# Transmission and Generation Investment in Electricity Markets: the Effects of Market Splitting and Network Fee Regimes

**Gregor Zöttl**

Vienna

November 4, 2014

**Joint work with V. Grimm, A. Martin, C. Sölch, M. Weibelzahl**

ENERGIE CAMPUS NÜRNBERG

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
FACHBEREICH WIRTSCHAFTSWISSENSCHAFTEN

# Grand Challenges

- Abandoning nuclear energy requires complete reorientation of power supply schemes.
- Old plants get dismanteld or need repowering.
- A lot of fluctuating renewable sources have been installed.
- We need market rules that generate adequate investment incentives:

  **=> right capacities**

  **=> right locations**

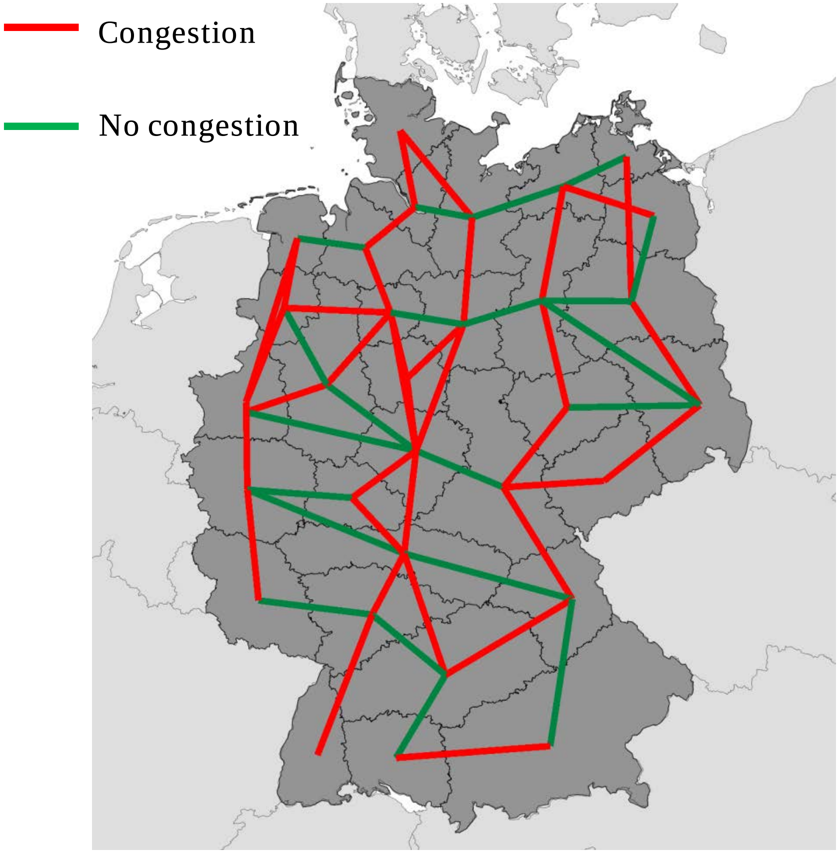
Quelle: Bundesamt für Strahlenschutz

# Transmission constraints become an issue

Transmission constraints become relevant – both within and between countries.

Possible solutions include: gas power plants, network capacity, demand side management, storage facilities and smart technologies

The locations and capacities of generation facilities have crucial relevance for the network expansion.




Source: EWI, Trendstudie 2022. Case: high wind in-feed.2022.

# The Current Literature

- **Models on optimal transmission and investment planning**
- ➢ Disregards incentives of different agents in liberalized markets

- **Investment models for generation facilities (e.g. peak load pricing literature, “Capacity-market”-discussion).**
- ➢ typically disregards network and network expansion (“copper plate”)

- **Models analyzing impact of different network management regimes (nodal pricing, zonal pricing, redispatch)**
- ➢ typically focus on the short run perspective (given network & generation facilities)

✓ For several important policy questions we also need to consider the interdependence of those issues!

# Questions we have in mind (examples)

- what is the impact of changed way of charging network fees on generation investment and associated network expansion
- What are the incentives to invest in responsive consumption units and what is the impact on optimal transmission investment?
- what is the quantifiable impact of adopting a different transmission management regime (e.g. market based redispatch, price zones,…, nodal pricing) taking into account long run investment

✓ We present a computable equilibrium framework which allows to analyze those issues

# Roadmap of this talk

(1) Introduction

(2) Computational Equilibrium Framework

(3) Testexample (6-node-network)

(4) Very first results on Germany&Neighbours

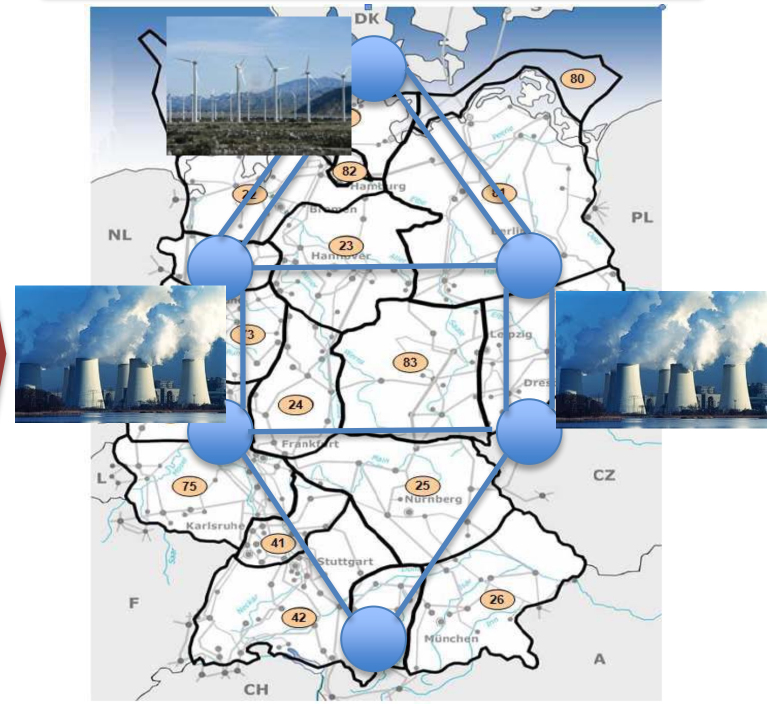
(5) Conclusion

# What we have in mind

## Model Components

- Network expansion by social planner
- Competitve Firms invest in different production technologies throughout the network
- Demand at the nodes (net of renewable feed-in) can be fluctuating and uncertain.
- We want to explicitly take into account impact of different network management regimes (redispatch, market splitting)

