Energy System Analysis

for the evaluation of Sector Coupling Technologies

K. Boblenz, V. Frank, C. Wolfersdorf, F. Baitalow, B. Meyer
Institute of Energy Process Engineering and Chemical Engineering (IEC)
TU Bergakademie Freiberg

Berlin, Germany
3-8 June 2018
Motivation

Challenges of Germany’s „Energiewende“

Figure adopted from [3], changed
Power plant concepts with electrical energy storage

Polygeneration power plants

- Coal
- Refinery Residues
- Natural gas
- Waste (plastics)
- Biomass

Gasification/Gas cleaning

Carbon Dioxide (CO₂) removal

El. energy / Heat

- Fuels (e.g., Kerosene)
- Basic chemicals (e.g., Methanol, Plastics monomers)
- Fertiliser
- SNG

Synthesis

Hydrogen

Electrolysis

Renewable Energy
Power plant concepts with electrical energy storage

Polygeneration-Annex Concepts

Lignite → Coal preparation → Thermal power plant

BoA1: 489-944 MW (el)
642 t/d SNG
150 MW (el)

500 MW (th) Annex-SNG:
342-1,554 MW (el)

Cross links
Annex plant

Thermal power plant → Electricity, steam, process water → Surplus steam, waste water/gases

EF gasification → Gas cleaning → Synthesis → Product storage → F-class gas turbine

Electricity

500 MW (th)
642 t/d SNG

Synthesis product (external use)

Air separation → Electrolysis and gas storage

Air → Oxygen → 150 MW (el)

Oxygen → EF gasification

Electricity, steam, process water

Surplus steam, waste water/gases

Synthesis product

F-class gas turbine → Electricity

Annex-SNG: 342-1,554 MW (el)

Nitrogen → Air separation
Model Development and Application

Model validation: Comparison of historical data with model results

Input parameter

- Historical data (reference year 2015)
- Specific power plant parameters
- Forecast data (e.g., for 2030)
- Balance data of the Polygeneration plant

System model of electric energy supply in Germany (MATLAB-Simulink®)

Simulation results

1. 2013
2. 2030
3. 2030-Poly

Estimation of electric power deficit and surplus („Storage demand“)

Assessment of the influence of Polygeneration systems

(Comparison of simulation results with / without polygeneration power plant)

Model validation: comparison of forecast data with simulation results

Quasi-dynamic modelling of the poly-generation power plant
(MS Excel)

Thermodynamic modelling of the poly-generation power plant
(ASPENplus™)
Balancing of plant components considering grid capacity

<table>
<thead>
<tr>
<th>Grid situation:</th>
<th>„Power surplus“</th>
<th>„Normal operation“</th>
<th>„Power deficit“</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant operating mode:</td>
<td>„Storage“</td>
<td>„Normal operation“</td>
<td>„Reconversion“</td>
</tr>
</tbody>
</table>

- $P_{el, \text{Thermal power plant}}$: $P_{\text{min}} - P_{\text{max}}$,
- $P_{ch, \text{chem. storage}}$: const.,
- $P_{el, \text{auxiliary}}$: const.,
- $P_{el, \text{Spitzenlast}}$: 0,
- $P_{el, \text{ASU (<0)}}$: $(P_{\text{max}})$,
- $P_{el, \text{Electrolysis (<0)}}$: $P_{\text{max}} - P_{\text{min}}$
## Database and examined scenarios

<table>
<thead>
<tr>
<th></th>
<th>Reference year 2015</th>
<th>Scenario 2030</th>
<th>Scenario 2030-Poly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power consumption</td>
<td>Data from ENTSO-E</td>
<td>Scaling the data of 2015</td>
<td></td>
</tr>
<tr>
<td>Renewable energy</td>
<td>Data from ENTSO-E</td>
<td>Scaling the data of 2015</td>
<td></td>
</tr>
<tr>
<td>Nuclear power, others</td>
<td>Data from Agora</td>
<td>Scaling the data of 2015</td>
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</tr>
<tr>
<td>Adjustable producers</td>
<td>Lignite, hard coal, nat. gas</td>
<td>Biomass, lignite, hard coal, natural gas</td>
<td></td>
</tr>
<tr>
<td>Compensation units</td>
<td>Pumped storage hydro power</td>
<td>Battery storage, electric mobility, Powert-to-Heat</td>
<td>Polygeneration concepts</td>
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<td>• Polygeneration-Annex</td>
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<td></td>
<td>• Power-to-Gas</td>
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<tr>
<td>Chemical storage</td>
<td></td>
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<td>SNG (to Grid), Methanol</td>
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<tr>
<td>Import and export</td>
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</tr>
</tbody>
</table>

Figure adopted from [3], changed
Selected results – system model validation for reference year 2015

