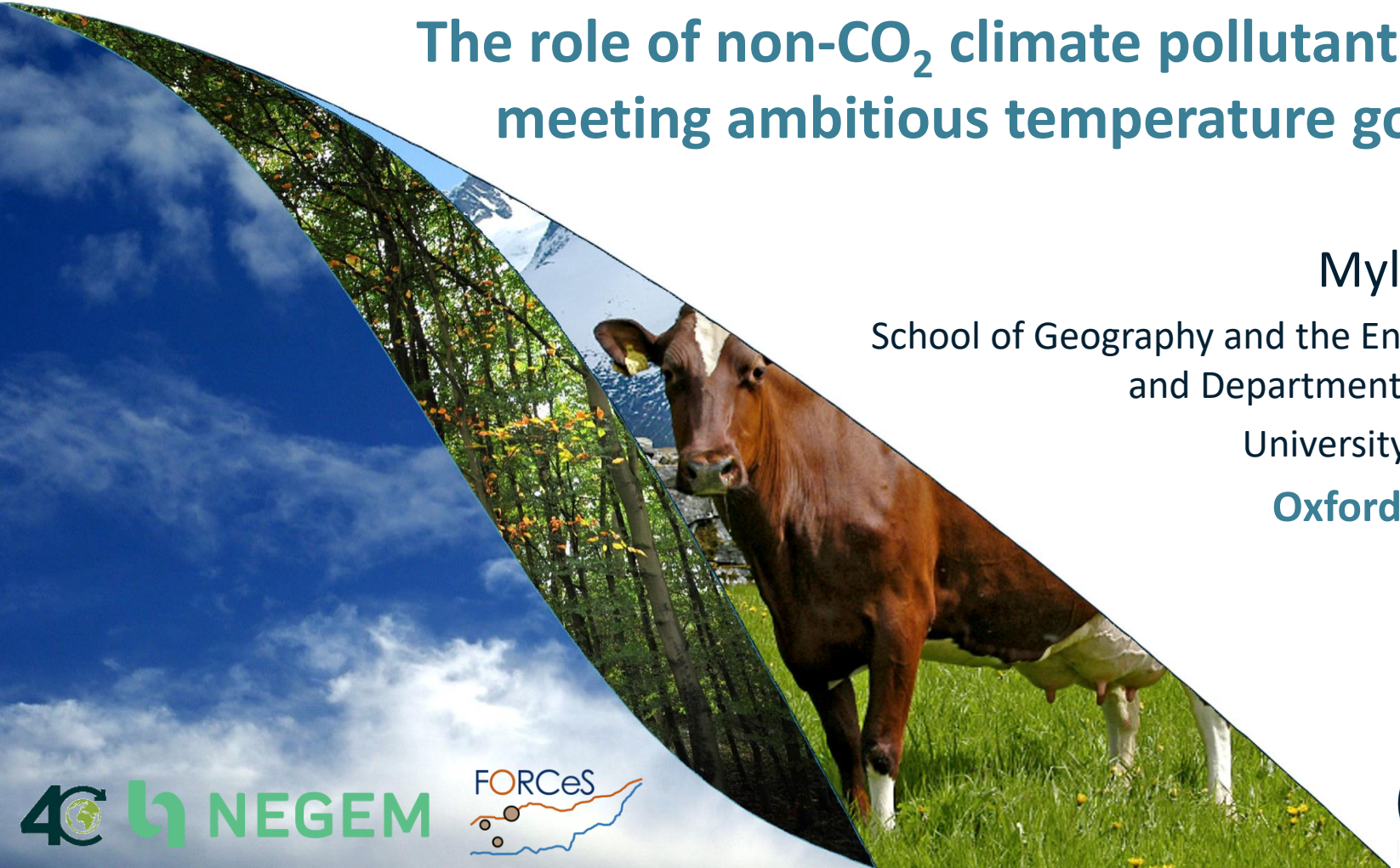
The role of non-CO_2 climate pollutants in meeting ambitious temperature goals



Myles Allen

School of Geography and the Environment
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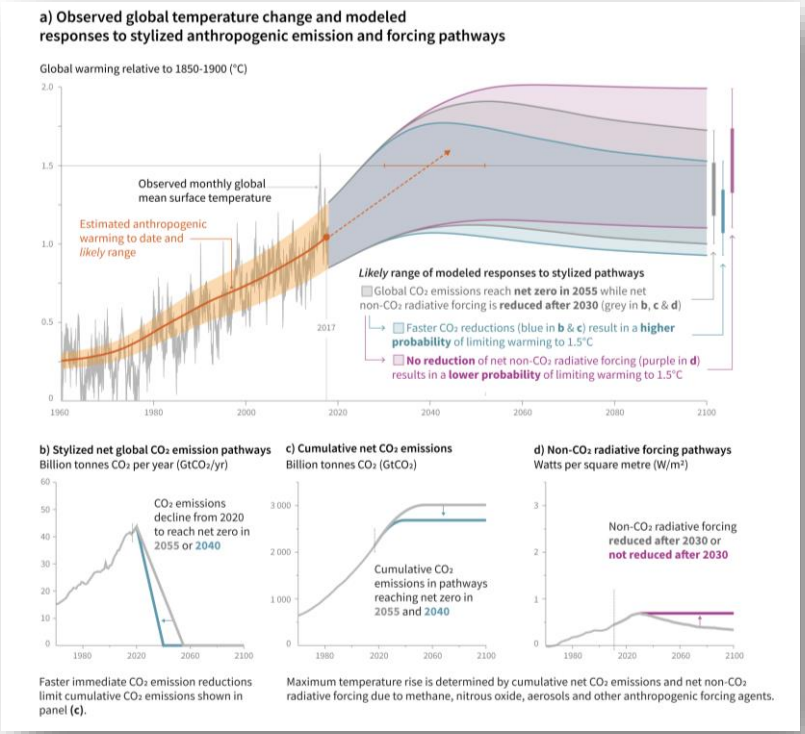
University of Oxford

Oxford Net Zero

IPCC SR1.5: "Reaching and sustaining **net-zero** global anthropogenic **CO_2 emissions** *and* **declining net non-CO_2 radiative forcing** would **halt** anthropogenic global warming on multi-decadal timescales (*high confidence*)."



