Multilevel mixed-integer nonlinear optimization for electricity market design: Motivation, models, solution techniques, and results

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@schmaidt

enOPTIMAL: Energy, Optimization and Learning

Virtual seminar series at the interface of energy, optimization and machine learning research

The people who really did the work ...

Mirjam Ambrosius | Veronika Grimm





Thomas Kleinert | Frauke Liers | Gregor Zöttl

Outlook

1. Motivation & Introduction
2. A Mixed-Integer Multilevel Model
3. Solution Approaches
4. Numerical Results
5. Real-World Case Study

Motivation & Introduction

PREMIUM EU REFORMIERT ENERGIEMARKT

Wenn der Strompreis geteilt wird

Die EU-Staaten treiben die Energiewende voran. Der Stromriese RWE warnt vor einem Kohleausstieg durch die Hintertür. Und sollte Deutschland beim Netzausbau nicht vorankommen, droht die Aufteilung in mehrere Preiszonen.

Till Hoppe   Klaus Stratmann

19.12.2017 - 18:26 Uhr • Kommentieren • Jetzt teilen

Die Energiewende erreicht Rest-Europa.
(Foto: dpa)

Frankfurter Allgemeine
Energiepolitik

ENERGIEWENDE

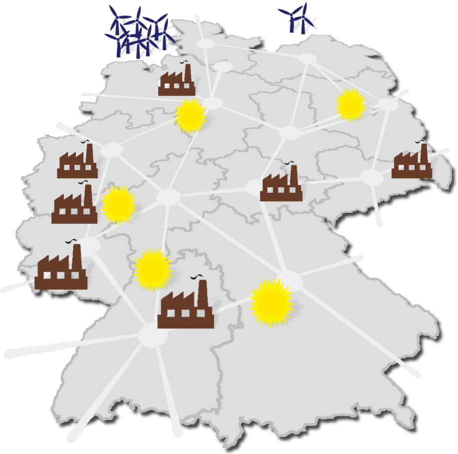
20 unterschiedliche Strompreiszonen in Deutschland?

VON HANNA DECKER - AKTUALISIERT AM 02.03.2017 - 10:27

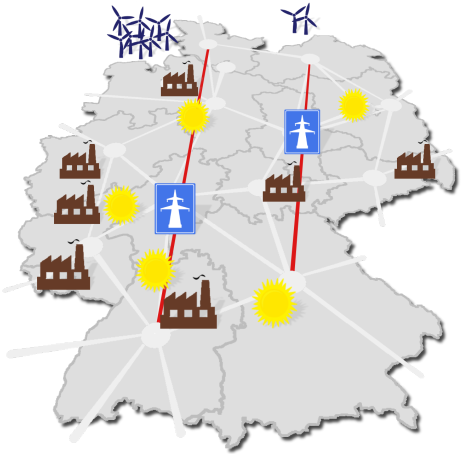
Bisher wird Strom zentral gehandelt. Rund herum strickt sich ein kompliziertes System aus Entgelten, Steuern, Abgaben und Umlagen. Ein einflussreicher Think Tank hat nun radikale Reformvorschläge vorgelegt.

- “The old system”
- Conventional producers
- Tailored network

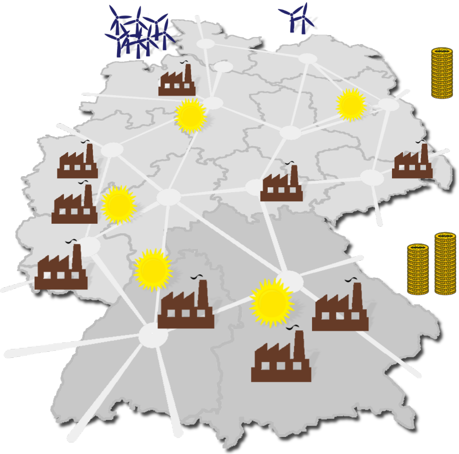
Electricity Market Design



- The system changed in the last years
- More and more renewable energy
- Most of it in the northern part of Germany