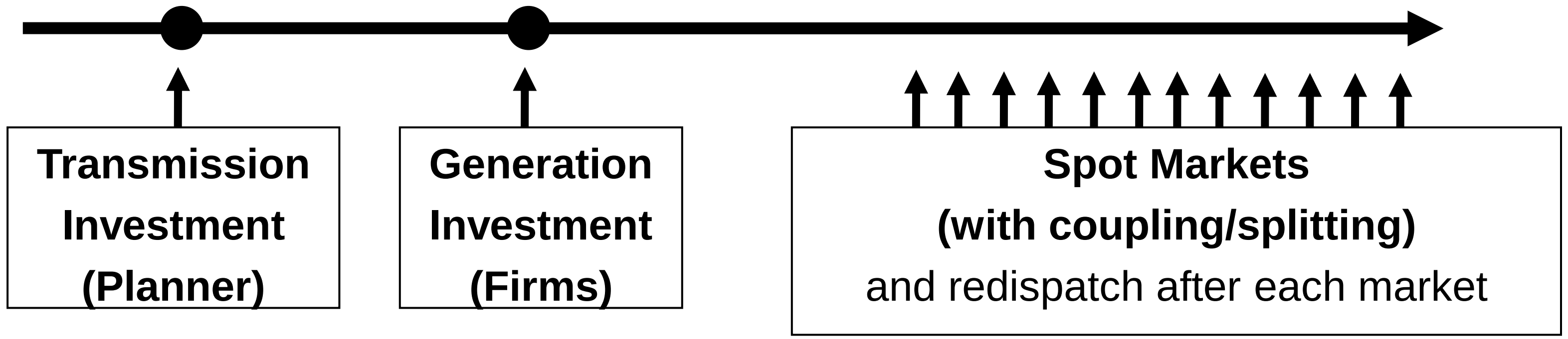
## Illustration




Main purpose: to identify the impact of market rules on investment decisions
(overall system optimization is just a benchmark!)

# Model: Timing

- The transmission system operator chooses to realize line investments from set of options (integer decisions).
- Competitive firms choose how much to invest in available production technologies at each node t=1,2,… ,each technology $(k_t,c_t)$ has marginal cost of production $c_t$, marginal cost of investment $k_t$ at the supply node.
- Spot market competition
- Management of network congestion by cost based redispatch.

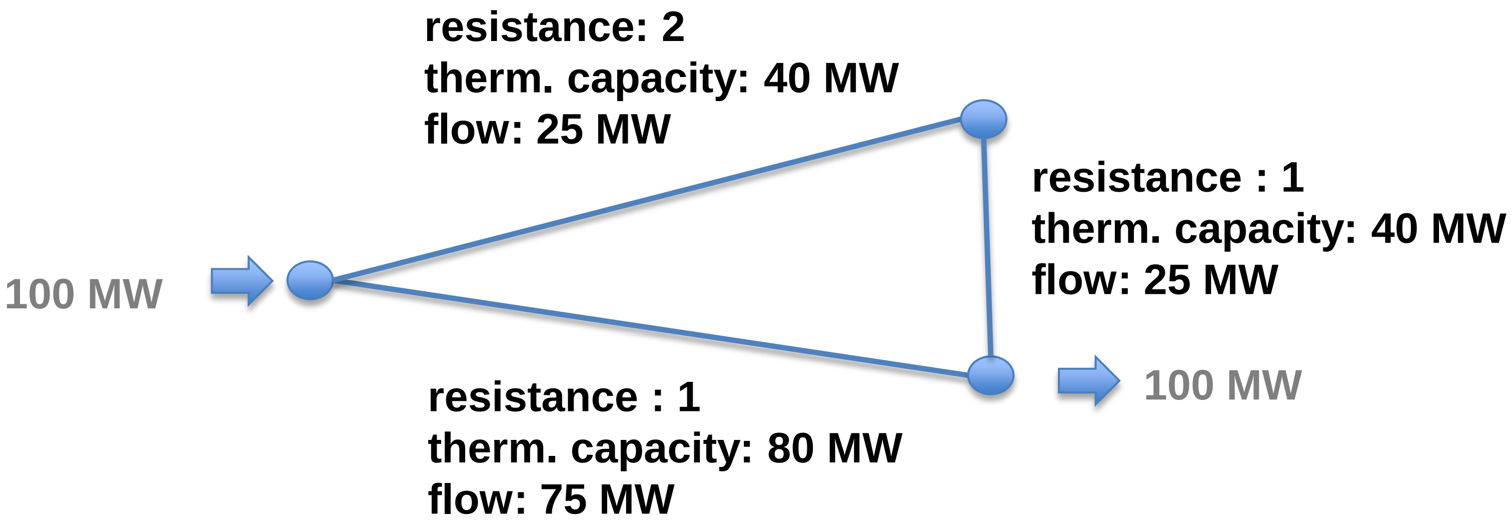


ENERGIE CAMPUS NÜRNBERG

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
FACHBEREICH WIRTSCHAFTSWISSENSCHAFTEN

# Model Components: modelling the physical network

- We consider the usual linear **lossless** DC-Approximation:



# Model Components: Network Management Regimes

**Cost based Redispatch:**

- All bids at the spot markets are made entirely independently of network constraints, we obtain a uniform price accross the entire market.
- Quantities traded may be physically unfeasible. Then the TSO has to find the cheapest possible re-dispatch to make final quantities physically feasible.