"net non-CO_2 radiative forcing" means net impact on global energy imbalance of climate drivers other than CO_2 affected by human activity, including:

- methane
- aerosols & soot
- nitrous oxide

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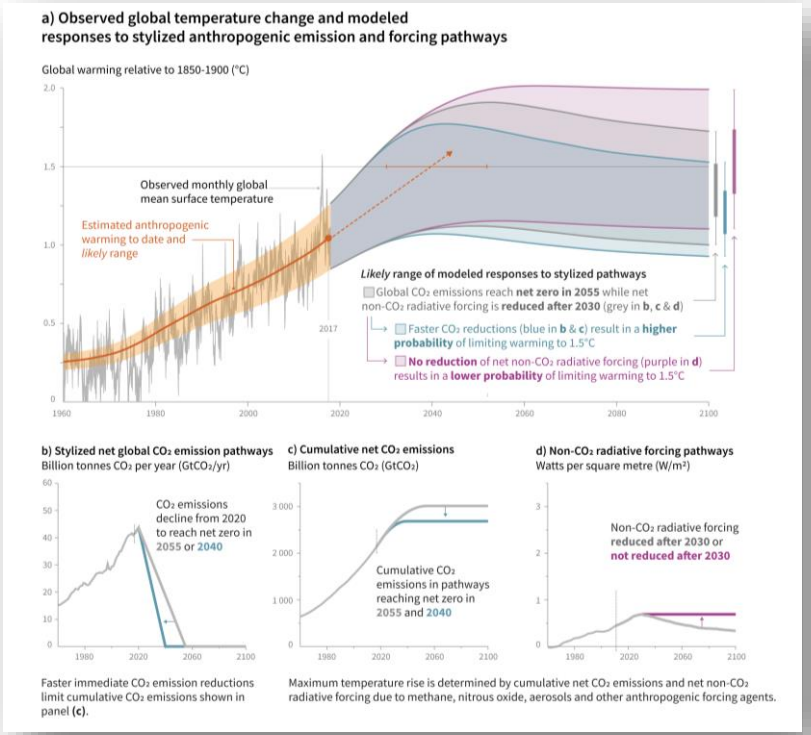
"The maximum temperature reached is then determined by **cumulative net global anthropogenic CO_2** emissions up to the time of net zero CO_2 emissions (*high confidence*) and the **level of non-CO_2 radiative forcing in the decades prior** to the time that maximum temperatures are reached (*medium confidence*)."



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Quantifying the SR1.5 statement

Human-induced warming (ΔT) over a time-interval (Δt) from a few years to a few decades is proportional to **total cumulative carbon dioxide emissions** over that time-interval ($\overline{E_C}\Delta t$) plus the **change in global energy imbalance** due to non-CO_2 human influences on climate (ΔF_N) plus an **adjustment to constant non-CO_2 energy imbalance** ($\overline{F_N}\Delta t$).

$$\Delta T = \kappa \left(\overline{E_C}\Delta t + \frac{\Delta F_N}{\alpha} + \frac{\rho \overline{F_N}\Delta t}{\alpha} \right)$$

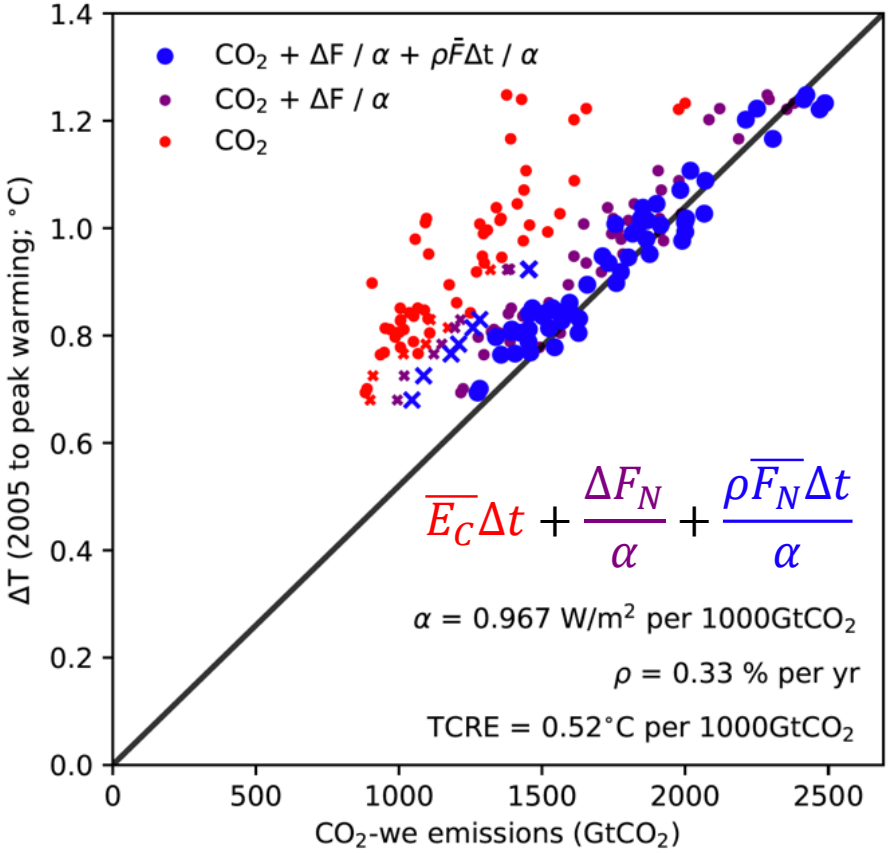
Warming-equivalent emissions have same impact on ΔT as CO_2 emissions so need to reach net zero to halt global warming

- κ = "Transient Climate Response to Emissions" ≈ 0.45 ºC per $TtCO_2$
- α = "Transient Forcing Response to Emissions" ≈ 1.0 W/m^2 per $TtCO_2$
  ≈ $AGWP_H/\gamma H$ where γ=0.85 for H=100 years (equating forcing response to steady emissions with AGWP)
- ρ = rate of energy imbalance decline under zero CO_2 emissions
  ≈ 0.3% per year = rate of decline required to give stable temperatures (hence SR1.5 statement)

NET ZERO

UNIVERSITY OF OXFORD

This simple equation predicts peak warming



Warming from 2005 to peak in IPCC mitigation scenarios versus cumulative CO_2-warming-equivalent emissions.