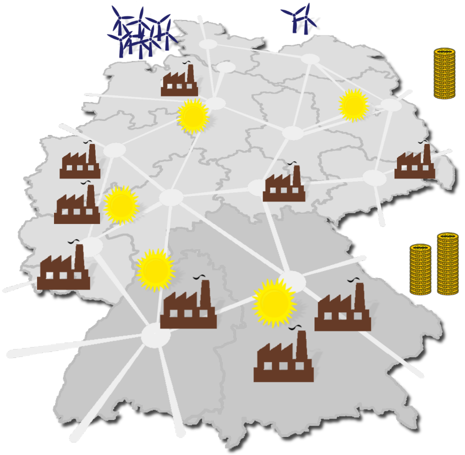


- Problem
  north-south bottlenecks in the network
- Remedy #1
  line expansion



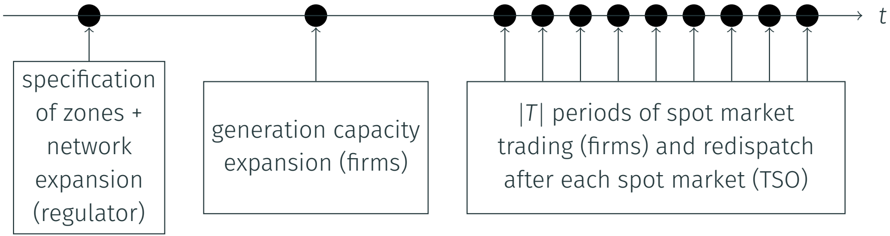
- Problem
  north-south bottlenecks in the network
- Remedy #2
  more power generation in the south
- Needs to be incentivized
- Higher electricity prices in the south

Electricity Market Design



- Given a number k of price zones
- What is the best configuration of price zones in combination with a possible network expansion?
- Graph partitioning
- Network design

1. Specification of price zones & network expansion
2. Generation capacity investment by profit-maximizing firms
3. Zonal spot-market trading
    - Intra-zonal network constraints: ignored at the spot market
    - Inter-zonal network constraints: (partly) respected at the spot market
4. Cost-based redispatch (if required)



Cost-Based Redispatch

- Technically infeasible spot-market results $\rightarrow$ redispatch
- Modification of traded quantities
  - Redispatched electricity can be transported
  - Objective: minimum redispatch cost

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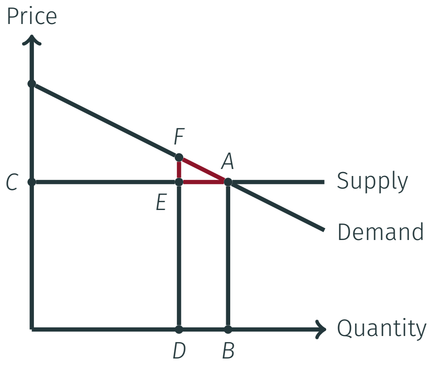


- Energy-only market
  equilibrium quantity *B*
  equilibrium price *C*
- Transmission constraints
  transportable capacity *D*
- Producer pays to TSO: *ABDE*
- TSO pays to consumer: *ABDF*
- TSO's cost: *AEF*

A Mixed-Integer Multilevel Model

Trilevel Market Model

max total social welfare (regulator)
s.t. network design
graph partitioning with connectivity constraints

> max profits (competitive firms)
> s.t. generation capacity investment
> production & demand constraints
> Kirchhoff's 1st law (zonal)
> flow restrictions (inter-zonal)
>
> > min redispatch costs (TSO)
> > s.t. production & demand constraints
> > lossless DC power flow constraints

$$
\begin{aligned}
\max \quad & \psi_1 = \sum_{t \in T} \sum_{n \in N} \left(\sum_{c \in C_n} \int_0^{d_{c,t}^{\text{red}}} p_{c,t}(\omega)\,\mathrm{d}\omega - \sum_{g \in G_n^{\text{all}}} c_g^{\text{var}} q_{g,t}^{\text{red}} \right) - \sum_{n \in N} \sum_{g \in G_n^{\text{new}}} c_g^{\text{inv}} \bar{q}_g^{\text{new}} - \sum_{l \in L^{\text{new}}} c_l^{\text{inv}} z_l \\
\text{s.t.} \quad & z_l \in \{0,1\}, \quad l \in L^{\text{new}}, \\
& x_{n,i} \in \{0,1\}, \quad n \in N,\ i \in [k], \\
& \sum_{i \in [k]} x_{n,i} = 1, \quad n \in N,
\end{aligned}
$$

... to be continued ...

1st Level Model (continued)

$$
\begin{aligned}
&\ldots \\
&s_{n,i} \in \{0,1\}, \quad s_{n,i} \le x_{n,i}, \quad n \in N,\ i \in [k], \\
&\sum_{n \in N} s_{n,i} = 1, \quad i \in [k], \\
&0 \le u_a^i, \quad a \in \{(n,m),(m,n)\},\ l = (n,m) \in L,\ i \in [k], \\
&u_a^i \le z_l, \quad a \in \{(n,m),(m,n)\},\ l = (n,m) \in L^{\text{new}},\ i \in [k], \\
&\sum_{a \in \delta_n^{\text{out}}} u_a^i \le M x_{n,i}, \quad n \in N,\ i \in [k], \\
&\sum_{a \in \delta_n^{\text{out}}} u_a^i - \sum_{a \in \delta_n^{\text{in}}} u_a^i \ge x_{n,i} - M s_{n,i}, \quad n \in N,\ i \in [k], \\
&y_l \in \{0,1\}, \quad x_{n,i} + x_{m,i} + y_l \le 2, \quad l = (n,m) \in L, \\
&x_{n,i} - x_{m,i} \le y_l, \quad x_{m,i} - x_{n,i} \le y_l, \quad l = (n,m) \in L.
\end{aligned}
$$

