International Institute for Applied Systems Analysis

CHALMERS

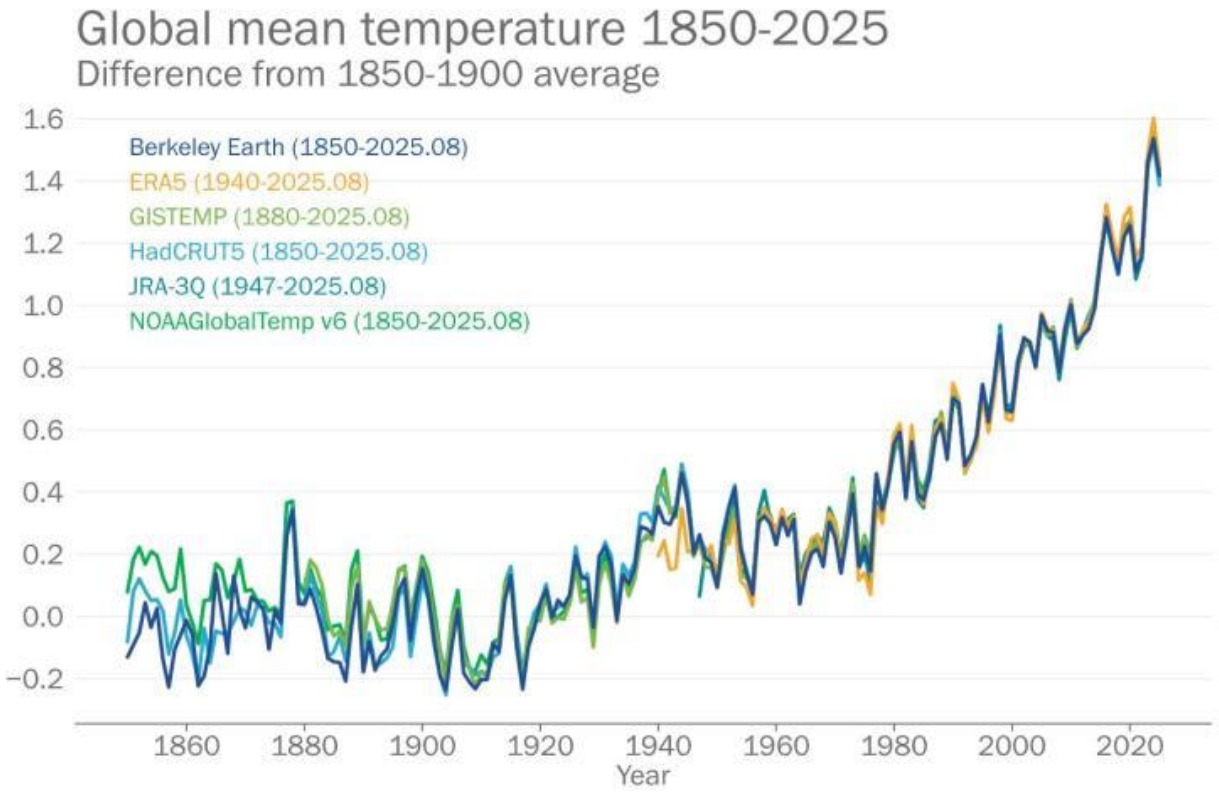
Climate overshoot and irreversibility: Implications for the social cost of short- and long-lived greenhouse gases

Daniel Johansson, Christian Azar, Jan S. Fuglestvedt,
Thomas Sterner & Katsumasa Tanaka

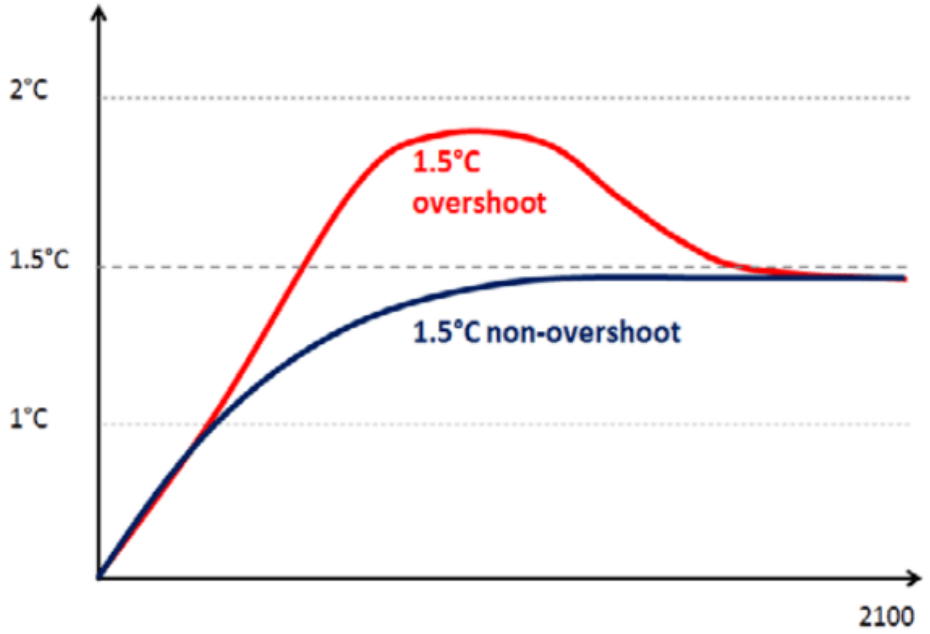
Malmsten Workshop in Sustainability Economics, January 21-23, 2026

