PROCUREMENT AUCTION DESIGN FOR PHOTOVOLTAIC ENERGY UNDER THE UNCERTAINTY OF GENERATION EFFICIENCY

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Overview

As the use of fossil fuel energy has been considered as the main cause of global climate change, power generation based on renewable energy receives great attention around the world. Among several renewable energy resources, photovoltaic (PV) energy accounts for the largest portion of renewable energy in many countries. However, PV generation fluctuates due to the weather uncertainty and seasonality, and this physical limitation is the main factor that increases the uncertainty of profits of PV generators and makes them reluctant to enter the electricity market. Many countries have adopted subsidy mechanisms to protect PV generators, and a procurement auction system has been widely implemented. In the auction system, winning bidders can make a contract to sell electricity generated by PV at the winning price for a fixed long-term period.

However, the current auction system, in which bidders bid their price and power generation capacity and winners are simply determined based on the price, can result in an inefficient outcome. It is because the power generation efficiency from PV energy is greatly influenced by external factors. If the auctioneer proceeds the auction based solely on capacity and price, it is impossible to distinguish between suppliers with poor generation efficiency and suppliers with good generation efficiency, and as a result, power supply through PV may be insufficient than expected. Therefore, a key consideration in the PV auction is to predict how the power generation efficiency of each PV generator will fluctuate during the contract period.

The main purpose of this study is to design an optimal procurement auction for long-term PV contracts considering the uncertainty of the power generation efficiency of PV generators using mechanism design theory. We design a direct mechanism in which bidders bid three elements: price, capacity, and initial generation efficiency, where price and initial generation efficiency are assumed to be private information, and capacity is assumed to be public information. Based on Myerson's approach, we find out an auction that is incentive compatible, individually rational, and auctioneer's cost minimizer. Simulation analysis based on the data of the Korean PV auction is conducted to compare the model we present with the current Korean auction system.

Methods

Mechanism design theory is the reverse engineering of games to achieve a specific desired outcome. Its concept has been widely used in various areas, especially in the auction system. The key issue of designing an auction system is to determine allocation rule and transfer rule to derive an efficient outcome when bidders bid their values for the object.

In this study, we consider an auction format where the types of PV generators are composed of their PV generation cost and initial generation efficiency. Each bidder privately knows their type and their capacity is publicly known. It is assumed that generation efficiency follows Brownian motion from the initial period to the expiration of the contract, reflecting the influence of external factors such as weather uncertainty and PV equipment obsolescence. When the auctioneer's objective is to maximize its expected present value of the payoff, which is composed of the benefit from the procurement of PV energy and the payment for the bidders. We use a direct mechanism and show how allocation rule and transfer rule should be formulated if a direct mechanism is incentive compatible and individually rational.

Results

We first define the objective function of the auctioneer and the payoff of bidders based on the expected present value of the long-term PV contract. By using Brownian motion to reflect the external uncertainty of generation efficiency, the model can be implemented in a linear environment. Several characterizations of the optimal direct mechanism are presented and the optimal allocation and transfer rules are derived in a closed-form. First, we figure out that the allocation rule and the payment should have a special form if and only if the mechanism is incentive compatible. With this result, the payoff maximizing allocation rule and consequent payment rule are derived. We conduct several comparative statics of the optimal allocation rule and find out that the winning probability of bidders increases if their production cost is low and generation efficiency is high which is consistent our intuition.

To implement the optimal direct mechanism (bidders bid their generation cost) to the actual auction system, we design a "Pay-as-Bid" auction where bidders bid their willingness to sell and the auctioneer evaluates their bids and makes a contract with the bidding price. In our designed indirect mechanism, the Bayesian Nash Equilibrium is derived and its form is consistent with the allocation rule and payment scheme of our direct mechanism.

Further, using Korean long-term PV contract auction data, we conduct simulation analysis and compare the proposed auction and the current system. The results show that the proposed model can reduce the risk of recovery of procurement. We also conduct the analysis when the symmetricity assumption does not hold. Sensitivity analysis shows that as the volatility of generation efficiency is greater, the proposed model can make better results.

Conclusions

In this study, an optimal procurement auction model for PV auction considering the uncertainty of generation inefficiency is presented. Since PV generation has great volatility, the existing auction schemes simply evaluating the bidding price and capacity may result in an insufficient procurement of PV energy. Therefore, we design a two-dimensional auction scheme, in which bidders report their generation cost and generation efficiency and the auctioneer evaluates the bidding price considering the bidders' procurement potential in the long-term period. The cost-minimizing, incentive compatible, and individually rational direct mechanism is derived, and we show that the model outperforms the existing auction scheme theoretically and numerically.

References

Che, Y. K. (1993). Design competition through multidimensional auctions. *The RAND Journal of Economics*, 668-680.

Dixit, R. K., & Pindyck, R. S. (2012). *Investment under uncertainty*. Princeton university press.

Iyengar, G., & Kumar, A. (2008). Optimal procurement mechanisms for divisible goods with capacitated suppliers. *Review of Economic Design*, *12*(2), 129-154.

Kreiss, J., Ehrhart, K. M., & Haufe, M. C. (2017). Appropriate design of auctions for renewable energy support–Prequalifications and penalties. *Energy Policy*, *101*, 512-520.

Kucsera, D., & Rammerstorfer, M. (2014). Regulation and grid expansion investment with increased penetration of renewable generation. *Resource and energy economics*, *37*, 184-200.

Kwon, T. H. (2018). Policy synergy or conflict for renewable energy support: Case of RPS and auction in South Korea. *Energy policy*, *123*, 443-449.

Matthäus, D. (2020). Designing effective auctions for renewable energy support. *Energy Policy*, *142*, 111462.

Myerson, R. B. (1981). Optimal auction design. *Mathematics of operations research*, *6*(1), 58-73.

Narahari, Y. (2014). *Game theory and mechanism design*. World Scientific.

Zhu, L., Li, L., & Su, B. (2021). The price-bidding strategy for investors in a renewable auction: An option games–based study. *Energy Economics*, *100*, 105331.