Optimal Electricity Generation Portfolios in the Presence of Fuel Price and Availability Risks

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Why Look Into Electricity Generation?

- Europe-Wide: considerable national and supranational measures for the composition of national electricity generation portfolios (announced or partially implemented already):
  - Nuclear Phase-Out: Italy, Germany, Belgium, Switzerland etc.
  - Subsidies: wind, solar, biomass, combined heat and power plants/systems
  - Targets: 27% renewables by 2030

- Climate Change: ecological motivation or pressure factor
  - CO_2-Emissions: caused by fossil energy
  - Pricing of Emissions: CO_2 European Emission Allowances

- Worldwide: projected growing demand

$\Longrightarrow$ **What is an optimal electricity generation portfolio?**

What is the Setting?

General (Research) Assumptions

- national decision maker
- economical decision criteria with technical considerations
- several technologies available:
  - thermal and
  - renewable → wind
- each technology type has both advantages and disadvantages
  - thermal: dispatchable but
    dirty and dependent on variable input prices
  - renewable: clean but
    non-dispatchable and with variable availability

What is the Research Question?

Question to Be Answered in This Presentation

What does a cost-optimal electricity generation portfolio consist of, if the decision-maker were to take into account:

- *volatility* of input prices,
- *volatility* of (wind) availability and with that coupled higher system costs?

How to Tackle the Research Question?

Portfolio Optimization

The process of choosing the proportions of various assets to be held in a portfolio in such a way as to make the portfolio better than any other according to some criterion.

Distinction Finance – Electricity Economics

- input: return
- weights: $+$ und $-$
- problem:

$$\begin{aligned} \max_{w} \quad & w^\top \mu - \frac{\beta}{2} w^\top \Sigma w \\ \text{s.t.} \quad & e^\top w = 1, \end{aligned}$$

- input: LCOE **or** CF
- weights: $+$
- problem:

$$\begin{aligned} \min_{w} \quad & w^\top \mu + \frac{\beta}{2} w^\top \Sigma w \\ \text{s.t.} \quad & e^\top w = 1, \\ & w \geq 0. \end{aligned}$$

Data
Overview

- Cost Structure:

  IC, FOM, VOM, *Fuel Costs*, Additional System Costs → Germany

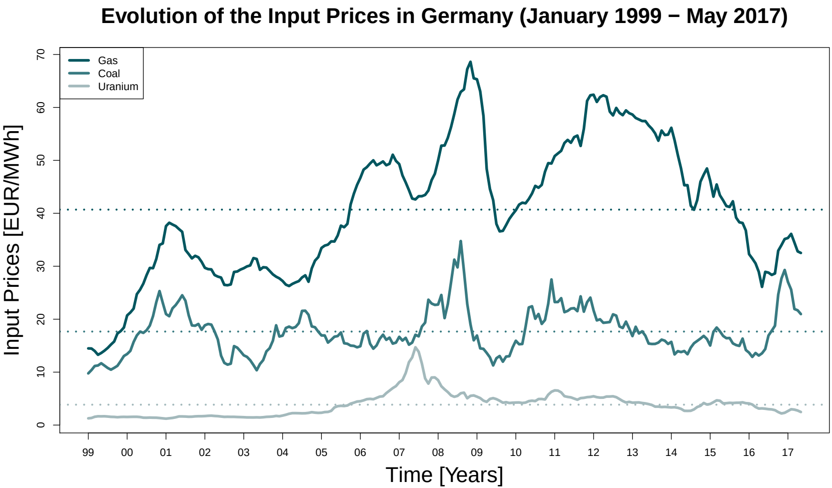
  - Additional System Costs:

    - Balancing Costs: short-term operational costs a system incurs through output variability and uncertainty.
    - Capacity Costs: costs associated with the required capacity that enables a system to provide system reliability at any time.

