Long-term strategies to ensure a robust performance of the European electricity system

Paul Nahmmacher, Eva Schmid, Brigitte Knopf, Michael Pahle

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MOTIVATION
Motivation

The European electricity system is...

...characterized by high capital intensity and long-living assets.

*Long-term planning is indispensable for investors, regulators, etc.*

Several investment models exist:
LIMES-EU  *Long-term investment model of the electricity sector*

**Objective**
- minimizing cumulated costs for electricity provision
- optimal investment and dispatch decisions for generation, storage and transmission capacities

**Linear optimization model**
- GAMS / CPLEX Solver

**Technologies**
- generation [*nuclear, hard coal (+ccs), lignite (+ccs), natural gas cc/gt, hydro, wind on-/offshore, solar pv/csp, biomass]*
- storage [*diurnal, seasonal*]
- transmission [*net transfer capacities between regions*]

**Geographical scope & resolution**
- EU28 countries w/o Malta & Cyprus
- plus Norway & Switzerland & Balkan

**Temporal scope & resolution**
- 5 year steps 2010 – 2050
- representative days per year
- perfect foresight

**Policy equations**
- CO₂ targets / RES targets
- EU or Member State level

**Exogenous parameters**
- electricity demand per region
- nuclear / ccs policies
- investment costs
- fuel costs
- …

Nahmacher et al. (2014)
Motivation

The European electricity system is...

...characterized by high capital intensity and long-living assets.

*Long-term planning is indispensable for investors, regulators, etc.*
Motivation

The European electricity system is...

1. characterized by high capital intensity and long-living assets.
   *Long-term planning is indispensable for investors, regulators, etc.*

2. constantly exposed to political, techno-economic and natural risks.
   *It is crucial to design the system in a way that it ensures security of supply and minimum costs for a variety of future scenarios and shocks.*
Motivation

The European electricity system is...

1. characterized by high capital intensity and long-living assets.
   *Long-term planning is indispensable for investors, regulators, etc.*

2. constantly exposed to political, techno-economic and natural risks.
   *It is crucial to design the system in a way that it ensures*
   *security of supply and minimum costs*
   *for a variety of future scenarios and shocks.*

*What are the characteristics of a cost-efficient and robust European electricity system*
*considering a large variety of possible future shocks*

*and*

*given the assumption that the liberalized market does not provide for these shocks*
*what are (political) strategies needed to achieve such a system?*
Scenarios – Strategies – Shocks

Scenarios

A scenario is a possible future development of external parameters. Scenarios can be expected but their probability is unknown. Investment decisions are taken based on scenarios.

Strategies

A strategy is an additional constraint that has to be satisfied when planning the electricity system.

Shocks

A shock is an unexpected sudden change of external parameters, such that assets of the electricity system cannot be changed accordingly. Shocks may result in a different dispatch, a shortage of electricity supply, and/or a failure to meet the emission target.
MODELLING FRAMEWORK
### Absence of certainty

Three levels of incertitude (the absence of certainty)

<table>
<thead>
<tr>
<th>Risk</th>
<th>Uncertainty</th>
<th>Ignorance</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Possibility is known</em></td>
<td><em>Possibility is known</em></td>
<td><em>Nothing is known</em></td>
</tr>
<tr>
<td><em>Probability is known</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Stochastic approaches</em></td>
<td><em>Scenario analysis</em></td>
<td><em>Diversity</em></td>
</tr>
</tbody>
</table>

Stirling (1994)
Scenarios

Optimisation for each scenario separately

• most studies usually cover less than five possible future scenarios

• what is the „right“ investment pathway?

Paul Nahmmacher
PIK – Energy Strategies Europe and Germany
**Scenarios**

Optimisation for each scenario separately
- most studies usually cover less than five possible future scenarios
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**Stochastic approaches**

Multiple possible future states are considered within one optimization run
- only limited number of future states computationally possible
- need to assign probabilities

*Both scenario analysis and stochastic analysis find the optimal solution for a specific set of assumptions and usually focus on a very limited number of futures*
Robust Decision Making

Lempert et al. (2006):

A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios

- “Robustness is an important criterion for good decisions under uncertainty” (Robustness vs. Optimality)

- “A robust strategy performs relatively well – compared to alternatives – across a wide range of plausible futures”

- Performance of a strategy for a specific scenario is measured by its regret (i.e. additional cost) compared to the best-performing strategy

Lempert et al. (2006)
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### Scenarios – Strategies – Shocks

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<th>Scenarios</th>
<th>Strategies</th>
<th>Shocks</th>
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</thead>
<tbody>
<tr>
<td>nuclear cost</td>
<td>none default</td>
<td>low wind / solar</td>
</tr>
<tr>
<td>ccs cost</td>
<td>diversity in fuels default</td>
<td>heat wave</td>
</tr>
<tr>
<td>wind FLH</td>
<td>import of electricity default</td>
<td>gas supply</td>
</tr>
<tr>
<td>solar investment cost</td>
<td>redundant (reserve) capacities target on excess capacity</td>
<td>gas price</td>
</tr>
<tr>
<td>biomass price</td>
<td>transmission expansion lower bound on transmission expansion</td>
<td>- deviation from expected gas price</td>
</tr>
<tr>
<td>gas price</td>
<td>RES-share lower bound on RES-share</td>
<td></td>
</tr>
<tr>
<td></td>
<td>nuclear power lower bound on nuclear capacity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>storage lower bound on storage capacity</td>
<td></td>
</tr>
</tbody>
</table>

- default / high
- default / low
- default
- upper bound on share of single fuel
- upper bound on share of imported electricity
- target on excess capacity
- lower bound on transmission expansion
- lower bound on RES-share
- lower bound on nuclear capacity
- lower bound on storage capacity
(PRELIMINARY) RESULTS
vRES shock

- Excess capacities avoid shortage of supply but add emissions
vRES shock

- Installation of excess capacities most viable option
Heat wave

- Excess capacities are the best way to mitigate the impacts of a heat wave.
- European-wide RES-target also helpful.
Heat wave

- Excess capacities are only viable, when high VOLL.
- European wide RES-target viable.
Transmission shock

- Overall, transmission shock no serious threat for security of supply
- Excess capacities increase security of supply
Transmission shock

- Excess capacities too expensive
- „No strategy“ is best

Overall costs
(VOLL = 500 €/MWh)

Overall costs
(VOLL = 1000 €/MWh)

Overall costs
(VOLL = 2000 €/MWh)
Gas supply (quantity) shock

- A RES-target mitigates the negative impact of a shortage in gas supply.
- NTC expansion also helpful.

![Shortage of supply and excess CO₂ emissions graphs](image-url)
Gas supply (quantity) shock

- A RES-target mitigates the negative impact of a shortage in gas supply.
- NTC expansion also helpful.
Gas price shock

- A gas price shock does not pose a threat to the security of supply
Gas price shock

- The additional costs for implementing the considered strategies are higher than their benefits in case of a gas price shock.
CONCLUSION
Conclusion

• Analysis of strategies for a large variety of possible shocks to the electricity sector
• Combination of optimization model with robustness analysis
• Useful in case that stochastic analysis fails to provide meaningful results
  • when probabilities of the shocks are unknown
  • when there are more than only a few possible futures.

• Viable strategies against considered shocks:
  • highly depending on VOLL
  • installation of excess capacities / RES expansion

• Work in progress: Suggestions for additional scenarios, strategies and shocks are welcome!
Thank you!

paulnah@pik-potsdam.de

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