Overshoot

Paris Agreement: “the increase in the global average temperature to well below 2°C above pre-industrial levels” and pursue efforts “to limit the temperature increase to 1.5°C above pre-industrial levels.”



https://wmo.int/news/media-centre/2025-set-be-second-or-third-warmest-year-record-continuing-exceptionally-high-warming-trend

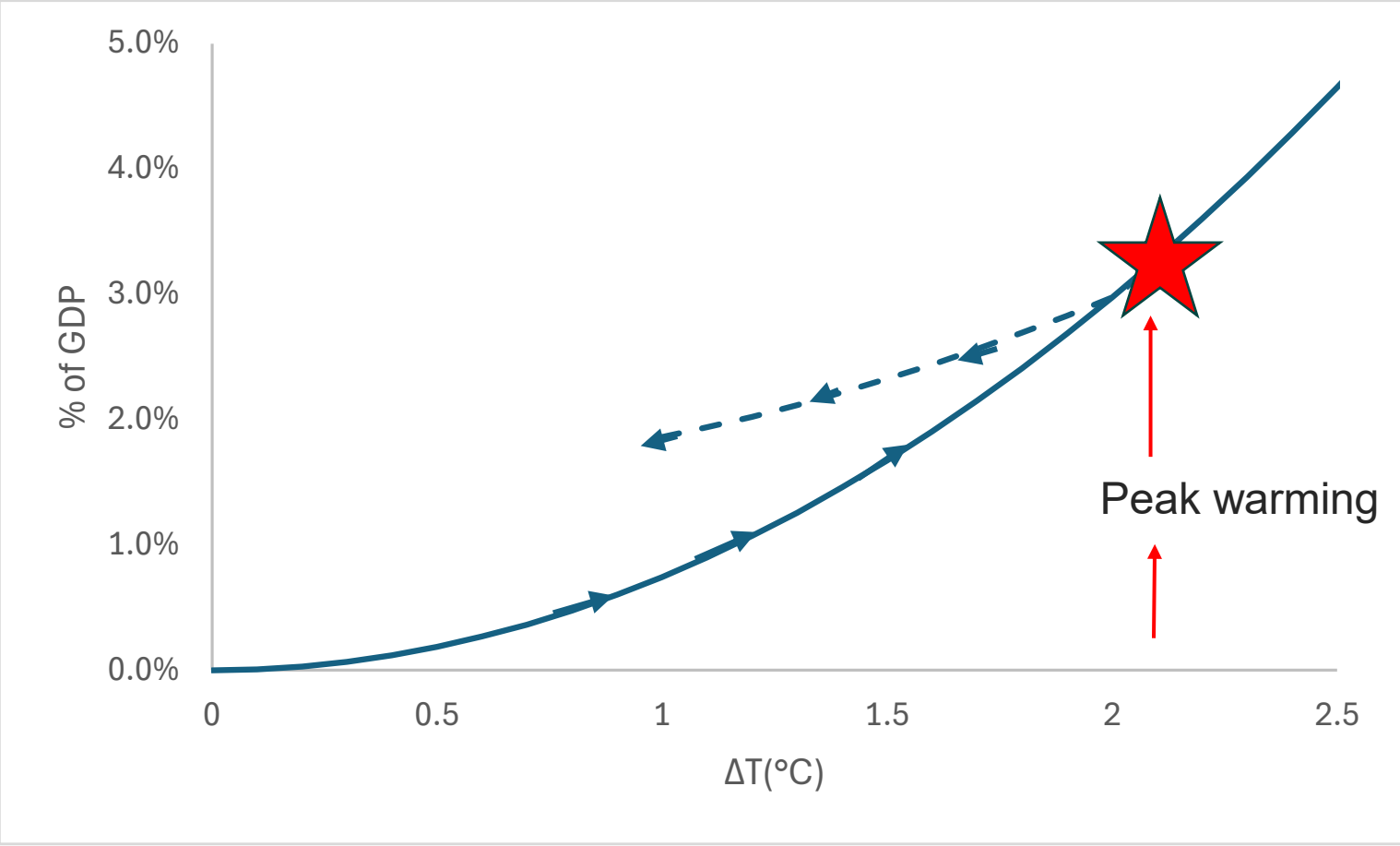


https://granthaminstitute.com/2023/11/29/overconfidence-in-overshoot/

Irreversibility

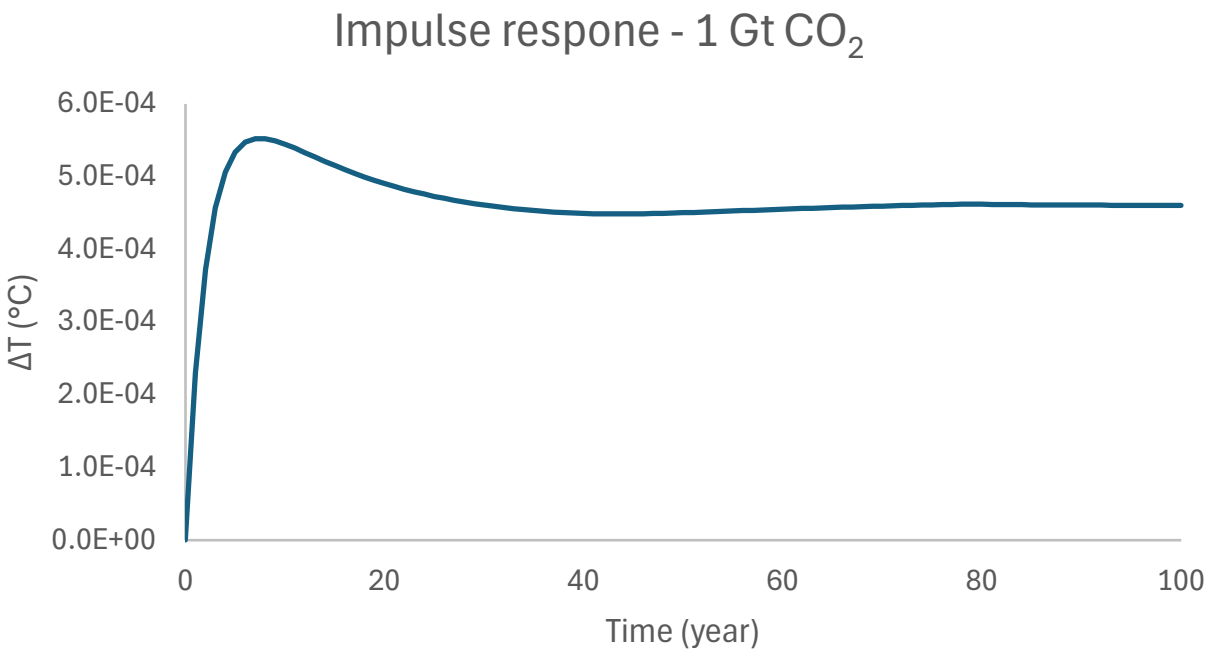
- Cimate impacts may be irreversible after a temperature overshoot.
- For example, an overshoot may cause:
  - irreversible impacts on glacier mass and runoff (Schuster et al, 2025).
  - irreversible changes in regional climate pattern (Kim et al, 2022 ; Schleussner et al, 2025; Steinart et al, 2025).
