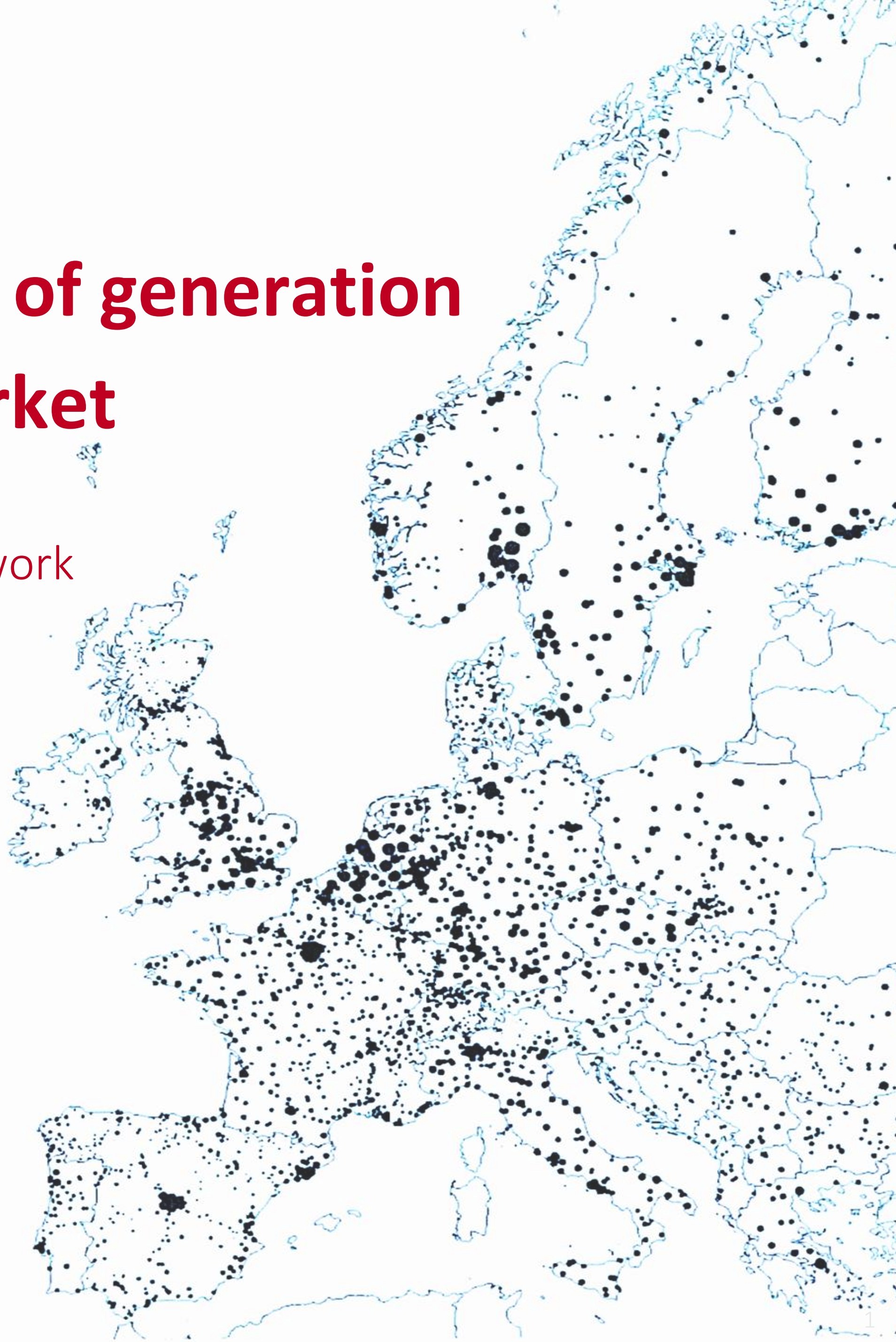
Cost-optimal placement of generation in a zonal electricity market