2nd Level Model

$$
\begin{aligned}
\max \quad & \psi_2 = \sum_{t\in T}\sum_{n\in N}\left(\sum_{c\in C_n}\int_0^{d_{c,t}^{\text{spot}}} p_{c,t}(\omega)\,\mathrm{d}\omega - \sum_{g\in G_n^{\text{all}}} c_g^{\text{var}} q_{g,t}^{\text{spot}}\right) - \sum_{n\in N}\sum_{g\in G_n^{\text{new}}} c_g^{\text{inv}}\bar{q}_g^{\text{new}} \\
\text{s.t.} \quad & -Mz_l \le f_{l,t}^{\text{spot}} \le Mz_l, \quad l\in L^{\text{new}},\ t\in T, \\
& d_{n,t}^{\text{spot}} = \sum_{c\in C_n} d_{c,t}^{\text{spot}}, \quad q_{n,t}^{\text{spot}} = \sum_{g\in G_n^{\text{all}}} q_{g,t}^{\text{spot}}, \quad n\in N,\ t\in T, \\
& D_{i,t} = \sum_{n\in N} x_{n,i} d_{n,t}^{\text{spot}}, \quad Q_{i,t} = \sum_{n\in N} x_{n,i} q_{n,t}^{\text{spot}}, \quad i\in[k],\ t\in T, \\
& F_{i,t}^{\text{in}} = \sum_{l=(n,m)\in L} (1-x_{n,i})x_{m,i} f_{l,t}^{\text{spot}}, \quad i\in[k],\ t\in T, \\
& F_{i,t}^{\text{out}} = \sum_{l=(n,m)\in L} x_{n,i}(1-x_{m,i}) f_{l,t}^{\text{spot}}, \quad i\in[k],\ t\in T, \\
& D_{i,t} + F_{i,t}^{\text{out}} = Q_{i,t} + F_{i,t}^{\text{in}}, \quad i\in[k],\ t\in T, \\
& \ldots \text{ to be continued } \ldots
\end{aligned}
$$

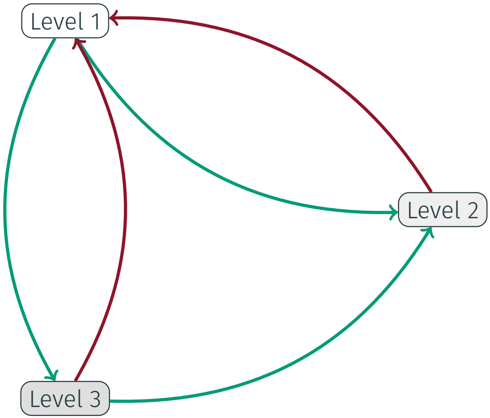
$$
\begin{aligned}
&\dots \\
&-\bar{f}_l - (1 - y_l)M \le f^{\text{spot}}_{l,t} \le \bar{f}_l + (1 - y_l)M, \quad l \in L,\ t \in T, \\
&\bar{q}^{\text{new}}_g \le \hat{q}^{\text{new}}_g, \quad g \in G^{\text{new}}_n,\ n \in N, \\
&0 \le q^{\text{spot}}_{g,t} \le \bar{q}^{\text{new}}_g, \quad g \in G^{\text{new}}_n,\ n \in N,\ t \in T, \\
&0 \le q^{\text{spot}}_{g,t} \le \bar{q}^{\text{ex}}_g, \quad g \in G^{\text{ex}}_n\ n \in N,\ t \in T, \\
&0 \le d^{\text{spot}}_{c,t}, \quad c \in C_n,\ n \in N,\ t \in T.
\end{aligned}
$$