**Market Splitting**:

- The market region is divided into price zones, potential congestion among zones (but not within zones!) is already taken into account at the spot markets.
- Remaining physical infeasibilities are still resolved through redispatch.

# Model Components: Network Fees

The TSO is facing the following cost:

- Network expansion investment
- Cost of redispatch

In our framework TSO is supposed to not make any profits, the above spendings have to be recovered by network fees. We consider the following cases:

- lump sum
- energy based fees (e.g. Germany, 5 €ct/KWh)
- capacity based fees
- Fees payed either by generators or by consumers

ENERGIE
CAMPUS
NÜRNBERG

FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG

FACHBEREICH WIRTSCHAFTS-
WISSENSCHAFTEN

# Illustration of our 3-stage approach

Network Expansion

(social planner)

Investment in Generation Facilities

Trading at Spot Markets

(competitive companies)

Redispatch taking into account renewable production

(social planner)

# Our 3-stage approach, more formally

Max Welfare(**N**,K,S,R)

s.t.

**K,S** is competitve equilibrium,

s.t.

**Traded quantities S can be produced by capacities K**

**Min R**EDCost(N,K,S,**R**)

s.t.

**quantities can be transmitted by network and can be produced by plants**

**Network expansion-stage:** Social planner chooses network(expansion) maximizing **WF**

**Market-stage:** Competitive Firms choose capacities and Spotmarket-bids to maximize profits.

**Redispatch-stage:** Social planner chooses Redispatch R to minimize Redispatchcost **REDCost,** s.t. all quantities are feasible.

# Benchmark: system optimization / first best

Max Welfare(**N**,K,S,R)

s.t.

**Production schedule is feasible**

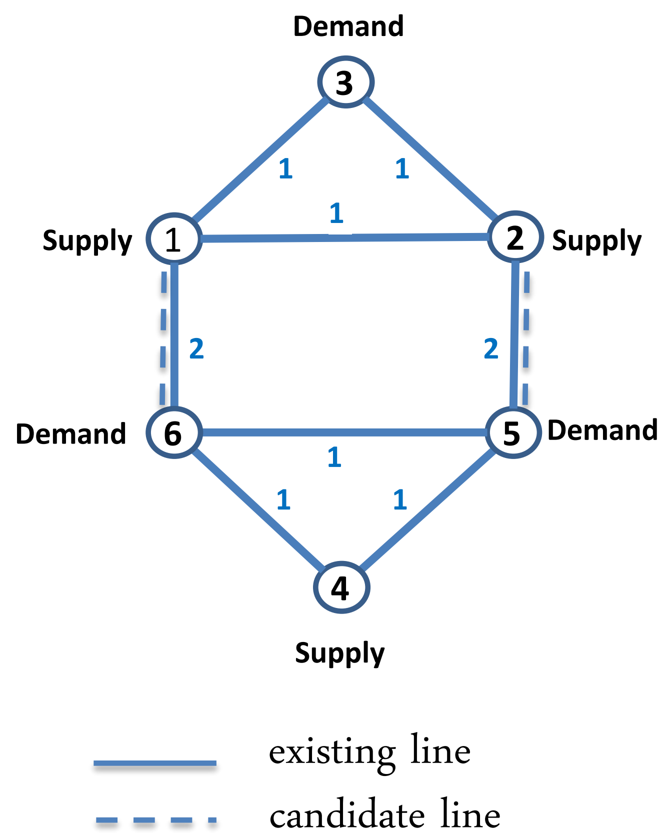
**Transmission is feasible**

**Integrated perspective:** Social planner chooses network(expansion), generation investment and production to maximize **Welfare**

s.t. feasibility constraints.

# Computational Results, 6 node test example

- To test our equilibrium framwork we consider a common 6-node-example (adapted for long run decisions).
- Lines connecting nodes 1,2,3 and nodes 4,5,6 have sufficient capacities. Only lines 1  6 and 2  5 cause problems. Potential line investment 1  6 and 2  5.
- Three demand nodes (3,5,6).
- Investment in generation facilities only at the supply nodes (1,2,4)
- Notice: Storage facilities are not (yet) included.



# Computational Results, 6 Node Test Example

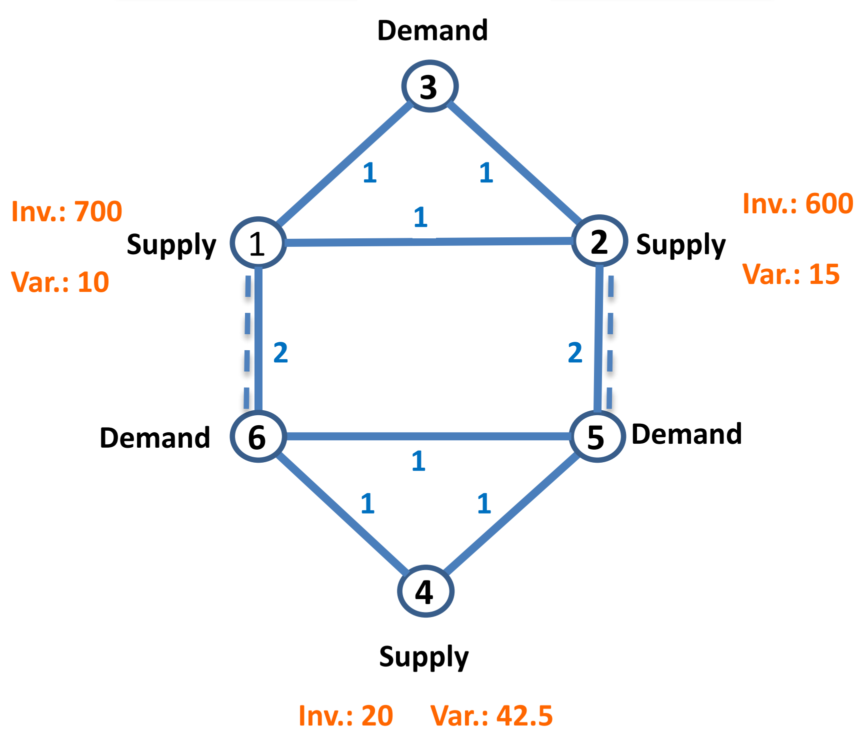



TABLE 3. Basic Demand Parameters

| Network Node | Intercept | Slope |
|---|---|---|
| 3 | 37.5 | 0.05 |
| 5 | 75 | 0.1 |
| 6 | 80 | 0.1 |