A bilevel model of location-specific network charges

Anselm Eicke

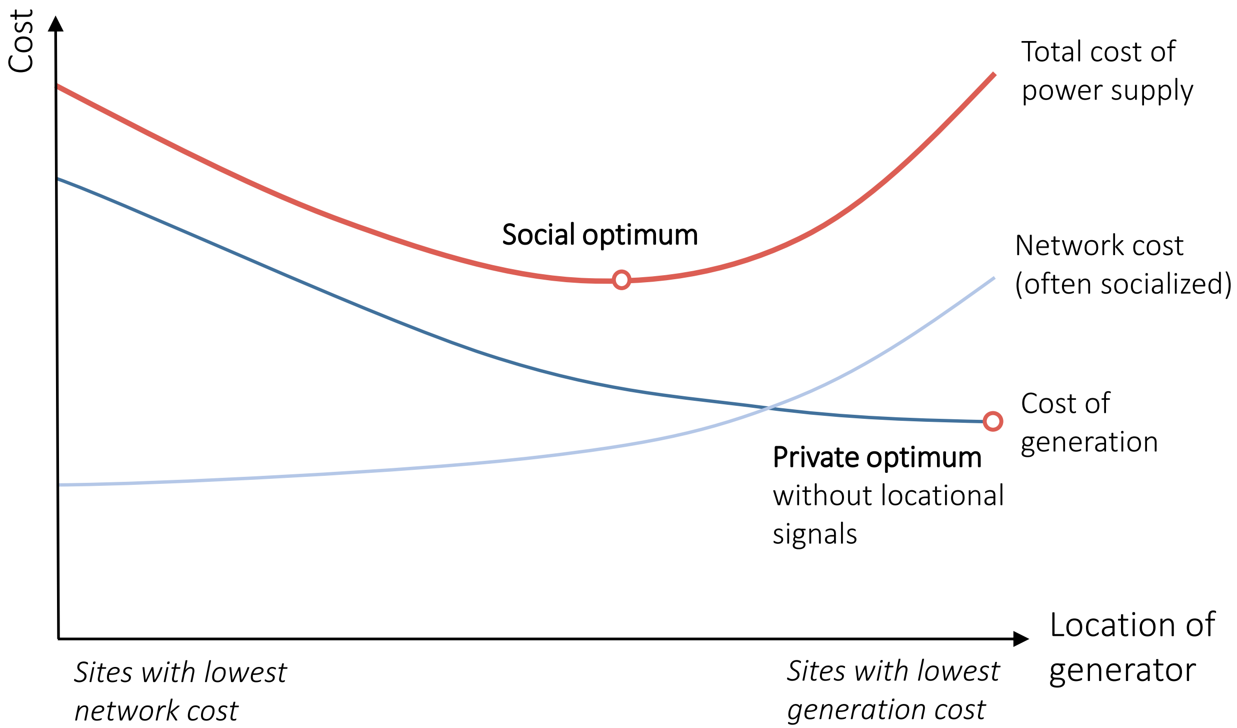


Hertie School

KOPERNIKUS Ariadne PROJEKTE
Die Zukunft unserer Energie

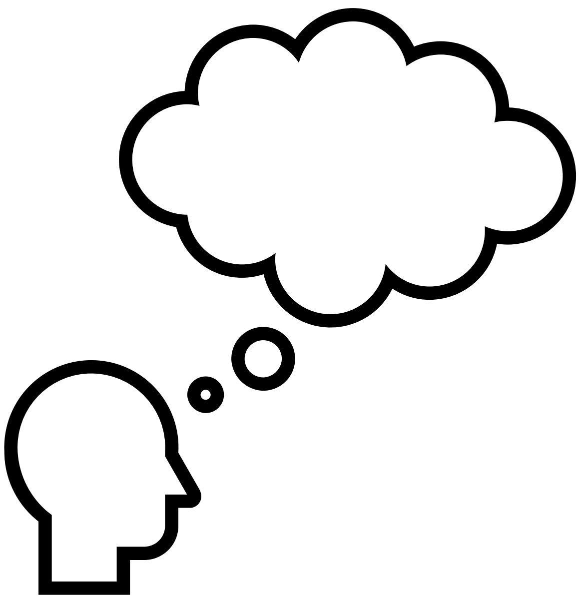
Trade-off between the cost of power generation and transmission

