

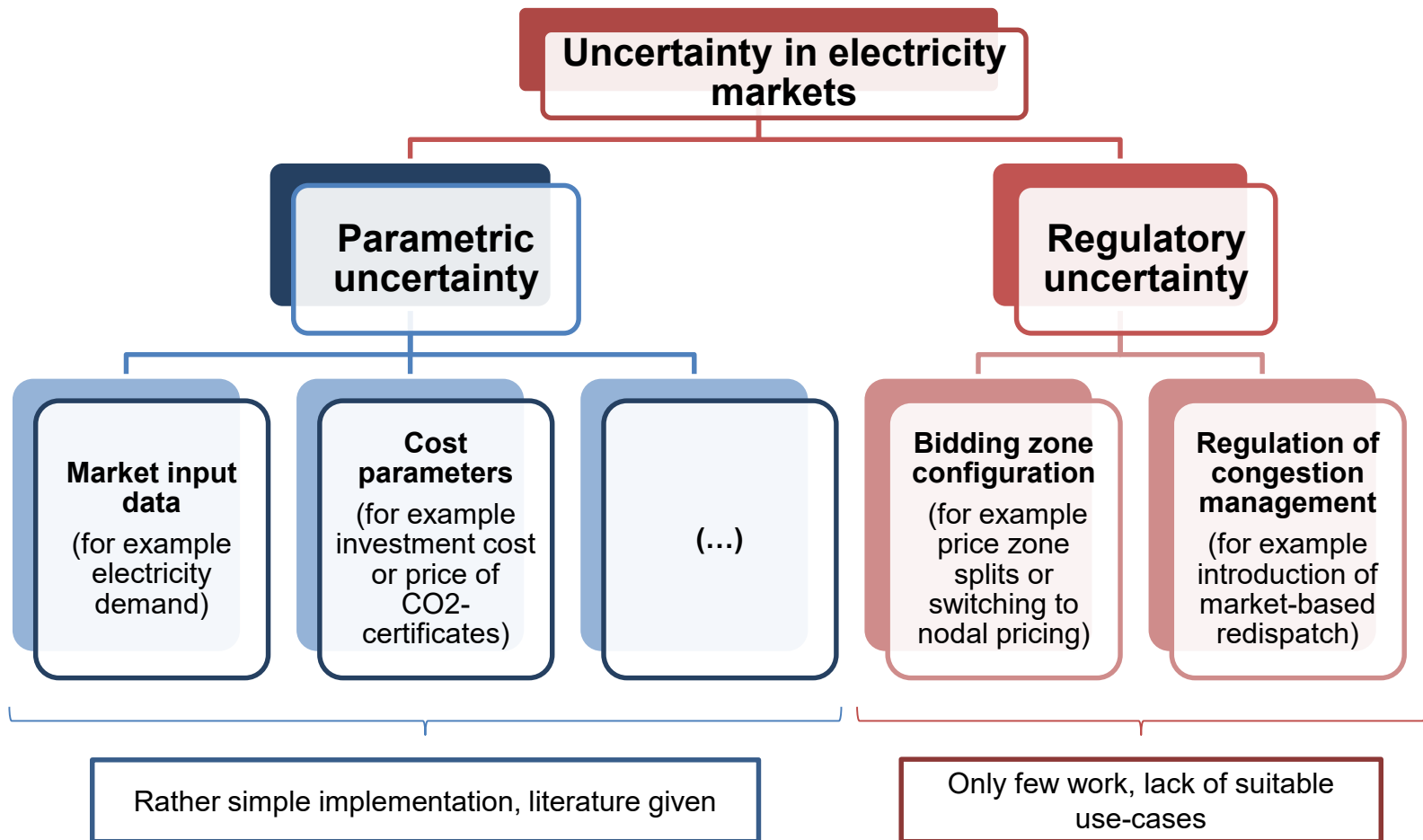
Uncertainty in Electricity Markets: The German Case

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1. Motivation

- The reduction of CO₂ emissions as a main goal of the European electricity system in the future
- Expansion of intermittent **renewable energy sources** to replace conventional generation
- Expansion of the **transmission infrastructure** necessary to utilize these renewable energy sources
- Imposing challenges for the **zonal market design** in the European countries (high congestion management needs, inefficient investment decisions)
- Inflicts different kinds of **uncertainty** on the market participants

