Market Design for Renewable Energy Auctions: An Analysis of Alternative Auction Designs

Martin Bichler, Veronika Grimm, **Sandra Kretschmer**, Paul Sutterer

8 June 2021

FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
FACHBEREICH WIRTSCHAFTS-
WISSENSCHAFTEN

ENERGIE
CAMPUS
NÜRNBERG

ONSHORE WIND ENERGY IN GERMANY

- Since 2017, capacities and feed-in premiums (FIPs) for renewable energy source (RES) plants determined in auctions
- Onshore wind energy as capacity-wise largest renewable energy technology
- Imbalanced distribution of capacity:
    - 58% Northern Germany
    - 32 % Middle Germany
    - 10% Southern Germany

→ High cost for transmission line investment and redispatch (€ 1.5 bn in 2017)

→ System optimal allocation with estimated savings of € 2.6 bn p.a. (Grimm et al. 2017)

Awarded capacity in German onshore wind auctions

ONSHORE WIND ENERGY IN GERMANY

- Since 2017, capacities and feed-in premiums (FIPs) for renewable energy source (RES) plants determined in auctions
- Onshore wind energy as capacity-wise largest renewable energy technology
- Imbalanced distribution of capacity:
  - 58% Northern Germany
  - 32 % Middle Germany
  - 10% Southern Germany

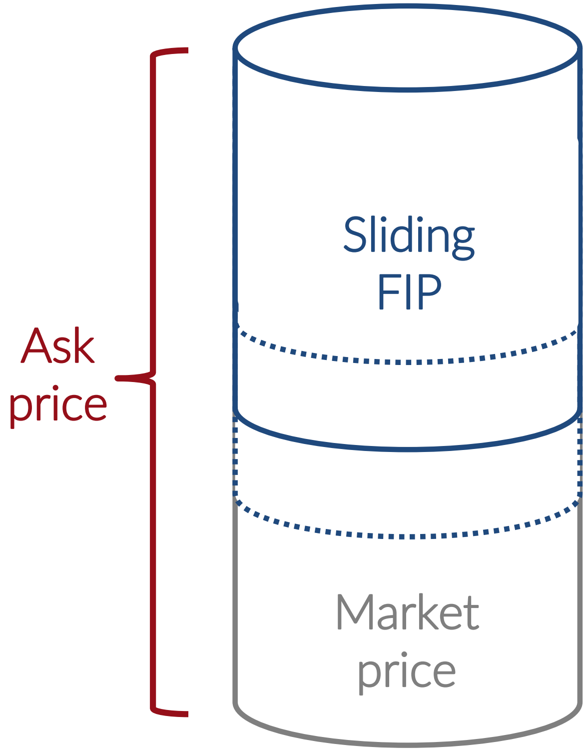
→ High cost for transmission line investment and redispatch (€ 1.5 bn in 2017)

→ System optimal allocation with estimated savings of € 2.6 bn p.a. (Grimm et al. 2017)

Awarded capacity in German onshore wind auctions

ONSHORE WIND AUCTIONS IN GERMANY

- 4 auctions per year (+ special tenders)
- Two types of bidders: institutional and BEG
- Pay-as-bid (institutional) and uniform price (BEG) sealed-bid auction
- Energy-related remuneration (capacity is tendered, electricity is remunerated)
- Sliding FIP in ct/kWh for 20 years



Reference yield model (REM)

- Definition of reference site
- Comparison of expected electricity production at actual and reference site → site quality
- FIP adjusted according to site quality

→ Disregards load proximity, network congestions, redispatch etc.

→ Inefficient allocation and remuneration

RESEARCH QUESTIONS

- Imbalanced capacity distribution (North vs. South)
- REM sets inefficient incentives
- System optimal capacity allocation can generate welfare gains up to € 2.6 bn p.a.

RESEARCH QUESTIONS

- Imbalanced capacity distribution (North vs. South)
- REM sets inefficient incentives
- System optimal capacity allocation can generate welfare gains up to € 2.6 bn p.a.

1 | Can minor adjustments to the existing auction design lead to an improved regional distribution of generation capacity?

2 | How do these affect the resulting allocation, remuneration (FIPs) and bidder diversity?

RESEARCH QUESTIONS

- Imbalanced capacity distribution (North vs. South)
- REM sets inefficient incentives
- System optimal capacity allocation can generate welfare gains up to € 2.6 bn p.a.

