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Putting renewable energy auctions into action – An agent-based model of onshore wind power auctions in Germany

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ABSTRACT

The following analysis looks into auctions for renewable energy, specifically onshore wind power in Germany. Following an agent-based modeling approach, the two most commonly applied auction pricing rules are compared (uniform and pay-as-bid) and first conclusions on outcomes are drawn for future policy design. The auctions are modeled to closely represent the auction design foreseen in the German Renewable Energy Sources Act (EEG, 2017) and replicate their parameters.

The analysis draws on auction theory. For both pricing schemes, individually rational agents with independent valuation are assumed. As support for renewable electricity through auctions is to be established permanently and auction rounds will be held multi-annually, a further focus lies on agents learning over time by adapting their behavior to new information.

The model results show that pay-as-bid exhibits lower prices and thus support costs than uniform pricing, whereas allocative efficiency suffers under pay-as-bid. Over time, one can observe a decline in the strike price, which is due to learning effects, whereas agents' profits increase in the course of the auctions. Furthermore, smaller actors will experience difficulties and agent diversity is likely to suffer in the long term, if this is not accounted for in other ways.

1. Introduction

The Renewable Energy Sources Act 2017 (EEG, 2017) was introduced in Germany in 2016. Under this act, auctions will determine the future sliding feed-in premiums for the support of renewable energies according to the directive 2009/28/EC on the promotion of the use of energy from renewable sources (European Parliament and Council Directive, 2009) and to the "Guidelines on state aid for environmental protection and energy 2014–2020″ (No. 2014/C 200/01) by the European Commission (2014). Starting in 2015, the first (pilot) rounds were already executed for solar PV and in 2017, onshore wind will become subject to tendering as well.

Onshore wind power in Germany has seen a substantial expansion during the past decade, due to ambitious goals for climate protection and successful support strategies implemented by the German government and specifically the Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie (BMWi)). So far, a price-based mechanism, namely a sliding feed-in premium with an administratively set, fixed strike price was used to subsidize all wind power plants in Germany equally (only adjusted by a certain locational correction factor – the so-called "Korrekturfaktor der Standortgüte" (EEG, 2017)). From this year on, the expansion will start being subsidized by an auction-based support scheme, in which different projects compete for support. A certain amount of electric capacity will be tendered, corresponding to the EU's goals for deployment of electricity from renewable energy sources (RES) for each member state. This amount is to be generated by RES according to the Renewable Energy Sources Act (EEG, 2014; EEG, 2017).

Under the pay-as-bid (PAB) pricing rule, which has been implemented in the first German wind onshore auctions, the agents holding a winning bid receive exactly their submitted bid as support for their fed-in electricity for the following 20 years. An exemption is made for citizens' energy companies, which will be awarded under a uniform pricing rule and enjoy several other advantages. Prequalification

Abbreviations: EEG, Renewable Energy Sources Act; BMWi, Ministry for Economic Affairs and Energy; RES, renewable energy sources; BImSchG, Federal Immission Control Act; PAB, pay-as-bid; ABM, agent-based modeling; LCOE, levelized cost of electricity; CDF, cumulative distribution function

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criteria that are required by the BMWi are a valid permit according to the Federal Immission Control Act (Bundesimmissionsschutz-Gesetz (BImSchG, 2017)) for the participating project and bid bonds of 30 €/kW. For citizens' energy companies, the bid bond amounts to 15 €/kW, followed by a second bid bond of 15 €/kW in case of being successful in the auction (EEG, 2017).

This paper presents insights into whether pay-as-bid pricing induces a more cost efficient outcome than the uniform pricing rule, the most prominent alternative. Under uniform pricing, the lowest not accepted bid or highest accepted bid determines the support level of all the successful agents in the auction. The comparison usually depends on the conditions and the environment of the auction (Fabra et al., 2006) and has thus far not been examined for renewable energy auctions to our knowledge.

Specifically, the question is examined in the context of the recently introduced German onshore wind power auctions by modeling the German auction design as precisely as possible. We then draw lessons learned for policy makers from our results, concerning prices, efficiency, as well as impacts on actor diversity.

2. Theoretical background and literature review

To find out whether a PAB pricing scheme is indeed more support cost efficient than uniform pricing in the upcoming German onshore wind power auctions, we applied an agent-based modeling approach in which the agents and the setting are modeled according to auction theory. By support cost efficiency, we mean minimizing the costs for consumers to support the renewables deployment and thus expansion. In our definition, we only account for direct payments to generators for fed-in electricity and no indirect costs occurring e.g. for the necessary grid expansion or the integration of RES. Our methodology thus builds on the foundations of economic theory, while making use of an effective way to model decision making (Dam et al., 2013). The focus hereby lies on agent behavior and long-term optimization strategies in the two auction schemes.

