Policy and Theoretical Implications of the Zero-subsidy Bids in the German Offshore Wind Tenders

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ABSTRACT

The German offshore wind tender, launched in April 2017, resulted in three out of the four winning projects being delivered with zero subsidies, relying only on the wholesale price. This result has been regarded as a turning point for the industry. This paper analyses the 2017/18 German offshore wind tenders and the bidding strategies of the winning developers. We then propose a re-design of the tenders with the aim of achieving optimality/zero-subsidies and efficiency - two key properties in mechanism design. The paper contributes to the discussion on how to design offshore wind tenders with both a policy and theoretical perspective. This is of particular relevance given the rapid expansion of this type of investment in Europe and the use of auctions to select developers.

Keywords: Energy, Policy, Mechanism design, Optimality, Efficiency

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1. INTRODUCTION

Wind energy has been an important technology in the aim to reach the renewable energy targets, mostly to be met by 2030.[1] The exploitation of offshore wind is recent when compared to that of onshore wind. Nonetheless, it increasingly contributes to the European Union renewable energy targets (Dedecca et al., 2016). Total offshore installed capacity in Europe has increased from about 1,471 MW at the end of 2008 to about 18,499 MW in 2018 (Wind Europe, 2018a). Although most of the existing installed offshore capacity is concentrated in a few European countries (Belgium, Denmark, Germany, Netherlands and the UK), the interest in offshore wind farms is widening rapidly.

Auctions have been widely used as an allocation mechanism to procure offshore wind projects. By 2017, six European Union Member States (Denmark, France, Germany, Italy, Netherlands and the UK) had introduced tendering procedures for procuring offshore wind projects (CEER, 2018). The recent offshore wind auctions incorporated some types of subsidy from the regulator/government to the developers, as an incentive mechanism. One example is from Germany that launched its first round of competitive tenders for offshore wind projects in April 2017, to construct

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[1] On 14 June 2018 it was announced an agreement setting a binding renewable energy target for the European Union at 32% for 2030, with a clause for an upwards revision by 2023 (European Commission Statement from 14 June 2018).

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and operate offshore wind farms. This tender is considered to be a turning point for the industry, given that of the four winning projects, three requested zero subsidies, relying only on the wholesale price (Huebler et al., 2017). As noted by the Executive Vice President and CEO of Ørsted[2]:

> "The zero subsidy bid is a breakthrough for the cost competitiveness of offshore wind, and it demonstrates the technology's massive global growth potential as a cornerstone in the economically viable shift to green energy systems."

The German energy regulator launched its second round in April 2018. As was the case for the 2017 tender, the 2018 tender also had bidders requesting zero subsidies. The 2017/18 tenders were part of the 2017 Offshore Wind Act (EEG 2017), aimed at auctioning existing offshore wind installations to be commissioned between 2021 and 2025.

From the perspective of mechanism design, the outcome of the German offshore wind tenders (hereafter, German tenders) can be regarded as being not far from optimal, if one defines optimality as the payment of the lowest amount of non-negative subsidies to the winning bidders.[3] Optimality is one of the key properties in mechanism design and auction theory, along with efficiency.[4] In terms of efficiency, the German tenders used a discriminatory (or pay-as-bid) auction format which, according to theory, does not achieve efficiency when units are identical and bidders have multiple demands. Indeed, optimality and efficiency are generally considered to be conflicting goals and a regulator usually needs to opt for one of them when designing a mechanism (Ausubel, 2003; Zhan, 2008).

The main purpose of this paper is to analyze the theoretical and policy implications of the zero-subsidy bids submitted in the German tenders. Our analysis is threefold. Firstly, we describe the design, study the bidding strategies and the outcome of the German tenders.

Secondly, we study an alternative design - a modified Vickrey-Clarke-Groves (VCG) mechanism - with the aim of exploring how the German auction could be re-designed to deliver both efficiency and optimality/zero subsidies. Our design is based on a key feature revealed in the 2017 German tender and its implications. The 2017 German tender gave bidders the opportunity to be awarded contracts of different time periods (contract lengths, i.e. 20, 25 and 30 years). The design of this feature was, however, not entirely clear to the bidders pre-auctioning, due to the lack of clarity regarding which bid(s) qualified for a 25- or 30-year contract. Nonetheless, this feature influenced the bidding strategies of the bidders. Our design incorporates the bidding strategies revealed in the tender, while allowing bidders to bid against a subsidy for periods of varying contract lengths with clear qualification rules. The mechanism asks each bidder to submit a vector of bids (i.e. a bid for each contract length/version) that is matched with the vector of willingness to pay (WTP) of the regulator. The mechanism chooses the winners and versions where social value is maximized (i.e., the sum of the regulator and bidders' surpluses is maximized).

Lastly, we discuss key theoretical and policy implications relating to our analysis of the German tenders and our proposed re-design. In terms of theoretical implications, our re-design contributes to the literature on mechanism design and auction theory. Our design uses a VCG mech-

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[2] Cited from GlobeNewswire News of 13 April 2017. Retrieved from https://globenewswire.com/news-release/2017/04/13/960298/0/en/DONG-Energy-awarded-three-German-offshore-wind-projects.html, accessed on 06/04/2019.

[3] In auction theory, optimality (optimal auction) is used when an auctioneer aims to maximize revenue or to minimize cost, e.g. see Ausubel (2003). Throughout the paper, optimality is used when the auctioneer aims to minimize cost/payment which corresponds to the zero-subsidy scenario.

