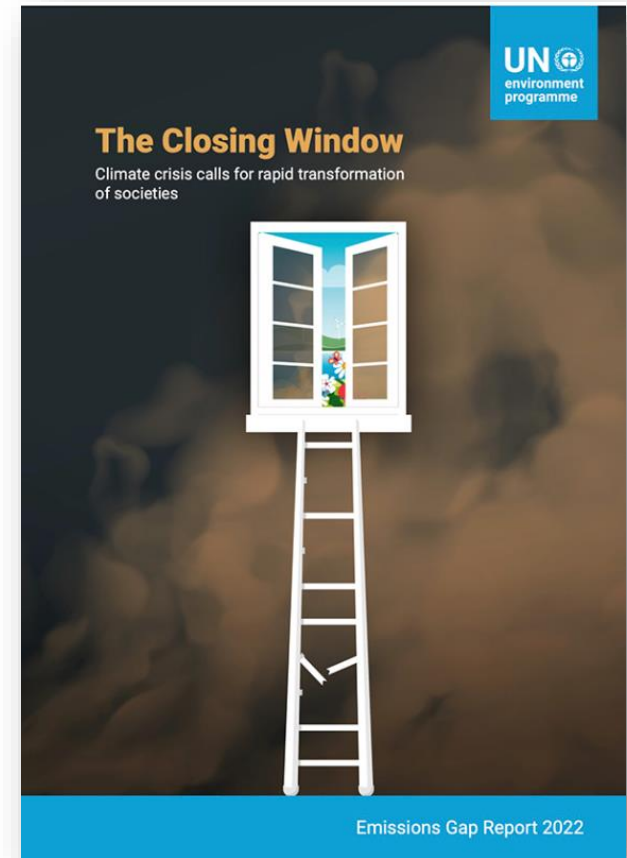
“Only an urgent system-wide transformation can avoid climate disaster.”

UNEP Gap Report, 2022



# The case for Geological Net Zero

“Only an urgent system-wide transformation  
or rapid scale-up of geological CO<sub>2</sub> storage  
can avoid climate disaster.”





# One of these has a plan to stop the fossil fuels they sell from causing global warming by 2050

Darren Woods  
ExxonMobil



Wael Sawan  
Shell



Bernard Looney  
BP



Vikki Hollub  
Occidental



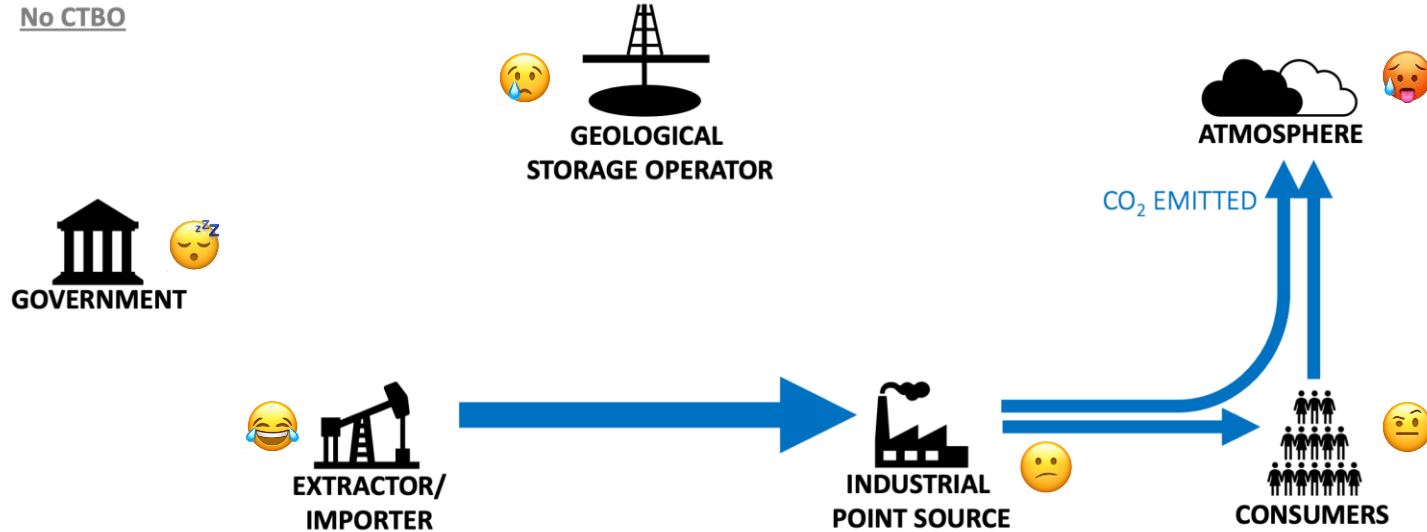
The catch...



