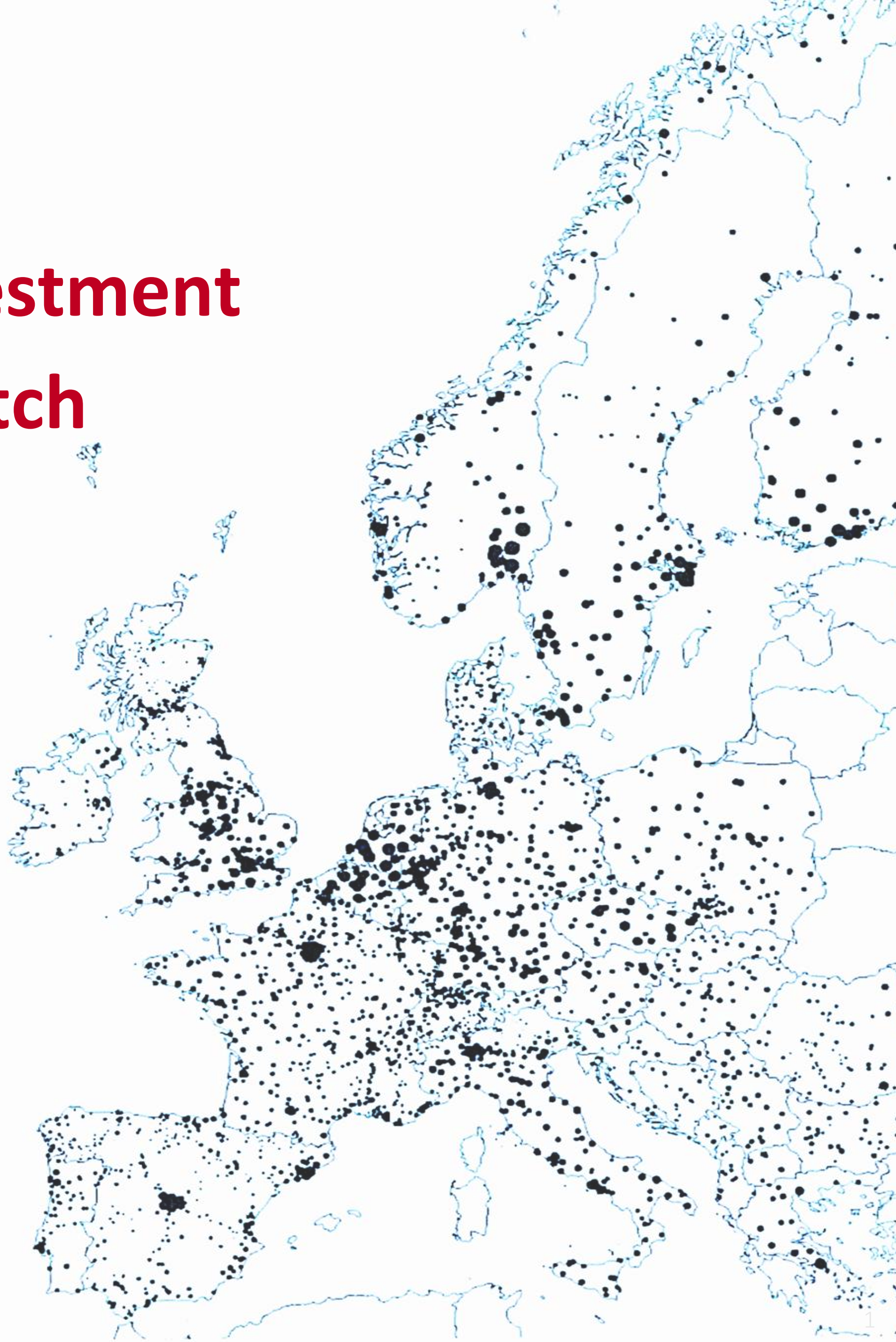
Optimal generation investment under suboptimal dispatch

