The Impact of Market Design on Transmission and Generation Investment in Electricity Markets

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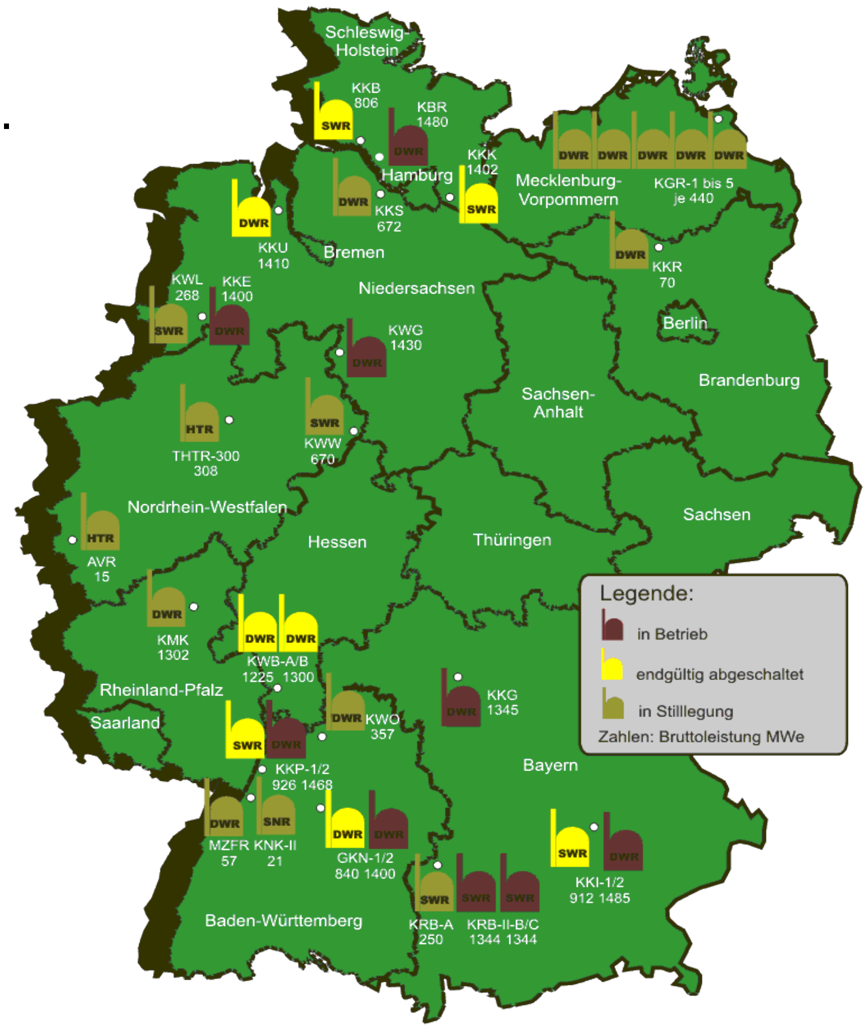
Grand Challenges

- Phasing out of nuclear energy until 2022.
- Dismantling or repowering of old plants.
- A lot of fluctuating renewable sources have been installed.

⇒ Requires complete reorientation of power supply schemes.

⇒ We need market rules that generate adequate investment incentives:

  - **right capacities**
  - **right locations**

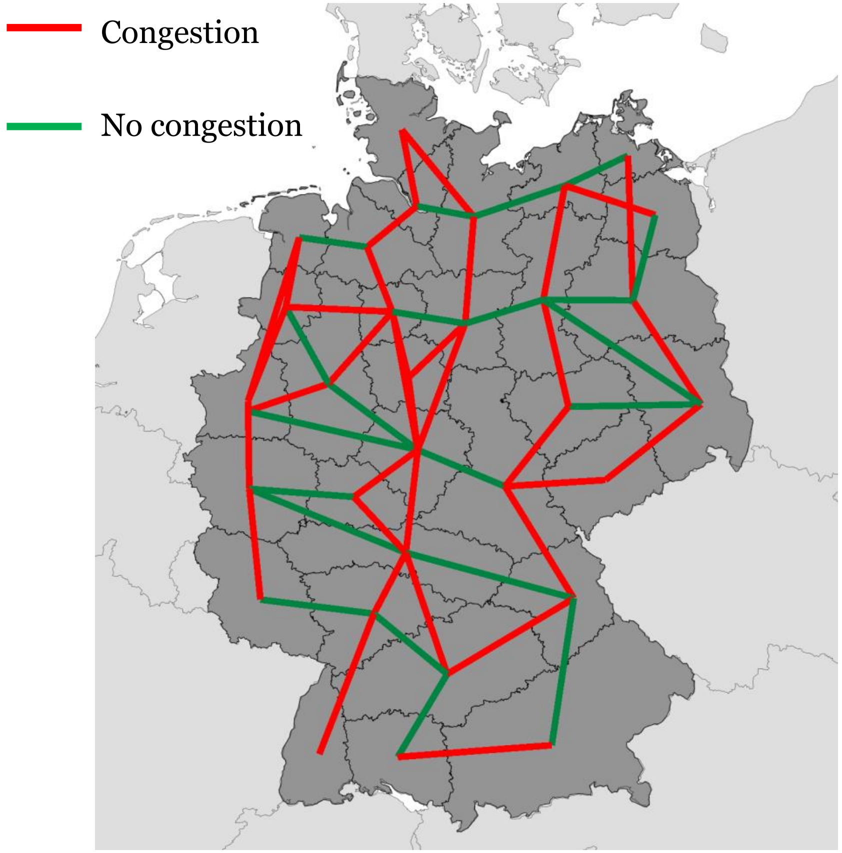


Source: Bundesamt für Strahlenschutz

Transmission constraints become an issue

- Transmission constraints become relevant – both within and between countries.
- Possible solutions include: gas power plants, network capacity expansion, demand side management, storage facilities and smart technologies
- The locations and capacities of generation facilities have crucial relevance for the network expansion.

⇒ **Main purpose:** to identify the impact of certain market rules on investment decisions on generation and transmission expansion



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

The Current Literature

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

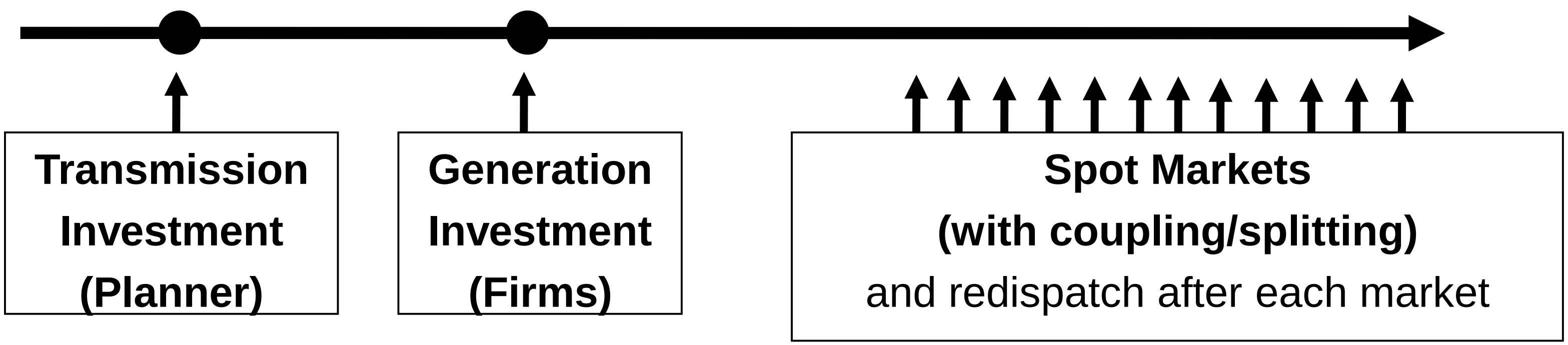
- **Investment models for generation facilities (e.g. peak load pricing literature, "Capacity-market"-discussion)**
- ➢ typically disregards network and network expansion ("copper plate")

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

✓ To analyze simultaneous network and generation expansion in liberalized electricity markets with price zones (e.g. Western European markets) we need to consider the interdependence of those issues!

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 n=1,2,… ,each technology (k_n,c_n) has marginal cost of production c_n, marginal cost of investment k_n at the supply node.
- Spot market competition
- Management of network congestion by cost based redispatch



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The GATE model, schematic overall presentation

[Grimm et al. (2016). Transmission and Generation Investment in Electricity Markets: The Effects of Market Splitting and Network Fee Regimes. In: European Journal of Operational Research, vol. 254, no. 2, pp. 493–509]

Max WF(**N**,K,S,R)
s.t.

K,S is market equilibrium
s.t.

Traded amounts of S are producible by power plants K

Min REDCost(N,K,S,**R**)
s.t.