# How to stop fossil fuels from causing global warming

## Current situation

No CTBO



- Actual or embedded CO<sub>2</sub>
- Regulation and compliance
- CTBO compliance costs
- Payments for GCS

Weight of arrow reflects relative size of cost and CO<sub>2</sub> flow.  
The relative size of CO<sub>2</sub> flows depends on many factors, including the CTBO's stored fraction, availability of industrial point source CCS and availability of DAC technologies.

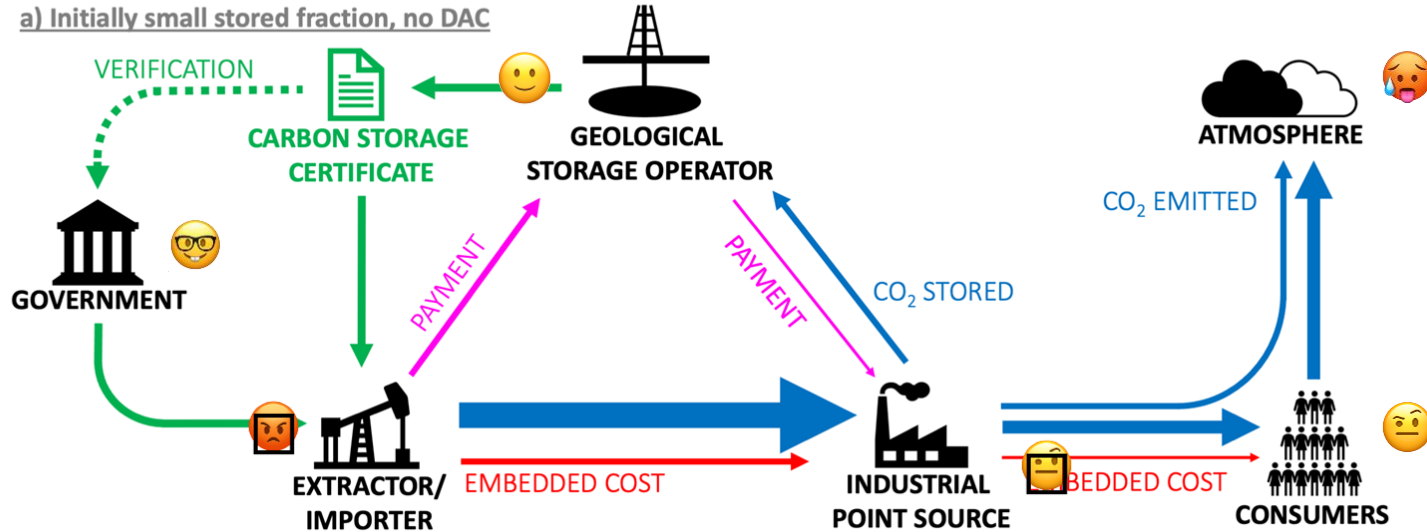
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# How to stop fossil fuels from causing global warming

CTBO introduced

a) Initially small stored fraction, no DAC



- Actual or embedded CO<sub>2</sub>
- Regulation and compliance
- CTBO compliance costs
- Payments for GCS

Weight of arrow reflects relative size of cost and CO<sub>2</sub> flow.  
The relative size of CO<sub>2</sub> flows depends on many factors, including the CTBO's stored fraction, availability of industrial point source CCS and availability of DAC technologies.