  - irreversible negative impacts on species, ecosystems, and societies (Reisinger et al, 2025).
- We analyse the implications of an **asymmetric damage function**, where damages do not decline with falling temperatures after a peak in the same way they increase with rising temperatures.

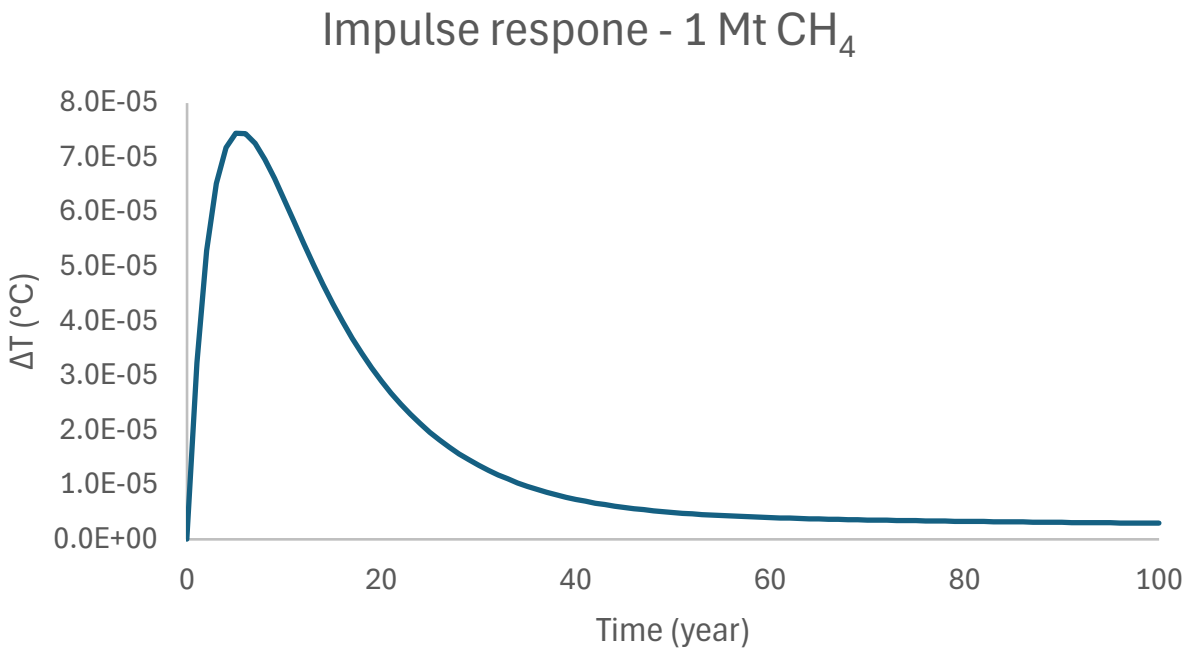
Damage irreversibility – illustration of principle



Research question

How does damage irreversibility affect the social costs of carbon dioxide (SCC) and methane (SCM) in overshoot pathways?





Method

- Modified version of DICE (M-DICE) (extension of Hänsel et al, 2020)

  Step 1. Generate pathways stabilizing at 1.5 °C above pre-industrial levels by 2100 and beyond, with an overshoot during the 21st century (damage function turned off)

  Step 2. Turn on damage function. Estimate the marginal damage implications of:

  - a CO_2 emissions pulse
  - a CH_4 emissions pulse.

