The relationship between different emission trajectories and 2100 CO$_2$-eq stabilisation targets

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Emission trajectories and CO$_2$eq targets in the carbon-budget approach

Carbon budgets: strengths, uncertainties, approximations

The different effects of different gases on climate
**CO₂ equivalent concentration**

A measure of radiative forcing

- CO₂ equivalent concentration (CO₂eq)
  - A measure of radiative forcing
  - CO₂eq is the concentration of CO₂ alone that would yield the RF obtained from multiple agents
  - Nonlinear relationship with RF
  - There is no “CO₂eq gas” – emissions, concentrations behave differently

- Two CO₂ equivalent concentrations:
  - CO₂eqGHG - describes RF from greenhouse gases (CO₂, CH₄, ...)
  - CO₂eqTot - describes total RF from all forcing agents

- Values:
  - CO₂ = 390.5 ppm (2011.5) (http://scrippsco2.ucsd.edu/data/data.html)
  - CO₂eqGHG = 471 ppm (2011) (http://www.esrl.noaa.gov/gmd/aggi/)
  - CO₂eqTot = 395 ppm (2005; approx, quite uncertain)
Representative Concentration Pathways (RCPs)
Climate scenarios for the IPCC 5th Assessment

Carbon dioxide
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IIASA (2011)
Representative Concentration Pathways (RCPs)

Total radiative forcing

Forcing - Total

>4 degree warming by 2100

- World - AIM - RCP 6.0
- World - MiniCAM - RCP 4.5
- World - IMAGE - RCP3-PD (2.6)
- World - MESSAGE - RCP 8.5
- World - ID - hist

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Representative Concentration Pathways (RCPs)

Negative radiative forcing from non-direct-GHG agents (mainly aerosols)

Strong improvements in air quality are postulated in all RCP scenarios

\( \Rightarrow \) Decreasing negative aerosol RF

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Cumulative CO$_2$ emissions as a clock for climate change

- **Cumulative emission (1750-2011):** 550 PgC (billion tonnes carbon)
- **Current (2011) emissions:** 10.0 PgC/y (growing at 3% per year)
Warming (T) as a function of cumulative CO$_2$ emissions (Q)

Reinforcing feedbacks:
- Ice-albedo
- Carbon cycle
- Ecosystem collapse

Non-CO$_2$ gases
Net aerosol (future)

Stabilising influences:
- Heat loss (Planck feedback)
- CO$_2$ removal by carbon sinks
- Logarithmic response to CO$_2$
Climate projections with SCCM

- Predictions with SCCM
  = Simple Carbon-Climate Model

- SCCM includes:
  - multiple forcings
    (CO$_2$, CH$_4$, N$_2$O, CFCs, aerosols)
  - Carbon-climate feedbacks

- Scenarios for future emissions:
  - CO$_2$: smooth trajectory with cap on cumulative CO$_2$ emissions (Q)
  - All-time Q = 1000 to 3000 PgC
  - Other GHGs: approx RCP4.5

- Plot results against time
Climate projections with SCCM

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- Plot results against cumulative emissions Q(t) at time t

Raupach (2013)
Relationship of $T$ to $Q$ for scenario families

- Global warming as a function of cumulative CO$_2$ emissions

- Predictions with SCCM
  - multiple forcings (CO$_2$, CH$_4$, N$_2$O, CFCs, aerosols)
  - Carbon-climate feedbacks
Effect of emissions trajectory

- Predictions with SCCM
- Here CO\textsubscript{2} only
- Prescribed CO\textsubscript{2} emissions:
  - All curves have same all-time cumulative emission, \( Q = 1500 \) PgC
  - Vary year of starting mitigation from 2011 to 2031
- Result is a “bump” in temperature predictions, of up to 0.5 degC, lasting several decades

Raupach (unpublished)
Carbon budget approach

Strengths, uncertainties, approximations

- Carbon budget approach:
  - Warming ($T$) is a defined function of cumulative $\text{CO}_2$ emissions ($Q$)
  - $\text{CO}_2$-only world: $T(Q)$ is nonlinear (curving down)
  - With non-$\text{CO}_2$ forcing (methane, aerosols ...): adopt scenario-based connections between $\text{CO}_2$ emissions and non-$\text{CO}_2$ forcings
    - Under most scenarios, $T(Q)$ becomes close to linear in $Q$

- Strengths:
  - Links policy commitments with warming outcomes
  - Flexibility in implementation (through timing of emission reductions)
  - Allows estimation of risks

- Uncertainties: climate sensitivity, feedbacks etc

- Approximations:
  - Dependence of $T(Q)$ on emissions pathways is assumed negligible
  - Associations are assumed between $\text{CO}_2$ and non-$\text{CO}_2$ forcings
Outline

- Emission trajectories and CO$_2$eq targets in the carbon-budget approach
- Carbon budgets: strengths, uncertainties, approximations
- The different effects of different gases on climate
Comparing the climate impacts of different GHGs

- **Global Warming Potential (GWP)**
  - Introduced in IPCC AR1 (1990); current tables in IPCC AR3 (2001)
  - Absolute GWP = time-integrated RF from a 1 kg pulse release
  - Relative GWP = AbsGWP(gas) / AbsGWP(CO$_2$)

- **Global Temperature Potential (GTP)**
  - Absolute GTP (from pulse, steady releases) = temperature change (ΔT) at time t due to unit (pulse, steady) release
  - Relative GTP = AbsGTP(gas) / AbsGTP(CO$_2$)

- Both GWP and GTP depend on time horizon – e.g. for CH$_4$:
  - GWP = (62, 22, 7), GTP$_{steady}$ = (69, 24, 7) (horizon = 20, 100, 500 y)

- Climate impacts also depend on emissions trajectory (e.g. rising, falling)

Emission-temperature response functions for various gases

Emission-temperature response function = \( \frac{\text{warming at time } t \text{ from pulse release of some gas}}{\text{warming at } t = \infty \text{ from same release, without decay of gas}} \)

Raupach (unpublished)
Summary

- Emission trajectories and CO$_2$ eq targets in the carbon-budget approach
  - Temperature: 2 degC
  - Radiative forcing: 2.6 W m$^{-2}$ (2/3 probability range: 1.8 to 4)
  - CO$_2$eqTot: 450 ppm (2/3 probability range: 380 to 550)
  - CO$_2$eqGHG: CO$_2$eqTot + (0 to 80) ppm
  - All-time C budget: ~1000 PgC (~700 to ~1200); 550 used up
  - 2000-2049 CO$_2$ budget: ~1000 PgCO$_2$ = 272 PgC

- Carbon budgets: strengths, uncertainties, approximations
  - C budgets link policy directly to warming
  - For non-CO$_2$ forcings, emitted carbon equivalents still done by GWPs

- The different effects of different gases on climate
  - Sensitivity to emission trajectory for short-lived gases
  - GTP and emission-temperature transfer functions improve on GWP

- [The problem of sharing global quotas between nations]
  - The biggest climate-mitigation problem of all
References