- *Availability Factors*: wind speeds → Germany

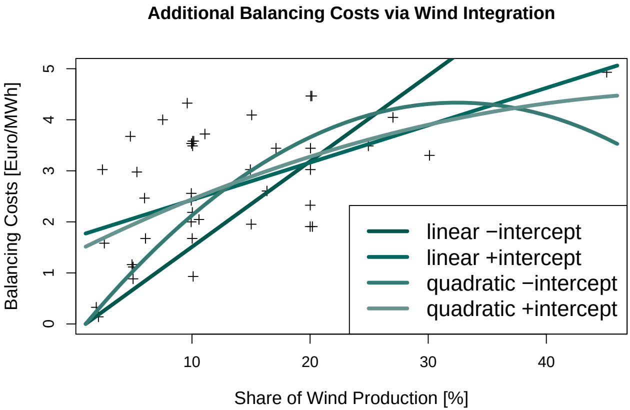
Data

Input Costs



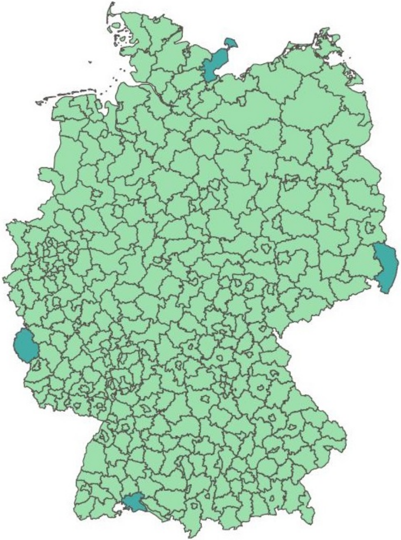
Balancing Costs Assumptions (Reliability Costs Identical)

- linear or quadratic growth in the share of wind generation.



Data

Wind Availability – Part 1



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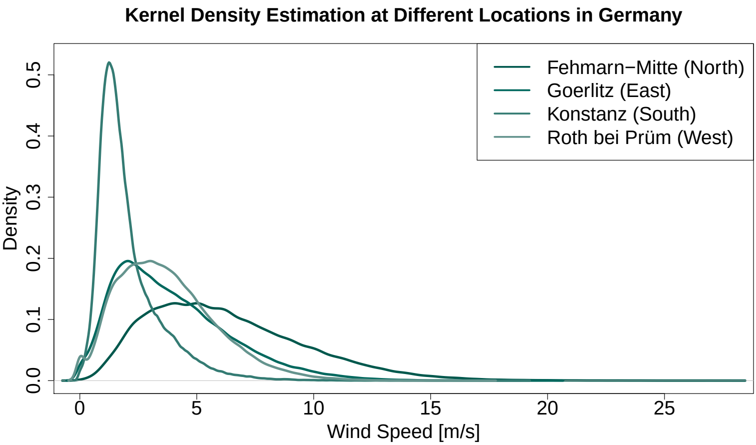
Wind Availability – Part 2



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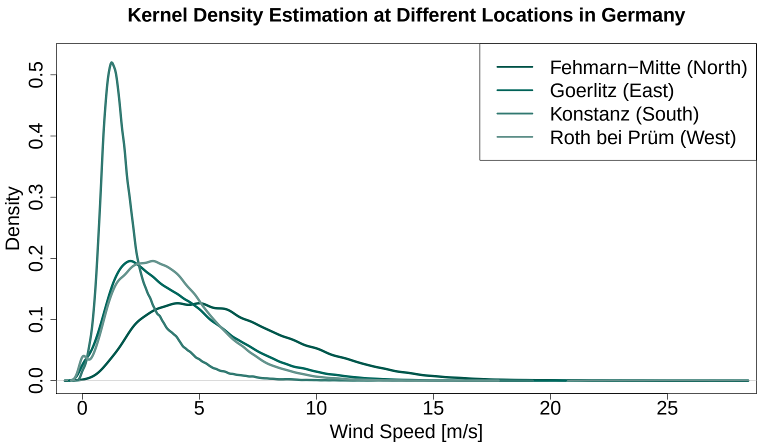
Wind Availability – Part 3