The next section provides a short outline of the most important auction theoretic elements that found their way into the design of our model and the agents participating in the auctions. Auctions are one form of market-based allocation mechanisms, which provide a support cost efficient[1] approach whenever information asymmetry between an agent and a principal exists (McAfee and McMillan, 1987). In the market for RES there is a basic knowledge of the cost distribution (Wallasch and Luers, 2013). Nevertheless, an auction mechanism could increase support cost efficiency by improving the allocation of overall subsidies (Klessmann et al., 2015). The present paper focuses on PAB and uniform pricing auctions[2] as these are the most widely used "in situations in which the marginal values are declining – that is, the value of an additional unit decreases with the number of units already obtained" (Krishna, 2010). This is also true for renewable energy auctions, where multiple goods are auctioned.[3]

Onshore wind power auctions are multi-unit auctions. Precisely, a certain capacity of wind power is tendered. In each round, different bidders enter with their projects of different scopes and sizes. Since the auctioneer procures a specific amount of power, the good can be defined as homogeneous from an auctioneer's point of view according to the theory of Myerson (1981). Nevertheless, as locations differ in their RES potential, i.e. more or less ideal wind conditions or solar irradiation, and thus capacity factors, the so-called correction factor (Korrekturfaktor) under the framework of the reference yield model (Referenzertragsmodell) – which accounts for the locational quality (EEG, 2017) – ensures a level playing field for all bidders. Nevertheless, one can argue, that the correction factor actually decreases allocative efficiency, on the terms that it makes the sites with the lowest locational quality the cheapest in terms of corrected costs. On the other hand, one could say that the overall economic costs decrease through correcting, because they allow for a more balanced expansion of renewable energy generation and therefore lower system costs (grid expansion, integration etc.). For more insights see e.g. Klessmann et al. (2015) or Bade et al. (2015). These estimations are however beyond the scope of our paper.

Aside of the pricing scheme, a variety of other design elements can be included in auctions. These elements help derive efficient outcomes and adapt the auction to the needs of the auctioneer and the market environment. In the following, a (non-exhaustive) overview on the most important design elements used in RES auctions is presented.

Ceiling prices are an important auction design feature that is regularly applied in renewables auctions. How to set this price is a crucial issue since it affects the level of competition and technological diversity in technology neutral auctions (Del Río, 2015).

In the German electricity market, limit prices were set for onshore wind power. According to the EEG (2017), a ceiling price of 7 €ct/kWh[4] will be introduced in the first three rounds. Beginning in the 4th round (01.02.2018), the ceiling price will adapt to the overall price level dynamically (EEG, 2017).

A further important criterion for RES auctions is whether to implement price-only or multi-criteria auctions. An example for multi-criteria auctions would be to award additional points to bidders who achieve more job creation with their projects, as is the case for instance in South Africa (Eberhard, 2013). Prequalification criteria are another way to influence the structure of bidders. In order to achieve a high realization rate and to ensure the support cost efficiency of the auction scheme (Maurer and Barroso, 2011), two prequalification criteria were implemented in Germany. Before the potential bidders can participate in the auction, they need to obtain a valid immission control permit for their specific project and a bid bond in form of a guarantee of 30 € for every kW of their wind project's generation capacity.[5]

The EEG (2017) also contains a so-called "de minimis clause", which states that projects with a capacity of less than 750 kW don't participate in the auctions but fall under a feed-in tariff scheme in order to include small actors and thus maintain actor diversity. Other than that, the German scheme is price-only (EEG, 2017). There are many other features from auction design that can be made use of in auctions for renewable energy, but as this analysis focuses on the difference between the two pricing rules, only this short outline is presented. For further auction theoretic analyses of renewable energy auctions, see e.g.: Ehrhart et al. (2015) or Kreiss et al. (2017).

The second important strand of literature for the present analysis is on agent-based modeling (ABM). According to Bonabeau (2002), agent-based models have certain benefits over other modeling techniques:

[1] We also discuss allocative efficiency of the two different auction schemes later on. The concept of allocative efficiency refers to the actual costs of the supported projects – i.e. as to how the resources are distributed. Allocative efficiency by definition is given when the price function, in our case the bid, intersects with the marginal cost curve, i.e. social surplus is maximized and no distortions in the form of deadweight loss occur (Markovits, 2008).

[2] We distinguish between static auctions, which include the two assessed formats (pay-as-bid and uniform pricing) and dynamic auction formats consisting of several consecutive bidding rounds. Dynamic auction formats allow agents to react on their competitors' bidding behavior during the course of an auction, whereas static auctions are so-called "one shot" auctions, meaning that each agent submits a bid and these bids are then ranked in order of their respective price.

[3] Single unit auctions, on the other hand, are usually applied when only one good with uncertain valuation to the auctioneer is sold (Krishna, 2010). In RES auctions, this is the case when a certain project is auctioned for realization, e.g. the offshore wind power auctions in Germany or in Denmark, in which the participants bid for the right of implementing one specific offshore wind farm, for which the plans have been already outlined.

[4] From here on, we will refer to €ct simply as ct.

[5] In contrast, citizens' energy companies only have to provide an advance guarantee of 15 €/kW and have to provide the other 15 €/kW only if they have bid successfully (EEG, 2017). The immission control permit only has to be obtained, if they were successful in the auction and is thus not a prerequisite for participation. Citizens' energy companies also benefit from a prolonged realization period compared to the other bidders.