In many systems, the cost of power generation is lowest at remote sites that result in high network costs



When grid costs are internalized to generators, the private optimum equals the social optimum

Research questions and methodological challenge



Research questions

- How to determine the welfare maximizing distribution of generation capacity in a zonal market?
- How to determine the locational signal that leads to this distribution?

Methodological challenge

- *Zonal system models* do to not account for network costs
- *Nodal system models* account for network costs but their dispatch differs from zonal markets. Is the optimal generation distribution of a nodal market also optimal for a zonal market? If not, how to obtain the latter?

Two perspectives on cost-minimizing locational signals

Internalization of network cost

- Estimate the effect of each generator on network costs (Cost-causality)
- Internalizing these costs leads to cost-minimizing distribution of generation

➢ This approach is used to calculate charges in practice

➢ Estimation of long-run equilibrium only iteratively possible

Signal that minimizes system cost

- Chose locational price signals for generators that minimize the total system costs
- Can be extended to maximize welfare:

Welfare = Gross consumer surplus – generation, network, and redispatch costs

➢ Approach applied in this contribution

➢ Allows estimation for all technologies and all locations within a single model

Methodology: Welfare maximizing signal as a Stackelberg game

Outer Problem (Regulator)

Chose the locational signal that minimizes system costs (including transmission)

Inner problem (Generator)

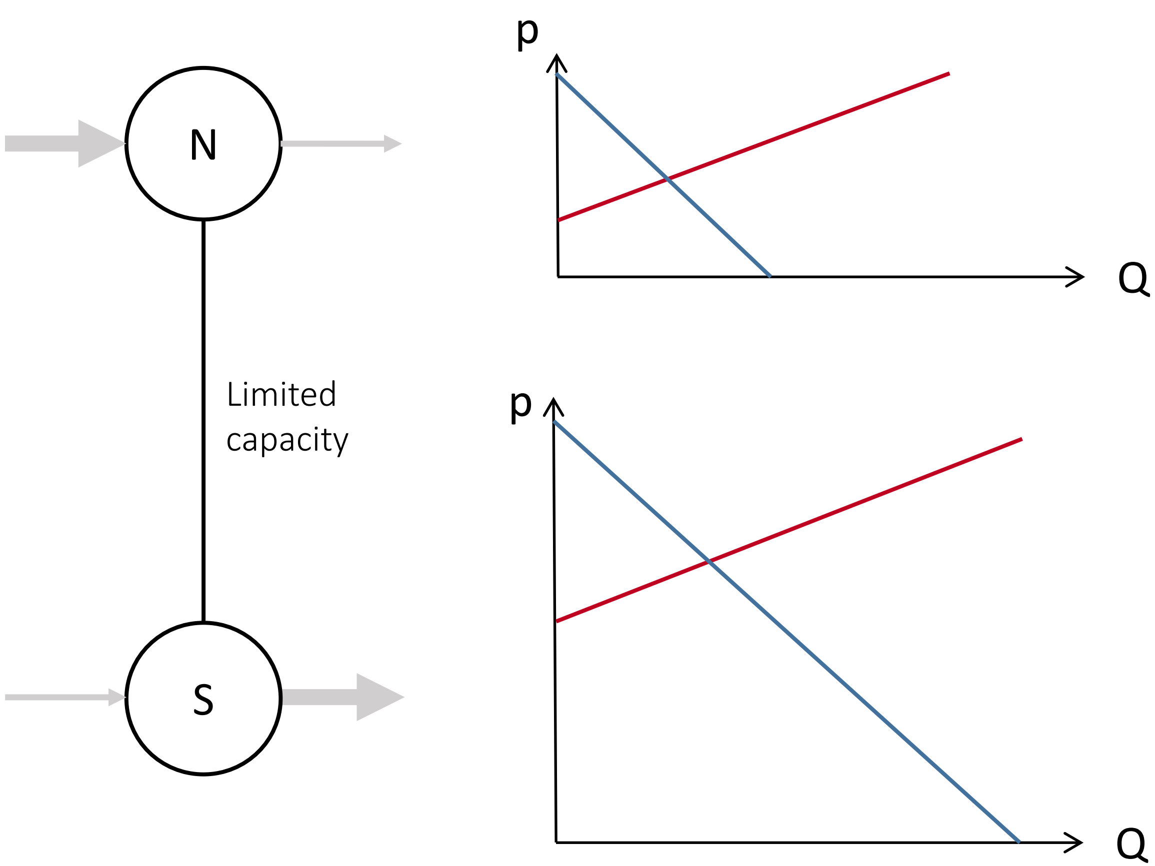
For a given locational signal within a uniform pricing zone, minimize the cost of power supply (excluding transmission) by choosing the mix and distribution of generation technologies

