CO₂ prices and system costs - a multi-scenario analysis with an agent-based electricity market model

Martin Klein, Felix Nitsch, Kristina Nienhaus

German Aerospace Center DLR
Institute of Engineering Thermodynamics
Department Energy Systems Analysis

Strommarkttreffen, 25.10.2019
Use of agent-based models in energy sciences

Agents:

Attributes + Methods (+ Interfaces)
Central: Behaviors / decision rules

Decision rules can be based on any model

- Logic (if…, then…; else…)
- Machine learning algorithm
- System dynamics model
- Dispatch model
- …

AMIRIS architecture

**Input**
- RE generation
- Load curves
- Power plants
- Efficiencies
- Availability
- Fuel costs
- CO₂ prices resp. CO₂ cap

**Output**
- DA electricity price
- Power plant dispatch
- Storage dispatch
- Market values
- CO₂ emissions resp. CO₂ prices
- System costs
Advantages of AMIRIS

AMIRIS can incorporate:
• „Non-rational“ decision rules
• Policy rules
• Market distortions

AMIRIS allows us to:
• Study emerging effects on power markets
• Yield exactly the same results as optimization model if parametrized the same way

**Fast**: 10 s/per model year on a standard Laptop with 8 GB RAM
Multi-scenario analysis – exploring the possibility space of power markets

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Mid</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 price [€/t]</td>
<td>5</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Electricity demand [%/a to 2016]</td>
<td>-1.0</td>
<td>+0.5</td>
<td>+2.0</td>
</tr>
<tr>
<td>Fuel prices [% to 2016]</td>
<td>-50</td>
<td>+0</td>
<td>+100</td>
</tr>
<tr>
<td>VRE share [%]</td>
<td>40</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Flexibility [GW]</td>
<td>6.2</td>
<td>12.4</td>
<td>18.6</td>
</tr>
<tr>
<td>Technological learning [%/a]</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Coal phase-out [%]</td>
<td>0</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

$3^7 = 2187$ scenarios
Multi-scenario analysis – exploring the possibility space of power markets

- Calculate 2187 times
- Exemplary evaluation in 2 dimensions
Multi-scenario analysis – exploring the possibility space of power markets

**CO₂ prices**

![Chart showing CO₂ prices and system costs with VRE low, mid, and high scenarios.]

**CO₂ Price**
- low
- mid
- high

**System Cost in Billion EUR**
- VRE low
- VRE mid
- VRE high

Klein, Deissenroth, Schimeczek (2019) - Mapping the challenge of renewable electricity market integration – Multi-scenario analysis with an agent-based electricity market model. *IEWT Wien*
Multi-scenario analysis – exploring the possibility space of power markets

CO₂ prices II

Klein, Deissenroth, Schimeczek (2019) - Mapping the challenge of renewable electricity market integration – Multi-scenario analysis with an agent-based electricity market model. IEWT Wien
Multi-scenario analysis – exploring the possibility space of power markets
Coal exit variations

Klein, Deissenroth, Schimeczek (2019) - Mapping the challenge of renewable electricity market integration – Multi-scenario analysis with an agent-based electricity market model, IEWT Wien
Agent-based optimization – new way of optimizing power systems

System cost

Multi-dimensional parameter set

> CO₂ prices and system costs - a multi-scenario analysis > Nitsch > 25.10.2019
Agent-based optimization – new way of optimizing power systems

System cost

Multi-dimensional parameter set
Agent-based optimization – new way of optimizing power systems

System cost

Multi-dimensional parameter set
Agent-based optimization – new way of optimizing power systems

System cost

Multi-dimensional parameter set
Agent-based optimization – new way of optimizing power systems

System cost

Multi-dimensional parameter set

> CO₂ prices and system costs - a multi-scenario analysis  > Nitsch > 25.10.2019
Agent-based optimization – new way of optimizing power systems

System cost

Multi-dimensional parameter set
Agent-based optimization – new way of optimizing power systems

- System cost
- Multi-dimensional parameter set
Agent-based optimization – new way of optimizing power systems

System cost

Multi-dimensional parameter set
Agent-based optimization – new way of optimizing power systems

System cost

Band of “solutions“ accepted

Multi-dimensional parameter set
System cost maps – concise way of depicting power market trade-offs

Klein, Deissenroth, Schimeczek (2019) - Mapping the challenge of renewable electricity market integration, IEWT Wien
Discussion and outlook

Scenario exploration using an agent-based energy system model

→ Fast model execution allows many scenario evaluations

Analyses reveal multi-dimensional dependencies

$\text{CO}_2$ price turns out to be robust against other parameter configurations regarding reduction of $\text{CO}_2$ emissions

Further research planned on parameter complexity and path dependence of energy systems

- Maps can show power system trade-offs at one glance
- Size and stability of system cost minima
Thank you for your attention!

Martin Klein, Felix Nitsch*, Kristina Nienhaus

German Aerospace Center DLR
Institute of Engineering Thermodynamics
Department Energy Systems Analysis

*felix.nitsch@dlr.de

Strommarkttreffen, 25.10.2019