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# An auction design for local reserve energy markets

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ABSTRACT

In this paper we develop an auction mechanism that is designed for a local energy market. It aims to enable regionally or virtually restricted trading of ancillary services, which enhances the position of the balance group responsible party beyond that of simple accounting. Furthermore, it makes local market participants somewhat more independent from the transmission grid operator, but at the same time provides incentives for investments in distributed generation technologies. A wider spread of these technologies can help to save $CO_2$ emissions, while at the same time a part of them can also be used to counter the fluctuations of energy from volatile renewable sources, such as wind and solar power. Because of their relatively high margins and small share in total production, ancillary services are well-suited for a remuneration scheme. Participants in the auction are, thus, private households, which impose specific design characteristics on the auction. Most importantly, it needs to be transparent and easy to understand, as homeowners will typically not have the insights of a professional trader as well as lack a similar position and motivation. Also, the confinement to a single balance group, i.e. a local market, means that especially in the beginning of the trading only a small number of bidders can be expected. Therefore, competition will initially be limited, so that the auction design needs to be adapted accordingly. In order to test the performance of the proposed auction market design under varying information policies, a simple agent-based simulation program has been developed. We find that the theoretical predictions hold and that competition quickly leads to price convergence.


## 1. Introduction

In recent years ancillary services in electricity markets and especially such providing reserve energy have received increasing attention. This is due to several facts. First of all, the increase of the share of unpredictably fluctuating renewable energy in total energy production has led to a higher demand for reserve capacities to buffer those fluctuations. Secondly, new technological and societal developments have started to offer new ways of meeting this demand. Smaller and larger consumers can offer some of their loads and capacities to external control or even offer load adjustments at certain times of the day themselves. They can further participate in virtual power plants (VPPs) to sell power produced in large numbers of small-scale, distributed home devices, such as micro combined-heat-and-power (CHP) plants or photovoltaics. So far, this has been limited to the trade of real power. Balancing energy market mechanisms have only been examined in pilot projects with microgrids, i.e. only under these special circumstances has household energy been used as reserve energy.

The purpose of this paper is to show how in current circumstances decentralized generation can be used beneficially for a regional energy system with an appropriate auction design. In particular, this paper aims at determining a valid auction mechanism that suits a local reserve energy market with all its special needs and characteristics, as discussed below. Once this mechanism is defined, it needs to be evaluated as to how bidders in such a market behave over time. The details with respect to how this mechanism can eventually be implemented optimally are side issues and will, therefore, only be treated briefly.

Keeping in mind the characteristics of bidders in a local energy auction, the problem that needs to be solved is, thus, to find an adequate and reliable remuneration for each provider of reserve capacity and energy. At the same time, the auction mechanism needs to be as simple and easily understandable as possible in order not to turn down potential participants, while reducing opportunities for strategic behavior to a minimum. Moreover, transaction costs in a market with such small quantities need to be low in order to leave room for at least a minimal profit. The analysis of an auction for such a matter entails many parts. Electricity auctions are a specific type of auction because the good is perfectly divisible and non-storable, which means transactions need to happen in real time or at least at a predefined point of time in the future. This type of auction can be compared to the treasury auction, which has received considerable scientific attention in the past. So far, game-theoretic analyses of reserve auctions with the properties needed in a local market are very limited.

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The remainder of the paper is structured as follows: In Section 2, the literature on theoretical analysis, electricity auctions, and reserve energy auctions is reviewed. In Section 3, the market is briefly described as a preparation of the auction model, which is explained in the same section. It is presented for both the asymmetric and the symmetric case and solved accordingly. Section 4 introduces the simulation and theoretical considerations of the strategies implemented, and the results of the simulation. Section 5 explains the technical backgrounds of the simulation as well as the results obtained. Section 6 provides a conclusion and some suggestions for future research.

## 2. Literature review

The liberalization of the electricity sector has fueled the desire to analyze markets and the behavior of market participants. Due to the complex nature of the good itself, each individual market and the interaction of several markets for different energy products have set strong limitations on analytical methods. Therefore, simulations have very quickly gained acceptance in this field.

Many different kinds of electricity market models are possible. Ventosa et al. [33] classify them as optimization models, equilibrium models, and simulation models, whereby simulation models can either be derived from equilibrium models or formulated as agent-based models. The main difference between these two is the static nature of the approach in the first case and the dynamic approach in the second. Sensfuß et al. [29] categorize these agent-based models as tools to analyze market power and market design, agent decisions and learning, and the interdependence of short-term and long-term decisions. At least for wholesale electricity markets, Weidlich and Veit [35] offer a very different way of distinguishing agent-based models, namely with regard to their algorithms. According to the authors, these may be model-based adaptation algorithms, genetic algorithms, and algorithms applying the reinforcement learning approach by Erev and Roth [14].