3rd Level Model

$$
\begin{aligned}
\min \quad & \psi_3 = \sum_{t \in T} \sum_{n \in N} \sum_{c \in C_n} \int_{d_{c,t}^{\mathrm{red}}}^{d_{c,t}^{\mathrm{spot}}} p_{c,t}(\omega)\,\mathrm{d}\omega + \sum_{t \in T} \sum_{n \in N} \sum_{g \in G_n^{\mathrm{all}}} c_g^{\mathrm{var}} (q_{g,t}^{\mathrm{red}} - q_{g,t}^{\mathrm{spot}}) \\
\text{s.t.} \quad & \sum_{c \in C_n} d_{c,t}^{\mathrm{red}} + \sum_{l \in \delta_n^{\mathrm{out}}} f_{l,t}^{\mathrm{red}} = \sum_{g \in G_n^{\mathrm{all}}} q_{g,t}^{\mathrm{red}} + \sum_{l \in \delta_n^{\mathrm{in}}} f_{l,t}^{\mathrm{red}}, \quad n \in N,\ t \in T, \\
& f_{l,t}^{\mathrm{red}} = B_l(\theta_{n,t} - \theta_{t,m}), \quad l = (n,m) \in L^{\mathrm{ex}},\ t \in T, \\
& M(z_l - 1) \le f_{l,t}^{\mathrm{red}} - B_l(\theta_{n,t} - \theta_{t,m}), \quad l = (n,m) \in L^{\mathrm{new}},\ t \in T, \\
& M(1 - z_l) \ge f_{l,t}^{\mathrm{red}} - B_l(\theta_{n,t} - \theta_{t,m}), \quad l = (n,m) \in L^{\mathrm{new}},\ t \in T, \\
& \theta_{t,\hat{n}} = 0, \quad t \in T \\
& -\bar{f}_l \le f_{l,t}^{\mathrm{red}} \le \bar{f}_l, \quad l \in L^{\mathrm{ex}},\ t \in T, \\
& -\bar{f}_l z_l \le f_{l,t}^{\mathrm{red}} \le \bar{f}_l z_l, \quad l \in L^{\mathrm{new}},\ t \in T, \\
& 0 \le q_{g,t}^{\mathrm{red}} \le \bar{q}_g^{\mathrm{new}}, \quad g \in G_n^{\mathrm{new}},\ n \in N,\ t \in T, \\
& 0 \le q_{g,t}^{\mathrm{red}} \le \bar{q}_g^{\mathrm{ex}}, \quad g \in G_n^{\mathrm{ex}},\ n \in N,\ t \in T, \\
& 0 \le d_{c,t}^{\mathrm{red}}, \quad c \in C_n,\ n \in N,\ t \in T.
\end{aligned}
$$

Trilevel Model Structure

$$
\begin{aligned}
\max \quad & \psi_1(W_2, W_3, X_1) \\
\text{s.t.} \quad & (W_1, X_1) \in \Omega_1 \\
& \max \quad \psi_2(W_2) \\
& \quad \text{s.t.} \quad (W_2, X_1) \in \Omega_2 \\
& \qquad \min \quad \psi_3(W_2, W_3) \\
& \qquad \quad \text{s.t.} \quad (W_2, W_3, X_1) \in \Omega_3
\end{aligned}
$$



Solution Approaches

Lemma (Kleinert, S. 2018)

Let $\mathcal{S}_T$ be the solution set of the trilevel problem and let $\mathcal{S}_B$ be the solution set of the bilevel problem

$$\begin{aligned} \max \quad & \psi_1(W_2, W_3, X_1) \\ \text{s.t.} \quad & (W_1, X_1) \in \Omega_1, \ (W_2, W_3, X_1) \in \Omega_3, \\ & W_2 \in \arg\max \{\psi_2(W_2) \colon (W_2, X_1) \in \Omega_2\} \, . \end{aligned}$$

Then, $\mathcal{S}_T = \mathcal{S}_B$ holds.

KKT Transformation

Lemma (Kleinert, S. 2018)

Let $\mathcal{S}_T$ be the solution set of the trilevel problem and let $\mathcal{S}_B$ be the solution set of the bilevel problem

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Then, $\mathcal{S}_T = \mathcal{S}_B$ holds.

- Reduction to a bilevel problem
- Lower level is a concave QP for fixed discrete first-level variables
- KKT reformulation + big-M linearization of KKT complementarity conditions
- Final result: single-level MIQP
- Still very(!) hard to solve
- Valid inequalities for stronger dual bounds (see paper)

Master problem (MIQP)

$$
\begin{aligned}
\max \quad & \tau - \sum_{l \in L^{\text{new}}} c_l^{\text{inv}} z_l \\
\text{s.t.} \quad & \tau \leq a^\top \begin{pmatrix} x \\ z \end{pmatrix} + b, \quad (a, b) \in O, \\
& \text{network design} \\
& \text{graph partition with connectivity} \\
& \text{inter-zonal line indicators}
\end{aligned}
$$

Benders-like Decomposition

Master problem (MIQP)

$$\begin{aligned} \max \quad & \tau - \sum_{l \in L^{\text{new}}} c_l^{\text{inv}} z_l \\ \text{s.t.} \quad & \tau \leq a^\top \begin{pmatrix} x \\ z \end{pmatrix} + b, \quad (a, b) \in O, \\ & \text{network design} \\ & \text{graph partition with connectivity} \\ & \text{inter-zonal line indicators} \end{aligned}$$

Subproblem(s)

- 2nd (spot market) and 3rd level (redispatch)
  - Convex quadratic problems
- Can be solved sequentially
- Construct cuts for the master problem based on the subproblem's solution

