Challenges for Modelling the Management of Global Commons: A Drama at Multiple Levels

MOCAP Workshop on Modelling Carbon Prices

Potsdam, 4 October 2012

Prof. Dr. Ottmar Edenhofer
Overview

1. The scope of the challenge

2. Managing the Global Commons

3. Global / Regional Scale:
   Prospects of International Cooperation

4. Regional / Domestic Scale:
   The German Energy Transition – Leading by Example

5. Multilevel Governance from Global to Micro
1. THE SCOPE OF THE CHALLENGE
Long term trends show clear evidence

• Temporal slow downs of global warming have occurred already in the past
• Recent independent examination of IPCC results (Berkeley Earth Surface Temperature Project) has confirmed results
“Tipping processes of the climate system” show a strong reaction already to small climate changes

Schellnhuber, 1996; Lenton et al., 2008
Burning Embers Diagram

Prognosis for 2100 (IPCC 2007)

2°C above pre-industrial level

Global warming above present temperature (°C)

- Arctic summer sea ice
- Greenland ice sheet
- Boreal forest
- West Antarctic ice sheet
- Amazon rainforest
- Sahara/Sahel and West African monsoon
- El Niño southern oscillation amplitude
- Atlantic meridional overturning circulation

Economic Growth in Perspective

Edenhofer et al. 2012
World Map of Wealth

Füssel (2007)
World Map of Carbon Storage in the Atmosphere

Fossil CO₂ emissions per person (1950-2003)

very low  high
low       mean
very high

Füssel (2007)
Carbon Debt and Wealth

Fitting line: \( \ln P = 0.987 \ln K + c \)

Füssel (2007)
Climate Policy as an Insurance

GHG emissions resulting from the provision of energy services contribute significantly to the increase in atmospheric GHG concentrations.
2. MANAGING THE GLOBAL COMMONS
Renaissance of Coal?

Prices of Energy Commodities
(U.S. dollars a barrel of oil equivalent)

- Asian liquefied natural gas
- U.S. gas
- Australian coal
- Oil

Source: IMF (2011)
We are not on Track – Renaissance of Coal!

Kaya decomposition of global CO2 emissions.

SRREN (IPCC, 2011)
The BAU Scenarios could exceed the Level of Greenhouse Gas Concentration of 600 ppm (~4°C Temperature Increase)

SRREN (IPCC, 2011)
The Atmosphere as a Global Common

Atmosphere: Limited Sink
~ 230 GtC

Resource Extraction
> 12,000 GtC
Managing the Global Commons

1) Determine Magnitude of Atmospheric Disposal Space
   → Balance Costs & Risks of Climate Change with Mitigation

2) Adopt efficient Policy Instruments: Carbon Tax or ETS

3) Distribute the Climate Rent
... and What About Energy Efficiency?

Mitigation technologies: 450ppm World

Luderer et al. 2011
The Costs of Renewables are often still higher than those of Non-Renewables but…
...some RE Technologies are already competitive

IPCC SRREN (2011)
Learning-by-Doing

![Graph showing the decreasing cost of solar and wind energy over time, indicating the concept of learning-by-doing.](image-url)
## Multiple Spatial and Temporal Scales

<table>
<thead>
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3. GLOBAL / REGIONAL SCALE:

PROSPECTS OF INTERNATIONAL COOPERATION
Pollution as a Prisoners Dilemma

The payoff-matrix

\[
\begin{array}{cc}
\text{Alice} & \text{Bob} \\
\hline
\text{Abate} & 3 & 5 \\
\text{Pollute} & 3 & -2 \\
\end{array}
\]

\[
\begin{array}{cc}
\text{Abate} & 5 & 0 \\
\text{Pollute} & -2 & 0 \\
\end{array}
\]
Prisoners Dilemma: Social optimum

- Social perspective: (Abate, Abate) is optimal
Prisoners Dilemma: Non-cooperative solution

- Social perspective: (Abate, Abate) is optimal
- Individual rationality: → players act selfishly
- **Dominant Strategy:** best response irrespective of the other players
- Players will realize inferior strategy set, which is the **Nash-Equilibrium** of the game
Pollution as a Chicken Game

Different payoff-matrix

<table>
<thead>
<tr>
<th></th>
<th>Player 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abate</strong></td>
<td></td>
<td><strong>Pollute</strong></td>
</tr>
<tr>
<td><strong>Abate</strong></td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>-2</td>
<td>-4</td>
</tr>
<tr>
<td>5</td>
<td>-4</td>
<td>-4</td>
</tr>
</tbody>
</table>

⇒ Payoffs are worse if no one abates: cf. if no one abates, catastrophe is reached
Pollution as a Chicken Game

- Social optimum remains unchanged
- Dominant strategies?