This Stackelberg game can be solved mathematically as a bilevel model (MPEC)

Analytical example

Setup for analytical example (single timestep)

Two locations N(orth) and S(outh) within a power system

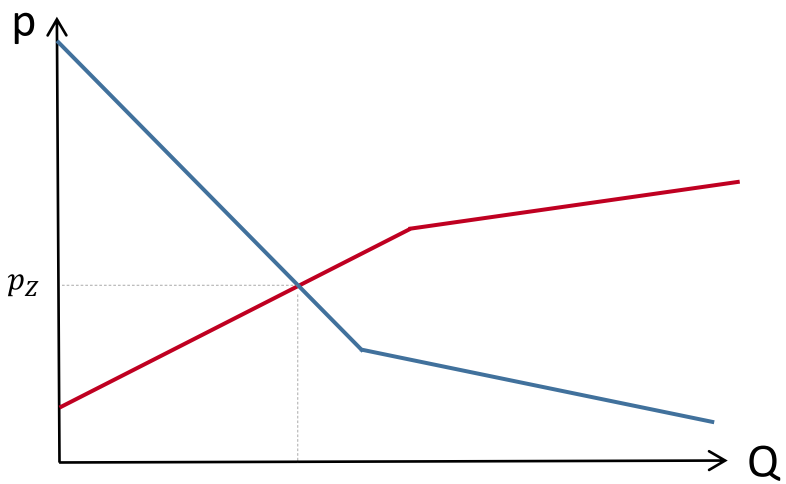


North is a region with lower demand and higher RE potential

South is a region with higher demand and lower RE potential

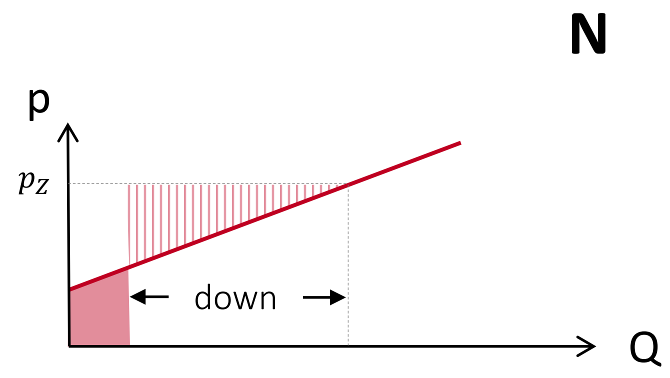
Zonal electricity market

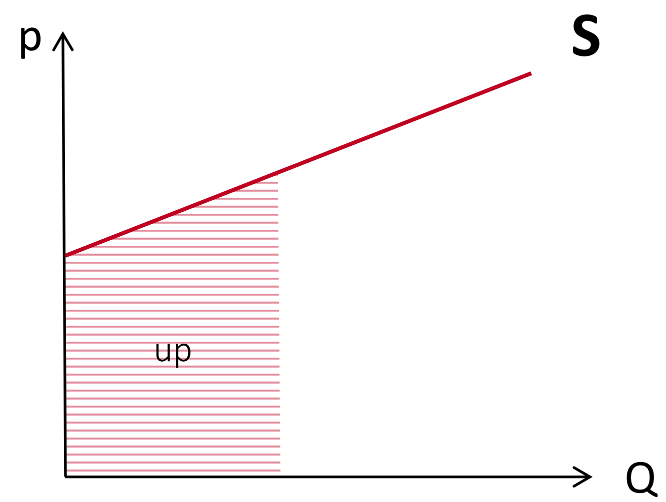
Market: Joint merit order curve



- In a uniform market, supply and demand respond to the same price
- Market-dispatched supply in N is higher than what can be transmitted, and redispatch becomes necessary