Suppose that “a reasonable assumption” holds. Let $\mathcal{F} \subseteq \mathcal{F}_1^{\text{proj}}$ and let $O = O(\mathcal{F})$ consist of the cuts

$$\begin{aligned}\tau \le\ & \psi_2^*(\hat{x}, \hat{y}, \hat{z}) - \psi_3^*(\hat{x}, \hat{y}, \hat{z}) \\ & + \psi_{\text{ub}}^* \left(\sum_{i \in [k]} \sum_{n \in N : \hat{x}_{n,i} = 0} x_{n,i} + \sum_{i \in [k]} \sum_{n \in N : \hat{x}_{n,i} = 1} (1 - x_{n,i}) \right) \\ & + \psi_{\text{ub}}^* \left(\sum_{l \in L^{\text{new}} : \hat{z}_l = 0} z_l + \sum_{l \in L^{\text{new}} : \hat{z}_l = 1} (1 - z_l) \right), \\ \tau \le\ & \psi_{\text{ub}}^*(\hat{z}) + \psi_{\text{ub}}^* \left(\sum_{l \in L^{\text{new}} : \hat{z}_l = 0} z_l + \sum_{l \in L^{\text{new}} : \hat{z}_l = 1} (1 - z_l) \right),\end{aligned}$$

for all $(\hat{x}, \hat{y}, \hat{z}) \in \mathcal{F}$. Furthermore, let O contain the cut

$$\tau \le \psi_{\text{ub}}^*.$$

Then for any point $(x, y, z, s, u) \in \mathcal{F}_1$, there exists a point $(x, y, z, s, u, \tau) \in \mathcal{F}_M^O$ that satisfies

$$\tau - \sum_{l \in L^{\text{new}}} c_l^{\text{inv}} z_l \ge \psi_1^*(x, y, z).$$

Input: The trilevel problem.

Output: A globally optimal solution for the trilevel problem.

Initialize $O \leftarrow \{(0, \psi^*_{\text{ub}})\}$, $\Theta \leftarrow 0$, $\phi \leftarrow \infty$, $\mathcal{Z} \leftarrow \emptyset$, $\mathcal{S} \leftarrow \emptyset$.

while $\Theta < \phi$ **do**

  Solve the master problem.
   Let $(\hat{x}, \hat{y}, \hat{z})$ be part of its optimal solution, set ϕ to its optimal value.

  Solve the second-level problem with fixed $(\hat{x}, \hat{y}, \hat{z})$.
   Let $(q^{\text{spot}}, d^{\text{spot}}, \bar{q}^{\text{new}})$ be part of its optimal solution and let $\psi^*_2(\hat{x}, \hat{y}, \hat{z})$ be its optimal value.

  Solve the third-level problem with fixed $(\hat{z}, q^{\text{spot}}, d^{\text{spot}}, \bar{q}^{\text{new}})$.
   Let $(q^{\text{red}}, d^{\text{red}}, f^{\text{red}}, \theta)$ be its optimal solution and let $\psi^*_3(\hat{x}, \hat{y}, \hat{z})$ be its optimal value.

  if $\psi = \psi^*_2(\hat{x}, \hat{y}, \hat{z}) - \psi^*_3(\hat{x}, \hat{y}, \hat{z}) - \sum_{l \in L^{new}} c^{inv} \hat{z}_l > \Theta$ **then**

   Set $\Theta \leftarrow \psi$ and $\mathcal{S} \leftarrow (\hat{x}, \hat{y}, \hat{z}, q^{\text{spot}}, d^{\text{spot}}, \bar{q}^{\text{new}}, q^{\text{red}}, d^{\text{red}}, f^{\text{red}}, \theta)$.

  Add first cut to O.

  if $\hat{z} \notin \mathcal{Z}$ **then** add second cut to O.

return $\mathcal{S}$.

Does it work? Yes

Correctness

Suppose that "some reasonable assumptions" hold. Assume further that for every (x, y, z) that is part of a feasible solution for the first-level problem, the second-level solution is unique, and that the network $G = (N, L)$ is finite and connected. Then, the algorithm terminates within a finite number of iterations and returns a globally optimal solution for the trilevel problem.

Does it work? Yes ... but ...

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Uniqueness

- The unloved child of applied multilevel power market models in OR
- Please take this seriously!

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- Grimm, Schewe, S., Zöttl (EJOR, 2017): "Uniqueness of Market Equilibrium on a Network: A Peak-Load Pricing Approach"
- Krebs, Schewe, S. (EJOR, 2018): "Uniqueness and Multiplicity of Market Equilibria on DC Power Flow Networks"
- Krebs, S. (OR Persp., 2018): "Uniqueness of Market Equilibria on Networks with Transport Costs"
- Grübel, Kleinert, Krebs, Orlinskaya, Schewe, S., Thürauf (Computers & OR, 2020): "On Electricity Market Equilibria with Storages: Modeling, Uniqueness, and a Distributed ADMM"

Numerical Results

Instances

$\lvert N \rvert$	$\lvert L^{\mathrm{ex}} \rvert$	$\lvert L^{\mathrm{new}} \rvert$	$\lvert T \rvert$
3	3	1	4
6	6	2	4
6	6	2	52
9	8	1	52
9	12	4	52
12	16	6	52

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$\lvert N \rvert$	$\lvert L^{\text{ex}} \rvert$	$\lvert L^{\text{new}} \rvert$	$\lvert T \rvert$
3	3	1	4
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6-node network with $k = 4$ zones leads to KKT-transformed MIQP with