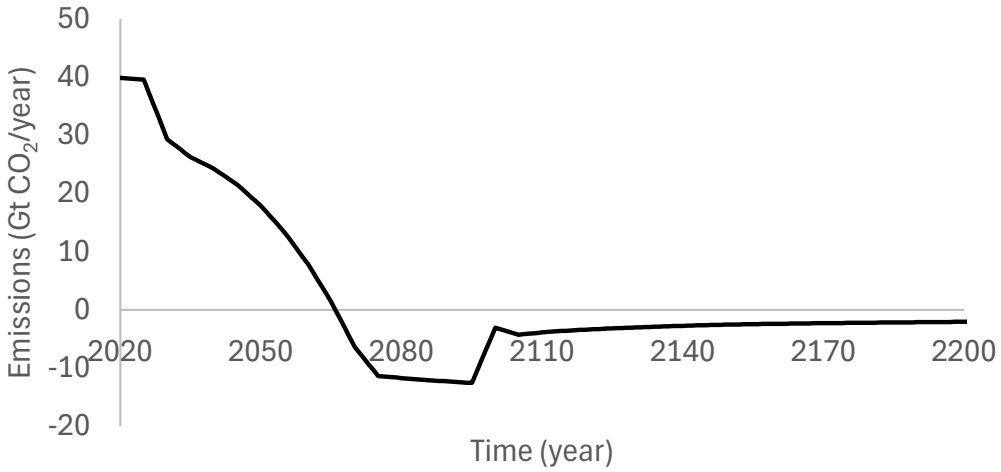
  Step 3. Make different assumption on how large share of damages are irreversible after a temperature peak and redo step 2.

- The damage function is based on a meta-analysis by Howard & Sterner (2017).The irreversibility assumption is our own.
- The discount rate is based on a Ramsey approach and calibrated according to the "median expert view" in Hänsel et al (2020) being $\eta=1$ and ρ=0.5%.