Passing amounts R are possible in the grid

Volumes to be produced can be generated by power plants K

Network expansion level: Government/Network operators chooses grid (expansion) N, so that overall welfare **WF** is maximized

Market level: Investors have chosen power plant expansion K and spot market bids S, so that their private gains are maximized.

Redispatch level: Government/Network operators chooses redispatch R, so that redispatch costs **REDCost** are minimized and all quantities can be represented.

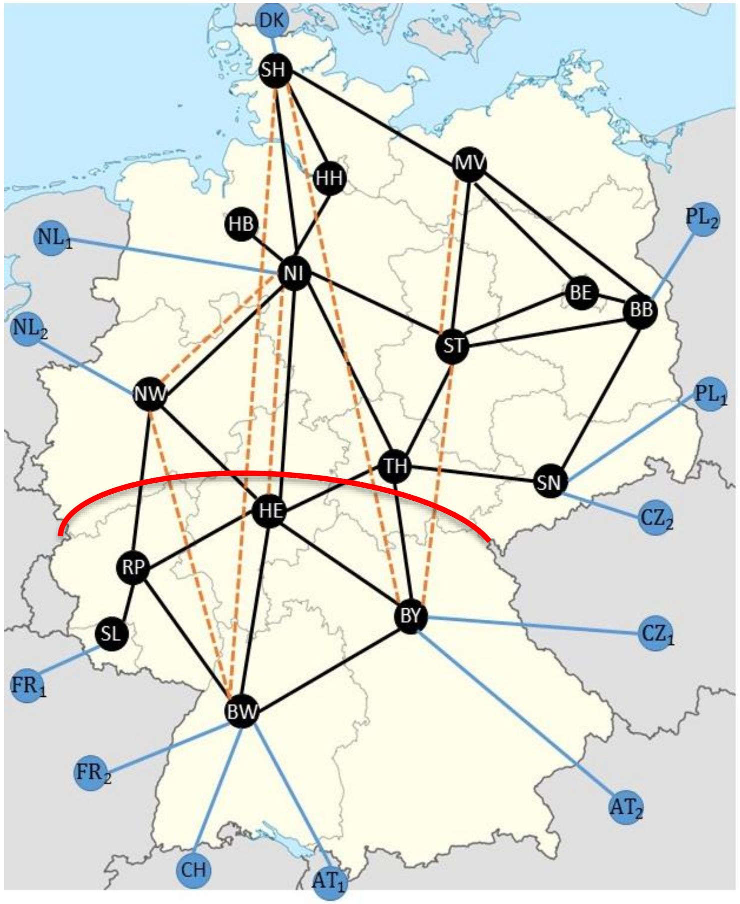
Case study for the German market (with neighbours)

[Grimm, Zöttl, Rückel, Sölch (2015), Report for Monopolies Commission;
Grimm, Zöttl, Ambrosius, Rückel, Sölch (2016), Report with Prognos for N-Ergie]

Starting point:

- **8760 hours, projection for the year 2035** (for numerical reasons only 2016 model hours)
- **16 regions for Germany** (Federal states) **and 12 regions for neighboring countries** (Austria, Benelux, Swiss, Czech Republic, Denmark, France, Poland)
- **15 HVDC-lines** (from NEP 2014) **as candidates for network expansion** (orange dashed lines)
- **Input parameters** where possible from the **scenario framework** and **network expansion plan** for comparability reasons!

Grid with one node for each federal state



Scenarios considered

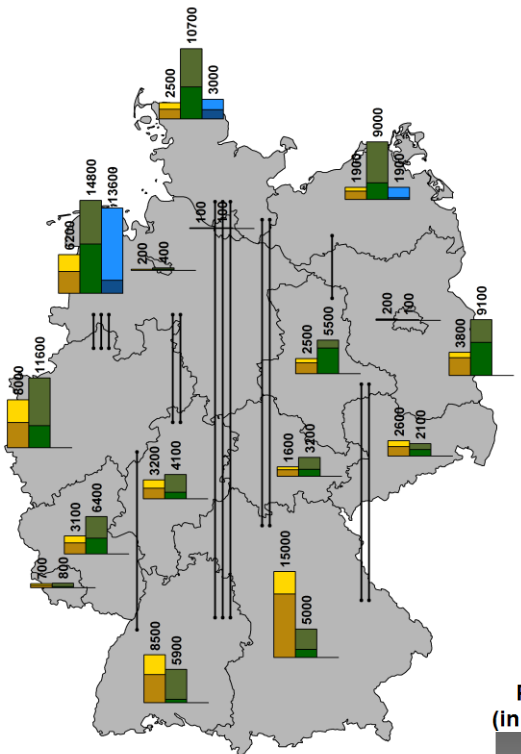
We compute the following scenarios:

- **ME_{SQ} :** current market design with a single price zone and cost-based redispatch
- **ME_{2Zones} :** Splitting of the spot market in two price zones.
- **FB_{SQ} :** The welfare optimum (presumably obtained by a system of nodal prices)

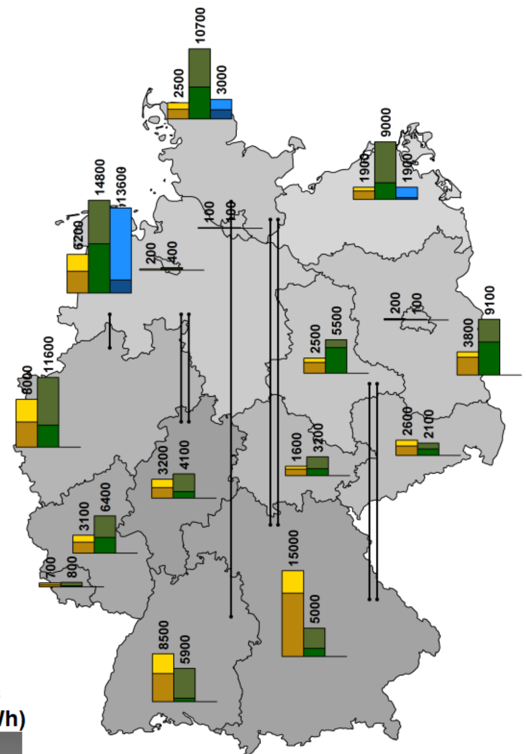
Note: under the current network planning mechanism the network has to be built such that no redispatch occurs, RES are never switched off. We thus further consider:

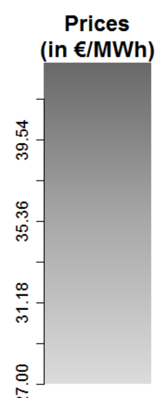
- **ME_{RED} :** Network plans allow for redispatch
- **$ME_{RED\&RC}$:** Network plans allow for redispatch and interrupted RES (renewable curtailment)
- **FB_{RC} :** Welfare optimum when RES can be curtailed