- 39 649 constraints
- 15 119 variables (thereof 1776 binaries)

Instances & Computational Setup

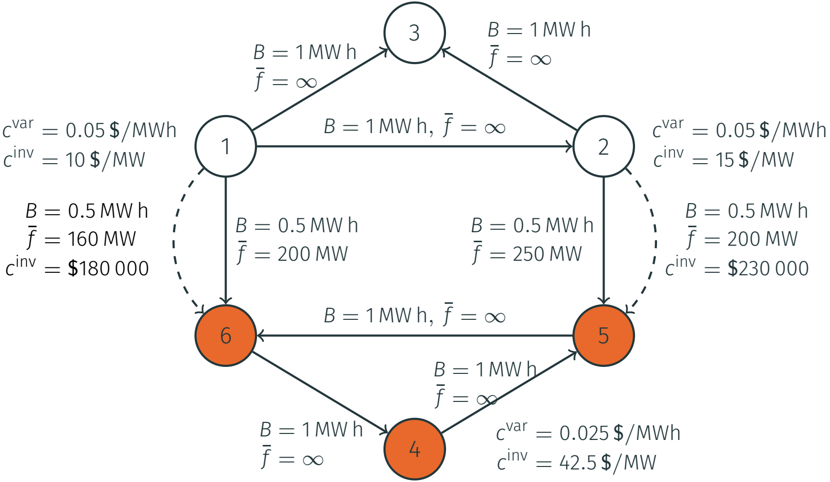
$\|N\|$	$\|L^{ex}\|$	$\|L^{new}\|$	$\|T\|$
3	3	1	4
6	6	2	4
6	6	2	52
9	8	1	52
9	12	4	52
12	16	6	52

6-node network with $k = 4$ zones leads to KKT-transformed MIQP with

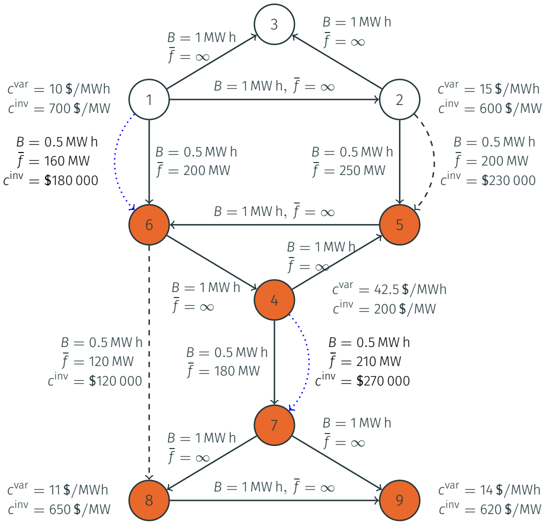
- 39 649 constraints
- 15 119 variables (thereof 1776 binaries)

- Python 2.7.12 using the graph library NetworkX within Anaconda 2.7
- Gurobi 7.5.1 for solving MIQPs, MIPs, or convex QPs

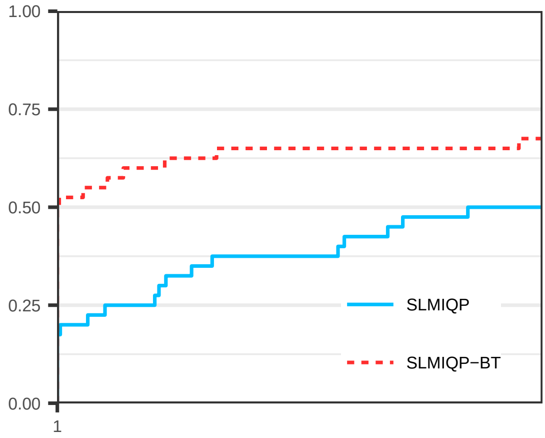
6-Node Network: Based on Chao, Peck (1998)