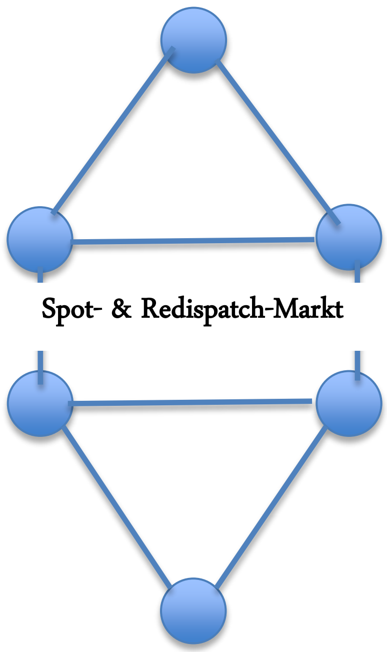
- We used 2011 data to generate 52 demand scenarios.

existing line

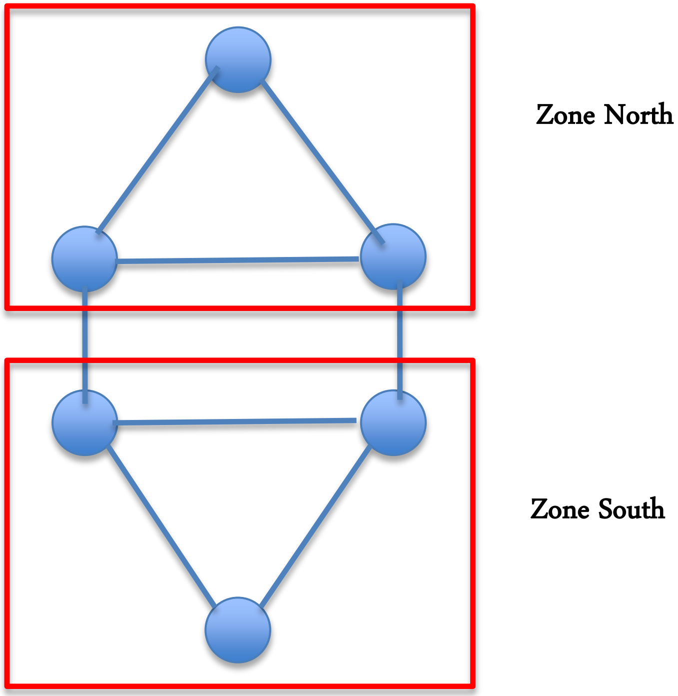
candidate line

# 6 node test example, scenarios analyzed

Szenario: Single Zone




Szenario: Two Zones



ENERGIE CAMPUS NÜRNBERG

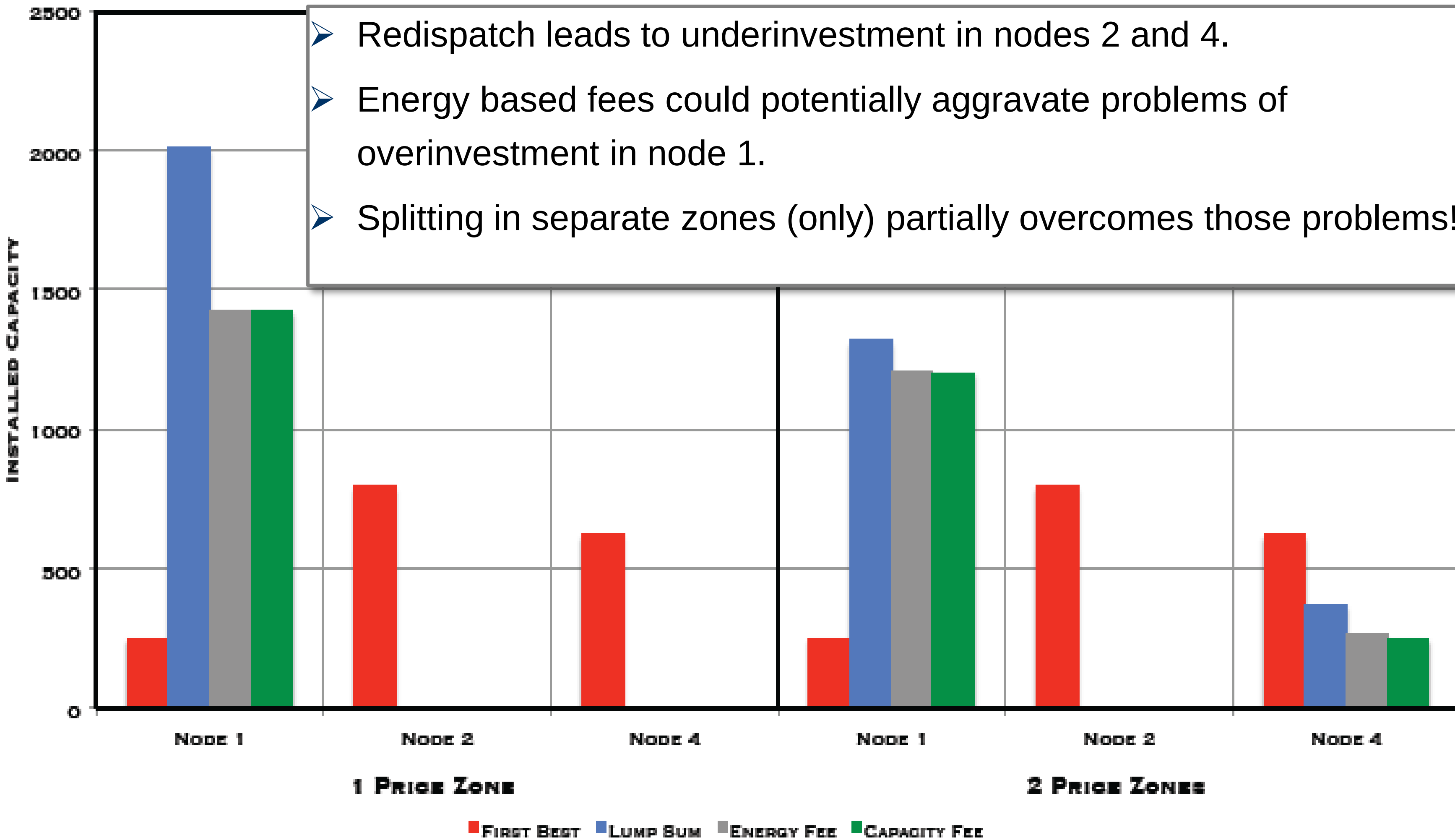
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
FACHBEREICH WIRTSCHAFTS-WISSENSCHAFTEN