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<tr>
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<td>5</td>
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Pollution as a Chicken Game

- Social optimum remains unchanged
- No dominant strategies
- Nash Equilibrium?
Pollution as a Chicken Game

- Social optimum remains unchanged
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- Nash Equilibrium?
Pollution as a Chicken Game

- Social optimum remains unchanged
- No dominant strategies
- 2 Nash Equilibria
  - Neither Nash Eq’m is socially optimal
  - Environment is better off (there is some abatement)
- A better model for current state of cooperation on climate change(?), i.e. a small coalition will form to avoid greatest damages
- But which Nash Eq’m will be played?
International Environmental Agreements as a Cartel Stability game

- Coalition acts as one player → maximizes its new ‘individual payoff’
- Non-signatories behave non-cooperatively towards coalition
- This new set of players behave non-cooperatively, play regular Nash-eq.

⇒ ‘Partial-Agreement-Nash-Equilibrium’

- Coalition cooperates among its members, if they sign the agreement
  → Compliance problem (separate issue, can be addressed by reciprocal strategies, see e.g. Heitzig/Lessmann/Zou PNAS 2011)
Coalition Formation: Example

- Specific payoff:

\[ \pi_i = B_i(Q) - C_i(q_i) = Q - \frac{q_i^2}{2} \]

- Consider Coalition of size \( k \), number of countries \( N \):

Coalition-member-payoff: \[ \pi_c = \frac{k^2}{2} + (N - k) \]

Free-rider payoff: \[ \pi_f = k^2 + (N - k - \frac{1}{2}) \]
Coalition Formation: Example

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![Graph showing member payoff and free-rider payoff increasing with coalition size.](image)
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- Stable coalition sizes: \( 2, 3 \) (independent of \( N \))
  \( \Rightarrow \) For large \( N \): stable coalition achieves little

- Reason: high Free-riding incentives
  \( \Rightarrow \) Almost same results as in the Prisoners Dilemma!

- What can we do about that?
Issue Linking

• Making cooperation work by introducing new incentives → Changing the payoff structure of the game

• Positive:
  – side payments
  – permit allocation
  – issue linking

• Negative:
  – reciprocal measures
  – financial penalties
  – trade restrictions
ISSUE LINKING: RESEARCH & DEVELOPMENT

- **R&D exhibits spillovers**
  - empirical evidence, e.g. Griliches (1992)

- **Research cooperation**
  - facilitates spillovers
    - transfer of technology/technical knowledge
    - increase efficiency and synergies though network
    - sharing R&D costs

- **Government policies**
  - cannot affect spillovers directly
  - may encourage cooperative R&D
    - EU Framework Programmes

- **Spillovers exclusive to the coalition (club good)**
Coalition Formation: Issue Linkage

- Specific payoff from before:
  \[ \pi_i = B_i(Q) - C_i(q_i) = Q - \frac{q_i^2}{2} \]

- Now consider: Additional benefit for each coalition member:
  \[ \pi_c(k) = B_i(Q) - C_i(q_i) = Q - \frac{q_i^2}{2} + (k - 1) \cdot \alpha \]

How could this be achieved?
Issue Linking: Trade Sanctions

- Coalition imposes tariffs on imports from free-riding countries

  - *Unfair advantage*: Not paying the costs of climate change is a subsidy
  - Other countries should ban or tax goods from such countries
  - “Energy tariffs” would simply restore the balance

- Perez (2005): “WTO Second Shrimp Ruling”
  - Extension to “pure global goods, such as [...] the atmosphere [...] seems to follow naturally [...] and does not seem to raise difficult questions”
Without measures: Coalition of size 2 is stable

