Model-Based Analysis to Evaluate the Contribution of the Gas Supply System for the Integration of Fluctuating Renewable Electricity Generation

16th IAEE European Conference
Ljubljana, 26 August 2019

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Energy Systems Analysis
Research topic

- Investigating the flexibility potential of the gas system in comparison with other flexibility options in a future energy system with a high share of RE
- Research project **MuSeKo**: Multi Sector Coupling
  - Examination of flexibility in the production and storage of synthetic gases
  - Interaction with other flexibility options
  - Identification of the least-cost dimensioning of converters and storages

REMIX OptiMo: Energy System Model

Input:
Techno-economic parameters, potentials, scenario data

Model:
Determining the least-cost composition and hourly operation of the power system
Minimize $C_{system} = \sum c_j x_j$

Output:
Hourly system operation, system costs, emissions, plant expansion

- Cost-minimizing model from an economic planner’s perspective, here only LP
- Deterministic optimization realized in GAMS, solved with CPLEX
- Hourly resolution, typically perfect foresight for one year (8760 time steps)
- Simultaneous optimization of plant expansion and operation

Evaluation of flexible energy sector coupling with REMix

**Power sector**
- Electricity storage
- Demand response
- RE power
- Conventional power

**Transport sector**
- Battery vehicles
- Fuel cell vehicles
- Electrolyser
- H₂-storage
- Fuel cell
- Gas turbine/CCGT

**Power grid**

**Heat pump, electric boiler**

**Heating sector**
- CHP
- Steam turbine, ORC
- Boiler
- Thermal storage
- Heat
- Heat demand

**Gas sector**
- CH₄-import
- Methanation
- CH₄-network
- CH₄-storage
- CH₄-demand
- Methane

**Methane**

**Network**
REMIX enhancement for the gas sector

• Goal:
  • Reduced, linearized representation of the gas sector

• Limitations:
  • Consideration of chemical energy only
  • Aggregation according to model regions

• Modules:
  • Modular structure for flexible combination of technologies
REMix gas sector: demand and production

- Gas Demand:
  - Household/Industry demand for $\text{H}_2$ and $\text{CH}_4$

- Elektrolyzer:
  - Produced $\text{H}_2$ and biogas can be fed into the methane transport system as well as separate $\text{H}_2$ transport system
  - Share of $\text{H}_2$ that is fed into $\text{CH}_4$ network can be limited

- Methanation:
  - Generic module to transform input-fuel to output-fuel
  - Considering multiple efficiencies
REMIX gas sector: transport, storage and import

- **Gas Network:**
  - Compression energy is needed for transport
  - Chemical energy of transported gas remains constant
  - No transport delay
  - No consideration of gas composition → Gas mixture

- **Gas Compression (pipelines and storages):**
  - Gas- or electricity-powered

- **Gas Import:**
  - Modelling of import flows
  - Different gases can be imported
Data basis for the gas system modelling in MuSeKo

- Salt domes for CH$_4$ or H$_2$ hydrogen storage
- Data on existing assets: storage locations and capacities
- Evaluation of gas transport capacities
- Assumption of reversible flows
- Compressor capacities from literature and inquiries
REMIX configuration in MuSeKo

• Regions:
  • Germany divided into states
  • Neighbouring countries
• Myopic application: 2020, 2030, 2040, 2050
  • Decommissioning at end of lifetime
  • No construction time
• Consideration of existing capacities:
  • Power/Gas network and storage
  • Wind/PV capacity w/o decommissioning
  • CHP/conventional capacity w/ decommissioning
• Capacity optimization of RE, gas power plants, CHP, electricity storage and
  of flexible sector coupling

→ Resulting problem size: ~100 Mio. variables, ~50 Mio. equations
Scenarios in MuSeKo

- Exogenously defined demand for electrical power, CH$_4$, H$_2$ and heat
- Exogenously defined fuel and CO$_2$-emission costs

<table>
<thead>
<tr>
<th>GHG 80</th>
<th>GHG 95</th>
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<tbody>
<tr>
<td>- Base-scenario</td>
<td>- 95% CO$_2$-reduction</td>
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<tr>
<td>- 80% CO$_2$-reduction</td>
<td>- Higher CO$_2$-emission costs</td>
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<td>- Increased electrical power and H$_2$-demand in transport and heating sectors</td>
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Development of electrical power supply in Germany in 2020 – 2050

- Phasing out of nuclear energy by 2022 and coal energy by 2038
- Biomass only in GHG 95-scenario considered
- No back-up capacity of gas turbines in GHG 95
- GHG 95: 30 % more generation in 2050

Preliminary results
Development of the gas sector in Germany

- Expansion of H$_2$-infrastructure
- Increase in methanation plant capacity only to fulfill CH$_4$-demand

Preliminary results
Synthetic fuel production (GHG 95)

- \( \text{H}_2 \)-production corresponds to electricity price and thus electricity production
- Methanation only comes into system at extremely low electricity costs
About 30% of the battery vehicle charging demand is shifted.
Thermal energy storage buffers wind generation peaks.
Endogenous battery storage installation only outside Germany.
Power transmission is the most important balancing technology.

Power transmission
Electrolyzer
Electricity storage
Curtailment
Load shifting industry
E-Boiler
Heat pumps
Heat storage
E-Mobility vehicle2grid
E-Mobility load shifting
Behaviour of gas sector components

- $\text{H}_2$ storage level in GWh
- Energy demand in GWh/h

**GHG 80**

**GHG 95**

**Gas**

**Electric**

Preliminary results
Summary

• Integrated consideration of all sector coupling options desirable
• Options of flexible sector coupling interact positively with each other
• Simplified representation of the gas sector improves analysis capabilities
• Flexible H₂-production can make a significant contribution to RE balancing
• Partial conversion of natural gas infrastructure to H₂ is an attractive option
• Methanation and seasonal storage become relevant in GHG 95 scenario
Outlook

- Comparison to business perspective
- Further analysis of interactions within the overall system
- Further scenarios and sensitivity analysis
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This presentation is based on results of the project “Modellbasierte Analyse der Integration erneuerbarer Stromerzeugung durch die Kopplung der Stromversorgung mit dem Wärme-, Gas- und Verkehrssektor“ (MuSeKo) funded by the German Federal Ministry of Economic Affairs and Energy (BMWi) under grant number FKZ: 03ET4038B.