# Computational Results, 6 Node Test Example

| | Benchmark (fist best) | Single Zone | Two zones |
|---|---|---|---|
| **Welfare (norm.)**: | **1** | **0.93** | **0.98** |
| **Generation. Invest.:** | All locations | Only node 1 | Only nodes 1 and 3 |
| **Network Invest.:** | Build no line | Build both lines | Build 2□ 5 |

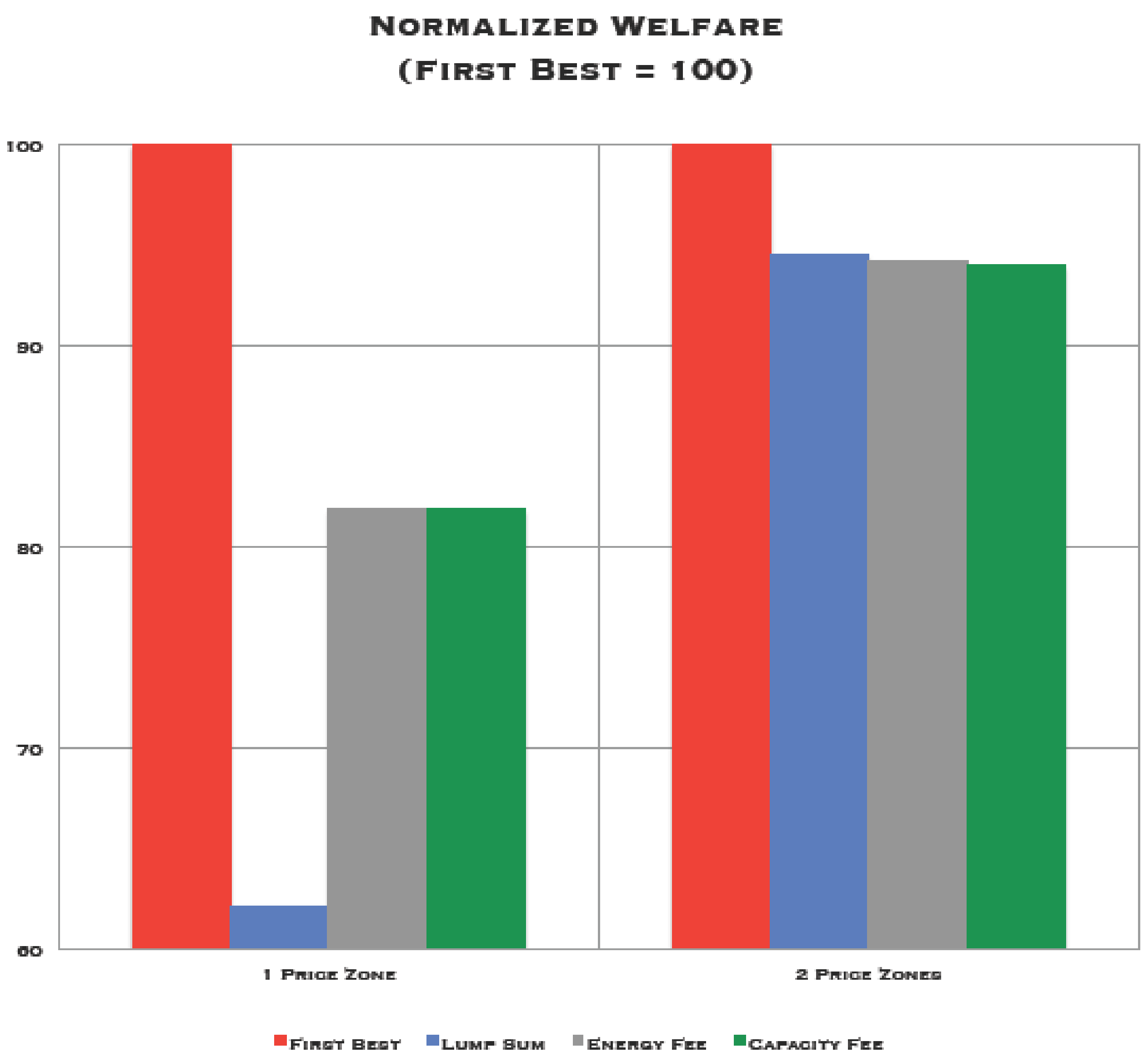
# Installed Generation Capacities

- Redispatch leads to underinvestment in nodes 2 and 4.
- Energy based fees could potentially aggravate problems of overinvestment in node 1.
- Splitting in separate zones (only) partially overcomes those problems!



