 Unsicherheiten im Elektrizitätssystem: Welche Methoden für welche Herausforderungen?

Prof. Dr. Christoph Weber
Abschlussworkshop LKD-EU

Berlin, 27.2.2019
Energy has been a risky business…
Oil price forecast from 2009 onwards

Result of a PhD
Structural econometric model
Including supply and demand fundamentals

... and will remain so: Electricity price forecasts from Friday 23 onwards

Probabilistic forecasts available online on https://www.uee.wiwi.uni-due.de/forschung/prognose-von-strompreisen/

- Short-term forecasts
- Huge uncertainties
  - Red: 1%/99% quantiles
  - Green: 25%/75% quantiles

Source: Florian Ziel (2019)
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structuring the issues at stake</td>
<td>1</td>
</tr>
<tr>
<td>Coping with uncertainties in operational decision-making</td>
<td>2</td>
</tr>
<tr>
<td>Coping with uncertainties in investment decision-support</td>
<td>3</td>
</tr>
<tr>
<td>Coping with uncertainties in decision support for policy makers</td>
<td>4</td>
</tr>
<tr>
<td>Final remarks</td>
<td>5</td>
</tr>
</tbody>
</table>
Dimensions of decisions under uncertainty

- What type of uncertainties is present?
  - Cf. next slide

- Who decides?
  - Individual vs. group
  - Policy makers vs. companies vs. households/citizens

- What is decided?
  - Operation
  - Investment
  - Regulation

- What interdependencies with other decisions are relevant?
Normative Decision Theory: Decision settings

- Decisions under certainty

- Decisions under risk
  
  Objective probabilities for events available
  
  - Optimal decision rule: Bernoulli Principle, Maximization of expected utility

- Decisions under incertitude
  
  in the Anglo-Saxon literature frequently: “Knightian uncertainty”
  
  No objective probabilities
  
  - Typical case for political uncertainty
  
  - Savage (1954) and others use subjective (Bayesian) probabilities
  
  - But also other, heuristic decision rules available: Maximin, minimum regret …
Decisions and decision makers in a national energy system perspective

1st level: Decisions on regulatory settings

- EU institutions*
- National institutions
- "Länder" institutions
- Municipal institutions

2nd level: Decisions on investments

- Grid: transmission & distribution
- Generation & storage
- Use: buildings, cars, machines etc.

3rd level: Decisions on operation

- Generation
- Storage
- Demand response

Grid & Market

* government, parliament, administrations, courts
<table>
<thead>
<tr>
<th>Structuring the issues at stake</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coping with uncertainties in operational decision-making</td>
<td>2</td>
</tr>
<tr>
<td>Coping with uncertainties in investment decision-support</td>
<td>3</td>
</tr>
<tr>
<td>Coping with uncertainties in decision support for policy makers</td>
<td>4</td>
</tr>
<tr>
<td>Final remarks</td>
<td>5</td>
</tr>
</tbody>
</table>
Characteristics of operational decisions

- Repeated decision making
- Varying circumstances, e.g.
  - Renewable infeed
  - Demand
  - Power plant & line availabilities
  - Fuel & CO\textsubscript{2} prices
- Considerable short-term uncertainty
  - Especially on first three factors
- Numerous situations rather standard
- But sometimes exceptional and critical situations occur
Examples of short-term decisions

- **Grid operators**
  - D-2: parameters for flow-based market coupling
  - D-1: procurement of secondary and tertiary reserve
  - D-1 & D: redispatch
  - D: operation of phase shifters and topology changes
  - D: activation of reserves

- **Power plant operators & portfolio marketers**
  - D-1: submission of bids to secondary and tertiary reserve markets
  - D-1: submission of bids to day-ahead trading (before DA auction)
  - D-1: day-ahead planning of power plant, storage and DSM operation (after DA auction)
  - D: submission of bids to intraday trading
  - D: intraday planning of power plant, storage and DSM operation
Methods for dealing with uncertainties

- Linear and Mixed Integer Optimization using the deterministic equivalent
- Sensitivity calculations
- Stochastic optimization
- Chance-constrained optimization
- (Stochastic) (Dual) Dynamic Programming
- Robust optimization
- Distributionally robust optimization
- Heuristic approaches

...
Unit Commitment and Dispatch: Examples for dealing with uncertainties

- **Linear and Mixed Integer Optimization using the deterministic equivalent**
  e.g. Sheble & Fahd (1994), Baldick (1995), Tovar-Ramirez (2016)

- **Two-stage stochastic optimization**
  e.g. Caroe et al. (1997), Dentcheva et al. (2000)

- **Multi-stage stochastic optimization**
  e.g. Carpentier et al. (1996), Takriti et al. (2000), Meibom et al. (2011)

- **Stochastic Dynamic Programming**
  e.g. Wolfgang et al. (2009), Felix, Weber (2012),