Source: Lessmann, Marschinski, Edenhofer (2009), Economic Modelling: “The effects of tariffs on coalition formation in a dynamic global warming game”
Issue Linking: Trade Sanctions

With measures: Coalition of size 6 is stable

Source: Lessmann, Marschinski, Edenhofer (2009), Economic Modelling: “The effects of tariffs on coalition formation in a dynamic global warming game”
Coalition Formation: Modelling Challenges

• Prevalent Model
  – studies stability of potential coalitions, not how they actually form
  – idealistic assumptions about preferences, rationality, commitment power etc. as common in game theory

• Coalition Formation as a Stochastic Process
  – model actual process of forming / merging / splitting coalitions (see poster Heitzig)
  – still based on many idealistic assumptions

• TO DO: Agent-Based Models?
  – model actual interactions (negotiations, agreements) more explicitly?
  – incorporate forms of bounded rationality, e.g. myopia?
  – incorporate network-type information or structures?
    e.g. on trust, conflict, trade relations, geographical proximity, …
<table>
<thead>
<tr>
<th>Country</th>
<th>Emissions (Gt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>6.0</td>
</tr>
<tr>
<td>Canada</td>
<td>0.74</td>
</tr>
<tr>
<td>WCI</td>
<td>1.1</td>
</tr>
<tr>
<td>California</td>
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</tr>
<tr>
<td>MGGA</td>
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</tr>
<tr>
<td>Mexico</td>
<td>0.64</td>
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<tr>
<td>Chile</td>
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</tr>
<tr>
<td>Brazil</td>
<td>1.0</td>
</tr>
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<td>Brazil</td>
<td>1.0</td>
</tr>
<tr>
<td>China</td>
<td>6.0</td>
</tr>
<tr>
<td>EU ETS</td>
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<tr>
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<tr>
<td>Australia</td>
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<tr>
<td>New Zealand</td>
<td>0.098</td>
</tr>
<tr>
<td>Japan</td>
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<tr>
<td>Tokio</td>
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<tr>
<td>S-Korea</td>
<td>0.6</td>
</tr>
<tr>
<td>India</td>
<td>1.5</td>
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⇒ Reduction of mitigation costs by establishing access to low-cost abatement options
⇒ Potential for strategic incentives
Research questions (global scale):

- What hierarchy of agents and their interaction patterns underlies real-world international coalition formation?
  - governments, lobby groups, science, media, …
  - reciprocity, learning, adaptation, anticipation, imitation?, …

- What evolutionary phenomena emerge from them?

- Which linked ETS systems can be expected to form?

- What are realistic scenarios for this process?

- How do reputation and status effects influence these decisions?

- What strategic implications does this have for decision-makers?
4. REGIONAL / DOMESTIC SCALE:
THE GERMAN ENERGY TRANSITION – LEADING BY EXAMPLE
The Current Market System: Merit Order Pricing

Electricity demand

Marginal Cost

Price without nuclear plants

Price with nuclear plants

Exit from nuclear energy

Capacity (performance)

Marginal Cost

Price without replacement

Price with replacement

Increasing penetration of renewables

Capacity (performance)
Wholesale Market Prices

Merit-Order effect of increasing shares of renewables: Decreasing power prices

(Knopf et al., 2011)
Integration Options for Renewables

- **Improved weather forecast**
  - better planning of renewable electricity feed-in

- **Demand side management**
  - adjust demand to renewable electricity feed-in

- **Flexible power plants**
  - provide residual load

- **Grid extension**
  - large area pooling of uncorrelated fluctuations (>300km):
    Import / Export between countries

- **Energy storage**
  - remove electricity from the grid in times of high renewable generation and feed-in electricity in times of low generation
Impact of Considering Fluctuations in an Energy System Model of Germany

Most models do not take into account fluctuations explicitly:

100% Renewables

Same scenario with consideration of fluctuations:

Mitigation Costs rise by 20% when considering the fluctuations of renewables!