[4] In auction theory, efficiency refers to the problem of allocating the goods for sale (e.g. electricity) to the bidders who value them the most. The objective of efficient auctions is to maximize the sum of the bidders' surplus, hence, maximize social welfare, e.g. see Ausubel (2003). We use this definition throughout the paper.

anism composed of a zero-subsidy benchmark and a vector of bids to achieve optimality and efficiency, together with strategy-proofness (i.e., truth-telling is optimal) and individual-rationality (i.e., utility from participation is non-negative). It obtains a social welfare optimum.

Given the increasing investment in offshore wind and the use of auctions to select the developers, it is vital to draw some policy implications of our analysis. In particular, our paper contributes to the policy discussion on how governments or regulators may design their offshore wind tenders to obtain zero-subsidies, while not giving up on efficiency and without the use of reservation prices. This is particularly relevant given that recent offshore wind tenders are now being designed with the aim of ensuring only no-subsidy bids. The recent Dutch offshore wind tender, opened in March 2019, introduced a no-subsidy requirement.[5] This design choice - with a zero-subsidy requirement - may force an optimal outcome from the outset, but may have significant implications in terms of efficiency, as this may easily be lost. Hence, our paper also contributes to the discussion on the design of future offshore wind tenders. This is particularly important given that around 10 GW of offshore installed capacity is already set in the plans of a number of European countries to be procured via auctions during the period May 2019 to 2022 (Wind Europe, 2018b).

The rest of the paper is organized as follows. Section 2 introduces the German tenders. In Section 3, we present our modified VCG mechanism. Section 4 discusses the theoretical and policy implications of the zero-subsidy bids in the German tenders and our proposed design. Section 5 concludes.

2. THE GERMAN OFFSHORE WIND TENDERS

As of January 2017, new legislation in Germany came into force to expand the use of offshore wind energy through competitive tenders (German WindSeeG 2017, 2017), as part of a wider reform of the Renewable Energy Sources Act (German EEG 2017, 2017).[6] This legislation envisages two different stages of tenders: (i) auctions for existing projects (first stage); and (ii) auctions for sites[7] which have been subject to a preliminary investigation (second stage).[8] The first stage, also known as the transition period, involves the 2017/18 auctions with projects to be commissioned between 2021 and 2025. The second stage will involve the projects to be commissioned from 2026 onwards, where the bidders will compete for specific sites which have been subject to the preliminary investigation. The focus of the present paper is the two tenders held during the transition period - the 2017/18 German tenders. Below, we discuss the details of these tenders, in particular, the design and the outcome.

Design. In both tenders, the German regulator asked each bidder to submit a volume in MW (a project) and a subsidy per kWh to be received in order to construct and operate the project. More specifically, each bidder was asked for a volume in MW and a subsidy per kWh in addition to wholesale electricity prices. The wholesale price was not part of the tender. Subsidies were capped at €12 ct/kWh in 2017 and at €10 ct/kWh in 2018, and negative subsidies were not allowed.[9]

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[5] The Dutch Government covers the cost of connecting the wind farms to the grid (Marsden et al., 2018).

[6] Amendments have been made to the German WindSeeG 2017 with the latest version, to date, from 13.05.2019.

[7] According to German WindSeeG 2017 (2017, Section 3, No. 4), sites correspond to *"sectors within areas in which offshore wind energy installations are to be constructed in a spatial relationship and for which a joint auction will therefore be held"*.

[8] Prior to WindSeeG 2017, contracts were allocated without the use of auctions. These contracts are to be commissioned before 1 January 2021.

[9] See German EEG 2017 (2017), German WindSeeG 2017 (2017) and the forward amendments to WindSeeG 2017 available at https://www.buzer.de/gesetz/12211/index.htm accessed on 31/08/2019

The format used was a discriminatory auction where the bidders submitting the lowest bids won the projects (or group of projects) they were interested in and thus, received the subsidy requested. In addition, the tenders provided the regulator with enough flexibility to award contracts of different lengths. A base contract was for a period of 20 years, however contract lengths of 25 years and 30 years were also available (German WindSeeG 2017, 2017; Huebler et al., 2017). According to Dannecker and Kerth (2017), in the 2017 tender documents, the regulator specified that these lengths were linked to the size of the subsidy submitted, but did not otherwise specify the qualifying criteria for these contract lengths. The 25-year and 30-year contracts were subject to an evaluation by the regulator after the end of the auction.

Results. In 2017, a total of 1,490 MW was procured.[10] Four projects were accepted, three of which requested zero subsidies (amounting to 1,380 MW out of 1,490 MW). Zero subsidies meant that the developers have pledged to develop the projects without any subsidies, relying on the market rate for the energy they sell (Huebler et al., 2017; Huebler, 2018). The developer Ørsted won three projects, two of which are to be developed without any subsidies and one with a subsidy of €6 ct/kWh. The closing contracts, including the contract lengths, were, by 2018, yet to be decided (Ørsted, personal communication, 7 February 2018).[11]

In 2018, a total of 1,610 MW was procured. There were six winning projects. The developer Ørsted won two, Iberdrola two and KNK Wind and Innogy won one project each.[12] The bids of Innogy and KNK have not been published, but two projects were awarded with zero-subsidy bids (one from Ørsted and one from Iberdrola; Müsgens and Riepin, 2018). The average winning bid was €46.60 /MWh, which was 10 times higher than the average successful bid in the 2017 auction (Huebler, 2018). In contrast to the 2017 German tender, all winners were offered a 25-year contract.[13]