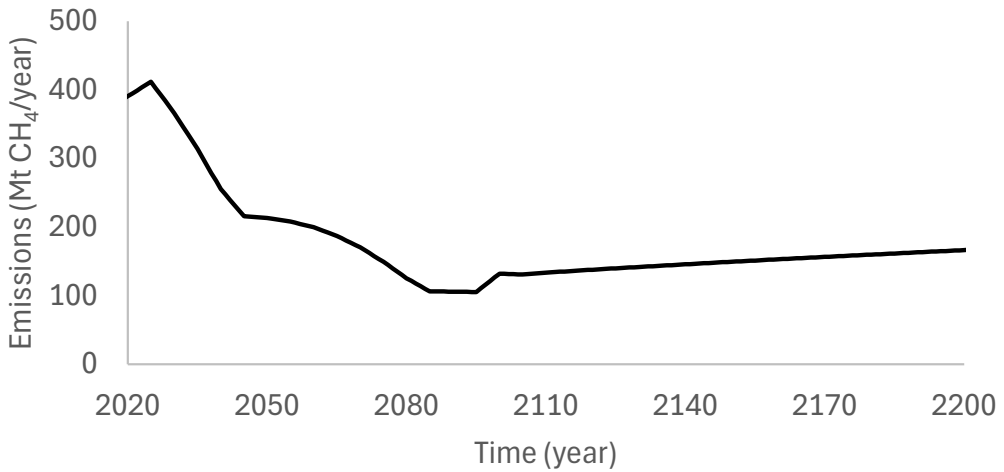
RESULTS

Pathways

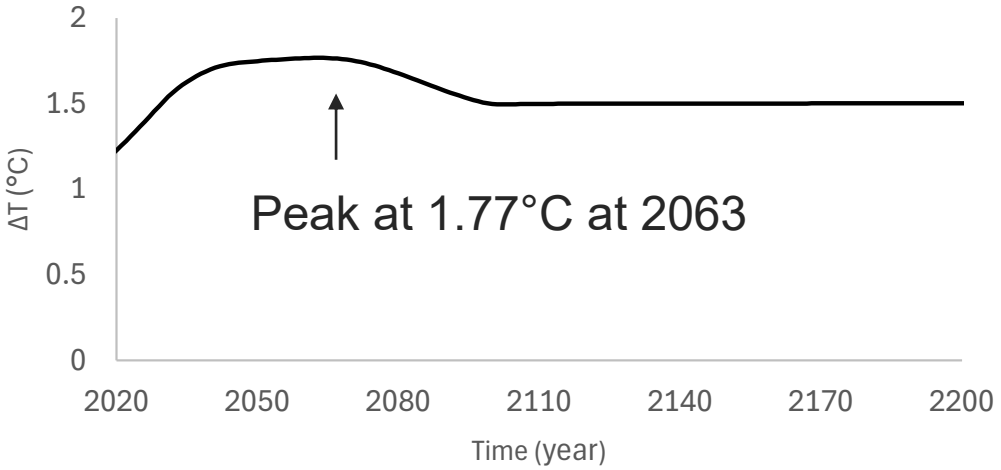
Annual CO_2 emissions



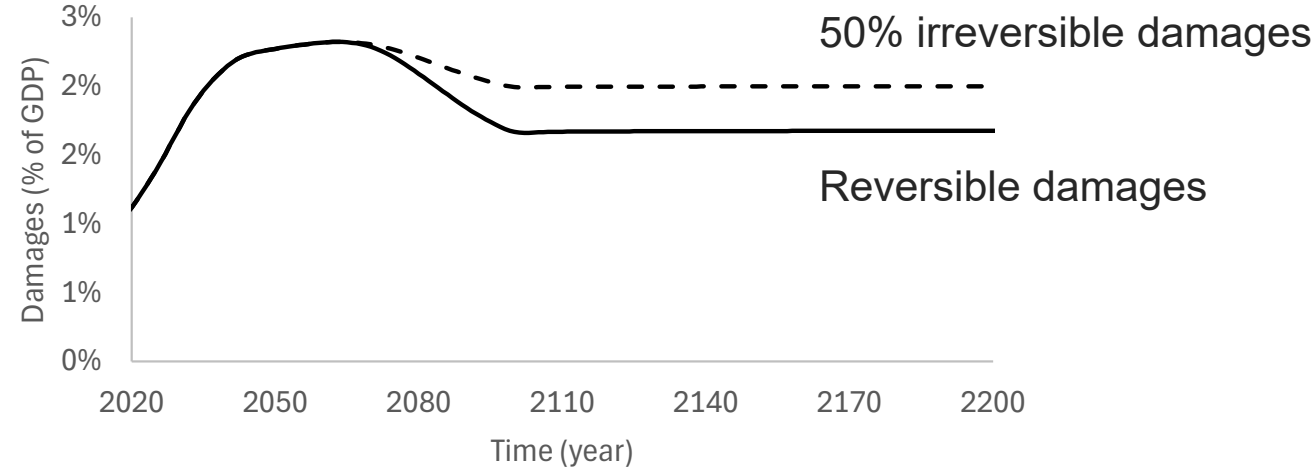
Annual CH_4 emissions



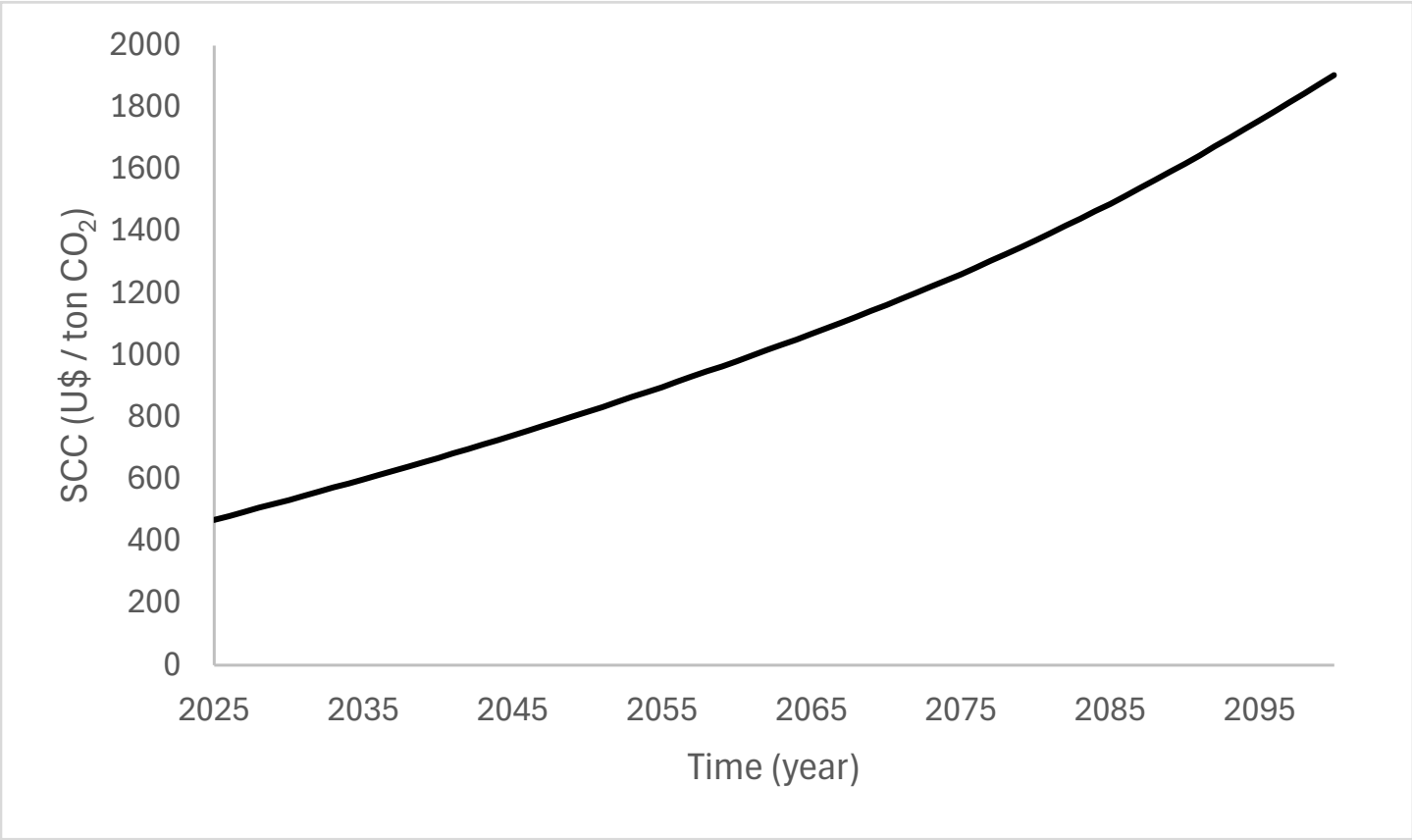