1 | Can minor adjustments to the existing auction design lead to an improved regional distribution of generation capacity?

2 | How do these affect the resulting allocation, remuneration (FIPs) and bidder diversity?

→ Simulate different auction designs

→ Compare resulting allocation quality, remuneration and bidder diversity

ANALYSED AUCTION DESIGNS

National - *benchmark*

- Four auctions p.a.
- Bids contain ask price b_j and capacity y_j for project j
- Bids sorted in ascending order by ask price b_j
- Bids accepted until tendered capacity D is reached
- Winning institutional bidders receive their ask price per kWh *(pay-as-bid)*
- Winning BEG receive remuneration per kWh of highest accepted bid *(uniform price)*

National REM – *Status quo*

- Like National
- \+ Bids placed according to REM for reference site
- \+ Remuneration per kWh adjusted according to relative site quality

Regional

- One auction p.a. in each German state
- Simultaneous
- System-optimal capacity according to Grimm et al. (2017) tendered in each state
- Within each region auction design like *National*

Combinatorial

- One auction p.a.
- Allows package bids
- BEG are local, only place bids in their region
- System-optimal target capacities in each state according to Grimm et al. (2017)
- Bids awarded such that allocation is as efficient and subsidy-minimising as possible

ANALYSED AUCTION DESIGNS

ENERGIE CAMPUS NÜRNBERG

FAU

National - *benchmark*

- Four auctions p.a.
- Bids contain ask price b_j and capacity y_j for project j
- Bids sorted in ascending order by ask price b_j
- Bids accepted until tendered capacity D is reached
- Winning institutional bidders receive their ask price per kWh *(pay-as-bid)*
- Winning BEG receive remuneration per kWh of highest accepted bid *(uniform price)*

National REM – *Status quo*

- Like National
- \+ Bids placed according to REM for reference site
- \+ Remuneration per kWh adjusted according to relative site quality

Regional

- One auction p.a. in each German state
- Simultaneous
- System-optimal capacity according to Grimm et al. (2017) tendered in each state
- Within each region auction design like *National*

Combinatorial

- One auction p.a.
- Allows package bids
- BEG are local, only place bids in their region
- System-optimal target capacities in each state according to Grimm et al. (2017)
- Bids awarded such that allocation is as efficient and subsidy-minimising as possible

ENERGIE CAMPUS NÜRNBERG

DATA AND EXPERIMENTAL DESIGN

FAU

- Installed and planned onshore wind capacity (Deutsche WindGuard, 2018; Grimm et al. 2017, ÜNB, 2017)
- Regional differences in site quality (Bundesverband WindEnergie, 2012)
- Spatially differentiated plant configurations and investment costs for wind power plants (Prognos, 2013)
- Hourly wind power generation in kWh/kW (Prognos, 2016)
- Reference yield per installed kW (FGW, 2017)

Numerical experiment analysing one year

National, National REM, Regional, Combinatorial auction design

Compare w.r.t. allocation of generation capacity, remuneration and bidder diversity

AUCTION MODEL

→ Submit: ask price (b_j), capacity (y_j), site quality factor (q_j)

National, National REM, Regional

1. Sort bids ascending by b_j
2. Assign bids to winning set W until $\sum_{j \in W} y_j \geq D$ (tendered capacity)
3a. Institutional bidders receive FIP $p_j = b_j \, q_j$
3b. BEG bidders receive FIP $p_j = \max(b_j q_j), j \in W$

AUCTION MODEL

→ Submit: ask price (b_j), capacity (y_j), site quality factor (q_j)

National, National REM, Regional

1. Sort bids ascending by b_j
2. Assign bids to winning set W until $\sum_{j\in W} y_j \geq D$ (tendered capacity)

3a. Institutional bidders receive FIP $p_j = b_j\, q_j$

3b. BEG bidders receive FIP $p_j = \max(b_j q_j), j \in W$

Combinatorial

Allocation Problem

min	weighted unit cost	
s.t.	winning capacity ≥ tendered capacity	(demand constraint)
s.t.	every project wins only once	(supply constraint)

Pricing Problem

min	remuneration / FIP payments	
s.t.	winner‘s remuneration ≥ winner‘s cost	(individual rationality)
s.t.	loser‘s potential remuneration < loser‘s cost	(no envy)
s.t.	FIP ≥ 0	