Analysis. In terms of design, the German regulator built in the opportunity to award contracts with different lengths of contract. The length of a contract is an important variable, since the regulator may not know the required length for a developer to be able to recover the invested capital. The regulator wants to secure the minimum cost while minimizing the length as to ensure that the contract is more often offered up for competition. Hence, the regulator may benefit from testing different lengths of contract as part of the auction design. This feature was, however, not entirely clear to the bidders pre-auctioning, due to the lack of clarity regarding which bid(s) would qualify for a 25- or 30-year contract. Nonetheless, this feature influenced the bidding strategies of the bidders. The possibility of being awarded a contract length of 30 years has been appointed by the developer Ørsted itself as a driver that led the developer to submit bids with zero-subsidies.[14] Other drivers for the zero-subsidy can be considered, e.g. the anticipated higher power prices, location, scale, the fact that grid connection was not included in the tender or a better understanding of the construction risk.

Optimality and efficiency are the main properties in mechanism design and auction theory. If we define optimality as the lowest amount of non-negative subsidies needed to pay the winning bidders, then the German tenders can be regarded as being not far from optimal. In terms of efficiency, the German tenders, most likely, did not obtain an efficient outcome due to the use of a dis-

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[10] See Bundesnetzagentur press release from 27 April 2018. Retrieved from https://www.bundesnetzagentur.de/DE/Service-Funktionen/Beschlusskammern/1_GZ/BK6-GZ/2017/2017_0001bis0999/BK6-17-001/Ergebnisse_erste_Ausschreibung.pdf?__blob=publicationFile v=3, accessed on 18/08/2019.

[11] We contacted Ørsted via e-mail asking for the length of contracts.

[12] See Bundesnetzagentur press release from 27 April 2018. Retrieved from https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2018/20180427_Offshore.html, accessed on 18/08/2019.

[13] Idem.

[14] See Ørsted A/S in GlobeNewswire News 14 April 2017. Retrieved from https://www.offshorewind.biz/2017/04/14/dong-explains-the-thinking-behind-subsidy-free-bids/, accessed on 15/08/2019.

criminatory auction format. According to Krishna (2009), a discriminatory auction, where bidders have multiple demands and units are identical, is not efficient. This applies to the current case, since electricity can be regarded as a physically identical good.

3. RE-DESIGNING THE GERMAN OFFSHORE WIND AUCTION

In auction theory (or mechanism design), optimality and efficiency are often regarded as conflicting goals, where the former aims to minimize the cost of the principal (e.g., government/regulator) and the latter has the objective to maximize social welfare. A government/regulator, as a social planner, cares about efficiency, but is also motivated by the lowest cost. Myerson (1981) shows that a principal may become too greedy to ensure the lowest cost and potentially, will not sell the projects to the bidders with the highest surpluses. In the context of the German tenders, a relevant question is whether this conflict between efficiency and optimality can be reduced.

In this section, we present a re-design of the German tenders that obtains efficiency and optimality simultaneously while using the length of contracts as an integrated part of the design. Our design follows a VCG mechanism, which is a sealed bid format for auctioning multiple objects/projects. This mechanism is comprised of two features: (i) an allocation rule, and (ii) a payment rule. The mechanism converts the indirect utility of an agent (e.g. bidder) into a social objective function. The payment is designed to incentivize each agent to deliver true information. The agent states true information because the agent itself does not take part of the determination of its own payment, e.g. lying to ensure a higher subsidy is irrelevant, since the agent has no influence on the subsidy it ends up receiving. Given true information, the allocation rule can allocate the projects for sale to the agents who value them the most. Hence, by design, truth-telling is a weakly dominant strategy for every agent, and it yields an efficient outcome.

Our design is a modified VCG mechanism in the sense that it introduces a vector of contract lengths, allowing bidders to bid against a subsidy for periods of varying contract lengths.[15] The number of contract lengths, predefined by the principal, may vary depending on the projects and the market. This added flexibility has the objective of ensuring that a winning bidder is allocated the contract length, within the subset of possible contract lengths, that best suits its proposal. The mechanism asks each bidder to submit a vector of bids (i.e., a bid for each contract length/version) that is matched with the vector of WTP of the principal. The mechanism chooses the winners and versions where social value is maximized (i.e., the sum of the principal and bidders' surpluses is maximized). The allocation rule is made clear to the bidders pre-auctioning, ensuring the needed clarity on the qualification rules for contract lengths. Hence, because the allocation rule states that the winners of the licences are the bidders maximizing social welfare, the qualification rule regarding which bids qualify for the different contract lengths is now clear pre-auctioning.

In the following subsections, we present our alternative design with an illustrative example and a generalized model.

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[15] One could argue that characteristics other than the contract length could differentiate a bid schedule for renewable energy sources, for example, location, technology, power prices, and macroeconomic factors. However, locations of the sites tend to be pre-defined, before the start of auctioning, and technology (and scale effects), power prices and macroeconomic factors tend to be relevant background information before determining the size of the bids. This paper takes contract length as the key variable when tendering offshore wind contracts, which is in line with the bidding strategies revealed in the 2017 German tender. In addition, for simplicity, the presented design does not contain any form of compensation (e.g. curtailment compensation) or penalty schemes.