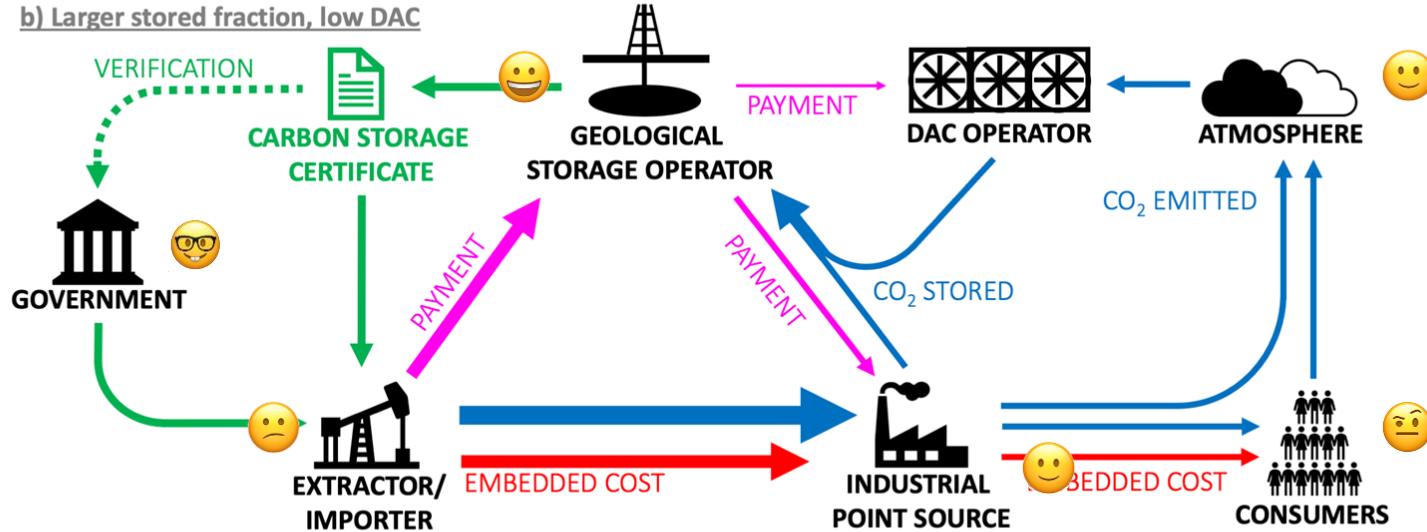
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# How to stop fossil fuels from causing global warming

## Scaling up the stored fraction

### b) Larger stored fraction, low DAC



- Actual or embedded CO<sub>2</sub>
- Regulation and compliance
- CTBO compliance costs
- Payments for GCS

Weight of arrow reflects relative size of cost and CO<sub>2</sub> flow.

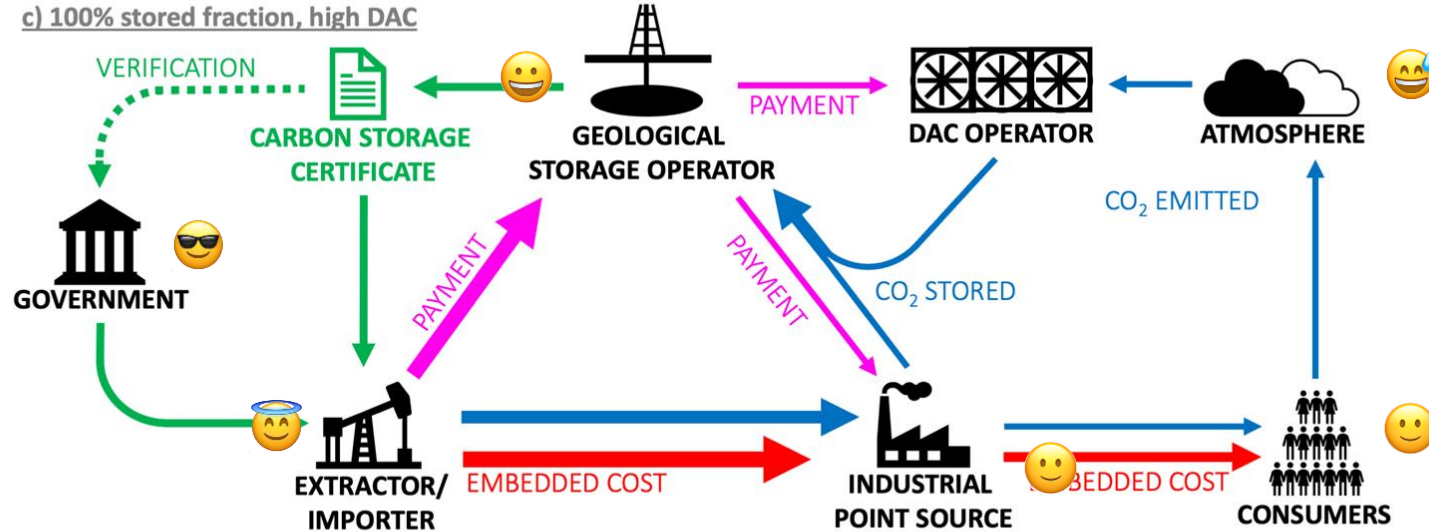
The relative size of CO<sub>2</sub> flows depends on many factors, including the CTBO's stored fraction, availability of industrial point source CCS and availability of DAC technologies.