2. The concept of uncertainty in electricity markets



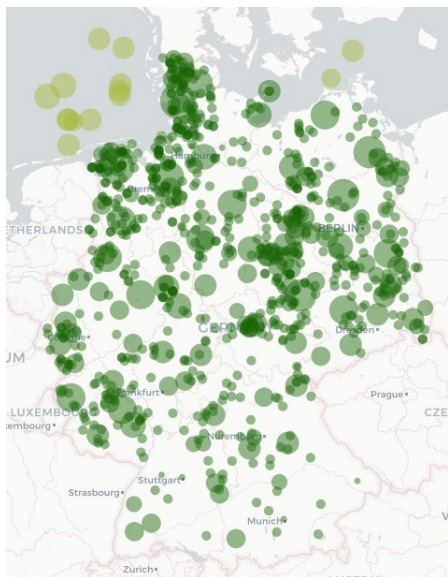
3. Literature context

- Strand of literature on applications of **parametric uncertainty** given
 - Transmission planning can be heavily influenced by parametric uncertainty [Conejo et. al. (2010)] [van der Weijde & Hobbs (2012)]
 - Generation expansion planning subject to uncertainty [Rebennack (2014)]
- Fewer work on uncertainty about regulatory settings, e.g. a potential price zone split
 - First attempt for Germany in an isolated use-case [Ambrosius et. al. (2019)]
- Connection to the discussion of **price zone reconfiguration** and nodal pricing given [Egerer et. al. (2016)] [Trepper et. al. (2015)]
- Gap in the literature: Uncertainty about the building of prizes in an **international context** (our example: The case of Germany in the European context)

4. The special case of Germany (1)

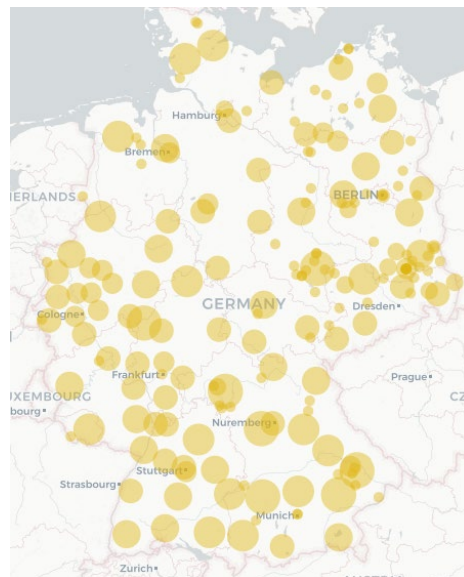
- Expansion path of renewable energy sources not equally distributed within the country:
 - High generation potential for wind energy in the northern part, large and clustered expansion in the future
 - Medium potential for solar in Germany
- Increasing **congestion** because of slow transmission expansion