3.1 An Illustrative Example

Consider a tender with one principal and two bidders. For the purpose of this example, only one project is to be launched.[16] The bidders submit bids for subsidies to be received for carrying out the project. The subsidy has a cap of €12 ct/kWh and a floor of €0 ct/kWh. A subsidy can be given for a period of 20, 25 or 30 years. It is common knowledge that a zero-subsidy bid qualifies a bidder for a 30-year contract. The principal is interested in buying the project for a subsidy below or equal to the revealed cap.

The contract lengths can be considered as versions in a vector of the following form:

$$\text{Bid} = \begin{pmatrix} 20 \text{ years} \\ 25 \text{ years} \\ 30 \text{ years} \end{pmatrix} = \begin{pmatrix} €b_1 \text{ ct/kWh} \\ €b_2 \text{ ct/kWh} \\ €b_3 \text{ ct/kWh} \end{pmatrix}$$

where b_1, b_2 and b_3 are non-negative numbers and versions.

As noted by Greve and Pollitt (2017), a shorter contract length usually demands a greater cost per kWh than a longer contract length due to the lower number of years to capitalize on an investment and so, a bidder may need to be compensated with a higher subsidy. We assume that a contract length of 20 years demands a greater subsidy per kWh than a contract length of 25 years, which demands a greater subsidy than the longest contract length possible (30 years), hence $b_1 > b_2 > b_3$. This assumption is in line with Greve and Pollitt (2017) and with the results of the 2017 German tender. In addition, we assume that $b_3 = 0$, i.e. a zero subsidy bid qualifies to a 30 years contract, which is consistent with the bidding strategies of the 2017 German tender.

Table 1 shows the submitted offers of the principal and the submitted bids of the bidders. For example, bidder 1 asks for a subsidy of €6 ct/kWh if the contract length is 20 years, €3 ct/kWh if it is 25 years and submits a subsidy equal to zero if it is 30 years.

Table 1: Welfare Effect

Length of contract (Years)	Principal (€/ct/kWh)	Bidder 1 (€/ct/kWh)	Bidder 2 (€/ct/kWh)	Welfare effect (€/ct/kWh)
20	12	6	5	+7
25	12	3	2	+10
30	12	0	0	**+12**

Using the allocation rule of the VCG, social value is maximized if either bidder 1 or bidder 2 is offered a 30-year contract (+ €12 ct/kWh). Hence, the winner is chosen by random selection. Suppose bidder 1 wins the project and is given a 30-year contract.

Next, using the payment rule of the VCG mechanism, we evaluate the welfare effect without the winning bidder, so as to determine the subsidy to pay bidder 1. Taking bidder 1 out of the table, social value is now maximized if bidder 2 is also offered a contract of 30 years (+ 12 ct/kWh). Using the VCG, bidder 1 wins the project on a 30-year contract and is paid a subsidy of €0 ct/kWh.[17] According to our definition, optimality is obtained. The outcome is efficient given that the surplus is maximized.

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[16] In the generalized model, more than one project can be launched and we allow for package bidding.

[17] –1 × (€12 ct/kWh - €0 ct/kWh) + €12 ct/kWh = €0 ct/kWh., where (€12 ct/kWh - €0 ct/kWh) is the principal's evaluation without the winning bidder 1, but offering bidder 2 a contract of 30 years, and €12 ct/kWh is the evaluation when bidder 1 is present and offered a 30-year contract.

In the next section, we present the general model, where one or more projects can be launched simultaneously, package bidding is allowed and vectors of k versions are used (i.e., k contract lengths). The €12 ct/kWh used should not be interpreted as a reservation price. This is rather an arbitrary number that reflects the principal's reported WTP for electricity. In the general model, this reported WTP is marked with a s and the true WTP is marked with a v.

3.2 The Model

Consider a tender with a set K of projects to be launched (e.g., if $K=1$ one project is to be launched). Each of the projects in K can be realized in several versions, so that the full description of the projects is given by (k,h), where $k \in K$ describes the type of the project and $h \in H$ is a particular version of project k. We let $\mathcal{P} \subseteq K \times H$ denote the set of all feasible projects (k,h).

There is a principal who invites N firms to submit bids to carry out the projects. A bidder may submit bids on some or all of the projects. We shall allow also for bids on combinations of projects, with a specified version for each project, to allow for situations where the bidders gain advantages from being assigned two or more projects, differing from the sum of the gains from the individual projects.

More specifically, a *bid* b^i of a bidder $i \in \{1,\ldots,N\}$ is a set consisting of single-project bids $b^i(k,h) \in \mathbb{R}$ for $(k,h) \in \mathcal{P}$ and package bids $b^i(A)$ for A, where A is a package and a subset of $\mathcal{P}$ such that each $(k,h),(k',h') \in A$ implies that $k \neq k'$ (i.e., each project can be obtained only once). The bid b^i may or may not be a truthful bid. We assume that if b^i is defined on all projects in some package A', then it is also defined on the package A', and if it is defined on two disjoint packages A' and A'' of projects, then it is defined on $A' \cup A''$. This assumption is not restrictive since it can be satisfied by adding bid values for each of the projects or packages. For simplicity, we assume that all bids b^i are defined on the empty package $\varnothing$ and take the value 0. We write $b=(b^1,\ldots,b^N)$ for the array of bids.