- Crosses highlight REMIND-MAGPIE simulations with unrealistic non-CO_2 forcing pre-2020.

Implications for methane and nitrous oxide

- Key other greenhouse gases contributing to F_N, reported as CO_2-e using GWP_{100}.
- CO_2-e emissions of any gas with a lifetime longer than $H = 100$ years (e.g. nitrous oxide) can be combined with CO_2 to give aggregate long-lived CO_2-e emissions, E_L
- Interdecadal forcing due any gas with a lifetime much shorter than H (e.g. methane) is given by $F_S = \mathrm{AGWP}_H \times E_S$ (CO_2-e emissions x AGWP of CO_2), so…

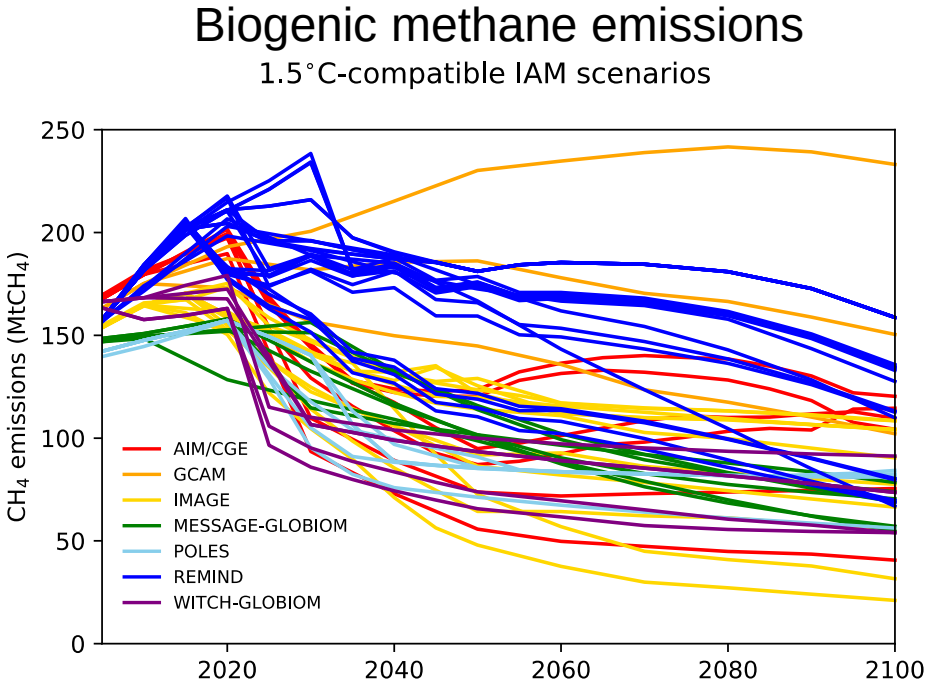
$$\Delta T = \kappa(\overline{E_L}\Delta t + \gamma H \Delta E_S + \gamma H \rho \overline{E_S}\Delta t)$$

- Using standard values from AR5:

$$\Delta T = \kappa(\overline{E_L}\Delta t + 85 \times \Delta E_S + 0.28 \times \overline{E_S}\Delta t)$$

- Constant 1 tCO_2-e/year methane emissions has same impact as 0.28 tCO_2/year.
- Change of ± 1 tCO_2-e/year methane emissions has same impact as ± 85 tCO_2 total.

Why not just read off required reductions from Integrated Assessment Models (IAMs)?



- Strong dependence of results on choice of IAM and assumptions of IAM modellers.
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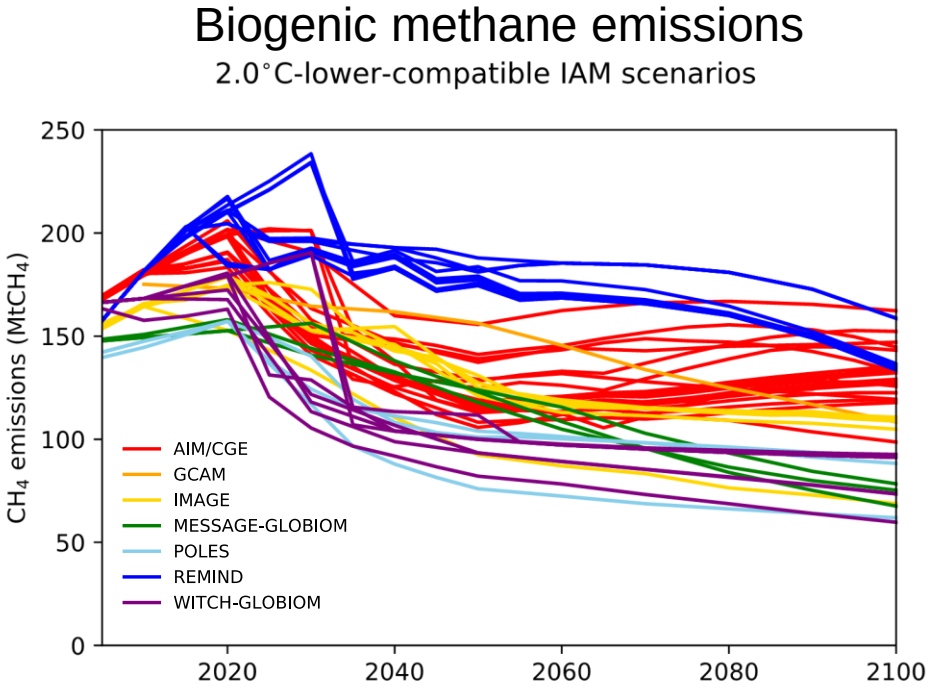