Installed capacity for wind generation 2016

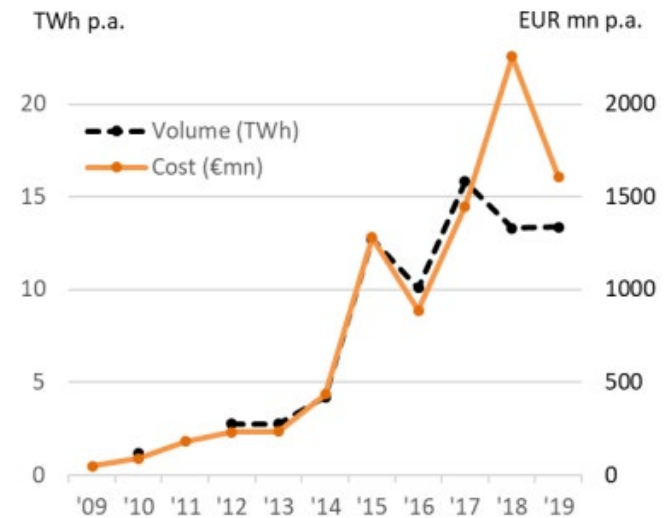


Source: <https://www.carbonbrief.org/>

Installed capacity for PV generation 2016



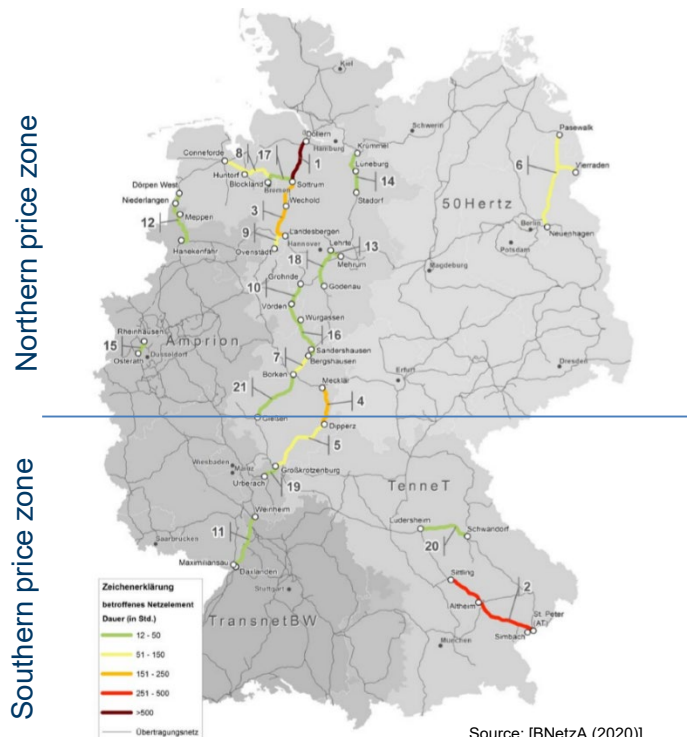
Source: <https://www.carbonbrief.org/>



Source: [Hirth & Schleich (2020)]

4. The special case of Germany (2)

- Both **duration** and **cost** of congestion management measures increasing also in the future
- Discussion about a price zone split between north and south active [Egerer et. al. (2016)] [Fraunholz et. al. (2021)]



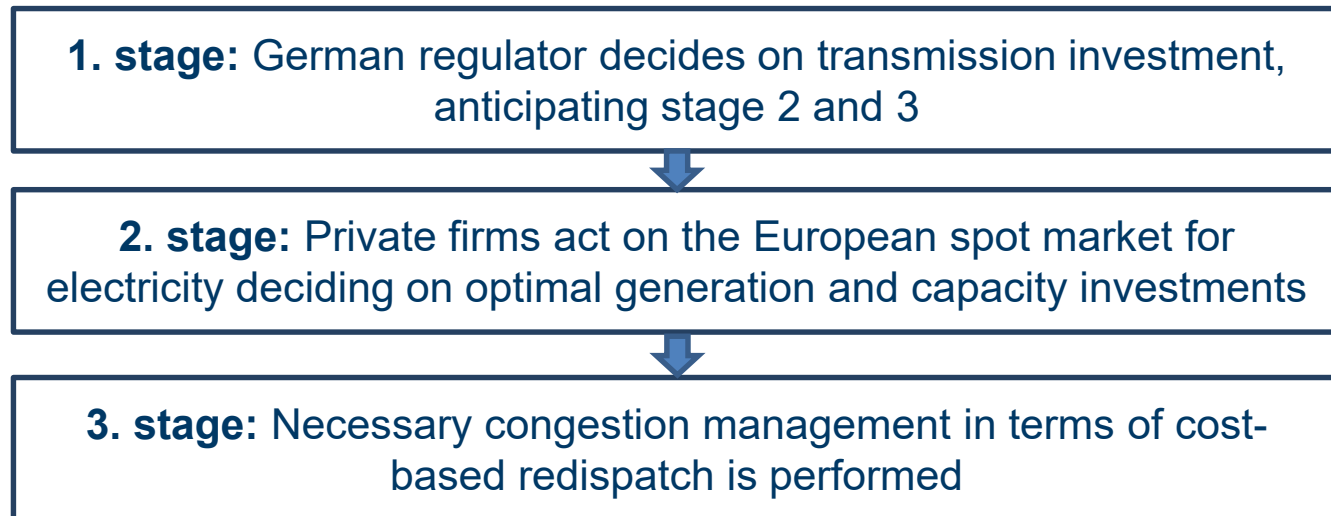
- Efficiency gains on both short-run grid operation and medium-term investment incentives expected
- Implementation of price zone split uncertain
- Even extent of price zone split towards nodal pricing uncertain

5. Research topics

- Analysis of uncertainty about a potential price zone split in Germany
 - International spot market for electricity:
 - Short-term capacity decisions about generation
 - Medium-term investment decisions in generation capacity
 - National transmission line investment
 - Short-term grid operation with congestion management
 - German centralized network planner decides on medium-term transmission investment in cost comparison to congestion management
 - Congestion management remains perfectly coordinated in Germany
- Our research complements the existing literature regarding uncertainty about a German price zone split with an international application of the day-ahead market
- How does uncertainty about a price zone split in Germany influence investments in different international contexts?