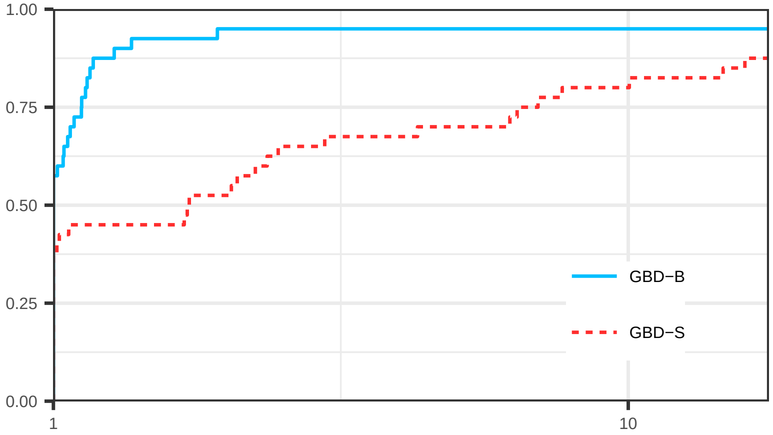
9-Node Network



KKT Transformation



Benders-like Decomposition



Solution Times: Networks with 3 and 6 Nodes

Network	Zones	SLMIQP	SLMIQP-BT	GBD-S	GBD-B
Grimm-et-al-2016-3	1	0.08	0.12	**0.04**	**0.04**
Grimm-et-al-2016-3	2	0.06	0.07	**0.04**	0.05
Grimm-et-al-2016-3	3	0.05	0.06	**0.01**	**0.01**
Chao-Peck-1998	1	0.34	0.22	**0.06**	**0.06**
Chao-Peck-1998	2	2.43	0.63	**0.12**	0.13
Chao-Peck-1998	3	2.50	4.78	**0.29**	**0.29**
Chao-Peck-1998	4	7.58	6.25	**0.25**	0.28
Chao-Peck-1998	5	3.89	0.96	**0.09**	0.10
Chao-Peck-1998	6	1.39	0.81	**0.02**	**0.02**
Grimm-et-al-2016-6	1	1.92	1.03	**0.16**	0.21
Grimm-et-al-2016-6	2	57.06	371.79	1.40	**0.81**
Grimm-et-al-2016-6	3	—	949.55	4.54	**1.84**
Grimm-et-al-2016-6	4	1843.84	1241.38	3.61	**1.53**
Grimm-et-al-2016-6	5	2018.33	381.15	1.29	**0.62**
Grimm-et-al-2016-6	6	3.10	2.74	0.24	**0.23**

Solution Times: Networks with 9 Nodes

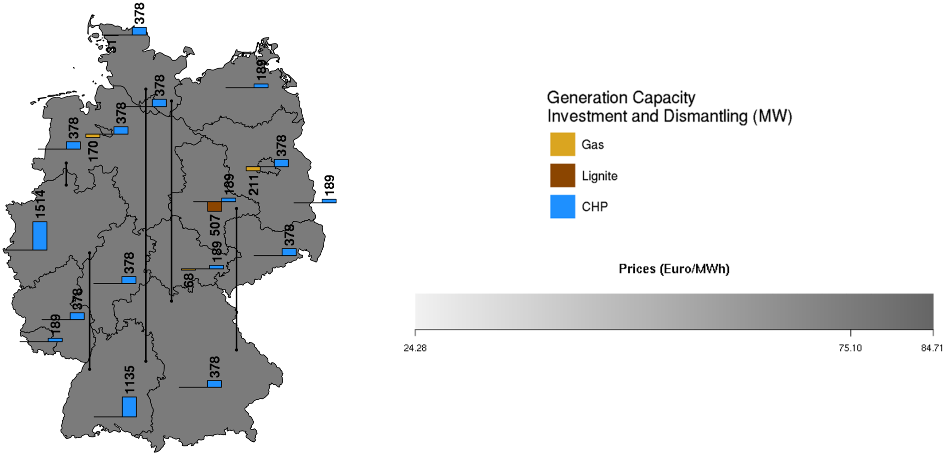
Network	Zones	SLMIQP	SLMIQP-BT	GBD-S	GBD-B
Haefner-2017	1	1.18	0.78	**0.12**	0.24
Haefner-2017	2	—	—	**0.25**	0.26
Haefner-2017	3	—	338.32	0.80	**0.47**
Haefner-2017	4	—	320.19	1.91	**0.12**
Haefner-2017	5	—	372.47	2.44	**0.24**
Haefner-2017	6	—	213.06	1.87	**0.13**
Haefner-2017	7	—	201.83	1.12	**0.15**
Haefner-2017	8	—	10.31	0.31	**0.14**
Haefner-2017	9	3.39	3.35	**0.10**	0.11
Kleinert-Schmidt-2018-9	1	4.65	**1.49**	3.82	4.38
Kleinert-Schmidt-2018-9	2	—	—	37.55	**12.67**
Kleinert-Schmidt-2018-9	3	—	—	1944.97	**303.54**
Kleinert-Schmidt-2018-9	4	—	—	—	**1563.77**
Kleinert-Schmidt-2018-9	5	—	—	—	**2281.35**
Kleinert-Schmidt-2018-9	6	—	—	4320.88	**694.21**
Kleinert-Schmidt-2018-9	7	—	—	350.40	**81.49**
Kleinert-Schmidt-2018-9	8	—	—	17.73	**10.37**
Kleinert-Schmidt-2018-9	9	14.03	18.34	3.94	**3.88**