Generation characteristics – natural gas power plants

Figure adopted from [4], translated
Power generation in some exemplary weeks

- Biomass
- Running Water
- Wind Power
- Solar Power
- Lignite
- Hard coal
- Natural Gas
- Water (PSHP)
- Others
- Load

<table>
<thead>
<tr>
<th>Power generation in GW</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
<th>Sunday</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
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</tbody>
</table>

2nd calendar week
Selected results – Simulation of scenario 2030

Power generation in some exemplary weeks

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Running Water</th>
<th>Wind Power</th>
<th>Solar Power</th>
<th>Lignite</th>
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<td>Hard coal</td>
<td>Natural Gas</td>
<td>Water (PSHP)</td>
<td>others</td>
<td>Load</td>
</tr>
</tbody>
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Power generation in GW

Power generation in GW

32nd calendar week

Monday  Tuesday  Wednesday  Thursday  Friday  Saturday  Sunday
Selected results – Simulation of scenario 2030

Power generation in some exemplary weeks

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Running Water</th>
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<td>Load</td>
</tr>
</tbody>
</table>

Power generation in GW

52nd calendar week

Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday
Selected results – Simulation of scenario 2030 and scenario 2030-Poly

Influence of the Polygeneration concept Annex-SNG

- Storage of renewable energy by water electrolysis: 0.07 TWh
- Generation and injection to natural gas grid: 3.02 TWh SNG
- Total power generation of the polygeneration concept Annex-SNG: 6.14 TWh
- Decreased power generation by lignite and hard coal: -0.98 and -0.5 TWh
- Increased power generation by pumped storage hydro power and natural gas: +0.68 and +0.09 TWh
- Decreased imports and exports of electricity (grid capacity): -0.08 and -0.07 TWh
Summary and Conclusions

System model of the german energy system
• Model established and validated
• Considering merit order principle and incremental costs
• Reproducing electricity rates at European Energy Exchange (EEX)
• Calculation of future scenarios

Polygeneration concepts
• Even small installed nominal capacities (gasifier: 500 MW, electrolysis: 150 MW) have significant impact
• Decrease of power generation from coal
• Strengthening of pumped storage hydro power and flexible natural gas power plants

Future works
• Evaluation of further Polygeneration concepts (fuels and chemical feedstock production)
• Economic evaluation under dynamic conditions of the german energy system
Thank you!

Dipl.-Ing. Kristin Boblenz
Institute of Energy Process Engineering and Chemical Engineering (IEC)
TU Bergakademie Freiberg

Email: kristin.boblenz@iee.tu-freiberg.de
Tel: 0049 3731 39 4481

Acknowledgements: This work was funded by BMWi project HotVeGasII (FKZ 0327773G), HotVeGasIII (Förderkennzeichen 0327773J) and the European Union. Financial support of this study by BMWi, ESF and industrial partners is gratefully acknowledged.


Motivation

Challenges of Germany’s „Energiewende“

- Storage time duration:
  - 1 year
  - 1 month
  - 1 week
  - 1 day
  - 1 hour
  - 1 min.
  - 1 sec.
  - 100 msec.

- Storage capacity:
  - 1 kWh
  - 1 MWh
  - 1 GWh
  - 1 TWh

- Storage types:
  - pore space storage (methane)
  - cavern storage (methane, hydrogen)
  - pumped-storage hydropower plant
  - district heating
  - heat storage
  - pressurised air (caverns)
  - batteries
  - capacitors
  - flywheels
  - inductors

Figure adopted from [7], translated
Modelling of German Energy System

Conceptual design

- Renewables
  - Wind power
  - Solar power
  - Running water
  - Biomass

- Adjustable producers
  - Lignite /Hard Coal
  - Natural gas/Oil
  - Nuclear power
  - Biomass

- Compensation units
  - Pumped storage hydro power
  - Batteries (bulk storage)
  - Electric mobility
  - Power to Heat (PtH)
  - Polygeneration concepts

Import and upscaling of historical data

Calculated in energy system model

Figure adopted from [3], changed
Modelling of German Energy System

Parameter Setting I

1. Merit order principle
   - Detailed consideration of individual power plant generation units
   - Dependent on incremental costs
   - start-up /shut-down costs
   - Fuel cost, CO₂ penalty

2. Characterisation of power generation
   - Historical data of renewable generation
   - Availabilities
   - Installed nominal capacity
   - Minimum capacity
   - Power gradient
Parameter Setting I

3. Characterisation of compensation units:
   • Pumped storage hydro power (storage capacity, installed nominal capacity)
   • Power to Heat (installed nominal capacity)
   • Electric mobility (quantity of vehicles, availabilities, charging capacity per vehicle)
   • Polygeneration concepts (correlations from quasi-dynamic modeling)
Selected results - system model validation for reference year 2015

Electricity rates at the European Energy Exchange (EEX)

Figure adopted from [4], translated
Electricity rates at the European Energy Exchange (EEX)

Selected results – Simulation of scenario 2030

Figure adopted from [4], translated