6. Solution approach

- Application of a multi-level electricity market model [Grimm et. al. (2016)] [Ambrosius et. al. (2019)]



- Reformulation into a two-staged model combining the first and third stage possible

7. Electricity market model – Concept

- Decisions are taken under uncertainty: stochastic optimization problems are created (welfare maximization / cost minimization)
- Implementation of the problems in GAMS as...
 - Linear problem for international spot market with continuous choices
 - Mixed-integer problem for transmission investment with discrete choice
- Market participants form an expectation about the German bidding zone configuration according to a probability distribution
 - Either Germany faces a price zone split [$P(k=2)$]...
 - or remains as a uniform price zone [$P(k=1)$]

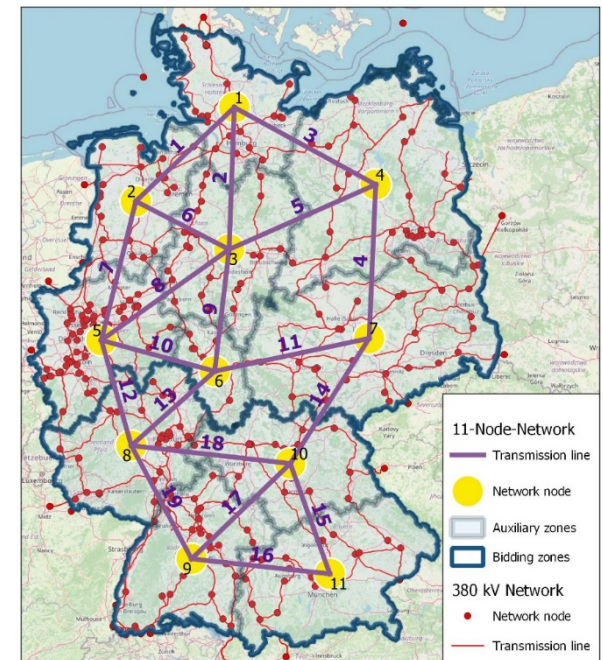
$P(k = 1)$	$P(k = 2)$
1.00	0.00
0.75	0.25
0.5	0.5
0.00	1.00

7. Electricity market model – Data input

- Electricity market data for Germany and the neighboring countries
 - Demand scenarios from ENTSO-E for 2030 and 2040 available
 - Generation status-quo for the year 2025
 - Investment candidates for gas generation
 - NTCs for the years 2030 and 2040 available

- Question on inner-German NTC:
We choose a value exogenously.

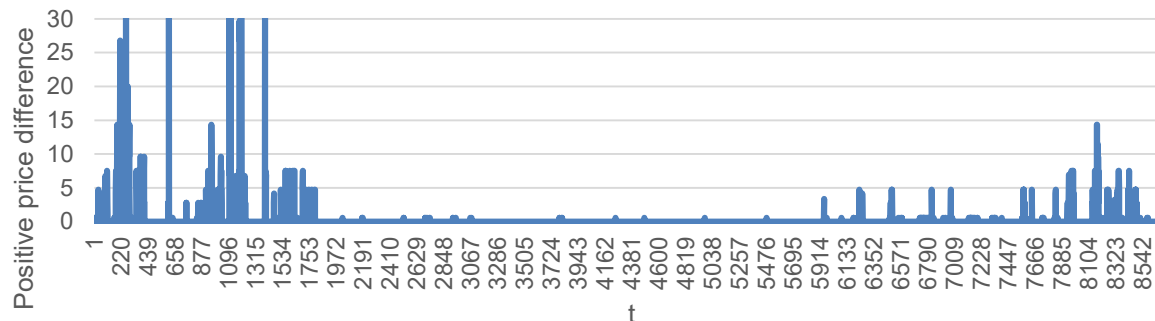
- Transmission network model for Germany
 - Dividing Germany into 11 nodes
 - Investment candidates to be reinforced
 - Aggregated grid data to connect the nodes



8. Preliminary results (1) – Price effects

- Price differences between price zones as the main incentive for generation capacity investment in price zones
- Positive price difference between the southern and northern German price zone predicted, when wind generation is dominant