Solution Times: The 12-Node Network

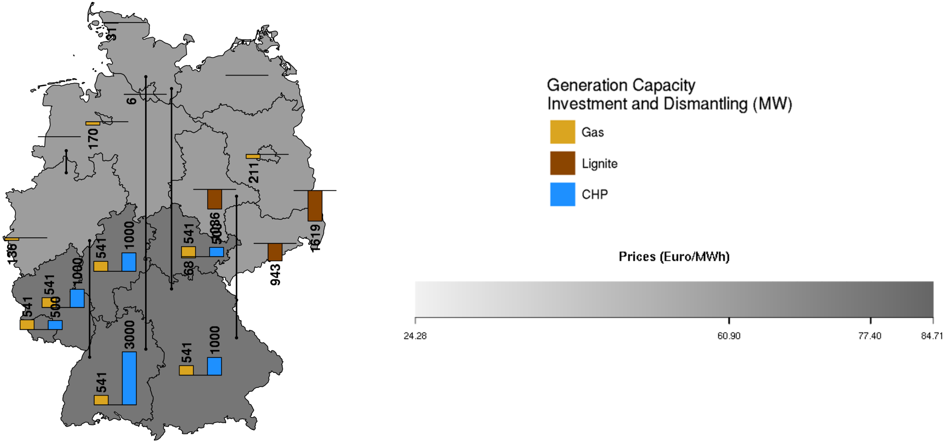
Network	Zones	SLMIQP	SLMIQP-BT	GBD-S	GBD-B
Kleinert-Schmidt-2018-12	1	7.81	**2.44**	8.35	11.41
Kleinert-Schmidt-2018-12	2	—	—	4770.68	**2338.93**
Kleinert-Schmidt-2018-12	3	—	—	—	—
Kleinert-Schmidt-2018-12	9	—	—	—	—
Kleinert-Schmidt-2018-12	10	—	—	—	**2590.91**
Kleinert-Schmidt-2018-12	11	—	—	305.93	**43.91**
Kleinert-Schmidt-2018-12	12	16.11	16.24	**8.92**	9.98

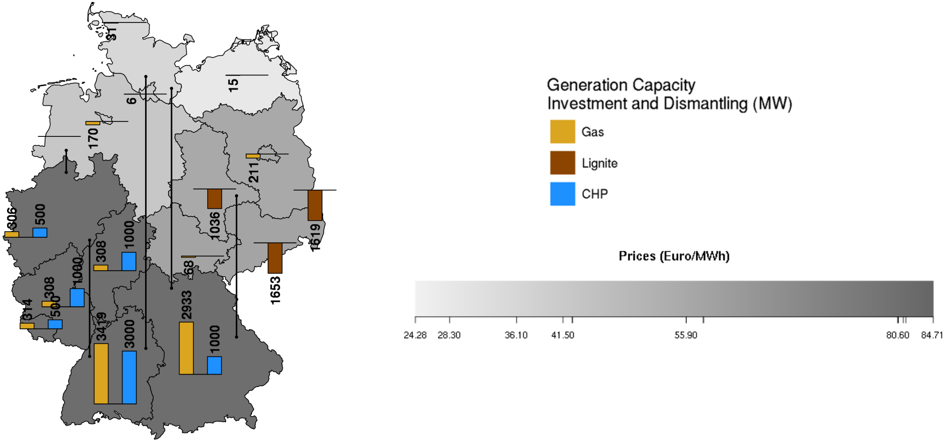
Real-World Case Study

Results for Germany: 1 Zone



Results for Germany: 2 Zones




Generation Capacity
Investment and Dismantling (MW)
Gas
Lignite
CHP
Prices (Euro/MWh)
24.28
28.30
36.10
41.50
55.90
80.60
84.71
15
6
170
211
500
1000
308
1036
1619
1653
68
2933
3000
1000

V. Grimm, A. Martin, M. Schmidt, Martin Weibelzahl, G. Zöttl

Transmission, Generation Investment in Electricity Markets:
The Effects of Market Splitting and Network Fee Regimes

European Journal of Operational Research (2016). DOI: 10.1016/j.ejor.2016.03.044

V. Grimm, T. Kleinert, F. Liers, M. Schmidt, G. Zöttl

Optimal price zones of electricity markets:
a mixed-integer multilevel model, global solution approaches

Optimization Methods and Software (2019). DOI: 10.1080/10556788.2017.1401069

T. Kleinert, M. Schmidt

Global Optimization of Multilevel Electricity Market Models
Including Network Design and Graph Partitioning

Discrete Optimization (2019). DOI: 10.1016/j.disopt.2019.02.002

M. Ambrosius, V. Grimm, T. Kleinert, F. Liers, M. Schmidt, G. Zöttl

Price Zones and Investment Incentives in Electricity Markets:
An Application of Multi-Level Optimization with Graph Partitioning

Energy Economics (2020) DOI: 10.1016/j.eneco.2020.104879

That's It!

Summary

- Highly interdisciplinary topic at the intersection of OR, multilevel optimization, economics, discrete optimization, ...
- Models and results can be used to understand decision making in a long- to short-term market environment
- No chance without problem-tailored methods

That's It!

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Future Work

- We are still at the beginning …
- What about uncertainties?
- What about market power?
- What about more realistic power flow models?
- What about unit commitment?

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