Global mean surface temperature change



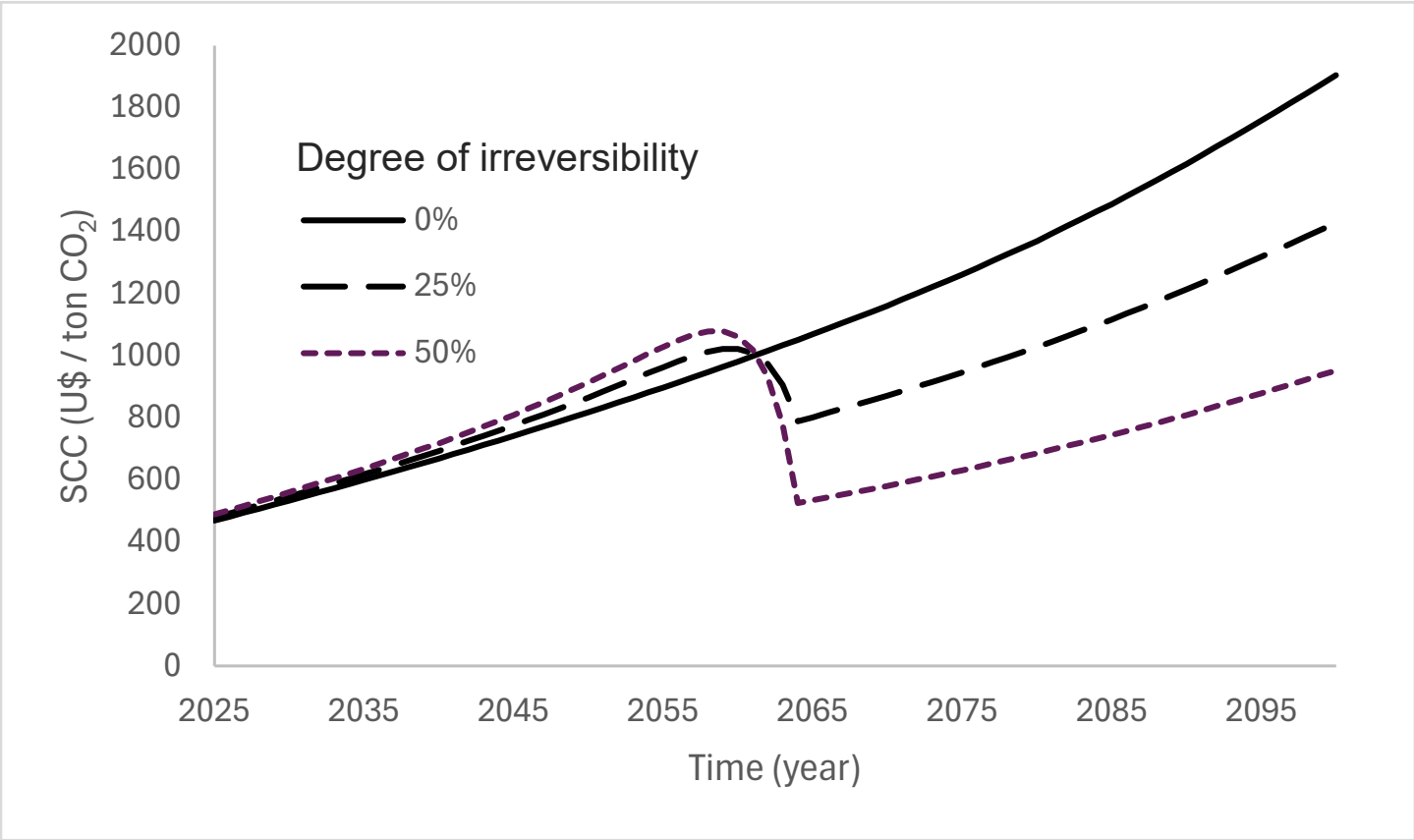
Climate change damages



Social cost of CO_2



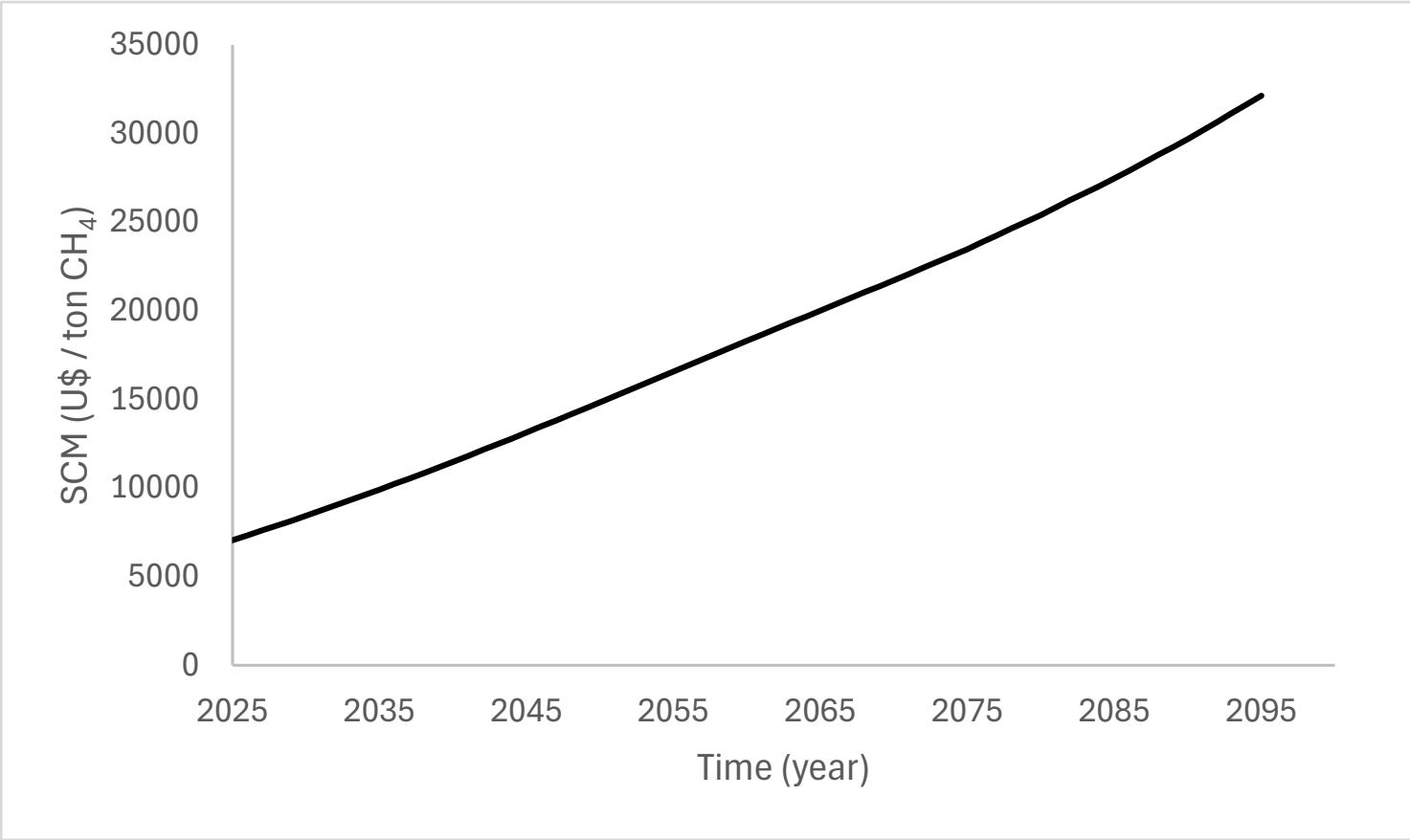
Social cost of CO_2



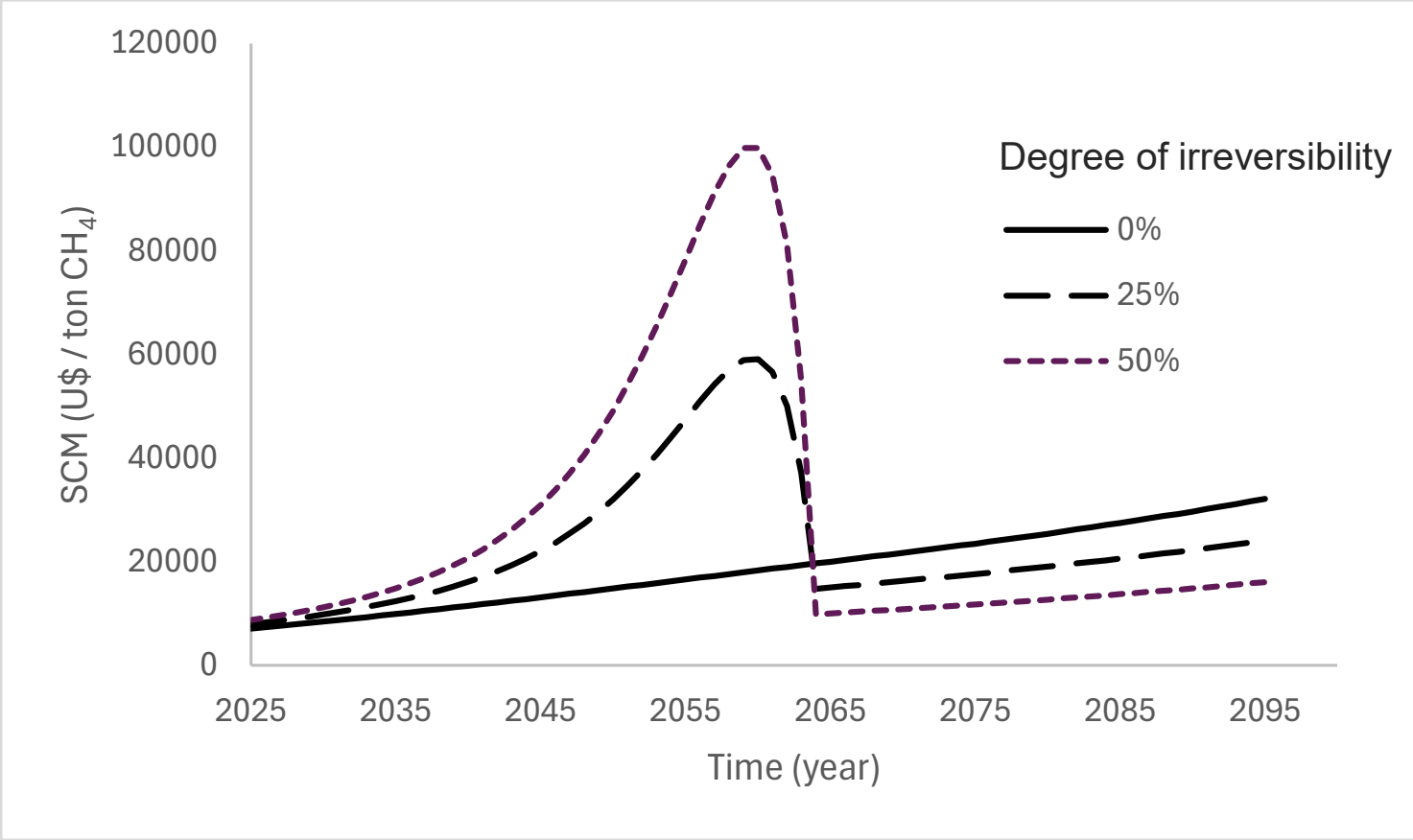
Key insight

- Before peak temperature, the SCC depends only weakly on damage irreversibility.
- *Why?* The temperature response of an CO_2 emission impulse is in itself irreversible so damage irreversibility does not have a strong impact on SCC prior to the peak.