From an economic point of view, the major problem with most of the recent electricity market modeling is the overemphasis on detailed modeling of generation equipment [11,21] or individual agents representing several interest groups [23,32], whereas a sound market model has rarely been analyzed. Two exceptions are the analysis of Wilson's design [37] by Otero-Novas et al. [22] and the comparison of uniform-price to discriminatory-price auctions by Bower and Bunn [8].

The remaining part of this section is used to review the literature on auction design in general and for our local market in particular. Especially research on treasury auctions and its accommodation of a small number of bidders or diverse technologies, as well as the literature on electricity and ancillary services auctions is of interest.

From a theoretical point of view, a reserve energy auction is a multi-unit (or share auction, i.e. an auction of a divisible good, with equivalent characteristics; [36]) as well as a multi-part auction. In the multi-unit part it resembles a treasury auction, which is an auction of a divisible good. A very important topic in this field is whether uniform pricing or discriminatory pricing, whereof the Ausubel auction [3] is treated as a special case, yields more favorable outcomes. A downside of uniform pricing is that bidders have an incentive to understate their demand for the second and following units in order to win those at lower prices in case of a demand auction. Transferred to a procurement auction like the one at hand, this means that bidders understate their supply, thereby creating an artificial scarcity, and are able to extract price premiums [4,13]. Back and Zender [5] describe this mechanism as "collusive", meaning that each bidder colludes with himself while trying to maximize his profit. Even more important is that this does not change with the number of bidders, i.e. no real competition may emerge. Discriminatory pricing does not exhibit these downsides, but helps to limit market power [20], which is especially prevalent in local markets. A disadvantage, however, is that revenues for the auctioneer are generally lower in discriminatory auctions [34]. Put differently, one could say that "competition needs to be bought with higher prices" (i.e. bids). Furthermore, Rassenti et al. [24] find that price volatility is reduced in discriminatory price auctions, which is an important feature for markets with household participation, as fluctuating prices can easily alienate this kind of participant and thereby reduce participation rates. Haghighat et al. [17], however, find no differences between the two auction formats under imperfect competition, i.e., for example, when bidders can exercise market power or are able to collude.

The model primarily meant for treasury auctions in [34] represents, in principle, a situation very similar to the one at hand. Besides simply equating demand and supply, the authors also allow for non-competitive bids, which reduce the quantity available. The size of this reduction, however, is not endogenous but random. Furthermore, their model uses common values with private signals, which is very straightforward for financial goods that are acquired in the hope that they will increase in value, determined by subsequent trading, which affects all holders of such items equally in a common market. This is very different for an energy auction, which comprises several differentiated units and technologies and, therefore, exhibits private values, or rather cost.

Burke and Auslander [9] specifically consider a residential electricity auction. While the design is directed at acquiring electricity by residential bidders and should, therefore, entail consumer behavior, it needs only one bid, composed of the maximum quantity desired and the maximum price to be paid. The mechanism then determines how much each bidder can obtain and what price he will need to pay. This is done by using uniform pricing and soft budget constraints, meaning that allocated quantities are reduced for increased prices, but the overall amount being paid remains the same.

Chao and Wilson [10] suggest an auction design with a robust incentive mechanism. Similar to the design currently in use, they require two bids, one for capacity and the other for energy. The capacity bids are used to construct a merit order in which the units are called. Upon being called, they are remunerated with the real-time spot price, which is thus outside their range of influence. As this seems to be a promising approach to limiting gaming in the auction process, the basic idea of independence between energy price and bid will be followed in the model presented in Section 3.

Swider and Weber [31] analyze the bidding behavior in the German minute reserve auction market, using a decision-theoretical framework. They are among the first to analyze the bidding behavior in the actual market as it occurs in reality. In particular, they address the difficulty of defining a probability density function for the price and thereby the expected price itself, by deriving it from historic time series. However, their investigation can only be applied to a limited extent to a local market, as they look at the behavior of one individual bidder and describe the rest of the market by a probability function. In a small market, this generalization cannot be justified due to the lack of statistical validity.

Another approach with a similar goal is presented in the work by Block et al. [7]. They describe a scenario of a microgrid where households can act as energy consumers and producers in an alternating fashion. For this purpose, they introduce a combinatorial double auction. While it is efficient and welfare-maximizing in theory, they do not examine possible gaming strategies or cooperation inherent in the auction design that the bidders might pursue. Also, it is not sensible to use this design in situations with only one buyer.

Hao [19] focuses on simple electricity auctions. While his design allows the usage of probabilities of other bidders bidding less or more, in our case it is too simple to be applied, as it uses fixed MWh blocks combined with a single price bid. The auction is then cleared at the price of the last accepted bid. As concluded in the paper itself, this leads to untruthful bidding and overstatement of costs.

Bernard et al. [6] compare the outcomes of several uniform auction designs with varying numbers of bidders. Similar to the theoretical