For the principal, an *offer* s is proposed, where s assigns a value $s(k,h) \in \mathbb{R}$ to each project in $\mathcal{P}$ and possibly a value $s(A)$ to some of the packages A that can be constructed from $\mathcal{P}$.[18] As for b^i, s may or may not be a truthful offer.

Notice that b^i for $i \in \{1,\ldots,N\}$ and s are partial functions on the set $\mathbf{P}$ consisting of the elements of $\mathcal{P}$ and all its subsets, i.e. functions defined on a subset of $\mathbf{P}$. For f a partial function on $\mathbf{P}$, we let $Dom\,f$ denote its domain of definition. We shall use the term *valuations* for such partial functions.

In the present section, we assume that the assignment of projects to bidders is established using a mechanism $\mathcal{M}$, a version of the VCG mechanism, adapted to our present setup. Given the valuations s of the principal and b^i of the bidders $i \in N$, an *allocation* is a map $a=(a_1,a_2): K \to (N \times H) \cup \{*\}$ such that $\{(k,h) \mid a_2(k)=h\} \subset \mathcal{P}$. In the interpretation, $a_1(k)=i$ signifies that bidder i has been assigned to project k, which is launched in version h; if $a(k)=*$, then project k will not be launched. The set of allocations is denoted by $\mathcal{A}$.

An allocation $a \in \mathcal{A}$ is *feasible* given (s,b) if it corresponds to the offers and bids, so that

(i) $\{(k,h) \mid a(k) \neq *\} \in Dom\,s$ (so that the subset of projects actually launched is acceptable for the principal),

(ii) for each i, the set $\{k \in \mathcal{K} \mid a_1(k)=i\}$ belongs to $Dom\,b^i$ (each bidder i is prepared to carry out the projects which is assigned to it by the allocation).

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[18] Even though package bidding is important to the paper following its application to the energy sector, we will ignore this for now for the purpose of focusing on the key results of the paper.

The set of feasible allocations is denoted by $\mathcal{A}_F$. Given the valuations (s,b), we can define the value of an allocation w.r.t. s for the principal as

$$s(a) = s\left(\{k \mid a(k) \neq *\}\right)$$

and for bidder i w.r.t. b^i as

$$b^i(a) = b^i\left(\{k \mid a_2(k) = i\}\right).$$

The *social value* of the allocation a is then given by

$$S(a;s,b) = s(a) - \sum_{i=1}^{N} b^i(a),$$

giving the net value when the values for the bidders which are assigned to the projects are subtracted from the value stated by the principal. Define $a^*(s,b)$ as an allocation which maximizes $S(a;s,b)$ over A_F. There may be more than one such allocation, but we assume that a particular one is selected, and the choice does not matter in the sequel.

The VCG mechanism M is described by its allocation and payment rules: For given offers and bids (s,b), the allocation rule selects $a^*(s,b)$, and a payment $\tau^i(s,b)$ for $i = 0$ (the principal) and $i = 1,\ldots,N$ (the bidders) is determined by

$$\tau^0(s,b) = -\sum_{i=1}^{N} b^i(a^*(b)) - \left[-\sum_{i=1}^{N} b^i(a^*(s,b))\right], \tag{1}$$

$$\tau^i(s,b) = -S(a^*(s,b^{-i});s,b^{-i}) + \left[S(a^*(s,b);s,b) - b^i(a^*(s,b))\right], i = 1,\ldots,N. \tag{2}$$

Here $a^*(s,b^{-i})$ is the allocation chosen when only the principal and those bidders different from i are present, and similarly, $a^*(b)$ is the allocation chosen when the principal is absent. As always, the payment of an agent (principal or bidder) is found to be the difference between maximal social value without the agent and the value to the other agents of the actual allocation.

Even though the mechanism outlined above is a special version of the VCG mechanism, it has the desired properties (Krishna, 2009). For this, we assume that the principal has *true* valuations v and strives to maximize $v(a) - \tau^0$. For the bidders, with *true* costs u^i, the objective function is to maximize $u^i(a) + \tau^i$.[19]

Proposition 1 *In the mechanism $\mathcal{M}$, the following hold:*

(i) Stating true valuations as offer and bids is a weakly dominant strategy for each of the agents.

(ii) If true valuations are chosen, then the mechanism yields an efficient outcome in the sense that social value is maximal at the equilibrium allocation.

(iii) It is individually rational for $i = 0,1,\ldots,N$.

Proof. See Appendix. ☐

In contrast to the discriminatory auction, our design obtains the desirable efficiency property. Efficiency is achieved because agents state true costs (or subsidies demanded), which makes it possible for the principal to allocate the projects to the bidders valuing them the most, thus maximizing surpluses.

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[19] Bidders can differ in their costs/technology and so, even if they have identical discount rates, bidders' true costs can still vary.

Now, we show that the mechanism is also optimal in the sense that it minimizes the principal's cost.

Lemma 1 *The optimal outcome for the principal is a payment that equals zero,* $\tau^0 = 0$.

Proof. See Appendix. ☐

Lemma 1 follows the constraint in the German tenders, where negative subsidies were not allowed. Hence, the lowest subsidy to pay must be zero euros per kWh.