Social cost of CH_4



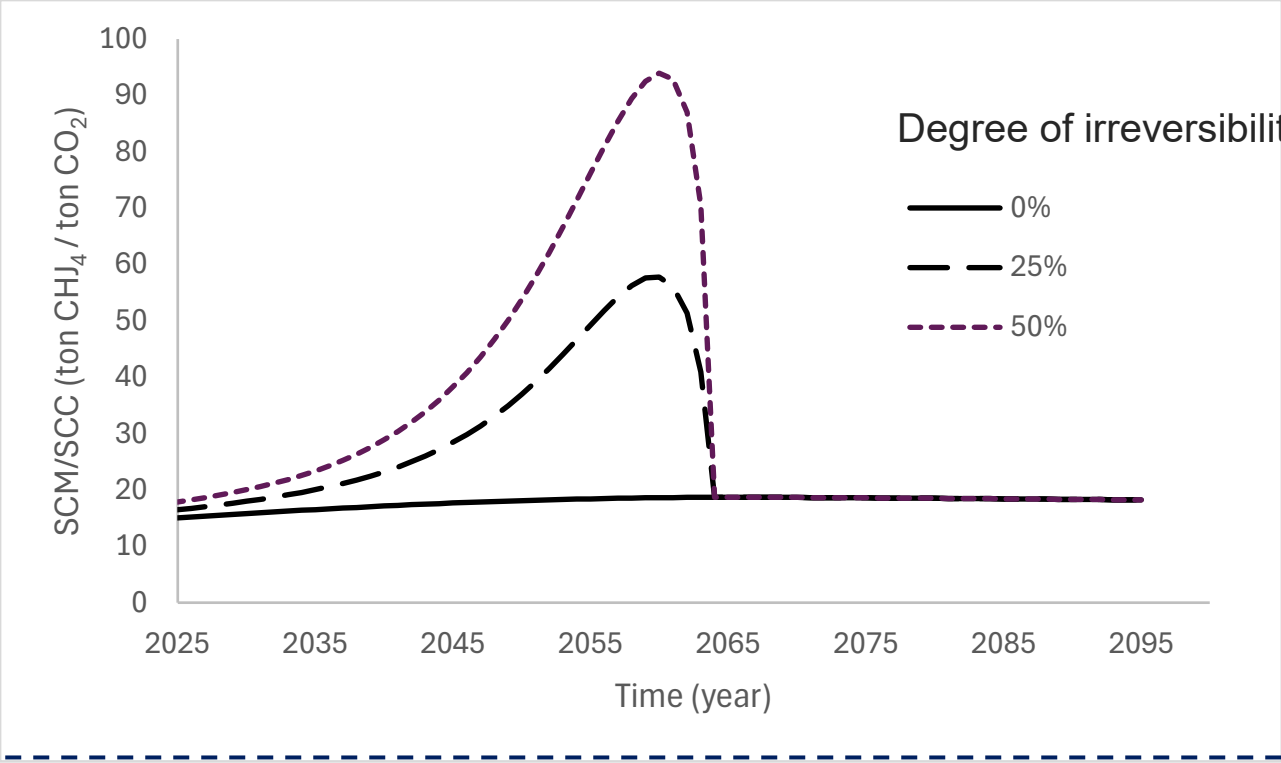
Social cost of CH_4



Key insights

- Before the temperature peak, and when damages are irreversible, the SCM depends strongly on the time remaining until the peak.
- *Why?* The temperature response of CH_4 is short-lived. With irreversibility, the remaining temperature response at the peak will triggers permanent damages.

Ratio of social cost of CH_4 to CO_2



Insights

- With reversible damages the social cost ratio is relatively stable over time with a value at about 15-20.
- Before the temperature peak, and with irreversible damages, the SCM/SCC ratio is highly sensitive to the time to peak.
- *Why?* The temperature response of CH_4 is short-lived. With irreversibility, the remaining temperature response of CH_4 emissions at the peak will trigger permanent damages, while the damages of CO_2 emissions are permanent irrespective of damage irreversibility.

Conclusions

- Social cost of CO_2 prior to the peak is only weakly affected by damage irreversibility.
- Social cost of CH_4 **near and prior to the** peak is strongly affected by damage irreversibility**; far from and prior to the peak the effect is small**.
- Reason:
  - CO_2 warming is irreversible causing irreversible climate impacts irrespective of damage irreversibility;
  - CH_4 warming is short-lived but cause permanent impacts if damages become irreversible at a temperature peak. **The warming caused by the emission impulse remaining at the peak is critical.**
- After the temperature peak, both the SCC and the SCM are affected by damage irreversibility: higher irreversibility leads to lower post-peak SCC and SCM values (since slope of the damage function is smaller).
- Implications: Global Warming Potential (GWP) with a fixed time horizon, e.g. 100 years, can approximate social cost ratios under reversible damages, but fails in overshoot pathways where damages are irreversible.

Thank you!

Background: Social cost of greenhouse gases

- Social cost of CO_2 (SCC) and Social cost of CH_4 (SCM) refers to **the net present value of climate damages per ton of CO_2 and CH_4 emitted in a certain year**.
- **The ratio of social cost of different greenhouse gases**, e.g. social cost of methane divided by the social cost of carbon, can serve as an **alternative** emission metric **to Global Warming Potentials (GWP)**.
- By analysing the ratio of social cost one can also understand potential weaknesses with using GWP for overshoot pathways.