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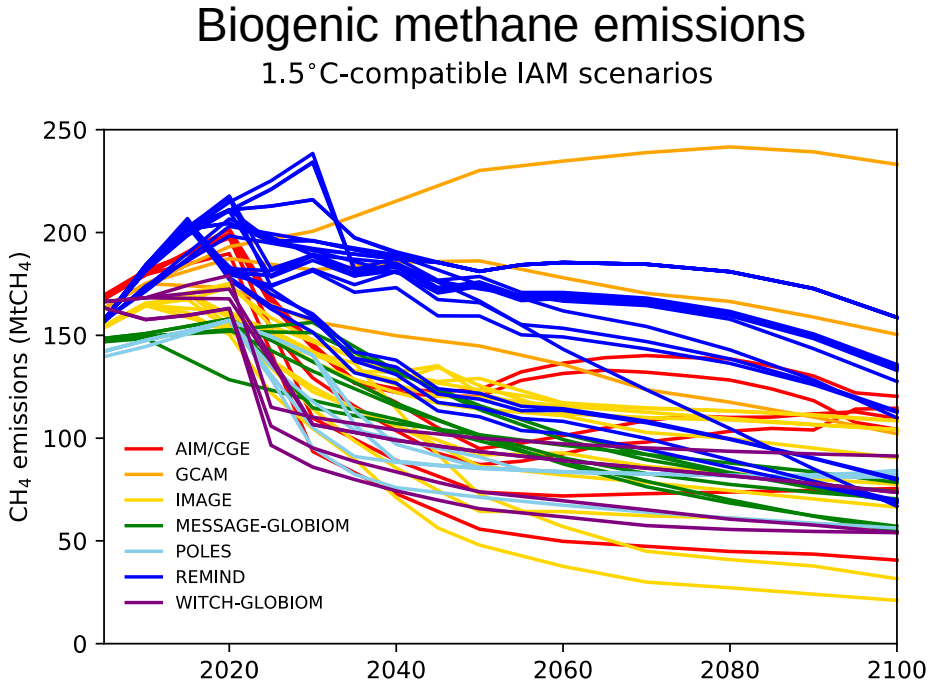

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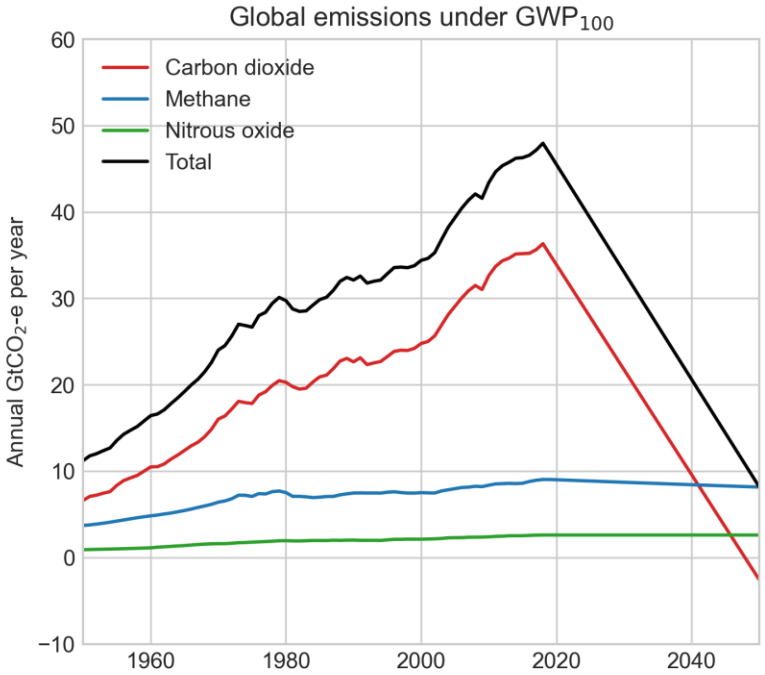
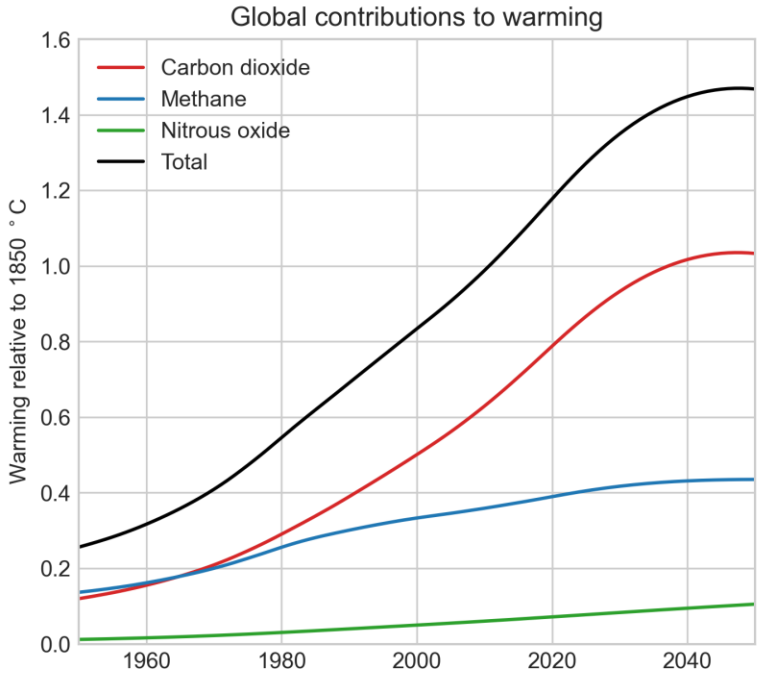
What it takes to halt global greenhouse-gas-induced warming by 2050