EXPERIMENTAL DESIGN

Parameter	Value
Institutional bidders	120 with 0-4 projects per auction, 0-16 p.a.
BEG	6 per state per auction, 384 p.a.
Number of projects	Proportional to state size with maximum 100

EXPERIMENTAL DESIGN

Parameter	Value
Institutional bidders	120 with 0-4 projects per auction, 0-16 p.a.
BEG	6 per state per auction, 384 p.a.
Number of projects	Proportional to state size with maximum 100

Treatment Variable	Value
Auction Design	{National, National REM, Regional, Combinatorial}
Synergy concept	{regional, cross-regional, national}
Synergy Level	{0,0.1,..,0.5}

ENERGIE CAMPUS NÜRNBERG

EXPERIMENTAL DESIGN

FAU

Parameter	Value
Institutional bidders	120 with 0-4 projects per auction, 0-16 p.a.
BEG	6 per state per auction, 384 p.a.
Number of projects	Proportional to state size with maximum 100

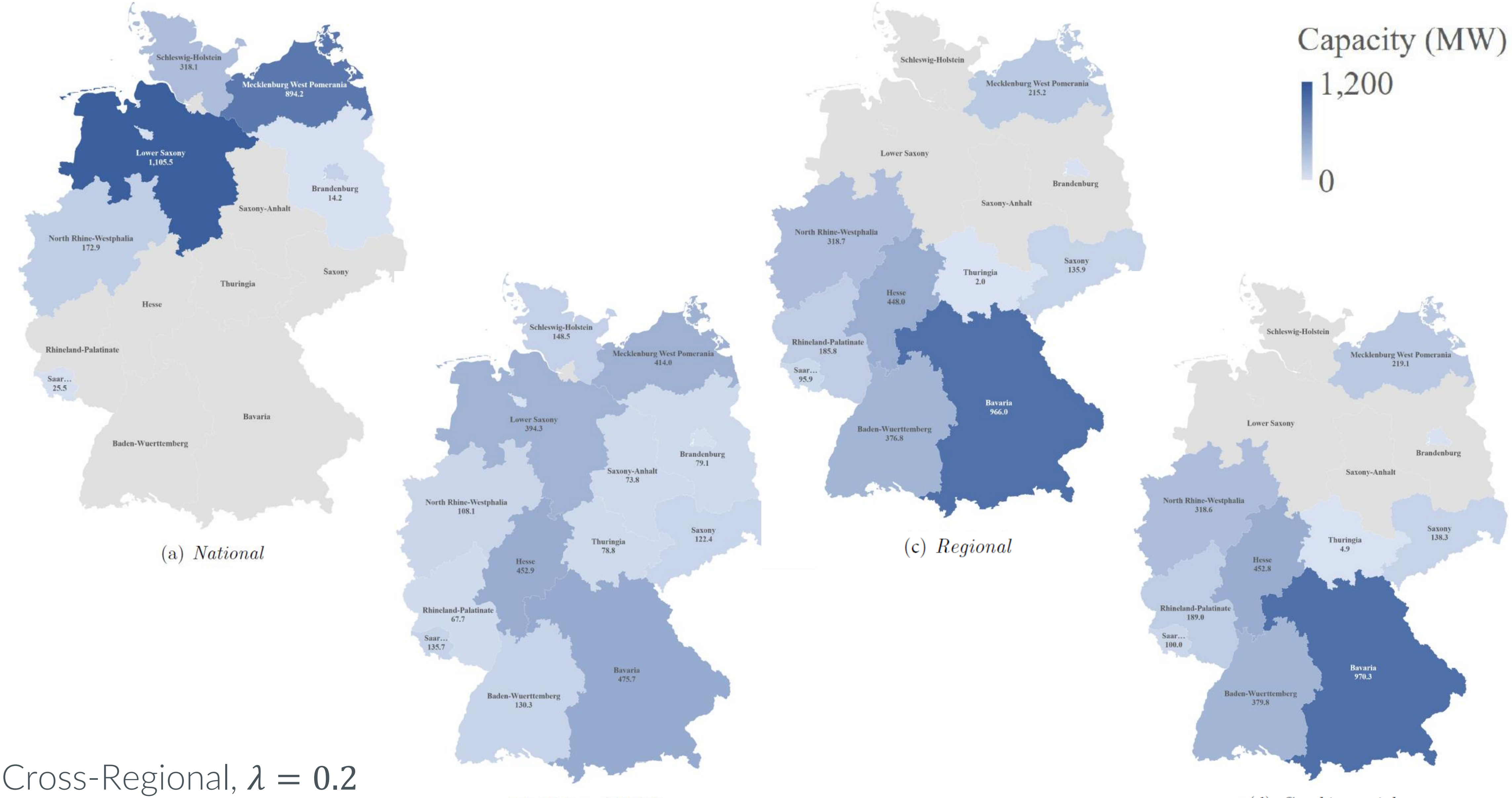
Treatment Variable	Value
Auction Design	{National, National REM, Regional, Combinatorial}
Synergy concept	{regional, cross-regional, national}
Synergy Level	{0,0.1,..,0.5}

