Policy implications of carbon cycle uncertainties

ASP Colloquium Lecture
NCAR, Boulder – CO
14 August 2013 – Joeri Rogelj
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Acknowledgments
Malte Meinshausen, Keywan Riahi, Reto Knutti, Andy Reisinger, David McCollum, Brian O’Neill and many others…
Outline

- Policy arena
- Incorporating carbon cycle uncertainties
- A few examples related to climate change
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- Incorporating carbon cycle uncertainties
- A few examples related to climate change
The policy arena

Where do carbon cycle and policies interact?
The policy arena

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- Policies -> carbon-cycle
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Images courtesy of: medomed.org, Ashworth Community, REVE, WWF
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The policy arena

What are the policy forums?
The policy arena

What are the policy forums?

- Local and regional level:
  - National and regional governments
  - Communities
The policy arena

What are the policy forums?
- Local and regional level:
  - National and regional governments
  - Communities
- Global:
  - UNFCCC
  - G20
  - UNCCD
Incorporating carbon cycle uncertainties
Assessment framework
Assessment framework

- Emission scenario
- Economy
- Energy system
- Societal preferences
- Demographics
- Politics

Image: Rogelj Joeri (2013)
Assessment framework

Emission scenario
- economy
- energy system
- societal preferences
- demographics
- politics

Climate forcing
- carbon cycle
- GHG concentrations
- direct/indirect
- radiative forcing

Image: Rogelj Joeri (2013)
Assessment framework

- **Emission scenario**
  - economy
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  - carbon cycle
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- **Geophysical impacts**
  - temperature
  - extreme events
  - hydrological cycle
  - acidification
  - Long-term geophysical impacts
  - sea-level rise
  - land-cover changes
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    - sea-level rise
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- **Societal impacts**
  - food
  - health
  - economic losses
  - ecosystem services
  - livelihoods

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- Societal impacts
  - food
  - health
  - water
  - economic losses
  - ecosystem services
  - livelihoods

loss & damage

Image: Rogelj Joeri (2013)
Assessment framework

Emission scenario
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Geophysical impacts
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Societal impacts
- food
- health
- water
- economic losses
- ecosystem services
- livelihoods

Policies
- ASSESS “DANGEROUS INTERFERENCE”

Level of mitigation

Loss & damage

Level of adaptation

Preferences

Example: How are carbon-cycle uncertainties incorporated in IAMs?

OBJECTIVE:
Representing IPCC AR4 uncertainty with a reduced-complexity model setup

- Uncertainty in:
  - carbon cycle
  - climate response
  - historical forcing and observations
Example: MAGICC

- Reduced complexity carbon-cycle and climate model
- Developers:
  - Tom Wigley
  - Sarah Raper
  - Malte Meinshausen
- Documentation
  - Meinshausen et al, ACP (2011)
  - www.magicc.org
MAGICC: carbon cycle

- Terrestrial and ocean carbon cycle
- Carbon-cycle climate interactions
MAGICC: carbon cycle

Terrestrial carbon cycle

Figure: Meinshausen et al (2011)

www.magicc.org – live.magicc.org
MAGICC: carbon cycle

- Terrestrial and ocean carbon cycle
- Carbon-cycle climate interactions

Figure C^4MIP tuning: Meinshausen et al (2011)
MAGICC: climate response

- Four-box energy-balance model
- Upwelling diffusion ocean model

Figure: Meinshausen et al (2011)
MAGICC: climate response

- Four-box energy-balance model
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Probabilistic approach (Bayesian)
- 82-dimensional joint-distribution of climate and forcing parameters
- Applying historical constraints:
  - 2005 AR4 uncertainty distributions for RF
  - Observed hemispheric land/ocean temperatures
  - Observed ocean heat uptake

Meinshausen et al (2009)
MAGICC: IPCC AR4 consistent setup

- C4MIP carbon-cycle emulation
- Probabilistic AR4 forcing & historic constraints

www.magicc.org – live.magicc.org
MAGICC: IPCC AR4 consistent setup

- C4MIP carbon-cycle emulation
- Probabilistic AR4 forcing & historic constraints
- AR4 climate sensitivity?
MAGICC: IPCC AR4 consistent setup

- C^4MIP carbon-cycle emulation
- Probabilistic AR4 forcing & historic constraints
- AR4 climate sensitivity?

IPCC AR4 climate sensitivity:
- likely to be in the range of 2 to 4.5°C
- with a best estimate of about 3°C, and is
- very unlikely to be less than 1.5°C.
- Values substantially higher than 4.5°C cannot be excluded
MAGICC: IPCC AR4 consistent setup

- C^4MIP carbon-cycle emulation
- Probabilistic AR4 forcing
- AR4 climate sensitivity?