# How to stop fossil fuels from causing global warming

100% stored fraction: Net Zero Achieved

c) 100% stored fraction, high DAC



- Actual or embedded CO<sub>2</sub>
- Regulation and compliance
- CTBO compliance costs
- Payments for GCS

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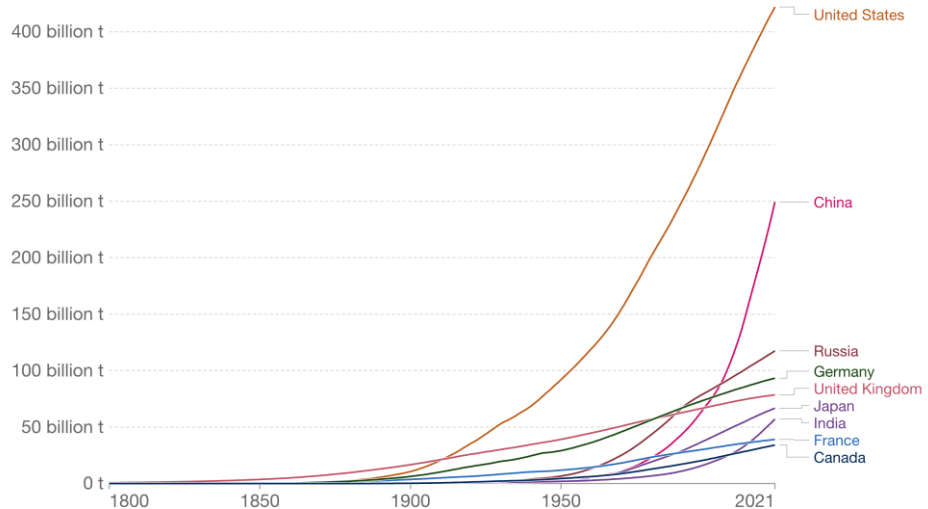
# But what about the trees?

- Carbon offsetting promises vast new resources for forest protection.
- But only geological storage actually compensates for fossil fuel use.
- Who will pay for ongoing ecosystem services in a geological net zero world?

## Cumulative CO<sub>2</sub> emissions

Cumulative emissions are the running sum of CO<sub>2</sub> emissions produced from fossil fuels and industry<sup>1</sup> since 1750. Land use change is not included.

Our World  
in Data



Source: Our World in Data based on the Global Carbon Project

OurWorldInData.org/co2-and-greenhouse-gas-emissions • CC BY

**1. Fossil emissions:** Fossil emissions measure the quantity of carbon dioxide (CO<sub>2</sub>) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production. Fossil CO<sub>2</sub> includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes. Fossil emissions do not include land use change, deforestation, soils, or vegetation.