A bidder *i* is interested in maximizing $u_h^i(a) + \tau_h^i$ with u_h^i and τ_h^i being the true cost and payment of providing version *h*, respectively. Let $h = 1$ be the first version in the vector, where

$$u_1^i \geq u_2^i \geq \cdots \geq u_H^i = 0, \tag{3}$$

meaning that for all versions $h = 1, \cdots, H-1$, bidder *i* has requested a premium compared to providing version H. The preference of bidder *i* is given with Lemma 2.

Lemma 2 *Despite (3) and not taking* τ_h^i*,* $h = 1, \ldots, H$*, into account, a bidder* i *is indifferent between* $u_1^i, u_2^i, \cdots, u_H^i$ *and therefore, it is indifferent between the associated versions.*

Proof. See Appendix. ☐

In the light of Lemma 1 and Lemma 2, we have Proposition 2, assuming that in the event of a tie the winner is chosen by a lottery where each bidder has an equal probability of winning.

Proposition 2 *As the mechanism* $\mathcal{M}$ *delivers an efficient outcome, it is at the same time an optimal mechanism.*

Proof. See Appendix. ☐

Efficiency and optimality are obtained because of the increasing order of *S*, where the distance between a WTP and a cost (e.g. demanded subsidy) becomes largest when reaching the last element of the vector (e.g. longest contract length). The increasing order of *S* was factored into the setup and outcome of the German tenders, where the WTP of the regulator was held constant across all versions and a bid was highest for the first version which steadily decreased to zero subsidies if given version H (a 30-year contract).

In addition, Proposition 2 does not violate individual-rationality since the winners are chosen where social value is maximized. Therefore, in the light of Proposition 2, if the payment of a bidder ends up being zero, it means that the bidder itself must have submitted a bid of zero for it to be chosen as the winning bid. Further, as long as the principal's WTPs for all projects are at least zero, individual-rationality holds also for the principal.

4. DISCUSSION

4.1 Theoretical Implications

Our design is a VCG mechanism combined of vector bidding and it is based on the bidding strategies revealed in the 2017 German tender, especially revealed in public statements made by the winner Ørsted in 2017. This modified design obtains optimality and efficiency simultaneously. Our design also obtains strategy-proofness and individual-rationality. The results hold for the sale of a single project as well as for the sale of multiple projects. Although it is based on the bidding strategies of the 2017 German tender, our design contributes to the literature on mechanism design and auction theory in the following ways.

First, our design contributes to the literature on prior-free designs. The existing literature on mechanism design and auction theory relies heavily on designs with a distribution over bidders' private information (see e.g. Zhan, 2008; Krishna, 2009). The VCG mechanism, used in our proposed design, is of interest because it is prior-free, as it can be implemented without any prior information and knowledge. This mechanism requires, however, the set-up of a benchmark in order to analyze optimality. In our design, we set the zero-subsidy as a benchmark. To the best of our knowledge, the benchmark of zero-subsidy has not yet been analyzed in this literature. Some authors have considered other benchmarks. Goldberg et al. (2006) design a revenue-benchmark that can be applied to a number of auction settings. Devanur et al. (2015) present a framework for a prior-free mechanism design built on Goldberg et al. (2006). The authors benchmark their framework to the VCG with the best reserve price and achieve positive results. They conclude that a mechanism in their framework approximates the optimal mechanism for the given distribution. However, without a distribution it "*still provably performs well*" (Devanur et al., 2015, page 1). They do not consider efficiency. Other authors, such as Goldberg and Hartline (2003), present a method based on statistical estimates. Hartline and McGrew (2005) and Chen et al. (2014) use approximation factors.

Second, the use of a vector of versions (i.e. lengths of contract) does not demand the number of bidders to increase significantly in order to achieve optimality as in Bulow and Klemperer (1996)[20] and Devanur et al. (2015). Greve and Pollitt (2017) present a VCG mechanism that uses a bidding set-up similar to the one presented in this paper.[21] However, and in contrast with our design, it does not minimize the cost to the principal.

Lastly, our design contributes to the literature on mechanism design applied to energy. This literature is large, as auctions have been used substantially in energy markets (e.g. see Hoffler and Wittmann, 2007; Voss and Madlener, 2017). More relevant to the present paper is Tang and Jain (2015) which applies a modified VCG mechanism to study: (i) an agent/aggregator's problem on how to select wind generators, and (ii) a system operator's problem on how to price wind energy for stochastic economic dispatch. Their mechanism achieves efficiency, dominant strategy incentive compatibility and individual rationality, but it does not obtain optimality as does our design. Tavafoghi and Teneketzis (2014) also study a VCG mechanism applied to energy, but bidders have multi-dimensional private information, as opposed to the present paper, where bidders have one-dimensional private information.

4.2 Policy Implications

Our design also has relevant policy implications given the rapid expansion of offshore wind energy in Europe and the use of auctions to support wind projects. Around 10 GW of offshore installed capacity are already planned by a number of European countries to be procured via auctions launched during the period May 2019 and 2022 (Wind Europe, 2018b).

The Netherlands is one of the key European countries that has been investing in offshore wind. The Dutch Ministry of Economic Affairs and Climate Policy issued, in March 2017, the Dutch

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[20] The seminal paper of Bulow and Klemperer (1996)studies single-project auctions and shows that the expected revenue of the prior-independent Vickrey auction with $n+1$ bidders is as good as the revenue-maximizing auction with n bidders tailored to the underlying distribution.

[21] Greve and Pollitt's (2017) mechanism works in the single-project environment. It is strategy-proof, individual-rational and efficient.