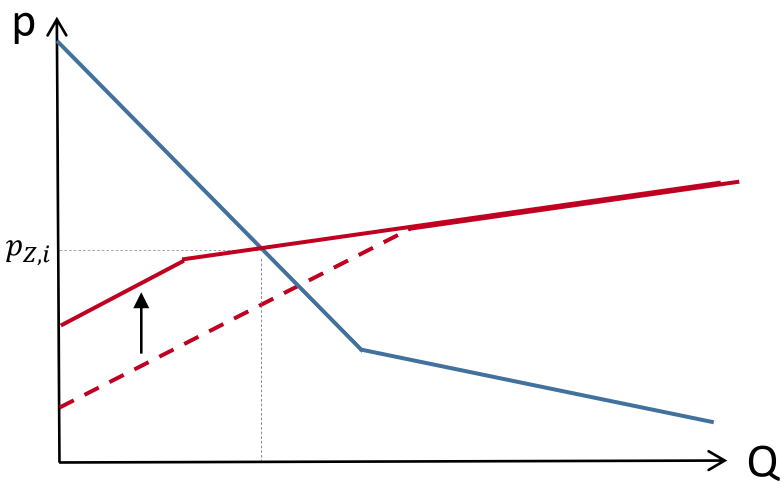
Network: Redispatch of generation





Zonal market design with revenue-neutral locational signals

Market: Joint merit order curve

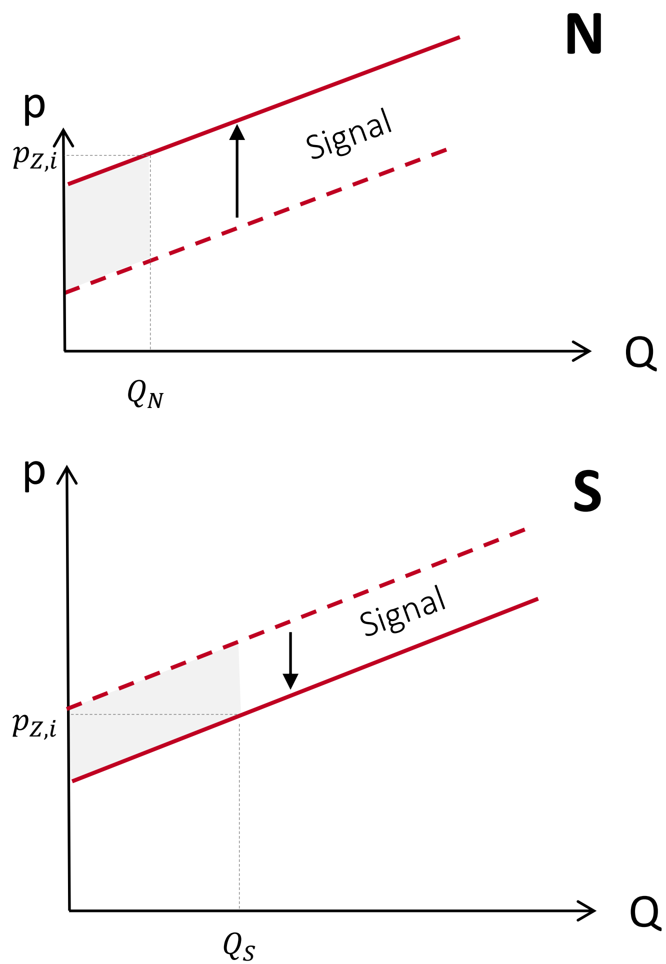


- In this static example, a revenue-neutral locational signal eliminates the need for redispatch:

$$I_N \cdot Q_N = I_S \cdot Q_S$$

- Compared to the reference case, the instrument drives up the electricity price

Locational signal



Simplifications in this example