Results ME_{SQ}



Results FB_{SQ}



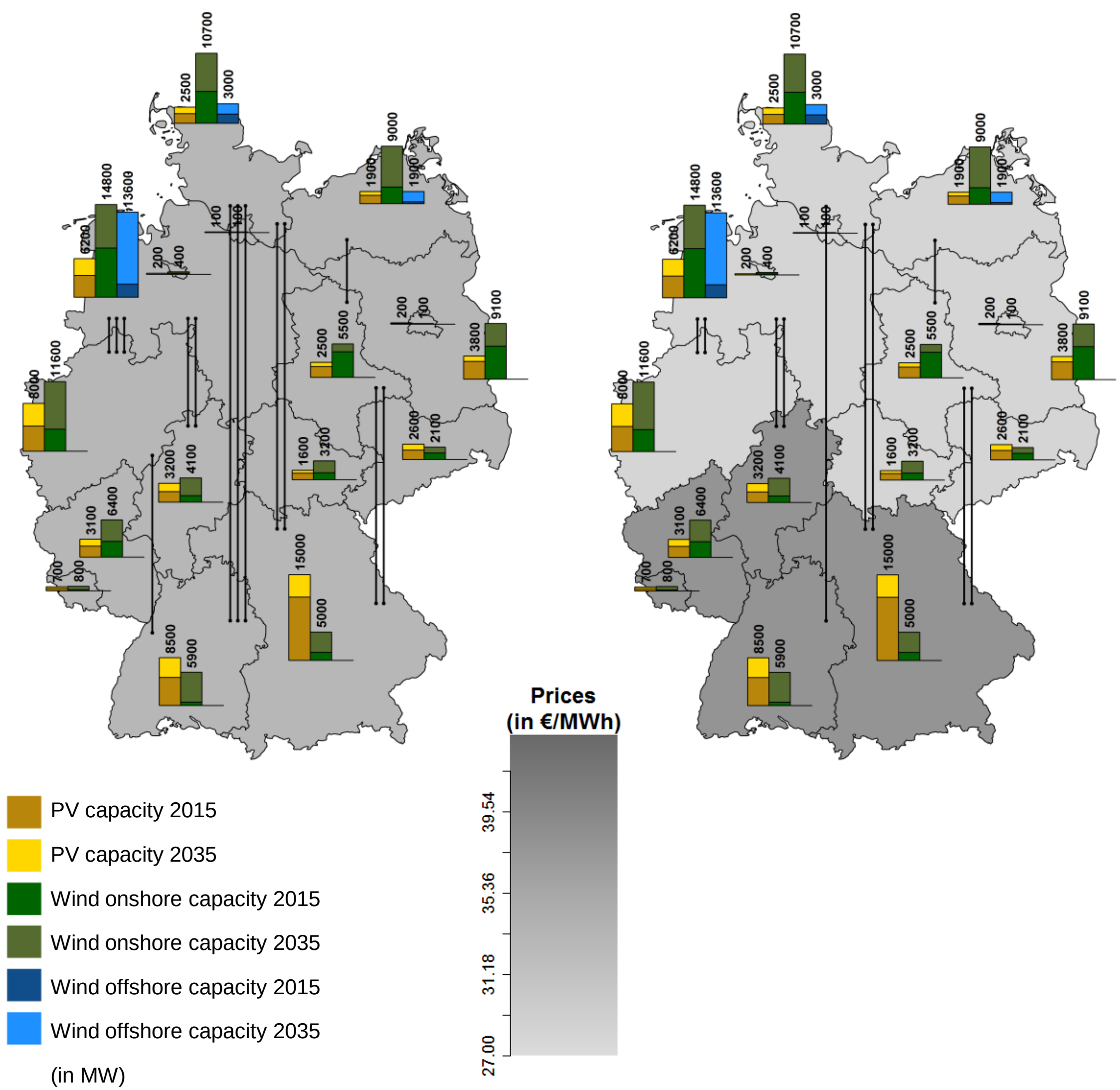


PV capacity 2015
PV capacity 2035
Wind onshore capacity 2015
Wind onshore capacity 2035
Wind offshore capacity 2015
Wind offshore capacity 2035
(in MW)

- The overall system optimum would lead to regionally differentiated spot market prices.
- The overall average price (after correcting for network fees and RES promotion) is lower in FB_{SQ}.
- In the system optimum additional gas plants are concentrated in the south (evenly distributed in ME_{SQ}).

➢ **Question:** How can market rules be changed such that the **market outcome** gets closer to the **overall system optimum?**