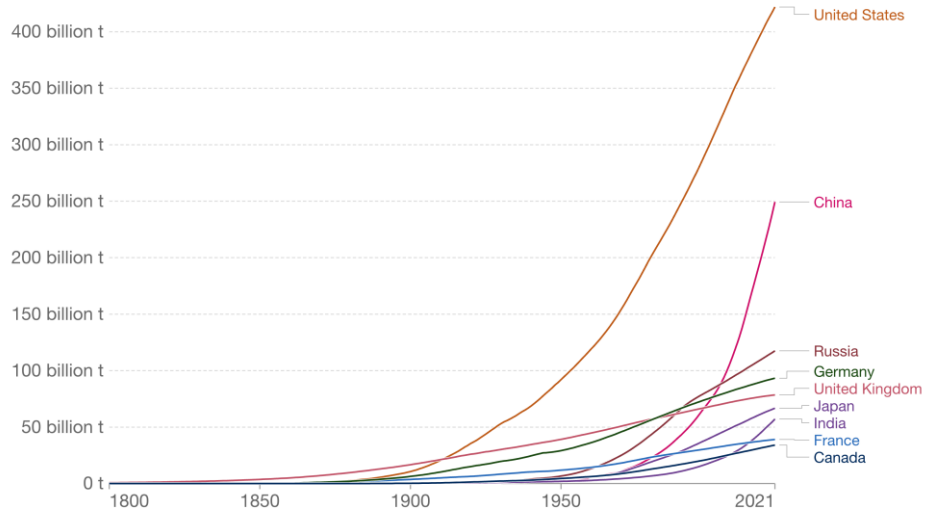
# But what about the trees?

- By 2050, the U.K. will have emitted 85 billion tonnes cumulative FFI CO<sub>2</sub> emissions.

## Cumulative CO<sub>2</sub> emissions

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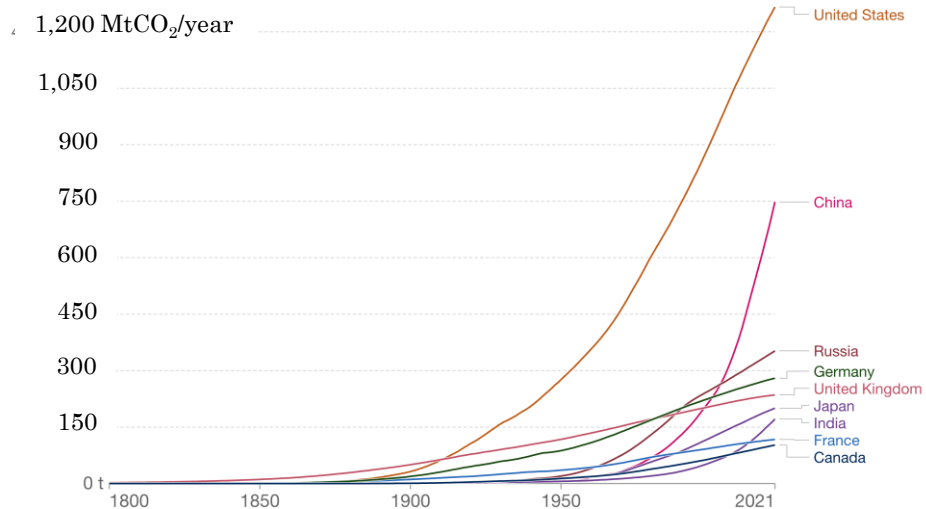
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# But what about the trees?

- By 2050, the U.K. will have emitted 85 billion tonnes cumulative FFI CO<sub>2</sub> emissions.
- Increasing natural uptake required for  $\Delta T_{CO_2} = 0$  by 0.3%/year x 85 billion tonnes:
  - 250 million tCO<sub>2</sub> per year

Commitment to protect ongoing passive CO<sub>2</sub> sinks:  
0.3% per year of cumulative emissions to date



Source: Our World in Data based on the Global Carbon Project

OurWorldInData.org/co2-and-greenhouse-gas-emissions • CC BY

1. **Fossil emissions:** Fossil emissions measure the quantity of carbon dioxide (CO<sub>2</sub>) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production. Fossil CO<sub>2</sub> includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes. Fossil emissions do not include land use change, deforestation, soils, or vegetation.



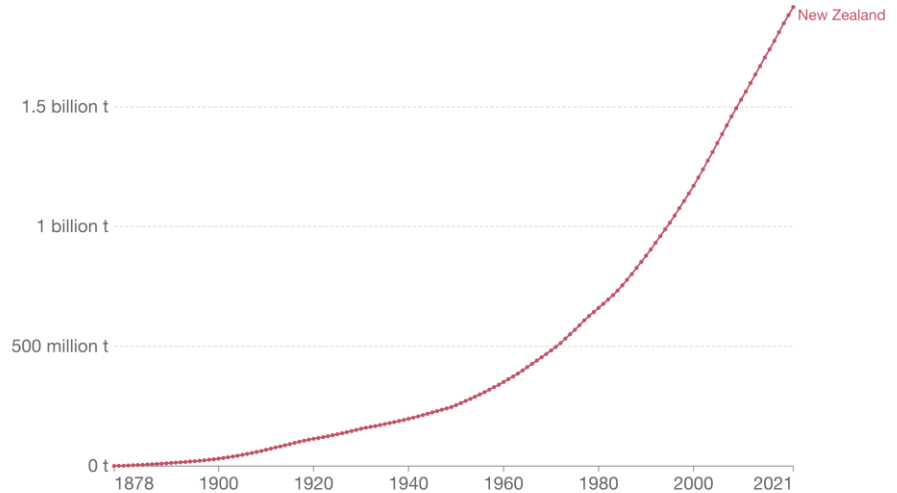
# But what about the trees?