- **Stochastic Dual Dynamic Programming**
  e.g. Pereira and Pinto (1991), Guiges and Römisch (2012)

- **Robust optimization**
  e.g. Jiang et al. (2012), Bertsimas et al. (2013), Zhao et al. (2013)

CF. also reviews by Zheng et al. (2015), van Ackooij et al. (2018)
Tree as a representation of stochastic states
- Numerical Stochastic Optimization solves a deterministic equivalent of the original stochastic problem
- I.e. the branches and leafs of the tree are taken as given

Strategy 1:
Solve the entire problem at once → **Stochastic Programming**
→ Only feasible for a limited number of branches and leaves

Strategy 2:
Decompose the problem using the Bellmann Principle*
→ **Stochastic Dynamic Programming**
→ Only feasible if the number of decision states is limited
  e.g. option exercised yes/no, plant on/off

*loosely: each part of an optimal trajectory must be itself optimal
Challenges of stochastic programming

1) Multidimensional trees are really hard

Example:
1 stochastic factor, 2 stages, trinomial tree: 9 leafs
2 stochastic factor, 2 stages, trinomial tree: 81 leafs
Scenario reduction techniques have been repeatedly developed e.g. Dupacova, Römisch (2003), Hoyland, Wallace (2001), Rubasheuski et al. (2014)

Yet the metrics used to determine the scenarios are generally not reflecting the cost differences

Importance (in terms of cost impact) based sampling of scenarios is preferable

Cf. Pöstges & Weber (2018) for time aggregation
Curse of dimensionality…

... and it is even worse:

- **Multiple stochastic factors**
  Power prices, fuel prices, inflows, temperatures...

- **Multi-factor models for stochastic models**
  e.g. seasonal factor, long-term factor...

- **Multiple decision states**
  several power plants with up/down times, large storages...

→ Making good stochastic models remains a challenge
Robust optimization

- **Stochastic Optimization:**
  - Minimization of Expected Cost or
  - Minimization of a Risk functional of Cost (Mean-Risk optimization), e.g. CVaR
    - Risk neutral or (mildly) risk averse approach

- **Robust Optimization:**
  - Minimization of the worst outcome
  - Minimax-strategy
    - Rather pessimistic approach
  - Security constrained optimal power flow may be considered as an example of a robust optimization (N-1 criterion satisfied)
    - Robustness always measured again a set of possible events (contingencies)
    - “Milder” forms of robustness: local robustness, distributional robustness
<table>
<thead>
<tr>
<th>Structuring the issues at stake</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coping with uncertainties in operational decision-making</td>
<td>2</td>
</tr>
<tr>
<td>Coping with uncertainties in investment decision-support</td>
<td>3</td>
</tr>
<tr>
<td>Coping with uncertainties in decision support for policy makers</td>
<td>4</td>
</tr>
<tr>
<td>Final remarks</td>
<td>5</td>
</tr>
</tbody>
</table>
What is different with investments?

- Discrete decisions
- Long-lasting impacts
- Heavy financial impact

- Empirical foundations for stochastic (or robust) optimization weaker
  - Less independent observations
  - Likelihood of structural breaks higher
  - Extrapolation of probabilities from the past to the future more dangerous

- More recourse actions
  - Modelling has to anticipate the multitude of operating decisions during lifetime
Coping with uncertainties in investment decisions (I)

Strategy 1:
Use of **high discount rates** (or low payback times)
& **deterministic equivalent**
- Implicit assumption: linear addition of uncertainty over time
- According to CAPM: uncertainty related to (market) systematic risk

Strategy 2:
Use of **scenarios**
  - e.g. Shell scenarios
- Reduction of multiple uncertainties to a limited number of scenarios (3 – 5)
- Focus on coherent and complementary world-views ("scenario family")
- In general no probabilities associated with scenarios
Strategy 3:
Use of **stochastic optimization with subjective probabilities**
- Or if probabilities based on statistical model: unknown model risk
- Agreement on subjective probabilities difficult to reach in multi-person decision-making context

Strategy 4:
Focus on **mean scenario + risk assessment**
- Standard approach in corporate reporting
- Risks are frequently not quantified
Analysis

- Or rather a key question:

Why are we developing and using scenarios?
Answer – Version 1:

- Scenarios enable good decision making under uncertainty
- They structure the multiple uncertainties that decision makers are facing
- Underlying decision model: (as taught in 1st year business administration course)

<table>
<thead>
<tr>
<th>Uncertainties</th>
<th>$s_1$</th>
<th>$s_2$</th>
<th>…</th>
<th>$s_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenarios</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decision</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>alternatives</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a_1$</td>
<td>$r_{11.}$</td>
<td>$r_{12.}$</td>
<td>…</td>
<td>$r_{1n.}$</td>
</tr>
<tr>
<td>$a_2$</td>
<td>$r_{21.}$</td>
<td>$r_{22.}$</td>
<td>…</td>
<td>$r_{2n.}$</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
<td>…</td>
<td></td>
<td>…</td>
</tr>
<tr>
<td>$a_m$</td>
<td>$r_{m1.}$</td>
<td>$r_{m2.}$</td>
<td>…</td>
<td>$r_{mn.}$</td>
</tr>
</tbody>
</table>