Scenario: 80% domestic CO₂ emission reduction in 2050 vs. 1990

(Ueckerdt et al., 2011)
Integration Options for Renewables

- **Improved weather forecast**
  - better planning of renewable electricity feed-in

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Aggregated Transmission in 2050 in an Electricity Sector model of Europe

Baseline, no climate policy:

90% CO₂ reduction in electricity sector:

Haller et al., 2012
Germany 2050: Electricity production with network expansion (European Interconnectors)

About 50% of demand covered by imports

Scenario: 90% CO₂ emission reduction in electricity sector

Large capacities of natural gas power plants required, especially in winter

Demand
- Gas CC
- Hydro
- Biomass
- Wind Onshore
- Wind Offshore
- Solar PV

Transmission
- day/night stor.
- interday stor.

Storage
- outflow
- Import
- Production

Export
- Storage
- inflow

Haller et al., 2012
Large back-up capacities of flexible gas power plants are required to provide residual load in extended times of low renewable electricity generation (European winter)…

…even with a European integrated electricity grid

…even with large day/night or medium-term storage capacities (e.g. pumped hydro)

What are the implications for the costs of renewables?
System Integration

- Demand: Fluctuating, Supply: Conventional only
- Price set by marginal plant, mostly natural gas
- Avg. price close to marginal cost of natural gas plants
- High price span due to supply curve curvature
The Energy Transformation in Germany: Increasing Share of Renewable Energy in Electricity Generation

x: government target
• **RES** entering the market at zero marginal costs
  → Peaking plants and less efficient natural gas no longer needed: Plants **decommissioned**
  → Low **average price** reduces invest. incentive for **plants**
  → Low **price span** reduces invest. incentive for **storage**
• But: **Fluctuations** matter if share of RES is high!
  → “Left shift” of convent. supply if RES supply is low
  → Insufficient supply if demand is high at the same time
  → **Reliability/security of supply** endangered
Case 1: Carbon Pricing is necessary and sufficient

Edenhofer et al. 2007
Case 2: Additional Promotion of Renewables is *not* reasonable

- Several stable equilibrium points (PE3 and PE1) are possible if the supply curves show a non-convex behavior (PE2 is not stable).

- Without additional policy support, the system will steer towards the neighboring equilibrium point PE3.

- PE3 > PE1: the system is efficient.

Edenhofer et al. (2007)
Case 3: Additional Promotion of renewables is reasonable

► The internalization of the social costs of energy supply (e.g. via a cap and trade system) improves the competitiveness of renewable energies

► As long as the cross-over point PE\textsubscript{3} does not vanish, this, however, still results in an inefficient state.

Edenhofer et al. (2007)
http://srren.ipcc-wg3.de/report
Climate Change, Justice and Sustainability
Linking Climate and Development Policy

Ottmar Edenhofer · Johannes Wallacher
Hermann Lotze-Campen · Michael Reder
Brigitte Knopf · Johannes Müller Editors

Springer
5. MULTILEVEL GOVERNANCE FROM GLOBAL TO MICRO
## Multiple Spatial and Temporal Scales

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Energy transition: Information flow across levels

Global
- Global Climate Negotiations

Regional
- Bottom-Up Coalition Formation (e.g. linking of ETS)

Domestic
- Energy Market Design ("Energiewende")

Micro
- Investments, R&D
- Spot Market Behaviour

→ How to send short-time signals consistent with long-term goals?
### Multilevel Governance

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<th>Agents</th>
<th>Institutions, Rules</th>
<th>Environment, Technology</th>
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<tr>
<td>Global</td>
<td>Governments, Multinationals, NGOs, …</td>
<td>IPCC, WTO, UN, …</td>
<td>Atmosphere, Oceans, Geo-engineering, …</td>
</tr>
<tr>
<td>Regional</td>
<td>Governments, Multinationals, NGOs, …</td>
<td>ETS, Economic Unions, Trade Blocs, …</td>
<td>Seas, Rivers, Transmission Networks, …</td>
</tr>
<tr>
<td>Domestic</td>
<td>Parties, Major energy producers, Lobby groups, …</td>
<td>Policies, Electoral Periods, …</td>
<td>Land use, Forests, Energy sources, Storage, …</td>
</tr>
<tr>
<td>Micro</td>
<td>Firms, Households, Banks, Mayors, …</td>
<td>Markets, …</td>
<td>Sunshine, Wind, “Backyards”, …</td>
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