Hourly Price Differences between Z=2 and Z=1, for price zone split

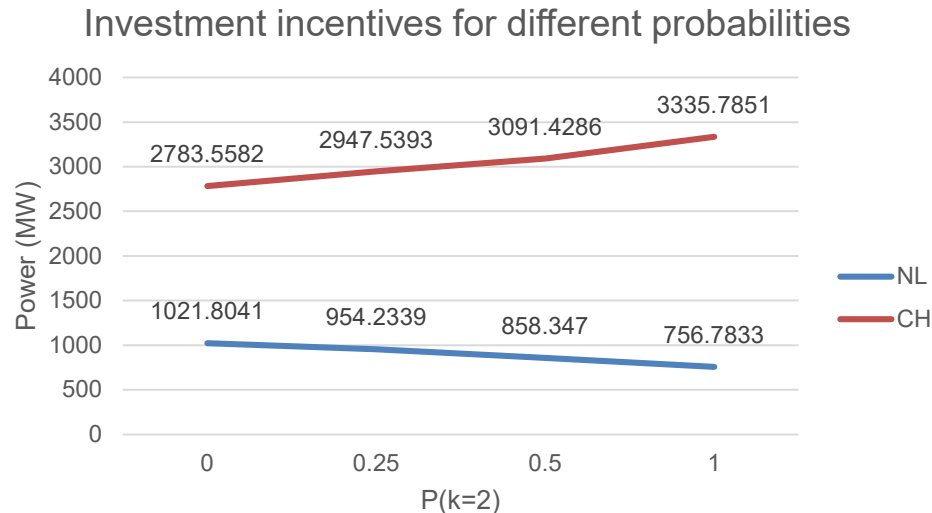


- Countries with connection to the potential southern German price zone should face additional investment incentive in generation capacity
- This influences line investments in the German grid

8. Preliminary results (2) – Generation investment results

• Example: Switzerland and the Netherlands

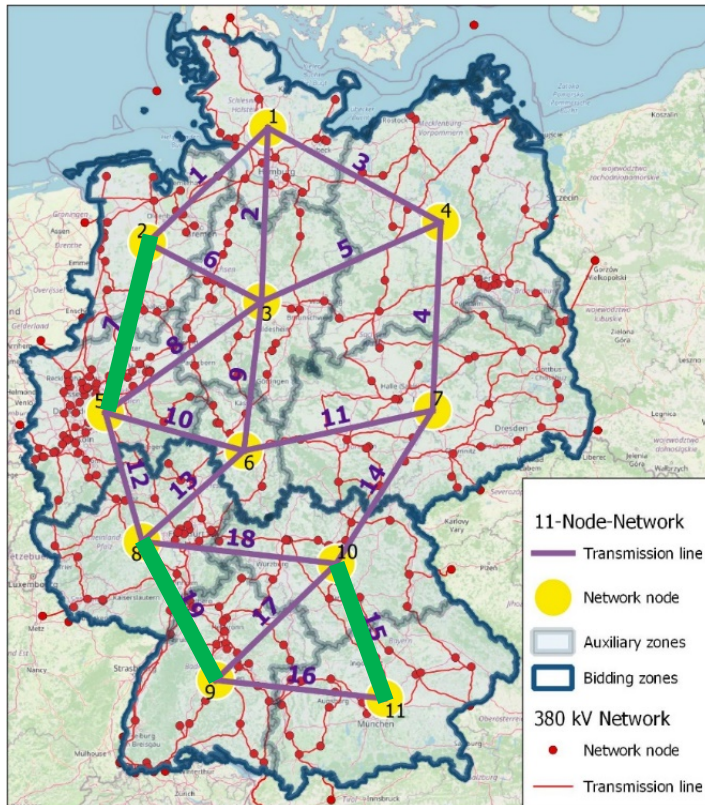
- Switzerland has connections exclusively to the potential southern German zone
- The Netherlands have connections exclusively to the potential northern zone



- The more likely a price zone split in Germany is estimated, the more the investment incentives in neighboring market change
- Investment incentives are not the same for each country!
(Composition of multiple factors relevant, e.g. demand / RES)
- Side note: Nearly no endogenous investment calculated in Germany

8. Preliminary results (3) – German line investment

- Uncertainty also changes optimal grid expansion in a national electricity system (here: Germany)
- Redispatch is assumed to be handled in perfect coordination between the northern and southern potential prize zones



- For a low probability of a prize zone split, lines 7, 15 and 19 are reinforced multiple times (green)
- For higher probabilities, only 7 and 19 remain relevant for reinforcement
- Reason: Trade flows affect optimal line investments in Germany (in composition with demand and generation)

9. Conclusion

- Results underline the importance of considering uncertainty
- The mere anticipation of one price zone split can lead to alternating investment incentives in the European electricity system consisting of price zones
- National optimal transmission investment might be influenced by this uncertainty
- Uncertainty cannot be used as a policy tool, however. Expectations and realization cannot diverge in the long-run!
- Future work can consider uncertainty about market parameters simultaneously to regulatory uncertainty, especially when it comes to 2040 scenarios of ENTSO-E
- Reference results for nodal pricing can be used as a measure for investment efficiency

Thank you for your attention!



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