Rule-based, rational decision making
Answer – Version 2:

- Scenarios help to make the right decisions
- Scenarios show pathways to achieve objectives
- Underlying decision model:

"decision making in political arenas multi-level stakeholder interactions"
If scenarios are focusing on **depiction of uncertainties**:  
- They should capture **key uncertainties exogenous** to the **decision maker**  
  E.g.  
  - World market **prices for fossil fuels** and **renewable technologies**  
  - **Global & European Climate Policy objectives** and **instruments**  
    – if the decision maker is a company or a national government  
- The same decisions should be evaluated against different scenarios  
  Key questions:  
  - Which decision yields the best outcome “on average”?  
  - Is there a scenario where a decision leads to extremely negative consequences?  
  - A not (fully) formal way of implementing a mean-risk perspective on decisions  
- The process of scenario construction and parameter selection is as important as the scenarios itself  
  - Avoidance of “group think” key for appropriate dealing with risk
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structuring the issues at stake</td>
<td>1</td>
</tr>
<tr>
<td>Coping with uncertainties in operational decision-making</td>
<td>2</td>
</tr>
<tr>
<td>Coping with uncertainties in investment decision-support</td>
<td>3</td>
</tr>
<tr>
<td>Coping with uncertainties in decision support for policy makers</td>
<td>4</td>
</tr>
<tr>
<td>Final remarks</td>
<td>5</td>
</tr>
</tbody>
</table>
What is different in political decision making?

- **Multiple objectives**
- **Multiple stakeholders**
  - Advocating the own cause important
  - Evoking the uncertainties may frequently be perceived as “not helpful” for the own cause
  - Scenarios rather used as in answer version 2

- **Cause-effect relationships** for many **policy instruments uncertain**
  - Not (as much) true for command & control type policies, e.g. schedule for coal phase out
  - But certainly true for price-based instruments and support mechanisms, e.g. CO₂ tax subsidies for electric vehicles or renewables

- **Multi-level decision hierarchy**
Decisions and decision makers in a national energy system perspective

1st level: Decisions on regulatory settings

- EU institutions*
- National institutions
- "Länder" institutions
- Municipal institutions

2nd level: Decisions on investments

- Grid: transmission & distribution
- Generation & storage
- Use: buildings, cars, machines etc.

3rd level: Decisions on operation

- Generation
- Storage
- Demand response

Grid & Market

* government, parliament, administrations, courts
Dealing with uncertainties in political decision support (I)

- Use scenarios
  - Reflecting also truthfully exogenous uncertainties, e.g. technology cost
- Make sensitivity analyses
  - Notably on uncertain behavioural assumptions
    e.g. on uptake of flexibility provision through V2G for electric vehicles,
    on restrictions on land use for renewables due to limited acceptance
  - But also on technological assumptions
cf. analyses by Wolf Schill

- Scenarios: many parameters are varied simultaneously
  - Enable an assessment of choices against contrasting world views
- Sensitivities: one parameter is at a time
  - Enable a transparent assessment of the impact of single parameter choices on results
Take into account behavioural heterogeneity among stakeholders:
- Energy users, investors, governments

cf. presentation by Sina Heidari

- Take existing empirical evidence serious
- Model behavioural uncertainty through parameter variations
- Conduct further empirical studies on key behaviours of stakeholders (investors and users)
Do not rely excessively on results from Linear programs

Explicit assumptions:
– one overarching, unique objective function
– homogenous technology classes with known parameters
  ➢ False certainty
  ➢ Penny-switching
  ➢ Control illusion

… or at least do sensitivity analyses

Investigate operational risks induced by policy instruments in detail
– Security of supply key challenge for energy transition
– Modelling of operational uncertainties can build on established stochastic methods

cf. presentation by Philip Hauser
<table>
<thead>
<tr>
<th>Section</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structuring the issues at stake</td>
<td>1</td>
</tr>
<tr>
<td>Coping with uncertainties in operational decision-making</td>
<td>2</td>
</tr>
<tr>
<td>Coping with uncertainties in investment decision-support</td>
<td>3</td>
</tr>
<tr>
<td>Coping with uncertainties in decision support for policy makers</td>
<td>4</td>
</tr>
<tr>
<td>Final remarks</td>
<td>5</td>
</tr>
</tbody>
</table>
- There is no silver bullet to cope with uncertainties

- A major step is already taken when uncertainties/risks are thoroughly identified

- When you use an optimization model, adjust your shot well to hit your target:
  i.e. reflect carefully your choice of method and your representation of uncertainties (distribution)
Thank you.

Questions?
References


References