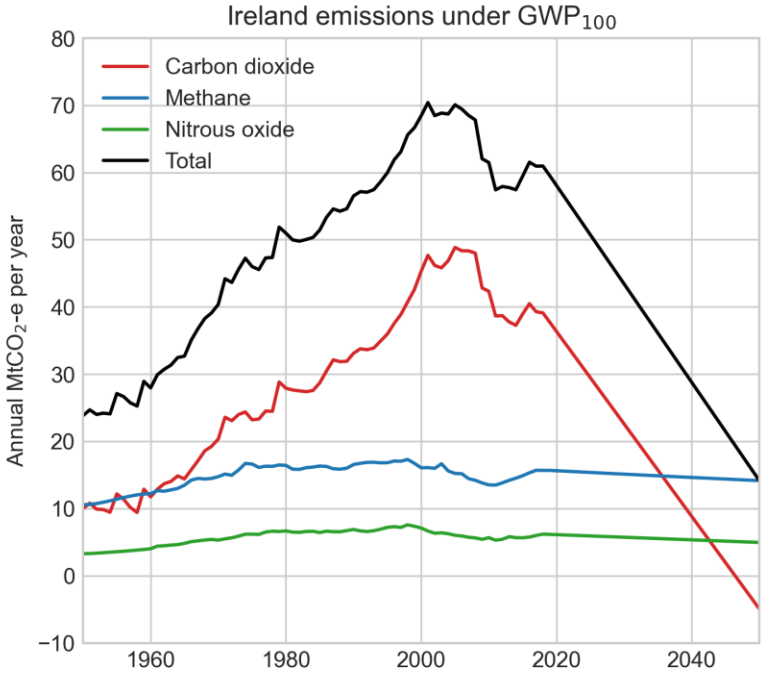


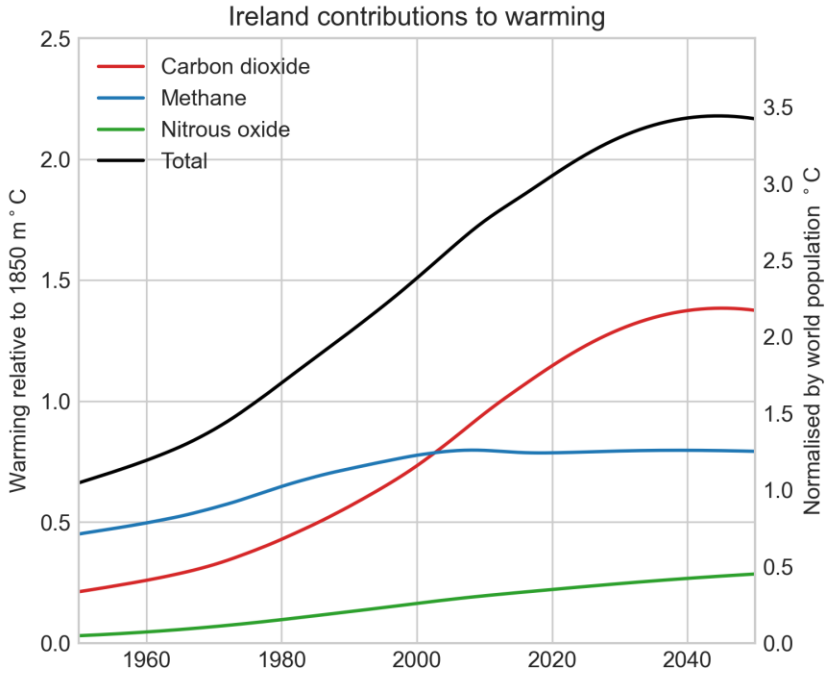


Net zero CO_2-e CO_2+N_2O & 3%/decade reduction in methane

Gütschow et al (2021): PRIMAP-hist v2.2. https://doi.org/10.5281/zenodo.4479172
Warming calculated using formula in Myhre et al (2013): Ch. 8 of IPCC WG1 AR5

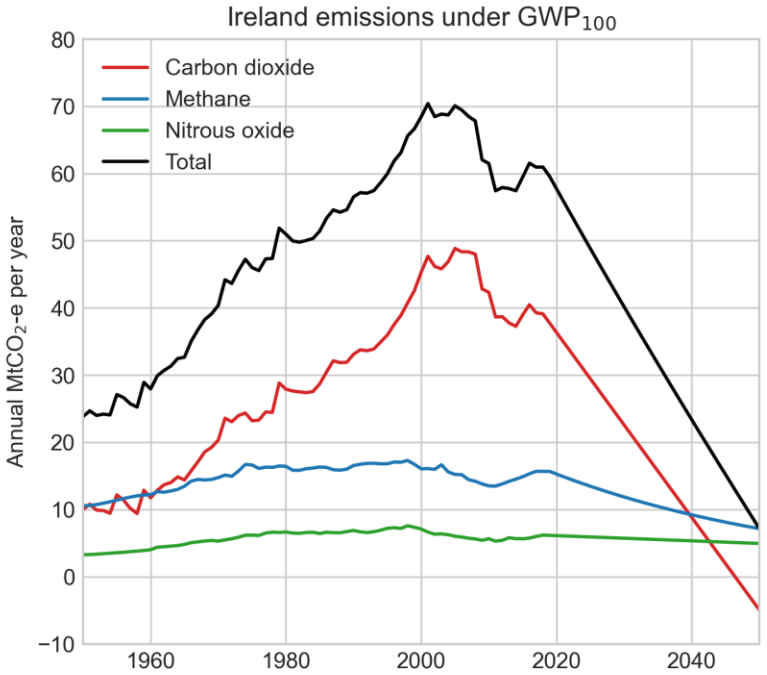
What it takes to halt Ireland's greenhouse-gas-induced warming by 2050