ENERGIE CAMPUS NÜRNBERG

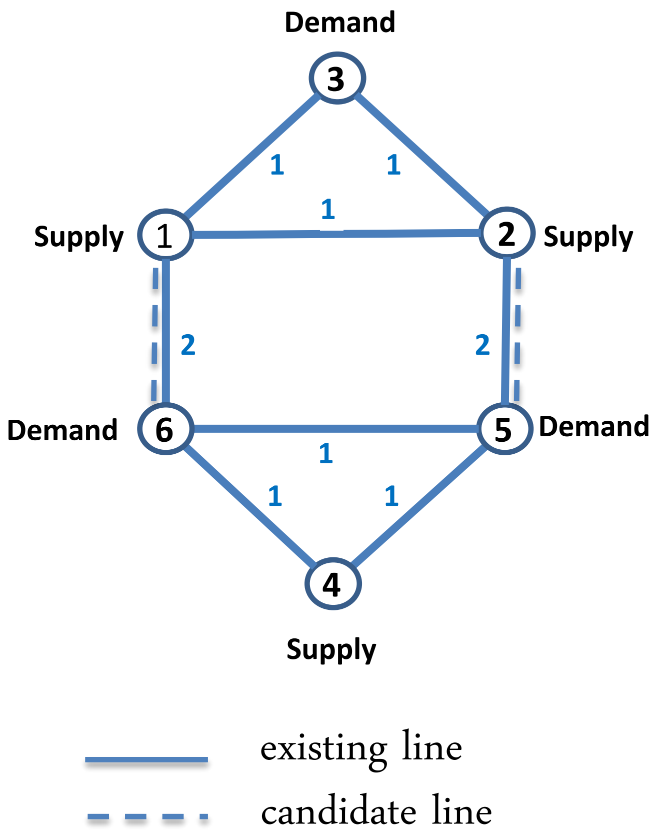
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
FACHBEREICH WIRTSCHAFTSWISSENSCHAFTEN




Pr

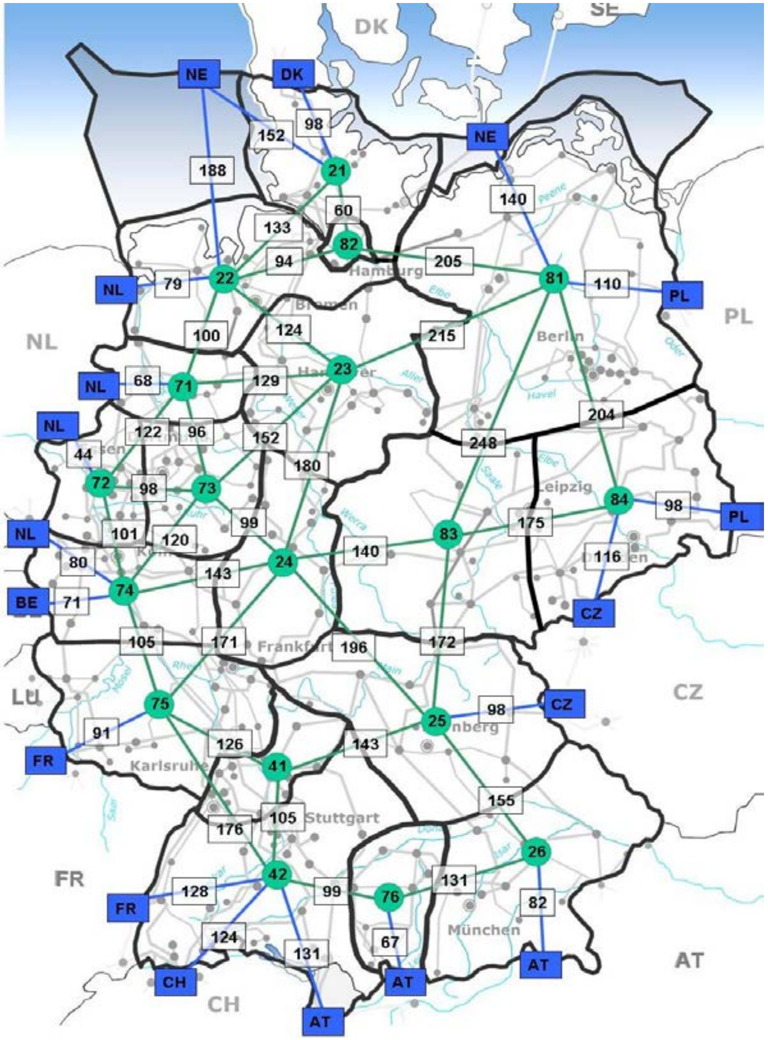
# 6 node test example, Summary of Results

- Under Cost Based Redispatch Regime investment in generation facilities in the „South“ is too low and network investments are too high (relative to the first best).
- Energy based fees potentially aggravate problems of overinvestment in the „North“.
- Consideration of different regions already at the spot market (market splitting) would aleviate but not eliminate distortions
- **Perspective:** Our framework allows to precisely quantify all those differences, also for detailled calibration of specific market regions.



# Regional Model "Electricity Transport 2013"

- **8784 hours (= year 2012)**
- **20 regions for Germany:**
  - 2 regions for off-shore wind energy plants (North and Baltic Sea),
  - 18 regions on the German mainland
- **9 regions for neighboring countries:**
  - Austria,
  - Belgium,
  - Switzerland,
  - Czech Republic,
  - Denmark (West),
  - France,
  - the Netherlands,
  - Poland,
  - Northern Europe (Denmark East, Norway, Sweden)



# Used data and parameters

Data for 2012 from:

- eex.com (German prices)
- entsoe.eu (Consumption)
- Transparency homepages of TSOs (solar, wind, cross border physical flow)
- Electricity market homepages of neighboring countries (prices)
- …