Evaluation Metrics	Value
$\bar{p}$ in $^{ct}/_{kWh}$	Average remuneration
δ in %	Allocative quality, i.e. share of capacity allocated to regions with capacity expansion in system-optimal case
η in %	Bidder diversity, i.e. share of capacity won by BEG

RESULTS

Auction design	Synergy level ($\boldsymbol{\lambda}$)	$\bar{\boldsymbol{p}}(\frac{ct}{kWh})$	$\boldsymbol{\delta}(\%)$
National	0	6.25	49
National REM	0	6.70	89
Regional	0	7.14	100
Combinatorial	0	7.17	100
National	0.2	5.81	46
National REM	0.2	6.23	74
Regional	0.2	7.14	100
Combinatorial	0.2	6.34	100
National	0.4	5.20	45
National REM	0.4	5.48	70
Regional	0.4	7.14	100
Combinatorial	0.4	5.50	100

RESULTS



(a) *National*

(b) *National REM*

(c) *Regional*

(d) *Combinatorial*

Cross-Regional, $\lambda = 0.2$

RESULTS

Auction design	**Synergy level (λ)**	$\bar{p}(\frac{ct}{kWh})$	$\delta(\%)$	$\eta(\%)$
National	0	6.25	49	24
National REM	0	6.70	89	27
Regional	0	7.14	100	19
Combinatorial	0	7.17	100	18
National	0.2	5.81	46	15
National REM	0.2	6.23	74	11
Regional	0.2	7.14	100	19
Combinatorial	0.2	6.34	100	5
National	0.4	5.20	45	8
National REM	0.4	5.48	70	7
Regional	0.4	7.14	100	19
Combinatorial	0.4	5.50	100	5

CONCLUSION

- Current auction design leads to inefficient allocation
- Combinatorial auction design
  - Bidders can leverage synergies and avoid exposure risk
  - Implements optimal allocation with minimal surplus cost
  - Maintains incentives to search and bid on the most efficient sites
  - Strategically simpler than having to bid in a sequence of auctions

  → candidate design for RES auctions

- Limitations
  - Bidder diversity can be a policy goal → synergies increase competitive advantage of institutional bidders → additional constraints
  - Not effective as long as legislative hurdles (e.g. 10H rule) and judicial proceedings limit the attractiveness of participation

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
SCHOOL OF BUSINESS AND ECONOMICS

ENERGIE CAMPUS NÜRNBERG

Thank you for your attention!

Sandra Kretschmer

sandra.kretschmer@fau.de

RESULTS - SYNERGIES

Dep. variable: avg remuneration $\bar{p}$	Coef.	SE	t	P> |t|
Intercept	6.5436	0.0280	233.51	0.0000
National REM	0.4597	0.0368	12.49	0.0000
Regional	0.8488	0.0368	23.06	0.0000
Combinatorial	0.8878	0.0368	24.12	0.0000
Cross-regional synergy	-0.3447	0.0180	-19.17	0.0000
National synergy	-0.3990	0.0180	-22.19	0.0000
National × syn. level*	-2.2605	0.0860	-26.29	0.0000
National REM × syn. level	-2.5355	0.0860	-29.49	0.0000
Regional × syn. level	-0.0102	0.0860	-0.12	0.9059
Combinatorial × syn. level	-3.7501	0.0860	-43.62	0.0000
R^2	0.93			
N	720			