Figure based on: Rogelj et al (2012)
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MAGICC: climate response

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MAGICC: IPCC AR4 consistent setup

- C$^4$MIP carbon-cycle emulation
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Figure based on: Rogelj et al (2012)
MAGICC: IPCC AR4 consistent setup

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MAGICC: IPCC AR4 consistent setup

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Figure based on: Rogelj et al (2012)
Policy implications of carbon cycle uncertainties

Three illustrative examples
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Three illustrative examples

- General characteristics of low temperature scenarios
Policy implications of carbon cycle uncertainties

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- General characteristics of low temperature scenarios
- Near-term implications of long-term emission constraints
Policy implications of carbon cycle uncertainties

Three illustrative examples

- General characteristics of low temperature scenarios
- Near-term implications of long-term emission constraints
- Integrating uncertainties for scenarios towards staying below 2°C
Examples: framing
Examples: framing

![Time series graph showing temperature rise relative to preindustrial levels.](Historical temperatures: HadCRUT4, Figure: Rogelj J.)
Examples: framing

Historical temperatures: HadCRUT4, Figure: Rogelj J.
Examples: framing

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Historical temperatures: HadCRUT4, Figure: Rogelj J.
General characteristics
General characteristics
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General characteristics

Likely (>66%) maximum temperature rise (T) before 2100

$T_{66\%} < 2^\circ C$

median

Figure based on: Rogelj et al (2011)
General characteristics

Likely (>66%) maximum temperature rise (T) before 2100

Figure based on: Rogelj et al (2011)
General characteristics

Figure based on: Rogelj et al (2011)
General characteristics

![Graph showing likely (>66%) maximum temperature rise (T) before 2100. The graph illustrates the total annual GHG emissions in GtCO₂e/yr from 2000 to 2100. The horizontal axis represents the years, and the vertical axis shows the total annual GHG emissions. The graph includes two key scenarios: T₆₆% < 2°C and T₆₆% < 3 to 4°C. The median line and two other lines indicate the range of emissions.](image)

Figure based on: Rogelj et al (2011)
General characteristics

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General characteristics

![Graph showing likely (>66%) maximum temperature rise (T) before 2100]

- \( T_{66\%} < 2^\circ C \)
- Median

**Total annual GHG emission (GtCO\(_2\)e/yr)**
- 44 GtCO\(_2\)e/yr
- 20 GtCO\(_2\)e/yr

**Years**
- 2000 to 2100

Figure based on: Rogelj et al (2011)
Policy implications of carbon cycle uncertainties

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Tools
Tools: societal representation
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GREENHOUSE GAS EMISSIONS SCENARIOS
Tools: societal representation
Tools: societal representation

- Light bulb
- Wind turbine
- Industrial plant
- Car

\[ \text{CH}_4 \quad \ldots \quad \text{CO}_2 \quad \text{SO}_x \quad \text{HFCs} \quad \text{BC/OC} \]
Tools

MESSAGE

MAGICC
“Feasibility window” in 2020

Figure based on: Rogelj et al (2013)
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Policy implications of carbon cycle uncertainties

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Integrating uncertainties
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Tools

MESSAGE

MAGICC
Methodology
Methodology

Figure based on: Rogelj et al (2013)
Methodology

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Methodology – cost-risk distributions

Figure based on: Rogelj et al (2013)
Cost-risk distributions

Figure based on: Rogelj et al (2013)
Cost-risk distributions

Probability to stay below 2°C

2012 Carbon Price [US$2005/tCO₂]

Reduced climate risks

Figure based on: Rogelj et al (2013)
Cost-risk distributions

Figure based on: Rogelj et al (2013)
Cost-risk distributions

![Graph showing the probability to stay below 2°C as a function of the 2012 carbon price. The probability increases as the carbon price increases.]

Figure based on: Rogelj et al (2013)
Cost-risk distributions

Figure based on: Rogelj et al (2013)
Technological uncertainties

2°C

Figure based on: Rogelj et al (2013)
Technological uncertainties

Figure based on: Rogelj et al (2013)
Societal choices (energy demand)

Figure based on: Rogelj et al (2013)
Societal choices (energy demand)

Figure based on: Rogelj et al (2013)
Societal choices (energy demand)

2°C

Figure based on: Rogelj et al (2013)
Political choices

$2^\circ$C

Figure based on: Rogelj et al (2013)
Political choices

Policy implications of carbon cycle uncertainties

Figure based on: Rogelj et al (2013)
Which uncertainties matter (most)?

2°C
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2°C

1.
2.
3. Societal (energy demand)
4. Technological
Which uncertainties matter (most)?

2°C

1. Political (delayed action)
2. Geophysical
3. Societal (energy demand)
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References
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Rogelj et al. (Nature, 2013)

More information on:
http://www.iac.ethz.ch/people/rogeljj

Thank you
Back-up

Figure: Rogelj et al (2013)
Back-up

Figure: Rogelj et al. (2013)

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Figure: Rogelj et al (2013)

Back-up

Mitigation technology sensitivity

Energy demand sensitivity

3°C

Increasingly delayed action

Political inaction sensitivity

Combined representation

Legend

Panel a and b:
- Reference full technology portfolio
- Advanced long-term non-CO₂ mitigation
- Advanced transportation
- No new nuclear
- Limited land-based mitigation measures
- No CCS

Panel a, b, c and d color coding:
- Intermediate future energy demand
- Low future energy demand
- High future energy demand

Panel c and d:
- Immediate action
- Delayed action until 2015
- Delayed action until 2020
- Delayed action until 2025
- Delayed action until 2030

Policy implications of carbon cycle uncertainties

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Figure: Rogelj et al (2013)
Uncertainty ranking

Results

2°C

1. Political (delayed action)
2. Geophysical
3. Social (energy demand)
4. Technological

Note: demographic and economic uncertainties not explicitly assessed.

Figure: Rogelj et al (2013)
Uncertainty ranking

Results

**2°C**

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**Figure: Rogelj et al (2013)**
Uncertainty ranking

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Figure: Rogelj et al (2013)
Figure: Rogelj et al (2012)
Back-up

Figure: Rogelj et al (2012)
feasibility windows of global 2020 greenhouse gas emissions required to limit warming to below 2°C