Offshore Wind Energy Roadmap 2030. This plan aims to enable the Netherlands to achieve a cumulative total of 11.5 GW of installed offshore wind capacity in the North Sea. The plan also deals with grid connection for specific wind farms.

Following the outcome of the 2017 German tender, the Netherlands opened offshore wind tenders with a requirement of zero-subsidies. In December 2017, the Netherlands tendered a site with 700 MW which Vattenfall won with a zero-subsidy bid (Huebler, 2018). More recently, the Netherlands opened a tender, in March 2019, to build and operate offshore wind farms without subsidies at the Hollandse Kust (zuid) III and IV zones in the Dutch North Sea. In the case that no applications were successful, a procedure with the option of subsidies would follow; this was not the case in the 2019 Dutch tender, since Vattenfall, again, won with a zero-subsidy bid.[22]

The Dutch government opted to introduce a zero-subsidy requirement and hence, forced an optimal outcome from the outset. This has, however, a drawback in terms of efficiency. Following Myerson's (1981) argument, if the reservation price (i.e. the demand of zero-subsidy bids), is set too low, the contracts may not be sold. Hence, surplus may not be maximized and so, efficiency may not be obtained. Although it is difficult to compare different designs, tenders and locations/countries, the design studied in the previous section achieves efficiency without the use of reservation prices and therefore, it overcomes the risk of not achieving efficiency, present in the Dutch design due to the zero-subsidy requirement.

In addition, the 2018 German tender resulted in 1/3 of the winning projects being delivered with zero subsidies in contrast to the 2017 German tender that delivered 3/4.[23] We cannot exclude the possibility that lessons learned from the previous competitive tender had influenced the bidding strategies. One example where learning, among other factors, played a role was in the 3G auctions to sell mobile-phone licenses, as argued by Klemperer (2002a). Following the successful UK 3G auction to sell mobile-phone licenses in March/April 2000, other 3G auctions in Europe were not as successful.[24]

Learning about other bidders' valuations of projects (in theory called interdependent values) or learning from cost/subsidies submitted in previous tenders (sequential sales) can change a bidder's behavior, which *per se* changes the standard properties of the different designs. The VCG mechanism keeps its desirable properties in the case of interdependent values if bidders are symmetric (i.e., values are drawn from the same probability distribution). Although, the efficiency does not hold for a tender where three or more bidders have multiple demands (Perry and Reny, 2002). In the case of sequential sales, both formats lose their desirable properties if bidders have multiple demands (Krishna, 2009).

We note, however, that rapid changes in the cost of offshore wind along with a certain time period between tenders may reduce the information value from previous and current auctions. In addition, if the design is moderately changed from tender to tender, then each tender can be regarded as a one-shot game (i.e., non-sequential). In these cases, the results of the proposed re-design likely still stand.

As noted in Klemperer (2002b), collusion is also a common concern in auction designs, since it can affect both optimality and efficiency. However, collusion is more likely to occur in

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[22] This information is from the Netherlands Ministry of Economic Affairs retrieved from https://english.rvo.nl/news/opening-call-subsidy-free-tenders-offshore-wind-energy-hollandse-kust-zuid and https://www.government.nl/latest/news/2019/07/10/vattenfall-to-build-second-unsubsidised-dutch-offshore-wind-farm, accessed on 31/08/2019.

[23] For the 2018 tender, we assume that the two unknown winning bids were not zero-subsidy bids.

[24] For example, the Netherlands' 3G auction ran in July 2000, only raised around €10bn less than expected. In November/December 2000, Switzerland ran their auction. The bidders ended up paying only the reservation price, one-fiftieth of expected. For more details see Klemperer (2002a).

open auctions than in sealed-bid auctions, which is the case for our design.[25] Bid preparation cost and complexity have also been highlighted as concerns as these may impact efficiency (Rothkopf, 2007). The theoretical literature is, however, scarce on this topic, although the experimental literature shows a high percentage of efficiency in second-price auctions (i.e. within the VCG family) (Kagel and Levin, 2008). In addition, some of the largest auction houses use designs from the VCG family to sell items and online search spaces to advertisers (e.g. Google, Yahoo, Microsoft, Amazon and eBay) (Che et al., 2017).

5. CONCLUSION

The German offshore wind tender, launched in April 2017, resulted in the majority of the projects being delivered with zero subsidies, relying only on the wholesale price. Following this result, the 2018/19 Dutch tenders have incorporated a zero-subsidy requirement as a way to ensure that the projects would be conducted with no subsidies (with the exception for the grid connection). This has, however, implications in terms of the efficiency of the auction.

This paper studied the German tenders, held in 2017 and 2018, and analyzed the bidding strategies of the winning developers. It presented a re-design of the German tenders with the aim of achieving an efficient and optimal/zero-subsidy outcome. In particular, the design is a modified VCG mechanism that (i) allows bidders to bid against a subsidy for periods of varying contract lengths with clear qualification rules and (ii) incorporates the bidding strategy identified in the 2017 German tender; that a zero-subsidy can be achieved with a longer contract. In contrast to the Dutch tenders, this design does not force zero-subsidies and obtains optimality and efficiency simultaneously.

Overall, this paper aims at contributing to the discussion on how to design offshore wind tenders with both a policy and theoretical perspective. This is of particular relevance given the rapid expansion of this type of investment in Europe and the use of auctions to select developers.