*e.g. 0.1

DISTRIBUTION OF AWARDED CAPACITY IN 2018 AND CAPACITY EXPANSION PATHS BY STATE AND ALLOCATION

State	2018	NEP	MaxW
Schleswig-Holstein (SH)	7.7 %	10.2 %	0 %
Mecklenburg-West Pomerania (MV)	8.8 %	16.6 %	7.8 %
Hamburg (HH)	0 %	0 %	0 %
Bremen (HB)	0.2 %	0.1 %	0 %
Lower Saxony (NI)	12.1 %	19.0 %	0 %
Saxony-Anhalt (ST)	6.2 %	8.8 %	0 %
Brandenburg (BB)	16.9 %	5.4 %	0 %
Berlin (BE)	0 %	0 %	0.5 %
North Rhine-Westphalia (NW)	13.9 %	4.9 %	11.5 %
Saxony (SN)	1.3 %	8.1 %	4.9 %
Thuringia (TH)	3.3 %	9.2 %	0 %
Hesse (HE)	8.0 %	2.8 %	16.2 %
Rhineland-Palatinate (RP)	10.2 %	7.2 %	6.7 %
Saarland (SL)	0.3 %	0 %	3.5 %
Bavaria (BY)	5.2 %	0 %	35.2 %
Baden-Wuerttemberg (BW)	6.7 %	7.7 %	13.7 %
Sum	100 %	100 %	100 %

Source: Own elaboration based on data from Deutsche WindGuard (2018), Grimm et al. (2017) and ÜNB (2017).

INVESTMENT COSTS FOR WIND POWER PLANTS

	Category	Investment costs [€/kW]	Plant configuration	Reference yield [MWh/MW]
2018	Onshore Wind 1 (HB, HH, MV, SH)	1,355	Hub height 95 m, 3 MW, 100 m rotor diameter	2,321
	Onshore Wind 2 (BB, BE, NI, NW, ST)	1,456	Hub height 105 m, 3 MW, 100 m rotor diameter	2,376
	Onshore Wind 3 (BY, HE, RP, SL, SN, TH)	1,630	Hub height 120 m, 2.5 MW, 110 m rotor diameter	3,915
	Onshore Wind 4 (BW)	1,732	Hub height 130 m, 2.5 MW, 115 m rotor diameter	4,065

Source: Own elaboration based on Prognos (2013) and FGW (2017).

ASSUMPTIONS

Wind parks (projects j)

- Capacity $y_j \in$ [750kW, 25MW]
- Wind efficiency w_j in kWh/kW
- Costs c_j in ct/kWh

Bidders (i)

- Set of projects P_i
- Institutional bidders ($|P_i| \geq 1$)
- BEG bidders ($|P_i| = 1$)

Synergy concept

- Regional synergies (e.g. BY)
- Cross-regional synergies (e.g. BY and BW)
- National synergies (e.g. BY and BE)
- Synergy levels $\in$ [0, 0.5]

Bidder type	**Number of bidders**	**Projects per bidder**	**Synergy concept**	**Synergy levels**
BEG	384	1	None	None
Institutional	120	0-16	{regional, cross-regional, national}	[0,0.5]

ONSHORE WIND ENERGY IN GERMANY

Auction design element	Implementation
Product	Installed capacity (MW)
Pricing rule	Pay-as-bid and uniform price sealed-bid auction (for BEG)
Type	Price-only multi-item auction
Auctioned volume	2800 MW per year, i.e. 700-1000 MW per round
Remuneration scheme	Energy-related remuneration (capacity is tendered, electricity is remunerated)
Price ceiling	7 ct/kWh in 2017; from 2018: average of highest accepted bid in the last three rounds, increased by 8% (6.3 ct/kWh in 2018)
Prequalification requirements	Bid bond of 30 €/kW of installed capacity (for BEG: 15 €/kW, secondary bid bond of 15 €/kW upon winning)
	BImSchG-approval 3 weeks before auction
Frequency	3 to 4 auctions a year (every 2-4 months)
Concentration rules	Min. 750kW
	Max. 6 bids for max. 18 MW in total for BEG
Penalties	10 €/kW after 24 (48)
	20 €/kW after 26 (50) months of delay (for BEG)
	30 €/kW after 28 (52)
Form of support	Sliding FIP per kWh
Support duration	20 years