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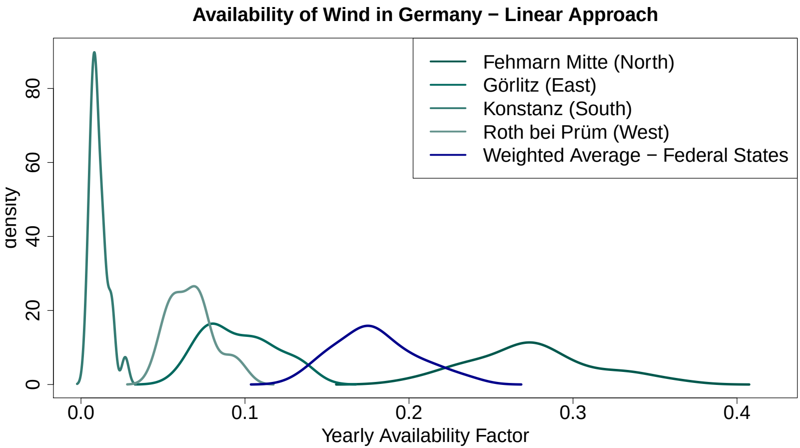
Wind Availability – Part 4



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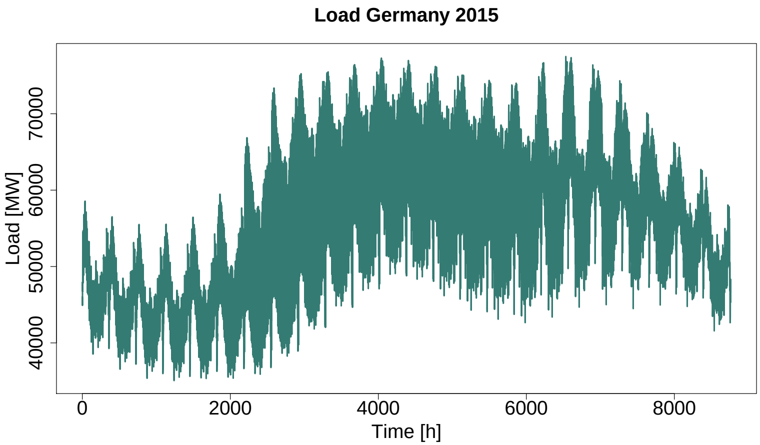
Load and Load Duration Curve – Part 1



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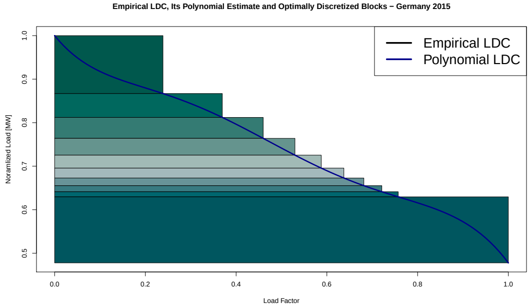
Load and Load Duration Curve – Part 2

$$\min_{\ell_n} \quad \sum_{n=1}^{N} (\ell_n - \ell_{n-1}) D(\ell_{n-1}) - \int_{\ell_{n-1}}^{\ell_n} D(l)\mathrm{d}l$$

$$\text{s.t.} \int_{\ell_{n-1}}^{\ell_n} D(l)\mathrm{d}l \approx \sum_{n=1}^{N} (\ell_n - \ell_{n-1}) \frac{D(\ell_{n-1}) + D(\ell_n)}{2}$$

$$\ell_0 = 0 \leq \ \ell_n \leq 1 = \ell_N,$$



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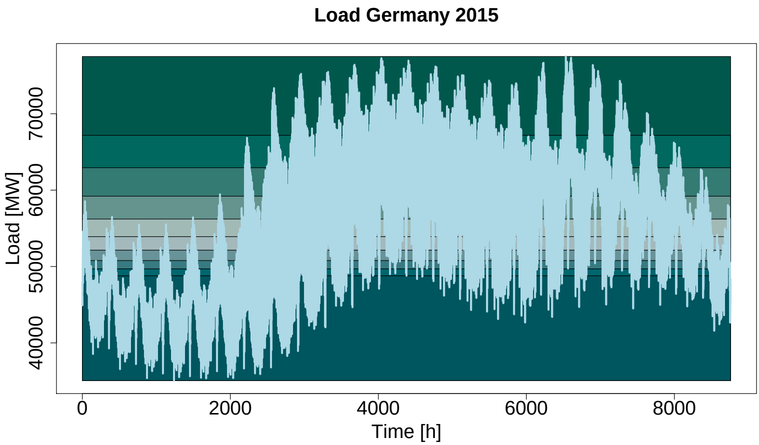
Load and Load Duration Curve – Part 3