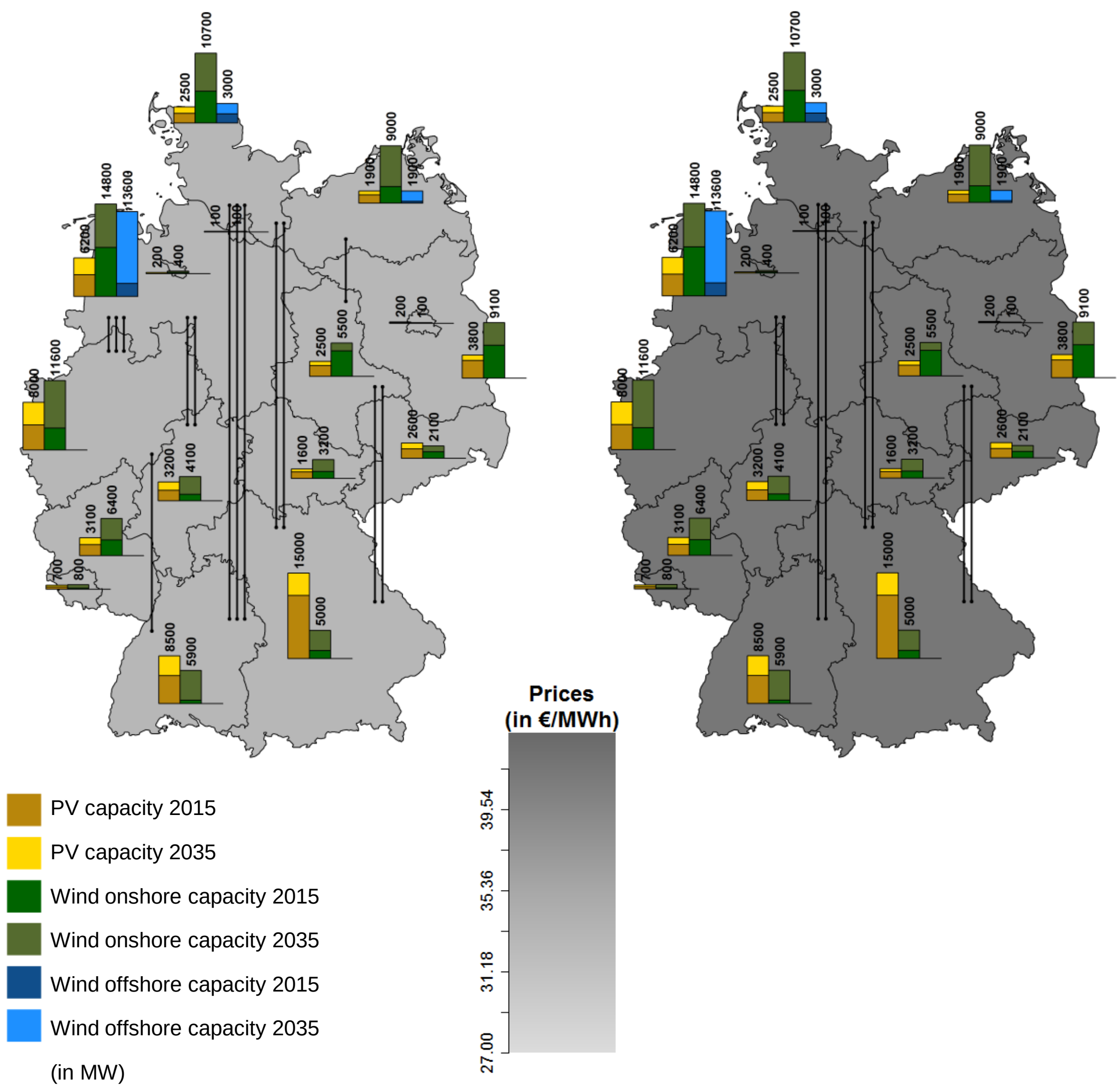
Results ME_{SQ} Results ME_{2Zones}



- We consider the introduction of **two price zones** at the spot market.
- This induces a concentration of additional gas plants in the south.
- We need less transmission lines than under the current market design.
- Corrected spot prices in the south are higher than under the current market design

➢ The introduction of two price zones increases welfare. But market outcomes are still far from the system optimum.

Results ME_{SQ} Results $ME_{RED\&RC}$



- The current practice of network planning in Germany (NEP) does not anticipate later possibilities of redispatch and feed-in management.
- If the possibility of redispatch and renewable curtailment is taken into account when planning the network, this yields significant gains and reduces network expansion.

➢ **But:** No locationally differentiated price signals! How to keep/get generation capacities in the south?

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The choice of market design seems to be absolutely essential!

	Δ W [Mio. €]	P_{AVG} [€/MWh]	Network fee [€/MWh]	Promotion of RES [€/MWh]	P_{CORR} [€/MWh]	Line Expansion [#]	Δ Gen [MW]
ME_{SQ}	0	32.83	6.39	24.97	64.19	14	4374.6
ME_{2Zones}	272.5	31.15	3.39	28.35	62.89	10	4375.3
ME_{RED}	118.1	32.83	6.17	24.97	63.97	13	4374.6
$ME_{RED\&RC}$	1315.9	41.61	5.71	14.14	61.46	8	4374.5
FB_{SQ}	612.3	32.25	2.48	26.82	61.55	8	4306.1
FB_{RC}	1566.8	41.39	2.56	15.44	59.38	5	4264.6

- If you use all efficiency potential, it is possible to save over 1.5 bn. € each year (however, not very realistic => first-best benchmark, system optimum)
- Welfare gains of 1.3 bn. € each year, **if**
  - redispatch is seen as an alternative to grid expansion and
  - optimal renewable curtailment is in operation – **otherwise not**!

Conclusion and outlook: Market design in electricity markets at FAU and EnCN

- The GATE electricity market model which has been developed at FAU and EnCN allows us:
  - to predict and quantify the potential consequences of changed market design,
  - to assess how close the obtained market outcomes are relative to the system optimum.
- Our work thus allows to analyze the impact of different proposals in the debate on electricity markets and quantify their impact.

Conclusion and outlook: Market design in electricity markets at FAU and EnCN

In the German case-study we have seen

- that the market outcome under the current market design is far from the outcome which obtains in the overall system optimum (nodal pricing) and
- that several measures might be suited to improve market efficiency, e.g.
  - the introduction of price zones which would lead to improved but far from optimal results or
  - the anticipation of redispatch and renewable curtailment for network expansion planning which is a simple but very efficient adjustment of the current market design.

Thank you for your attention!

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