RESULTS

Auction design	Synergy level (λ)	$\bar{p}(\frac{ct}{kWh})$	$\delta(\%)$	$\eta(\%)$	θ(€m p.a.)	$\bar{c}(\frac{ct}{kWh})$
National	0	6.25	49	24	366	6.11
National REM	0	6.70	89	27	389	6.60
Regional	0	7.14	100	19	421	7.11
Combinatorial	0	7.17	100	18	417	7.13
National	0.2	5.81	46	15	332	5.43
National REM	0.2	6.23	74	11	355	5.86
Regional	0.2	7.14	100	19	413	6.52
Combinatorial	0.2	6.34	100	5	362	6.14
National	0.4	5.20	45	8	294	4.51
National REM	0.4	5.48	70	7	308	4.79
Regional	0.4	7.14	100	19	407	5.95
Combinatorial	0.4	5.50	100	5	310	5.04

RELATED LITERATURE

RES auction design

- Auctions can reduce remuneration and avoid overcompensation (de Vos & Klessmann, 2014; del Río & Linares, 2014; Mora et al., 2017)
- Large consent on RES auction design elements (Cramton, 2010; IRENA and CEM, 2015; Klemperer, 2004; Maurer & Barroso, 2011; del Río et al., 2015)
- Trade-off between cost-efficient support levels, reaching capacity expansion targets and actor diversity (del Río, 2017; Grashof, 2013; Hauser et al., 2014; Hauser & Kochems, 2014)

RELATED LITERATURE

RES auction design

- Auctions can reduce remuneration and avoid overcompensation (de Vos & Klessmann, 2014; del Río & Linares, 2014; Mora et al., 2017)
- Large consent on RES auction design elements (Cramton, 2010; IRENA and CEM, 2015; Klemperer, 2004; Maurer & Barroso, 2011; del Río et al., 2015)
- Trade-off between cost-efficient support levels, reaching capacity expansion targets and actor diversity (del Río, 2017; Grashof, 2013; Hauser et al., 2014; Hauser & Kochems, 2014)

System-optimal capacity allocation

- Decentralised allocation of generation capacity that accounts for existing network infrastructure and potentially arising network constraints (Benz et al., 2015; Grimm et al., 2017)
- Can reduce prospective network congestion and the need for transmission line expansion (Benz et al., 2015; Grimm et al., 2017, 2018, 2019)
- RES well suited for distributed generation (Ackermann et al. 2001, Amado et al. 2017)

ENERGIE CAMPUS NÜRNBERG

RELATED LITERATURE

FAU

RES auction design

- Auctions can reduce remuneration and avoid overcompensation (de Vos & Klessmann, 2014; del Río & Linares, 2014; Mora et al., 2017)
- Large consent on RES auction design elements (Cramton, 2010; IRENA and CEM, 2015; Klemperer, 2004; Maurer & Barroso, 2011; del Río et al., 2015)
- Trade-off between cost-efficient support levels, reaching capacity expansion targets and actor diversity (del Río, 2017; Grashof, 2013; Hauser et al., 2014; Hauser & Kochems, 2014)

System-optimal capacity allocation

- Decentralised allocation of generation capacity that accounts for existing network infrastructure and potentially arising network constraints (Benz et al., 2015; Grimm et al., 2017)
- Can reduce prospective network congestion and the need for transmission line expansion (Benz et al., 2015; Grimm et al., 2017, 2018, 2019)
- RES well suited for distributed generation (Ackermann et al. 2001, Amado et al. 2017)

→ Combine RES auction design & system-optimal allocation in numerical experiments

LITERATURE

Ackermann, T., Andersson, G., & S□oder, L. (2001). Distributed generation: a definition. Electric Power Systems Research, 57 , 195-204.

Amado, M., Poggi, F., Ribeiro Amado, A., & Breu, S. (2017). A Cellular Approach to Net-Zero Energy Cities. Energies, 10 , 1826.

Anatolitis, V., & Welisch, M. (2017). Putting renewable energy auctions into action An agent-based model of onshore wind power auctions in Germany. Energy Policy, 110, 394-402.

Anaya, K. L., & Pollitt, M. G. (2015). The role of distribution network operators in promoting cost-effective distributed generation: Lessons from the United States of America for Europe. Renewable and Sustainable Energy Reviews, 51 , 484-496.

Barroso, L. A., Street, A., Granville, S., & Pereira, M. V. (2011). Oering Strategies and Simulation of Multi-Item Iterative Auctions of Energy Contracts. IEEE Transactions on Power Systems, 26, 1917-1928.