Mathematical Optimization Model

$$\min_{x_{i,j}, i \in I, j \in J} \quad \mathbb{E}\left[\mathbf{c}^{LCOE}\right] + \frac{\beta}{2} \mathbb{V}\text{ar}\left[\mathbf{c}^{LCOE}\right]$$

$$\text{s.t.} \underbrace{\begin{pmatrix} x_{1,1} & \cdots & x_{1,J-1} & x_{1,J} \\ \vdots & \ddots & \vdots & \vdots \\ x_{I,1} & \cdots & x_{I,J-1} & x_{I,J} \end{pmatrix}}_{X} \begin{pmatrix} 1 \\ \vdots \\ \mathbb{E}[A(s)] \end{pmatrix} = \begin{pmatrix} \ell_N D(\ell_{N-1}) \\ \vdots \\ \ell_1 (D_{max} - D(\ell_1)) \end{pmatrix}$$

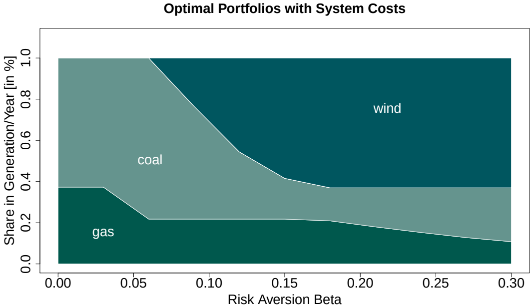
$$X \geq 0,$$

- $I \ldots = 3$ number of load blocks
  - base, intermediate, peak
- $J \ldots = 4$ number of technologies
  - thermal: coal, gas, nuclear
  - renewable: wind
- $x_{ij} \in X$
  - electricity generation load block i with technology j
  - decision variable

- consideration of the load via the Load Duration Curve (LDC)
- 2 random variables
  - $A \ldots$ availability factor wind
  - $C^{\text{Fuel}} \ldots$ input prices
- system costs function $f(AX_W)$
  - none
  - linear in share of wind generation

Results

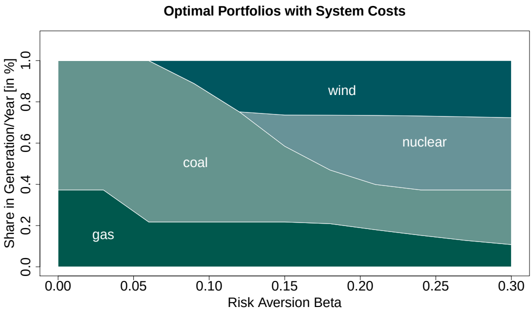
Without the Consideration of System Costs



- Gas: due to low CF and volatile input costs $\rightarrow$ peak load for high β
- Coal: lower volatility than gas $\rightarrow$ replaced by wind for high β (base load)
- Nuclear: too expensive to be a part of the portfolio
- Wind: covers base load only

Results

With the Consideration of System Costs



- Gas: unchanged
- Coal: slightly more
- Nuclear: additional diversification mean → base and intermediate load
- Wind: clearly less → base load only

Conclusion

- A simultaneous consideration of both risk factors appears to be indispensable.
- The diversification effect of wind is
  - overestimated, without considering system costs
  - smaller, with the consideration of system costs.
- The consideration of system costs leads to a non-linear, non-quadratic optimization problem $\rightarrow$ curse of dimensionality.

  $\Rightarrow \exists$ **trade-off** between precision and solvability.

Outlook

- Find a better algorithm to compute the solutions.
- Add several technologies:
  - hydro,
  - solar,
  - lignite.
- Think of a way of modeling the intermittency problem.
- Implement a higher degree system costs function.

Thank You for Your Attention!

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