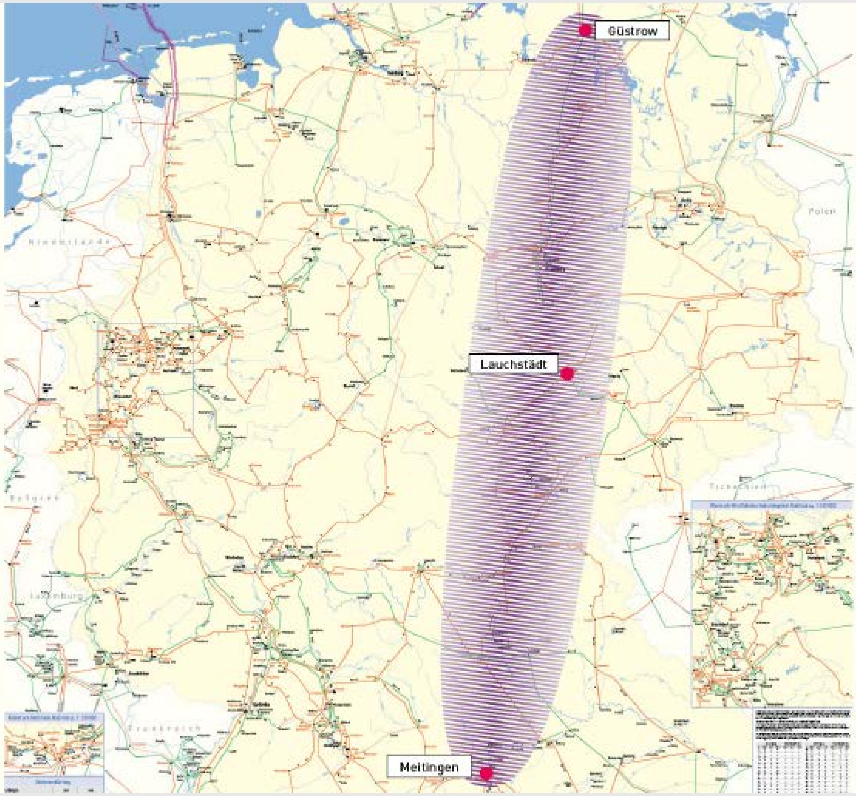
Parameters:

- Price elasticity: -0.25
  => slope of demand function: -4
- Generation technologies:

| Type | Investment cost (€ / (MW * a)) | Variable cost (€) |
|---|---|---|
| Nuclear | no new investment | 10,00 |
| Lignite | 235730 | 27,32 |
| Hard coal | 202330 | 40,69 |
| Gas | 80100 | 73,68 |

# First Results I

- First best model vs. Redispatch model (single zone, lump sum)
- Without net investment vs. (forced) investment  in 1 line: high-voltage DC-link
  - start: Lauchstädt (Saxony-Anhalt)
  - end: Meitingen (Bavaria)
  - capacity: 2 GW
  - length: 450 km
  - cost: 1.40 m €/km
  - annuity: 0.11 m €/(km*a)

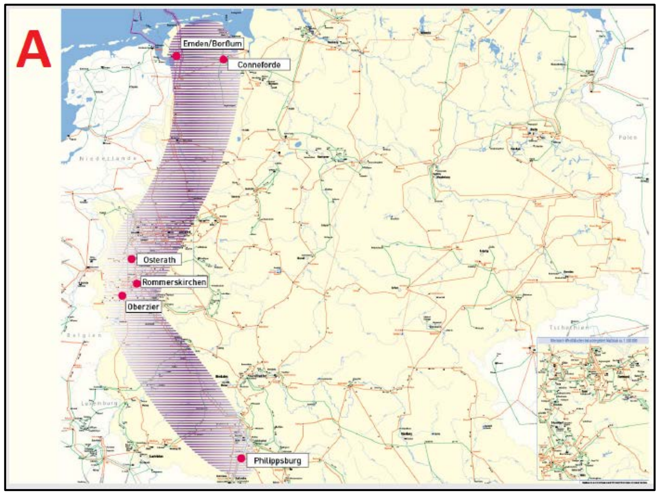


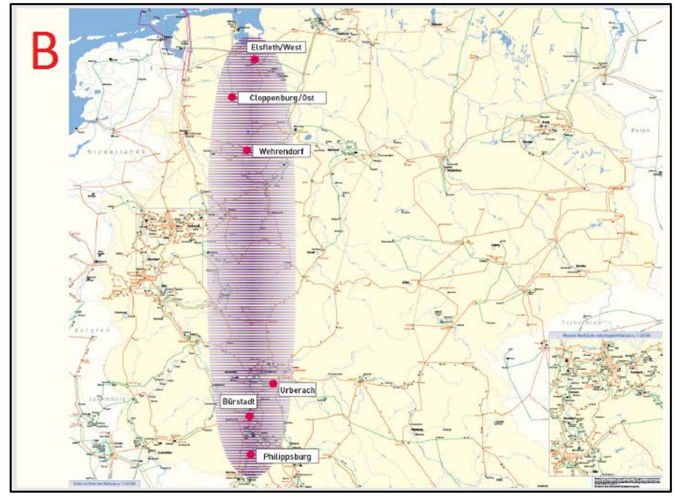

| Maßnahme | NOVA | Trassenlänge | Zusätzl. Korri-dorbedarf | Szenario | | | |
|---|---|---|---|---|---|---|---|
| | | | | A 2022 | B 2022 | B 2032 | C 2022 |
| Nr. 09: Lauchstädt – Meitingen HGÜ-Verbindung | Netzausbau | 450 km | 450 km | 2 GW | 2 GW | 2 GW | 4 GW |