Benz, T., Dickert, J., Erbert, M., Erdmann, N., Johae, C., Katzenbach, B., Glaunsinger, W., Muller, H., Schegner, P., & Schwarz, J. (2015). Der zellulare Ansatz: Grundlage einer erfolgreichen, regionenübergreifenden Energiewende. Technical Report VDE.

Cozzi, P. (2012). Assessing Reverse Auctions as a Policy Tool for Renewable Energy Deployment. Technical Report The Fletcher School, Tufts University Medford.

Cramton, P. (2010). How best to auction natural resources. In P. Daniel, M. Keen, & C. McPherson (Eds.), The Taxation of Petroleum and Minerals (pp. 289-316). London and New York: Routledge.

Grashof, K. (2013). Herausforderungen bei Ausschreibungsverfahren für Onshore-Windenergie und PV. In U. Leprich, K. Grashof, H. Guss, U. Klann, A. Weber, & A. Zipp (Eds.), Stromsystem-Design: das EEG 2.0 und Eckpfeiler eines zukünftigen Regenerativwirtschaftsgesetzes. Saarbrücken: IZES.

Grimm, V., Sölch, C., & Zöttl, G. (2017). Regionalkomponenten bei der EE-Vergütung. Technical Report Report on behalf of the German Monopoly Commission.

Hauser, E., & Kochems, J. (2014). Ausschreibungsmodelle für Wind Onshore: Erfahrungen im Ausland. Technical Report IZES Saarbrücken.

Hauser, E., Weber, A., Zipp, A., & Leprich, U. (2014). Bewertung von Ausschreibungsverfahren als Finanzierungsmodell für Anlagen erneuerbarer Energienutzung.

Technical Report IZES Saarbrücken.

Held, A., Ragwitz, M., Gephart, M., De Visser, E., & Klessmann, C. (2014). Design features of support schemes for renewable electricity. Technical Report Ecofys Utrecht, Netherlands.

LITERATURE

IRENA and CEM (2015). Renewable Energy Auctions - A Guide to Design. Technical Report.

de Jager, D., & Rathmann, M. (2008). Policy instrument design to reduce financing costs in renewable energy technology projects. Technical Report by Ecofys.

Kardakos, E. G., Simoglou, C. K., & Bakirtzis, A. G. (2013). Short-term electricity market simulation for pool-based multi-period auctions. IEEE Transactions on Power Systems, 28 , 2526-2535.

Klemperer, P. (2004). Auctions: theory and practice. Princeton: Princeton University Press.

Maurer, L. T., & Barroso, L. A. (2011). Electricity Auctions: An Overview of Efficient Practices. Washington DC: The World Bank.

Mora, D., Kitzing, L., Rosenlund Soysal, E., Steinhilber, S., del Río, P., Wigand, F., Klessmann, C., Tiedemann, S., Amazo, A., Welisch, M., Kreiß, J., Fitch-Roy, O., & Woodman, B. (2017). Auctions for renewable energy support - Taming the beast of competitive bidding. Technical Report AURES Final report.

del Río, P. (2017). Designing auctions for renewable electricity support. Best practices from around the world. Energy for Sustainable Development, 41 , 1-13.

del Río, P., Haufe, M.-C., Wigand, F., & Steinhilber, S. (2015). Overview of Design Elements for RES-E Auctions. Technical Report AURES Report D2.2.

del Río, P., & Linares, P. (2014). Back to the future? Rethinking auctions for renewable electricity support. Renewable and Sustainable Energy Reviews, 35 , 42-56.

Rosen, C., & Madlener, R. (2013). An auction design for local reserve energy markets. Decision Support Systems, 56 , 168-179.

Tang, L., Wu, J., Yu, L., & Bao, Q. (2017). Carbon allowance auction design of China's emissions trading scheme: A multi-agent-based approach. Energy Policy, 102 , 30-40.

Toke, D. (2015). Renewable Energy Auctions and Tenders: How good are they? International Journal of Sustainable Energy Planning and Management, 08 , 43-56.

de Vos, R., & Klessmann, C. (2014). How to design a successful auction for renewable energy projects. URL: https://energypost.eu/design-successful-auction-renewable-energy-projects/.

Zhang, L., Li, Z., & Wu, C. (2014). Randomized auction design for electricity markets between grids and microgrids. SIGMETRICS Performance Evaluation Review, 42, 99-110.