Although our focus is offshore wind tenders, our design can be used in other tenders or investments where a project or service is to be delivered in different versions. One example could be electricity balancing services, where each element in the vector is a response time (Greve, 2017). Other examples could be rural electrification and interconnections between countries, where each element is a distance to a specific area/country.

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[25] Sealed-bid auctions have advantages over open auctions since the outcome (winners and losers) of an allocation procedure will only be available to the bidders after the closing of the auction.

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APPENDIX

Proof of Proposition 1 (i): Suppose that the principal and bidders have submitted valuations s at $b=(b^1,\dots,b^N)$, and that bidder i replaces b^i by the true valuation u^i. Then, the resulting allocation is changed to $a^*(s,(u^i,b^{-i}))$, and the new situation is assessed by

$$\begin{aligned}
u^i(a^*(s,(u^i,\ b^{-i})))+\tau^i(s,(u^i,b^{-i})) &= u^i(a^*(s,(u^i,b^{-i})))-S(a^*(s,b^{-i});s,b^{-i})+\\
&\quad \left[S(a^*(s,(u^i,b^{-i}));s,(u^i,b^{-i}))-u^i(a^*(s,(u^i,b^{-i})))\right]\\
&= S(a^*(s,(u^i,b^{-i}));s,(u^i,b^{-i}))-S(a^*(s,b^{-i});s,b^{-i})\\
&\geq S(a^*(s,b);s,b)-S(a^*(s,b^{-i});s,b^{-i})\\
&= u^i(a^*(s,b))-S(a^*(s,b^{-i});s,b^{-i})+\left[S(a^*(s,b);s,b)-b^i(a^*(s,b))\right]\\
&= u^i(a^*(s,b))+\tau^i(s,b),
\end{aligned} \tag{4}$$

where the inequality follows from the definition of $a^*(s,(u^i,b^{-i}))$. Equation (4) says that bidder i is at least as good after the replacement as before. For the principal, similar reasoning can be used to show that stating the truth is as good as stating any other offer. We have

$$\begin{aligned}
v(a^*\quad &(v,b))-\tau^0(v,b)\\
&= v(a^*(v,b))-(-\sum_{i=1}^{N}b^i(a^*(b))-\left[-\sum_{i=1}^{N}b^i(a^*(v,b))\right])\\
&= \sum_{i=1}^{N}b^i(a^*(b))+S(a^*(v,b));v,b)\\
&\geq \sum_{i=1}^{N}b^i(a^*(b))+S(a^*(s,b);s,b)\\
&= v(a^*(s,b))-(-\sum_{i=1}^{N}b^i(a^*(b))-\left[-\sum_{i=1}^{N}b^i(a^*(s,b))\right])\\
&= v(a^*(s,b))-\tau^0(s,b),
\end{aligned} \tag{5}$$

showing also that the principal is at least as well off after the replacement.

(ii): The efficiency property follows easily from its definition, given that all agents state their true valuation.

(iii): For each bidder i, individual-rationality follows from the fact that the cost is zero if a bidder does not win the assignment procedure. If it wins one or more projects, we have from (4) that

$$u^i(a^*(s,(u^i,b^{-i}))) + \tau^i(s,(u^i,b^{-i})) = S(a^*(s,(u^i,b^{-i}));s,(u^i,b^{-i})) - S(a^*(s,b^{-i});s,b^{-i}),$$

where the first member on the right-hand side is greater or equal to the second member by the definition of a^*, meaning that the payment is at least equal to $u(a^*(s,(u^i,b^{-i})))$. For the principal, we have from (5) that

$$v(a^*(v,b)) - \tau^0(v,b) = \sum_{i=1}^{N} b^i(a^*(b)) + S(a^*(v,b));v,b),$$

where the right-hand side is non-negative by definition. Hence, M satisfies the individual-rationality constraint. □

Proof of Lemma 1 Assume that $\tau^0 < 0$ is not possible. Suppose that $\hat{\tau}^0 > 0$, so that $v(a) - \hat{\tau}^0 < v(a) - \tau^0$. This is not optimal for a principal, showing that it is better off with $\tau^0 = 0$. □

Proof of Lemma 2 By Proposition 1, stating true valuations is a weakly dominant strategy for each of the bidders. This is true for all bids submitted and therefore, it is true for all associated versions. □

Proof of Proposition 2 Let $S_1(a^*;v,u)$ be the chosen allocation if $H = 1$, and let $S_\alpha(a;v,u)$, $\alpha = 2,\dots H$, be alternative options if $H > 1$. Suppose that for one allocation $S_2(a^*;v',u')$ we have that

$$S_2(a^*;v',u') > S_1(a;v,u)$$

Then, there is also an $a^*(v'',u'')$ such that

$$S_3(a^*;v'',u'') > S_2(a;v',u') > S_1(a;v,u)$$

For any offers and bids (v''',u'''), let $P_{win,\alpha}(a^*;v''',u''')$ be the probability of winning the assignment procedure with (v''',u''') when the another option is (v,u). Then,

$$P_{win,\alpha}(a^*;v''',u''') > P_{win,1}(a^*;v,u) \geq 0,$$

since $a^*(v''',u''')$ will be chosen over (v,u) if (v''',u''') is an option, showing there is a probability equal to one that the payment offered to a winner of the assignment procedure will be zero when using M. The mechanism is at the same time efficient, given that it still chooses the outcome where social value is maximized. □

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