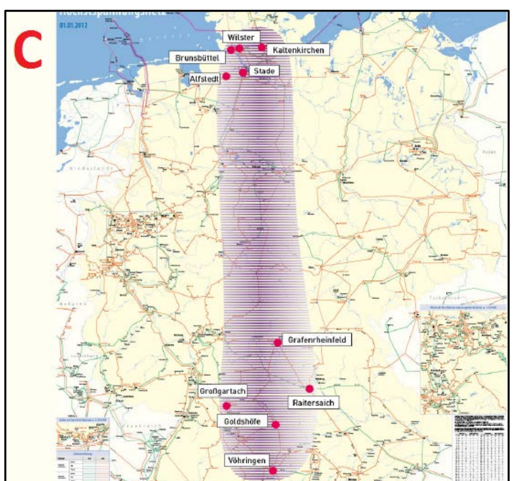
# First Results I

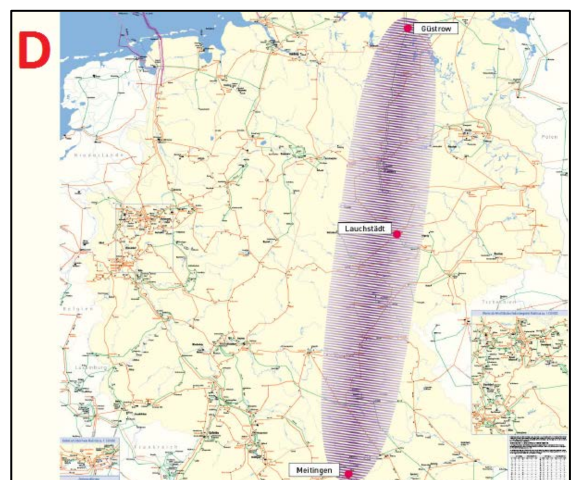
| | Benchmark (first best) | Single Zone |
|---|---|---|
| **<u>Welfare (p.c.)</u>:** | | |
| No line invest. | ▪ **100.00 %** | ▪ **96.37 %** |
| Forced line invest. | ▪ **99.99 %** | ▪ **96.38 %** |
| **<u>Generation. Invest.:</u>** | | |
| No line invest. | ▪ Build Gas (596 MW) in Baden-Wuerttemberg | ▪ No investment |
| Forced line invest. | ▪ Build Gas (414 MW) in Baden-Wuerttemberg | ▪ No investment |

# First Results II



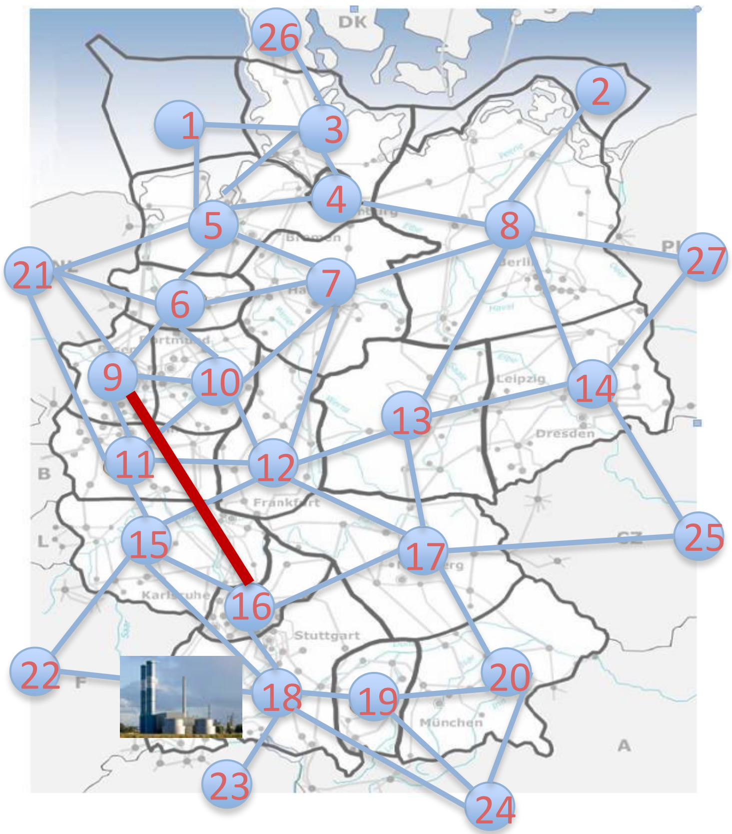



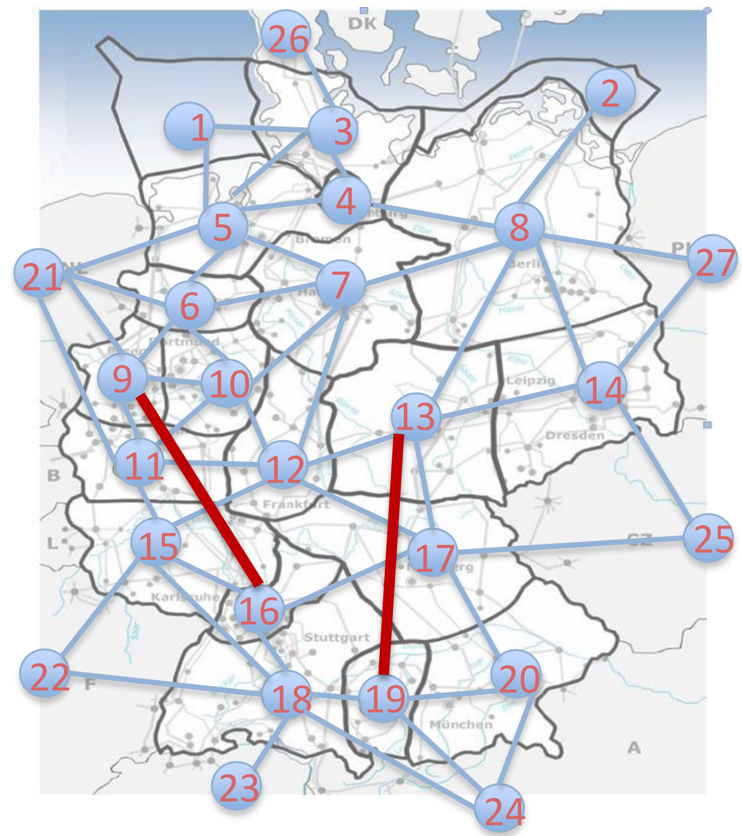



# First Results II

First best Solution




Market Solution (Cost based redispatch)



# Summary

- We have established a framework where a planner chooses transmission line investment and competitive firms invest in generation facilities.
- The framework allows to explicitly analyze the impact of different network management regimes (network fees, price zones,…) on generation and network investment.
- First qualitative results based on test example:
  1) Redispatch leads to underinvestment in the „South“.
  2) Energy based fees aggravate problems of overinvestment in the „North“.
  3) Splitting in separate zones only partially overcomes those problems!
- Future work: analyze regional differentiation of transmission fees, those might at least partially heal the problems!