Deriving carbon budgets for IAM models

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Why focus on CO\textsubscript{2} budgets

- Part of the community does not have all gases / full climate model CO\textsubscript{2} budget could link these models to other targets

- Running under CO\textsubscript{2} budgets reduces uncertainty and focus analysis on the area where most of the action would need to occur

- Budget might be interesting for policy-makers, allows for substitution in time – but also communicates the “eating away the cake “concept well (Nature budget papers from 2009)
**CO₂ budgets**

- Claim paper Meinshausen et al: CO₂ budgets up to 2050 very good predictor for overshoot 2°C

- Uncertainties:
  - Climate system (if related to temperature)
  - Carbon cycle (CO₂ removal rate; carbon cycle feedback)
  - Forcing from other gases:
    - CH₄, N₂O etc
    - Aerosols
  - Distribution CO₂ energy vs. CO₂ land

- Literature at the time of Meinshausen paper small at the low side (just a few models’)
Concentration to radiative forcing

Total forcing

CO2 forcing
Emissions to concentrations

[Graph showing cumulative CO2 emissions and estimated fraction borne in baseline]
AMPERE Method to derive CO2 budgets

1. Existing IAM Model runs
2. Step 1: Use WG-1 info for climate (remove unnecessary uncertainty)
3. Step 2: Use WG-3 info for determining derived targets
4. MAGICC-6
5. Forcing
6. Weighted for proximity to RF target
7. Emission budgets per gas and over time for each RF level
Methods

AMPERE Method to derive CO2 budgets

- AME and EMF24 scenario collections
- MAGICC6 Monte-Carlo setup
  (e.g. Meinshausen et al 2009; 2011 for RCPs)
  - 9 carbon-cycle model emulations (C4MIP)
  - 600 observationally constrained climate-model parameter sets reproducing climate sensitivity PDFs
AME & EMF24 scenario library

- 27 baseline scenarios
- 74 scenarios with all WMGHGs and aerosol precursors, as well as land-use CO2
- 125 scenarios with at least energy-CO2, CH4, N2O, SOx
- 263 scenarios with at least energy-CO2, CH4, N2O
- Total 318 scenarios (with at least energy-CO2)
2°C probability all scenarios vs subset

![Graph showing the probability of exceeding 2°C compared to cumulative emissions of CO2 between 2000-2050. The graph plots cumulative emissions (Gt CO2) on the x-axis and the probability of exceeding 2°C on the y-axis, with separate markers for all scenarios and a subset.]
Warming by 2100 compared to RCPs

Not so clear relationship
Warming by 2100 compared to RCPs

- AME
- EMF24
- RCPs

Global-mean temperature increase (°C above PI)

Cumulative Total CO2 emissions 2000-2050 (GtCO2)
Effect of non-CO2 emissions on budgets

2000-2100 total CO2

CO2 budget vs temperature

‘Unexplained’ temperature vs non-CO2 forcing (2100)
Effect of net-negative CO2 emissions on budgets

2000-2050 total CO2 vs. cumulative emissions (Gt CO2)

2000-2100 total CO2 vs. cumulative emissions (Gt CO2)

Positive emissions (blue) vs. negative emissions (green)

Median ΔT in 2100
pCO2eq/RF budgets

Cumulative Total CO2 emissions 2000-2050 (GtCO2)
### pCO2eq/RF budgets

Top row in each cell: median and 20-80%tile
Lower row in each cell: mean ±1SD

<table>
<thead>
<tr>
<th>target</th>
<th>450 ppm CO₂eq in 2100</th>
<th>500 ppm CO₂eq in 2100</th>
<th>550 ppm CO₂eq in 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil-fuel CO₂ 2020 (GtCO₂/yr)</td>
<td>30 (28-33)</td>
<td>31 (27-33)</td>
<td>36 (34-37)</td>
</tr>
<tr>
<td></td>
<td>30 ±3</td>
<td>30 ±4</td>
<td>35 ±2</td>
</tr>
<tr>
<td>Fossil-fuel CO₂ 2030 (GtCO₂/yr)</td>
<td>24 (22-28)</td>
<td>28 (22-31)</td>
<td>36 (31-38)</td>
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<td></td>
<td>24 ±4</td>
<td>27 ±6</td>
<td>35 ±4</td>
</tr>
<tr>
<td>Fossil-fuel CO₂ 2050 (GtCO₂/yr)</td>
<td>12 (8-14)</td>
<td>17 (13-20)</td>
<td>26 (23-28)</td>
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<td>12 ±4</td>
<td>17 ±4</td>
<td>26 ±3</td>
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<tr>
<td>Fossil-fuel CO₂ budget 2000-2049 (GtCO₂)</td>
<td>1200 (1200-1400)</td>
<td>1300 (1200-1500)</td>
<td>1600 (1500-1700)</td>
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<td>1200 ±100</td>
<td>1300 ±100</td>
<td>1600 ±100</td>
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<tr>
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<td>1300 (1300-1500)</td>
<td>1900 (1500-2000)</td>
<td>2400 (2300-2600)</td>
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<td>1400 ±200</td>
<td>1800 ±300</td>
<td>2400 ±200</td>
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<td>41 (35-46)</td>
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<td>Total GHG 2050 (GtCO₂e/yr)</td>
<td>21 (17-25)</td>
<td>27 (24-30)</td>
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<td>1900 (1800-2000)</td>
<td>2100 (1800-2200)</td>
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<td>2400 (2300-2600)</td>
<td>3000 (2600-3200)</td>
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"Predictive skill" of budgets

450 ppm CO$_2$eq by 2100
Constraint: Fossil CO2

Total GHG concentration in 2100 (ppmv CO2eq)

450 ppm CO$_2$eq by 2100
Constraint: Total Kyoto GHGs

Total GHG concentration in 2100 (ppmv CO2eq)

- Unconstrained scenario collection
- Perfectly (a posteriori) constrained scenario collection
- Constraint: 2020 emissions
- Constraint: 2030 emissions
- Constraint: 2050 emissions
- Constraint: cum. emissions 2000-2050
- Constraint: cum. emissions 2000-2100
Conclusions

- CO2 budgets can help to connect different models
- But much more uncertain than suggested earlier
- We have a method to estimate budgets and uncertainty... but realize that at the low side, actually uncertainty might be even larger than suggested by our uncertainty ranges.