A bilevel equilibrium model of optimal investment incentives in zonal markets

Anselm Eicke

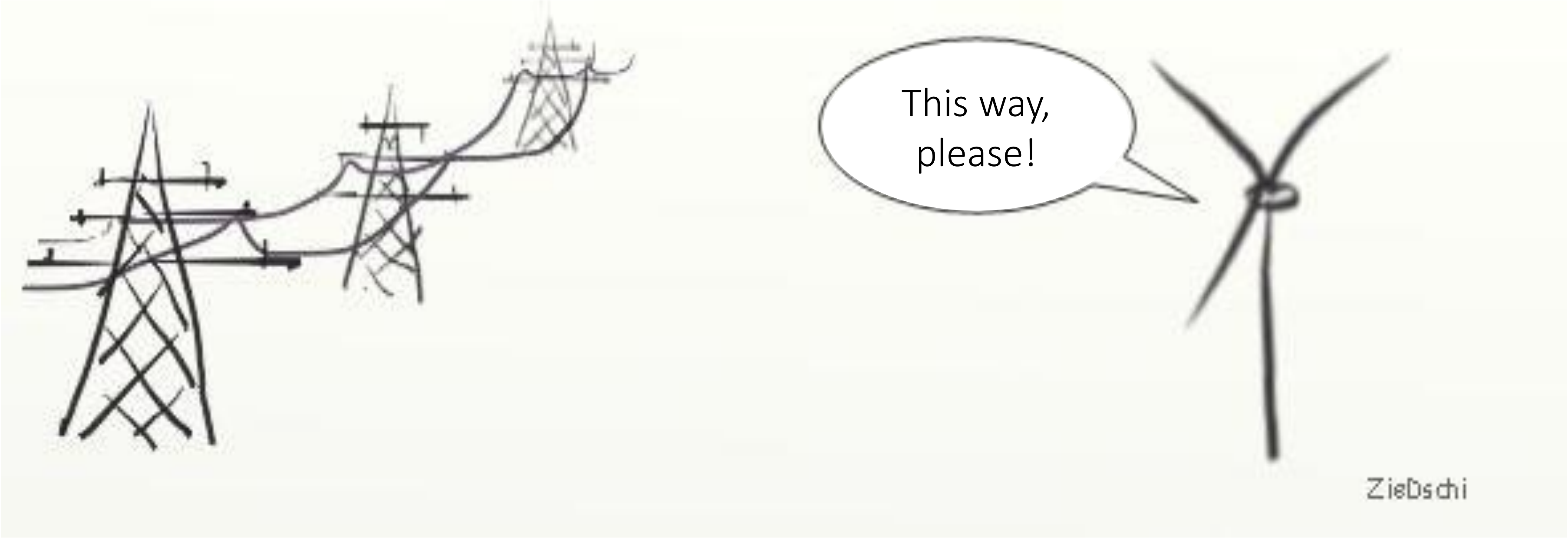


Hertie School

KOPERNIKUS PROJEKTE
Ariadne
Die Zukunft unserer Energie

Where to place new generators?

- In many systems, the cost of power generation is lowest at sites with high network costs
- Trade-off between the cost of power generation and transmission
- Economic approach: the internalization of network costs leads to efficient investment signals for generators and consumers



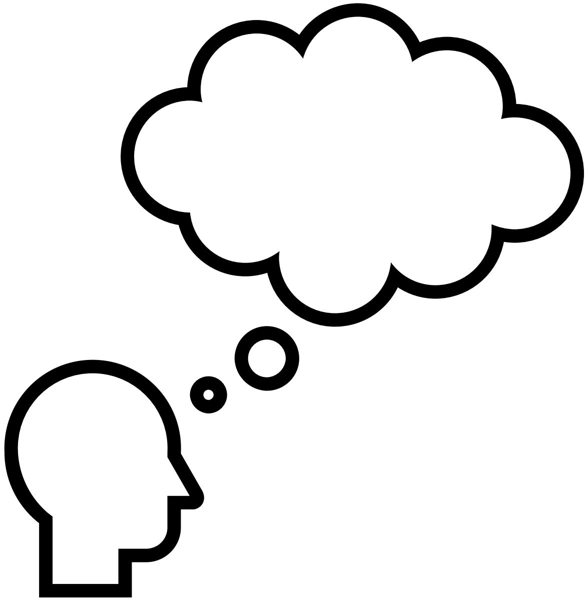
Locational incentives: power market and extra instruments

