European Power System Long-term development with Flexibility
A study on demand projections

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Outline

1. EMPIRE (European Model for Power Investments with high shares of Renewable Energy)
2. Uncertainty - Where?
3. Multi-horizon Stochastic Optimization
4. Results
EMPIRE (European Model for Power Investments with high shares of Renewable Energy) Uncertainty - Where? Multi-horizon Stochastic Optimization Results

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Multi-horizon Stoch. Plan.
Multi-horizon Scenario Tree

Reduces tree size by a factor of

(# of nodes)^# of strategic periods
Multi-horizon Stochastic Program

Modelling Assumptions
Multi-horizon Stochastic Program

- Long-term dynamics (multi-period investments)

Modelling Assumptions
Multi-horizon Stochastic Program

- Long-term dynamics (multi-period investments)
- Short-term dynamics (multi-period operation)

Modelling Assumptions
Multi-horizon Stochastic Program

- Long-term dynamics (multi-period investments)
- Short-term dynamics (multi-period operation)
- Short-term and long-term uncertainty

Modelling Assumptions
Multi-horizon Stochastic Program

- Long-term dynamics (multi-period investments)
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- Short-term and long-term uncertainty

Modelling Assumptions

- Perfect Competition (multi-period investments)
Multi-horizon Stochastic Program

- Long-term dynamics (multi-period investments)
- Short-term dynamics (multi-period operation)
- Short-term and long-term uncertainty

Modelling Assumptions

- Perfect Competition (multi-period investments)
- Generation capacity aggregated by technology
Multi-horizon Stochastic Program

- Long-term dynamics (multi-period investments)
- Short-term dynamics (multi-period operation)
- Short-term and long-term uncertainty

Modelling Assumptions

- Perfect Competition (multi-period investments)
- Generation capacity aggregated by technology
- Investments are continuous outcomes
Modelling Assumptions

- Perfect Competition (multi-period investments)
- Generation capacity aggregated by technology
- Investments are continuous
- Lines are independent
- Elastic demand (Demand Response)
Modelling Assumptions

- Perfect Competition (multi-period investments)
- Generation capacity aggregated by technology
- Investments are continuous
- Lines are independent
- Elastic demand (Demand Response)
- Uncertain foresight of future
Uncertainty - Where?

- Wind and solar generation
- Fuel prices
- CO2 prices
- Energy policy
- Technology costs
- Energy demand
Electricity Demand Projections

- PRIMES / EU reference case
- GCAM
- TIMES
Long-term Demand Uncertainty Approaches

- Probabilistic Pathways Sets
- Pathway Uncertainty Estimation
- Stochastic Partial Decomposition Approach
## DR costs

<table>
<thead>
<tr>
<th>Technology</th>
<th>Investment Cost (€/kW)</th>
<th>Fixed OM (€/kW) pr. yr.</th>
<th>Variable OM (€/MWh)</th>
<th>Efficiency</th>
<th>Fuel Cost</th>
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<tbody>
<tr>
<td>HeatingAC</td>
<td>250</td>
<td>7,50</td>
<td>10</td>
<td>0,97</td>
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<td>HVAC-ComInd</td>
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<td>ProcessShift-Ind</td>
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<td>150</td>
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<td>StorHeat-ResCom</td>
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<td>ProcessShed-Ind</td>
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<td>Battery Storage (Li-ion)</td>
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<td>Gas CCGT</td>
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<td>30,38</td>
<td>0,45</td>
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</tbody>
</table>

Source: 2015, H. C. Gils
Results
Long-term scenarios

Yearly Demand (TWh)

- Scenario 1
- Scenario 2
- Scenario 3

2010 2015 2020 2025 2030 2035 2040 2045 2050
Europe’s Capacity Portfolio Comparison

- Nuclear
- Unabated Gas
- Gas CCS
- Hydro/Geo/Ocean
- Wind Offshore
- Unabated Coal
- Coal CCS
- Bio
- Wind Onshore
- Solar PV
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Solar and storage uncertainty

Solar PV capital cost scenarios [€2010/kW]

- Solar PV high
- Solar PV low

Li-ion battery capital cost scenarios [€2010/kWh]

- Li-ion battery high
- Li-ion battery low
Solar and storage uncertainty

- 2015
- 2020
- 2025
- 2030
- 2035
- 2040
- 2045
- 2050
Solar and storage uncertainty

High costs

Low costs

[GW]

Solar PV
Wind Offshore
Wind Onshore
Hydro/Geo/Ocean
Bio
Gas CCS
Coal CCS
Unabated Gas
Unabated Coal
Nuclear
Solar and storage uncertainty

High costs

Low costs

- Solar PV
- Wind Offshore
- Wind Onshore
- Hydro/Geo/Ocean
- Bio
- Gas CCS
- Coal CCS
- Unabated Gas
- Unabated Coal
- Nuclear
Solar and storage uncertainty

Installed capacity solar PV

- Perfect foresight high cost
- Perfect foresight low cost
- Stochastic model high cost
- Stochastic model low cost

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