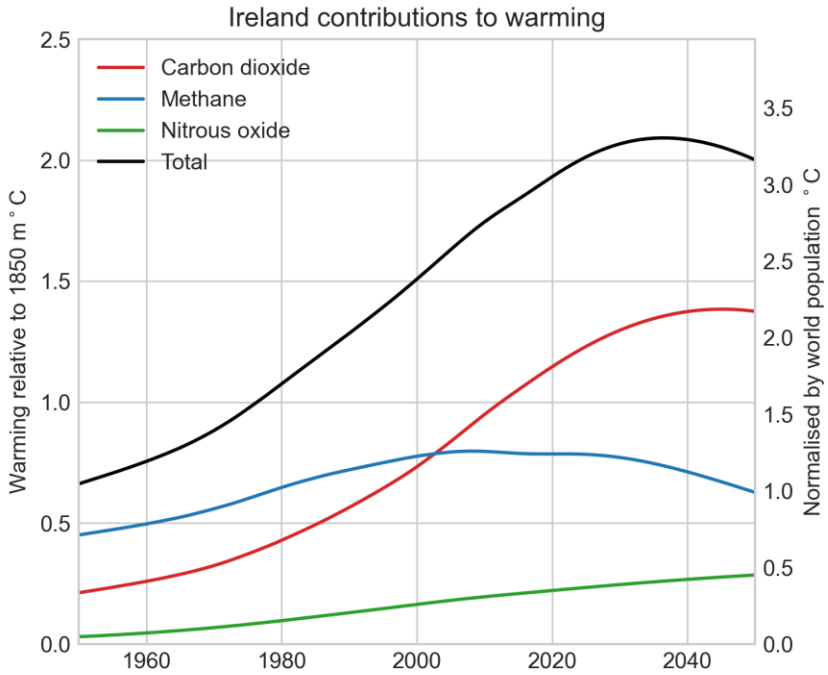




Net zero CO_2-e CO_2+N_2O & 3%/decade reduction in methane

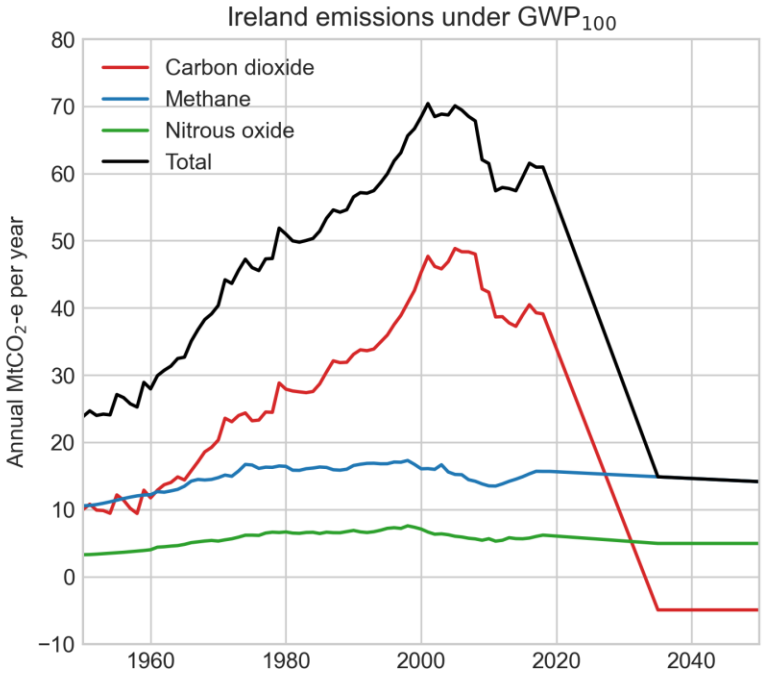
Impact of deeper methane reductions (50% by 2050)