Locational granularity of the power market →

Additional instruments outside and on top of the power market	Large zone	Small zones	Nodal Pricing
Deep grid connection charges			
Grid usage charges			
Support schemes for renewable energy			
Capacity mechanisms			

Can be combined
(with each other and with power market design)

Research questions



Research questions

1. What is the welfare-optimal distribution of generators given the suboptimal dispatch incentives of a zonal market?

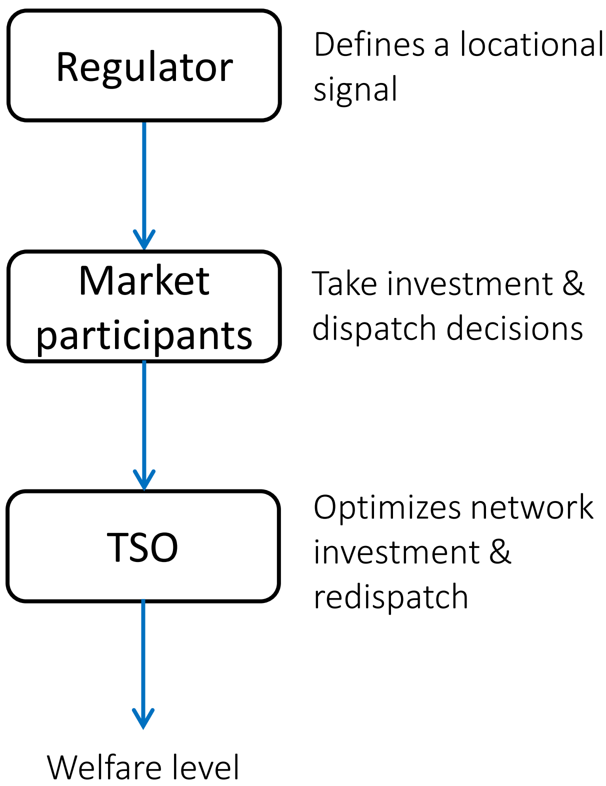
2. How must location-specific price signals be designed to lead to this distribution?

Methodological challenge

- *Zonal system models* do to not account for network costs
- *Nodal system models* account for network costs but their dispatch and price sensitive electricity demand differs from the one in zonal markets.

Model formulation

Stackelberg game of regulator and market participants



Outer Problem: Regulator / TSO (Leader)

Objective: Welfare maximization

Spatial resolution: Subzones / nodes

Main decision variables:

- Locational signal (per technology and per node)
- Network investment
- Redispatch

Inner problem: Market participants (Follower)

Objective: Profit maximization

Spatial resolution: Bidding zone

Main decision variables:

- Investment and dispatch decisions
- Level of electricity consumption

Mathematical solution strategy

Outer Problem: Regulator (Leader)

Objective: Welfare maximization

Spatial resolution: Subzones / nodes

Main decision variables:

- Locational signal (per technology and per node)
- Network investment
- Redispatch

Inner problem: Market participants (Follower)

Objective: Profit maximization

Spatial resolution: Bidding zone

Main decision variables:

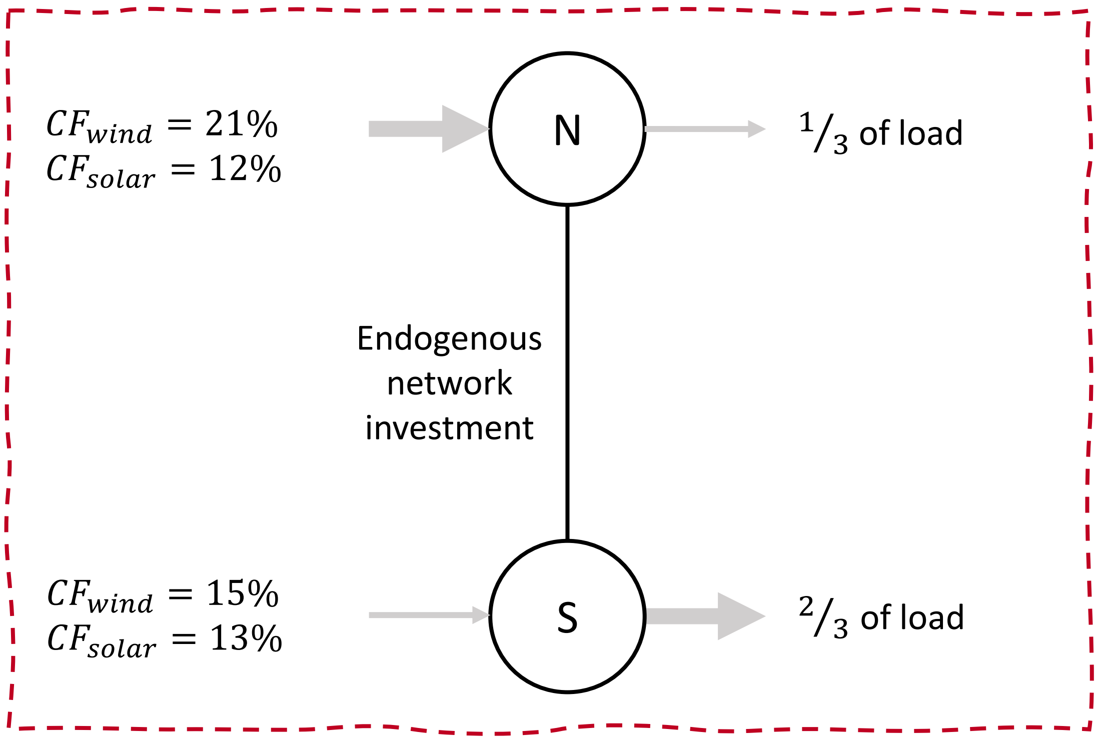
- Investment and dispatch decisions
- Level of electricity consumption

1. Replace the inner problem by its optimality conditions (KKT) → resulting model is a (non-linear) MPEC
2. Linearize complementarity conditions with big-M approach
3. Relax non-linearity in SWF: $R_{t,z,n}^{down} \cdot (\lambda_t - c_{z,n}^{var})$ → the resulting model is a MIQP
4. Use the starting points from the MIQP to (hopefully) find the global optimum of the MPEC

Numerical example

Model setup: Generation and demand

Uniform pricing zone



- 48 timesteps with availability of wind and solar
- Short-term price-elasticity of demand: -0.25

Model setup: Costs

	c^{var}	c^{fix}
	€/MWh	€/ kW per a
Base	55	95
Peak	80	32
Onshore wind	-	85
Solar	-	50

Generation costs:

$$\sum_{tec,n}\left(P_{tec,n}\cdot c_{tec,n}^{fix}+P_{tec,n}^{2}\cdot m_{C}\right)$$
$$+\sum_{t,tec,n}\left(G_{t,tec,n}\cdot c_{tec,n}^{en}+G_{t,tec,n}^{2}\cdot m_{G}\right)$$

- Linearly increasing marginal capacity costs account for a reduced profitability of sites at increasing deployment
- These increasing capacity costs enable a locational steering through price signals