- By 2050, ANZ will have emitted 2.3 billion tonnes cumulative FFI CO<sub>2</sub> emissions.

## Cumulative CO<sub>2</sub> emissions

Cumulative emissions are the running sum of CO<sub>2</sub> emissions produced from fossil fuels and industry<sup>1</sup> since 1750. Land use change is not included.

Our World  
in Data



Source: Our World in Data based on the Global Carbon Project  
OurWorldInData.org/co2-and-greenhouse-gas-emissions • CC BY

**1. Fossil emissions:** Fossil emissions measure the quantity of carbon dioxide (CO<sub>2</sub>) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production. Fossil CO<sub>2</sub> includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes. Fossil emissions do not include land use change, deforestation, soils, or vegetation.

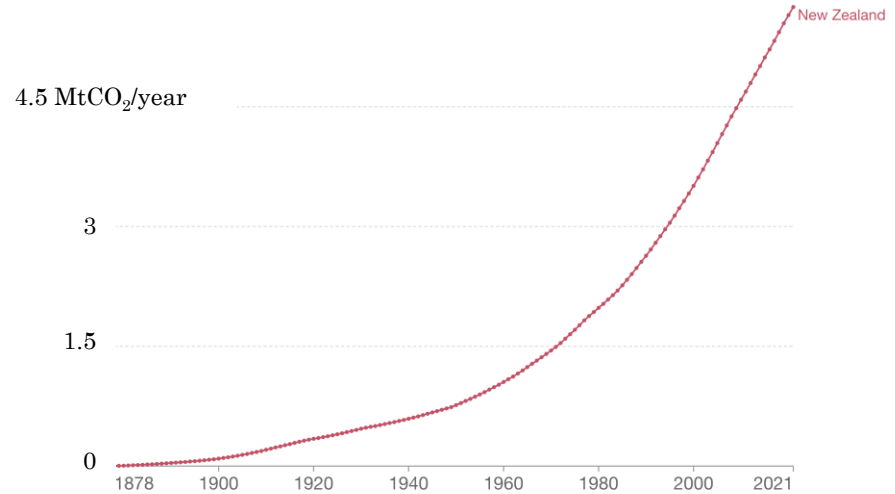


# But what about the trees?

- By 2050, ANZ will have emitted 2.3 billion tonnes cumulative FFI CO<sub>2</sub> emissions.
- Increasing natural uptake required for  $\Delta T_{CO_2} = 0$  by 0.3%/year x 2.3 billion tonnes — 7 million tCO<sub>2</sub> per year

Commitment to protect ongoing passive CO<sub>2</sub> sinks:  
0.3% per year of cumulative emissions to date

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# Policy implications

- Accounting ambiguities mean balancing geological CO<sub>2</sub> sources with biological sinks may not stop global warming at all.
- Geological Net Zero – balancing geological sources with geological sinks – is necessary for a durable halt to warming.
- National policies and corporate strategies need to focus on transition to geological net zero by mid-century.
- Cumulative geological emissions to date provide a basis for allocating responsibility for protecting passive biological sinks.



# We need to stop fossil fuels from causing global warming – before the world stops using fossil fuels

- “In a pragmatic, just and well-managed energy transition, we must be laser focused on phasing out fossil fuel emissions, while phasing up viable, affordable zero-carbon alternatives.”

COP28 President Sultan Al Jaber



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- The Stone Age didn't end because we ran out of stones.
- The Oil Age won't end because we run out of oil.
- Global Warming must end before we stop using fossil fuels.