Single timestep

- No time-patterns in costs and availabilities
- Locational instrument can eliminate the need for redispatch
- No differentiation between investment and operation cost

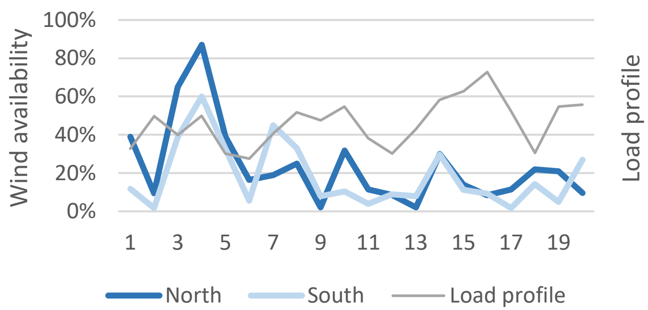
Fixed network capacity

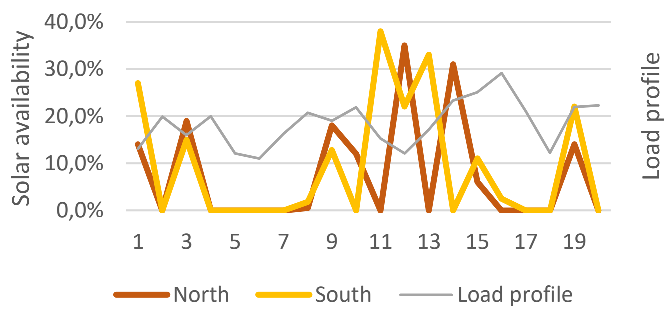
- Estimated signal is a short-run signal

Numerical example

Model extension

- Four generation technologies: Wind, Solar, OCGT and CCGT, 20 timesteps
- Variability of RES availability