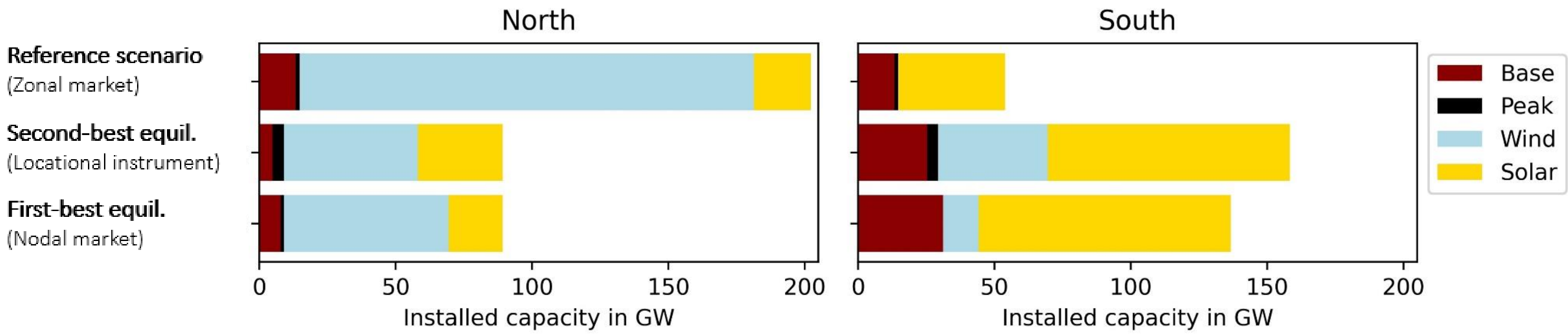
Model results

Model results: Cost and welfare analysis

- Locational signals **increase welfare by about 5 %** compared to a zonal market without locational signals
- This is a significant part of **the benefits of a nodal market** featuring a **welfare improvement of 9 %** compared to a zonal market.
- Locational signals **strongly reduce network costs** but lead to slightly higher generation costs. The signals also increase electricity prices and therefore lower the consumer surplus
- Even with locational signals, **zonal markets lack adequate dispatch incentives and local incentives for demand flexibility**

Costs and Welfare (in M€)	Network cost	Generation cost	Gross consumer surplus	Welfare
Reference scenario (Zonal market)	80	308	1,000	614
Second-best equil. (Locational instrument)	8	324	990	648
First-best equil. (Nodal market)	4	328	998	668

Model results: Placement of generators



- The welfare-maximising regional distribution of generators and the capacity mix differs by market design
- Compared to the nodal benchmark, additional redispatch costs in zonal markets make a siting of generators closer to demand centers more attractive
- Locational signals in zonal markets (both for generation and demand) cannot be calculated with a nodal model – a bilevel model is required instead

Model results: Welfare-optimal locational signals

- The optimal locational signal is both **location- and technology-specific**
- The estimated locational signal is an indicator for the **network costs of each technology under zonal dispatch.** Driven by generation profiles, some technologies result in higher network costs than others.
- Some technologies even feature a negative locational signal
- The locational signals are specific for a power system

	North		South		$\mathbf{C_{fix}}$
	Signal (€/kW)	Share of C_{fix} (%)	Signal (€/kW)	Share of C_{fix} (%)	(€/kW)
base	206 €	40%	187 €	36%	521 €
peak	20 €	11%	21 €	12%	175 €
solar	7 €	3%	12 €	5%	274 €
wind	181 €	39%	-17 €	-4%	466 €

Summary and policy recommendations

- The numerical example indicates a significant cost-saving potential of locational signals in zonal markets
- Optimal locational signals differ between locations and technologies. This is not the case in most real-world instruments
- Model results are an upper bound for the welfare gains – locational signals will remain imperfect in practice due to limited data availability and foresight.
- But even imperfect signals are likely to outperform a setting without any locational incentives
- The welfare-optimal placement of generators in a zonal market differs from the nodal market outcome – a bilevel model is thus required

Thank you for your attention

More on locational instruments in our OA article:
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