Optimal Investments in Flexibility Options – An Analysis of Interactions and Sensitivities

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Effects of Renewable Energy Sources (RES) Extension

**Example: Germany**

- **RES generation, load and residual load 2016**
- **Sorted residual loads with increasing RES share**
- **Sorted residual load 2016**

- Increasing number of hours with surplus energy
- High surplus peaks
- High residual load gradients

Own assumptions based on Data of ENTSO-E 2018
Theoretical Applications for Flexibility Options

Smoothing of the residual load

Applications for flexibility options

Flexibility Options

- Conv. Power Plants
- Dispatchable RES
- Load Reduction

Storages
- Load Management
- Electricity Grid

Power-to-X
- RES-Curtailment
Influence of the PV-Wind-Mix on the Need for Flexibility

- Development of RES-extension scenarios based on RES-potentials in 17 countries
- In total 80% share of PV- and Wind generation on electricity demand

![Sorted residual load with 80 % RES](image)

<table>
<thead>
<tr>
<th></th>
<th>High WIND</th>
<th>High PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV-Wind-Share</td>
<td>20:80</td>
<td>80:20</td>
</tr>
<tr>
<td>Ø full load hours of PV and wind</td>
<td>1.847 h</td>
<td>1.191 h</td>
</tr>
<tr>
<td>Average correlation of RES generation between countries</td>
<td>0.40</td>
<td>0.79</td>
</tr>
</tbody>
</table>

(own calculations based on ENTSO-E 2018)
Installed Capacities in the Countries

Total Capacities

- High Wind: 1,173 GW
- High PV: 1,820 GW

Installed Wind and PV Capacities [GW]
- 0 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120
- 120 - 140
- 140 - 160
- 160 - 180
- 180 - 200
- 200 - 220
- 220 - 240
Research Questions

Forschungsfragen

Which influence has the need for flexibility at a high share of RES on the optimal combination of flexibility options?

Which effect does the PV-Wind-Mix have?
# Using and extending ELTRAMOD

<table>
<thead>
<tr>
<th>Input</th>
<th>Linear Optimization</th>
<th>Output</th>
</tr>
</thead>
</table>
| • Hourly profiles for load and RES generation for 17 countries  
• Conventional power plants  
• Export/import capacities (NTC) for transnational exchange | Objective: cost-minimizing investment and dispatch of flexibility options | • Installed capacities  
• Generation and use of electricity  
• System costs  
• Emissions  
• … |
| • In total 21 flexibility options including storages, RES power plants, DSM processes, Power–to-Heat  
• Technical and economical characteristics: efficiencies, number of activations, shifting durations, fuel costs, investment costs, ramp-up and –down costs, … | • Additional restrictions for observed flexibility options  
• Endogenous investment decision  
• Greenfield approach | • Optimal combinations of flexibility options  
• Synergies and competition of technologies  
• Interaction between need for flexibility and flexibility provision |

**Model Extensions**

- Greenfield approach
- Linear Optimization
- Model Extensions
- Objective: cost-minimizing investment and dispatch of flexibility options
- Additional restrictions for observed flexibility options
- Endogenous investment decision
- Greenfield approach
- Optimal combinations of flexibility options
- Synergies and competition of technologies
- Interaction between need for flexibility and flexibility provision
Installed capacities and Meeting of the Residual Load

Example: Netherlands
Sensitivities of Investment Costs on Total Installed Capacities – Example: Storage

- **High Wind**
  - Capacities [GW]
  - Changes in Installed Capacity [GW]
  - Changes in Storage Investment Costs

- **High PV**
  - Capacities [GW]
  - Changes in Installed Capacity [GW]
  - Changes in Storage Investment Costs
Summary

- PV-Wind-Mix effects optimal combinations of flexibility options regarding the optimal investments and dispatch
- Availability and Simultaneity of RES generation have high influence on flexibility mix
- Technologies to shift energy regionally and temporarily play a major role in the flexibility provision
- When investment costs are increased/decreased these effects increase/decrease optimal investments in flexibility options
Thank You for Your Attention

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Some Interactions between need for flexibility and flexibility provision

<table>
<thead>
<tr>
<th>Power Plants</th>
<th>Application</th>
<th>Factors influencing the flexibility need</th>
<th>Value of flexibility option</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dispatchable electricity generation</td>
<td>Availability of fluctuating RES</td>
<td>Increasing with higher PV share</td>
</tr>
<tr>
<td>NTC</td>
<td>Regional Shifting of Energy</td>
<td>Simultaneity of RES generation</td>
<td>Increasing with higher PV share</td>
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<tr>
<td>Storages</td>
<td>Temporal Shifting of Energy</td>
<td>Simultaneity of RES generation</td>
<td>Decreasing with higher PV share</td>
</tr>
<tr>
<td>Power-to-x</td>
<td>Increase Load</td>
<td>RES surplus peaks</td>
<td>Increasing with higher PV share</td>
</tr>
</tbody>
</table>
Full Load Hours in the Observed Region

Mean Full Load Hours 2012 - 2016

Source: EMHIRES Dataset 2018
## Cost Assumptions

<table>
<thead>
<tr>
<th>Flexibility Option</th>
<th>Specific investments [kEUR/MW]</th>
<th>Fuel Costs [EUR/MWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>REF</strong></td>
<td></td>
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</tr>
<tr>
<td>OCGT</td>
<td>400</td>
<td>33,7</td>
</tr>
<tr>
<td>CCGT</td>
<td>800</td>
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<tr>
<td>Coal</td>
<td>1.300</td>
<td>10,4</td>
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<tr>
<td>Lignite</td>
<td>1.500</td>
<td>1,5</td>
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<tr>
<td>CCGT_chp</td>
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<td>33,7</td>
</tr>
<tr>
<td>Coal_chp</td>
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<td>10,4</td>
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<td>Lignite_chp</td>
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<td>1,5</td>
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<tr>
<td>Reservoir</td>
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<td>---</td>
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<tr>
<td>RoR</td>
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<td>PSP</td>
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<td><strong>DRES</strong></td>
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<td>Biomasse</td>
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<td>Geo</td>
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<td><strong>PTX</strong></td>
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<td>Boiler</td>
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<td><strong>SHIFT</strong></td>
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<tr>
<td>DSM</td>
<td>0 - 250</td>
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<tr>
<td>NTC</td>
<td>400 [EUR/MW/km]</td>
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<tr>
<td>HOU</td>
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</tr>
<tr>
<td>DAY</td>
<td>640</td>
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<tr>
<td>SEA</td>
<td>900</td>
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