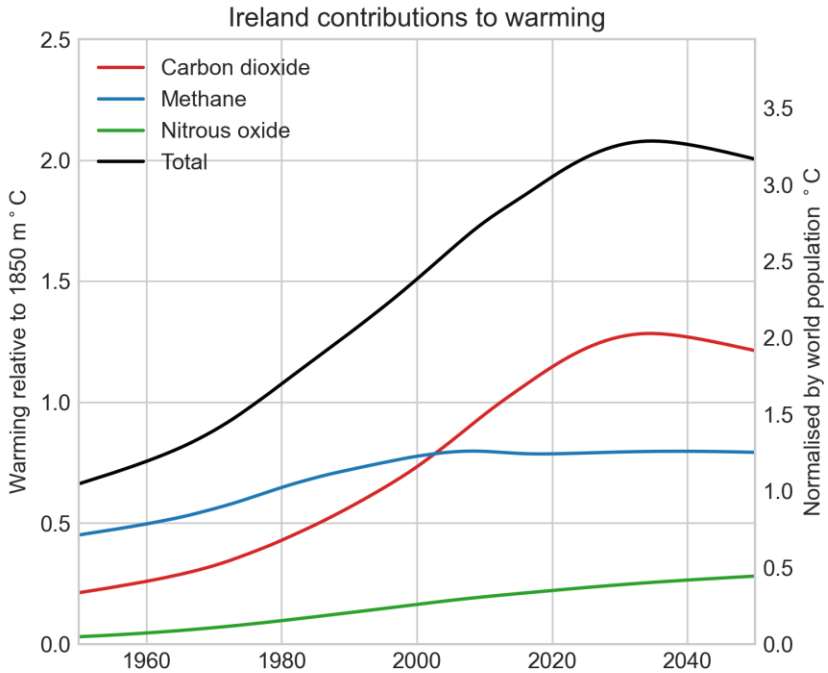




Net zero CO_2-e CO_2+N_2O & 22%/decade reduction in methane

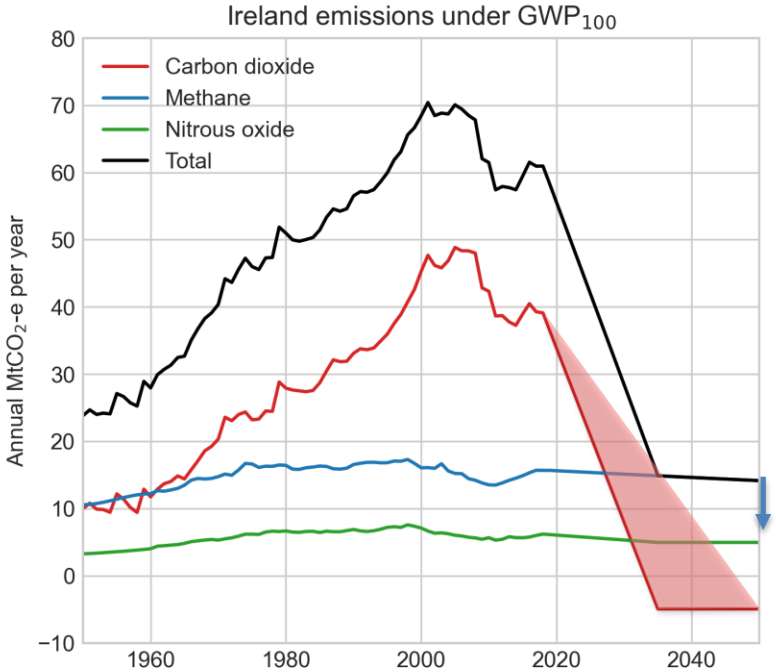
CO_2 reductions required to have the same impact

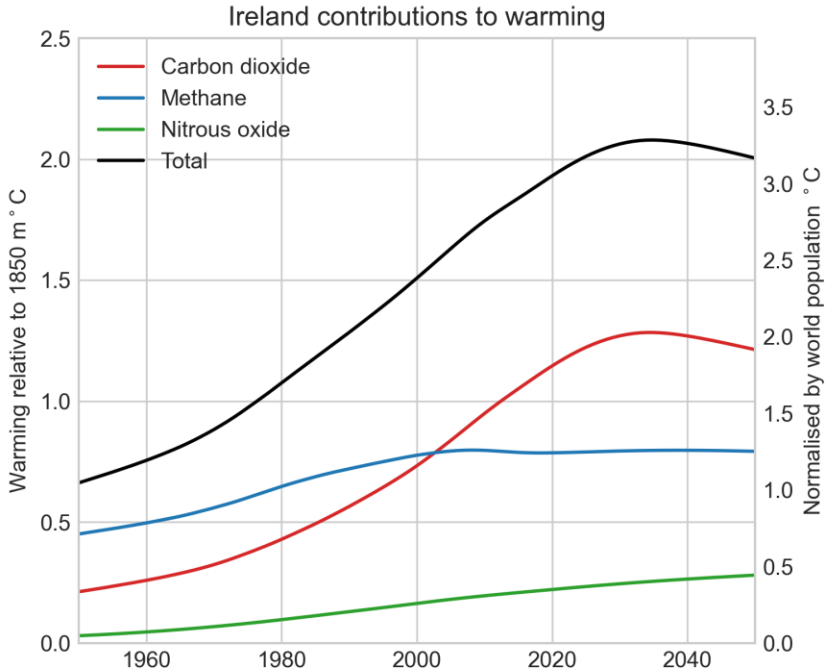




Net zero CO_2-e in 2035 & 3%/decade reduction in methane

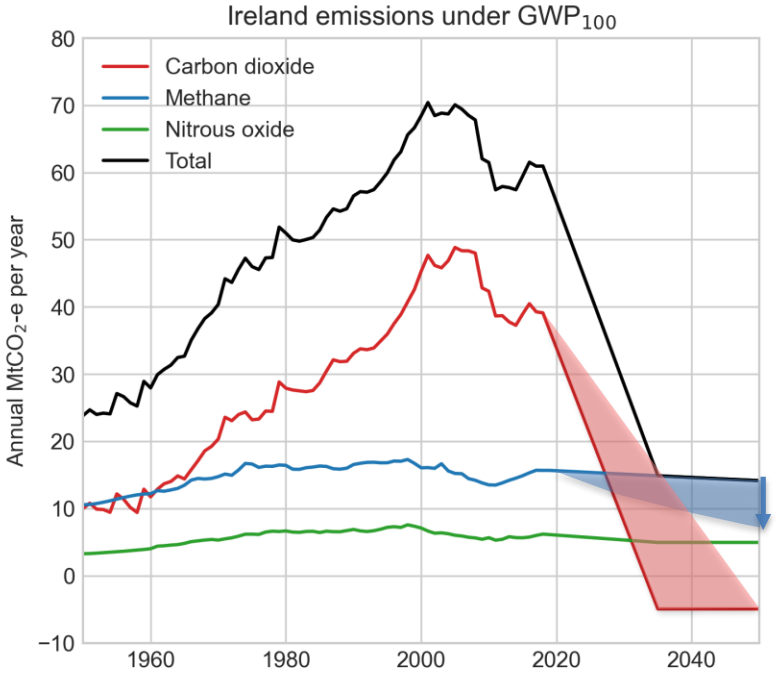
Extra 7 $MtCO_2$-e_{100}/year reduction in methane emissions in 2050 = 622 $MtCO_2$ avoided CO_2 emissions