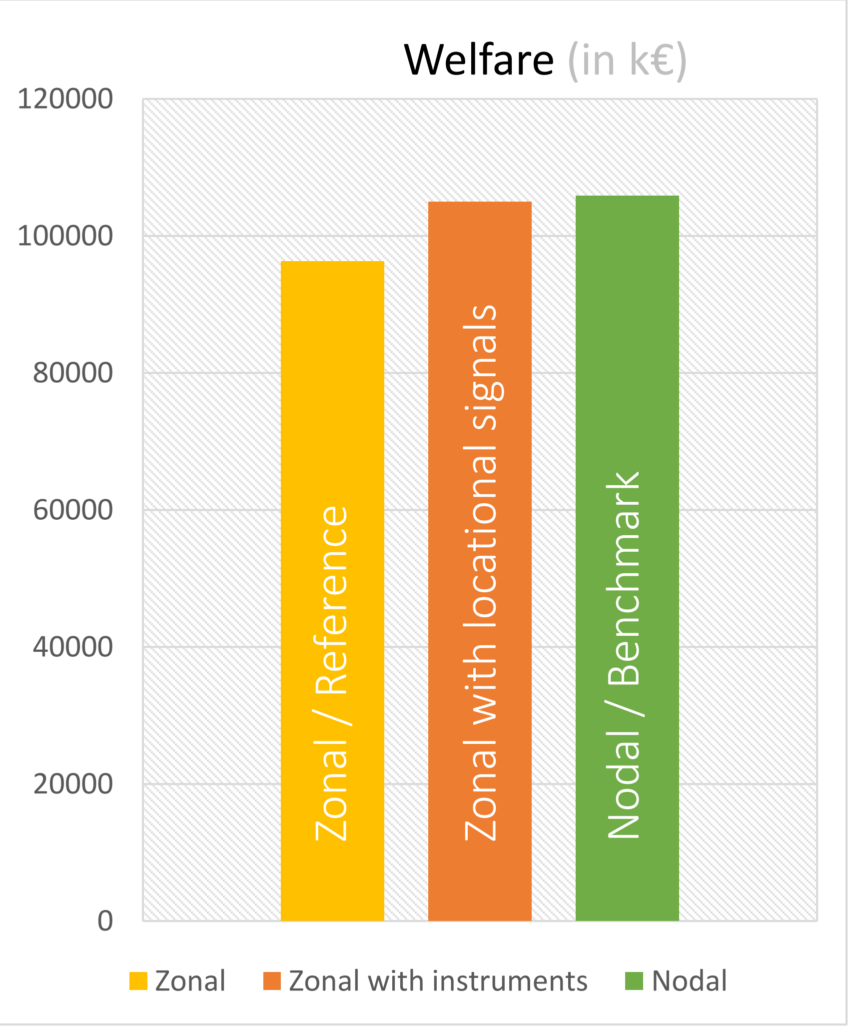


CF	Wind	Solar
North	24%	8%
South	18%	11%

- Same profile of demand in both locations but magnitude is two times higher in South
- Increasing investment cost by locational and by technology to reflect diminishing profitability of sites
- Endogenous network investment

Model results: Welfare and cost analysis

- Locational signals **increase welfare by nearly 9.1%** compared to the scenario without locational signals
- This improvement **gets close to the additional welfare improvement of a nodal market** (10% compared to zonal without instruments)
- Locational signals **reduce network costs by about 90%** but lead to slightly higher generation costs of 3%
- Also with locational signals, **zonal markets lack adequate dispatch incentives and local incentives for demand flexibility**. This seems to be less relevant compared to investment signal



Model results: Technology-specific signals

- The optimal locational instrument is not only location-specific but also technology-specific

- Due to the different generation profiles, some technologies result in higher network costs than others, which is reflected in the diverging level of charges.

All in €/MW per 20h	Signal north	Signal south	C_{fix}
CCGT	-23 (-8%)	-22 (-7%)	292
OCGT	n/a	-79 (-68%)	116
Onshore wind	37 (+17%)	-9 (-4%)	215
Solar	n/a	7 (+5%)	137

Model results: RES shares

- Instrument strongly increases share of RES in generation mix (after curtailment)
- Possible reasons:
  - Better siting of conventional generation
  - Less curtailment and upward dispatch

Installed capacity (GW)	**Zonal**		**Zonal with signal**		**Nodal**	
	north	south	north	south	north	south
CCGT	20	20	15	23	14	23
OCGT		(5)		1		
Onshore wind	90		31	69	35	68
Solar		38		70		72
RES share (% of generation)	46 %		56 %		57 %	

Summary and contributions

Methodology contribution

- Novel modelling approach for estimating the long-run effect of locational signals in zonal power markets
- Formulation as a bilevel model

Insights on locational signals

- Non-representatitive examples indicate a high benefit of locational signals in zonal markets
- Locational signals typically differ between location and between technology: this is not always the case in practice
- Estimation is an upper bound for the benefit of locational price signals

Thank you for your attention

Our open access article in The Energy Journal has more on locational instruments:
Locational Investment Signals: How to Steer the Siting of New Generation Capacity in Power Systems?

Contact
Anselm Eicke
eicke@hertie-school.org

Hertie School

KOPERNIKUS PROJEKTE
Ariadne
Die Zukunft unserer Energie