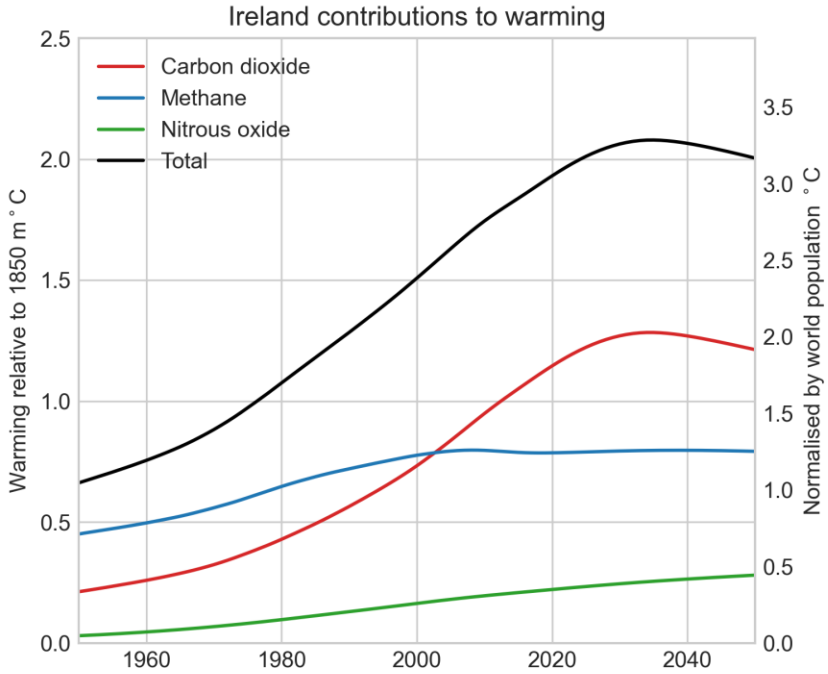




Net zero CO_2-e in 2035 & 3%/decade reduction in methane

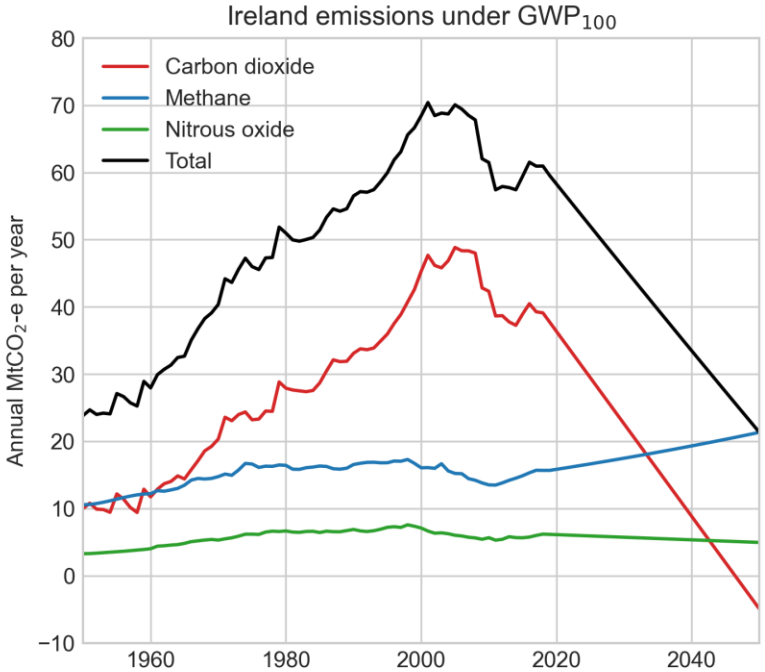
Treating methane emissions as CO_2-equivalent (GWP_{100}) understates impact of these reductions by a factor >3

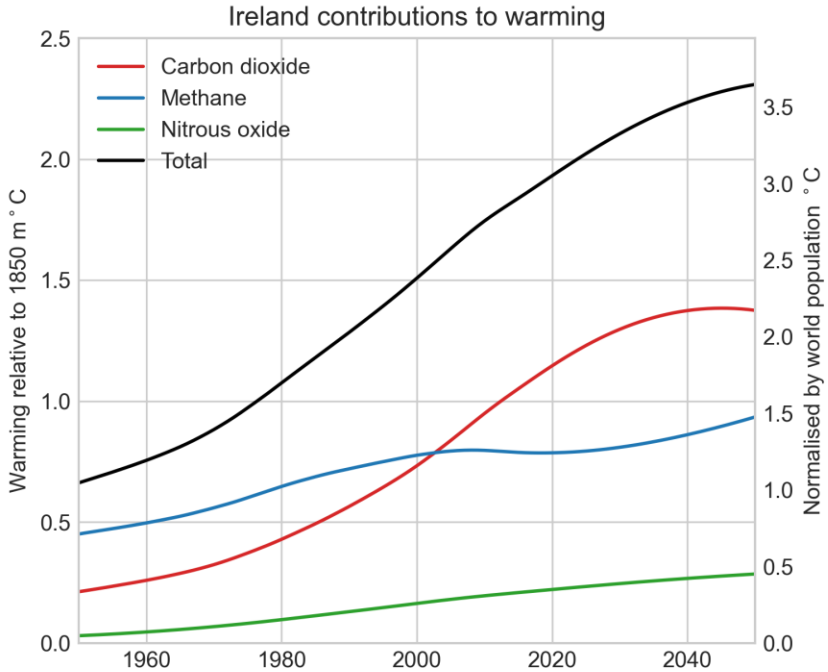




3%/decade = 203 $MtCO_2$-e_{100} avoided emissions by 2050

Undervaluation matters, because failure to reduce methane would negate impact of CO_2 reductions





Net zero CO_2-e CO_2+N_2O & 10%/decade **increase** in methane

Framing climate policy in terms of warming outcomes rather than emissions inputs

- Policy anomalies under “input based” accounting:
  - A crop farmer who converts to forestry to contribute to reducing global temperature by removing CO_2 from the atmosphere would be rewarded.
  - A livestock farmer who contributes to reducing global temperature by reducing methane emissions would not be.
  - Both farms may have identical impacts on global temperatures.
- In pursuit of a temperature goal, we need to:
  - **Penalize** actions that contribute to increasing global temperature,
  - **Reward** actions that reduce global temperature, and
  - **Ensure** reductions are permanent

Framing climate policy in terms of warming outcomes rather than emissions inputs

- **Recognize** that climate impacts primarily depend on warming, not "CO_2-equivalent" emissions.
- Set a **separate, ambitious but realistic target** for reducing methane emissions, recognizing their temperature impact:
  - 3%/decade decline in methane emissions ≈ no additional warming
  - Additional 1 $MtCO_2$-e_{100}/year reduction in methane emission rate ≈ 85 $MtCO_2$ avoided (not too precise: "a bit less than 100 $MtCO_2$")
- **Align incentives** with temperature outcomes.
- **Invest** in research and innovation to lock in progress.