Report D3.1, January 2016

Assessment of Auction Types Suitable for RES-E

AURES

European Commission

HORIZON 2020

Short about the project

Auctions for Renewable Energy Support: Effective use and efficient implementation options (AURES)

This project helps assessing the applicability of different auction types to renewable support under different market conditions. It also explores which auction types and design specifications suit particular requirements and policy goals in European countries. By establishing best practices and a knowledge sharing network, we contribute to informed policy decision-making and to the success of auction implementations across Europe.

Target-oriented analysis: Through analysis of empirical experiences, experiments and simulation, we will create a flexible policy support tool that supports policy makers in deciding on the applicability of auction types and certain design specifications for their specific situation.

Capacity building activities: We undertake specific implementation cases to derive best practices and trigger knowledge sharing amongst Member States. We strive to create a strong network with workshops, webinars, bilateral meetings, newsletters, a website that will serve as capacity building platform for both policy makers and market participants (including project developers, auctioneers, etc.). Wherever required, we can set up specific bilateral and multilateral meetings on specific auction issues and facilitate cooperation

This report is a deliverable of Work Package 3, which deals with auction designs, implications and application options for RES-E. It contributes to two tasks in the work package:

Task 3.1 - Assessment of auction types suitable for RES-E

Task 3.2 - Chances and risks of identified auction types in the context of specific market conditions

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Report D3.1, January 2016

Assessment of auction formats suitable for RES-E

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Project deliverable:

WP3 – Auction designs, implications and application options for RES-E

Task 3.1 – Assessment of auction types suitable for RES-E

Task 3.2 – Chances and risks of identified auction types in the context of specific market conditions

AURES; a coordination and support action of the EU Horizon 2020 program, grant number 646172.

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1 Introduction

1.1 Aim and methods of the WP3 analysis

Auctions are not a panacea, however, they involve a lot of favourable characteristics that make them a promising approach for the support of electricity from renewable energy sources (RES-E). The aim of this report including WP3.1 and WP3.2 is to assess relevant auction formats for RES-E identified in WP2 per se as well as under specific market and framework conditions from an auction theoretical perspective. That is, pros and cons of relevant auction formats are discussed under different assumptions regarding RES-E specific market and framework conditions. The entire approach of WP3 is described in the following and additionally illustrated below in Figure 1.

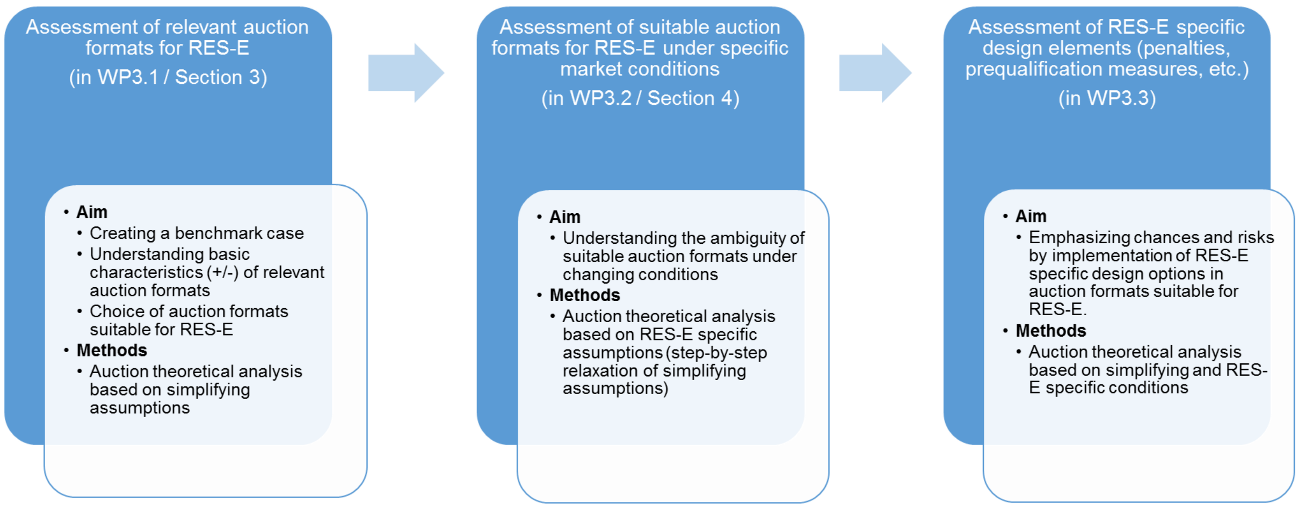
In order to promote a deeper understanding of those auction formats per se, we start with a first overview of their fundamental characteristics and emphasise general differences between them (WP3.1). For that, we base our theoretical analysis on simplifying basic assumptions for the beginning and refer to those as benchmark case. As an important result from auction theory, under these particular assumptions, there are no crucial differences between certain auction formats due to which the auctioneer should prefer one over another. Nevertheless, we emphasise smaller differences that become decisive for real-world applications, identifying those auction formats that are not considered suitable for the RES-E context, and consequently skip these auction formats in the subsequent analysis.

In the next step (WP3.2.), we neglect and extend the simplifying assumptions in order to investigate the remaining auction formats under market and framework conditions relevant for RES-E. We will find that auction formats differ widely in several situations, because they “react” differently to specific conditions. Hence, in some situations the negative characteristics of a particular format prevail, whereas under different conditions this format will be the most suitable compared to others. As a result, this section provides guidance about which chances and risks are involved in particular auction formats under certain RES-E specific market and framework conditions and consequently which is the most appropriate one in each case.
Furthermore, potential lessons learnt from other industries are discussed and transferred in to the RES-E context in order to extend the auction theoretical results by further use-oriented aspects.

Based on this report we will focus on additional design elements (WP3.2), e.g. prequalification measures or penalties that become necessary in the RES-E context and their impacts on the auction outcome. For that, fundamental characteristics of those RES-E specific design elements will be introduced and their compatibility with different auction formats analysed.

Finally, a comprehensive assessment of suitable auction formats under given market and framework conditions and their compatibility with additional design elements will be reached.

Figure 1: Approach of the auction theoretical analysis in WP3



1.2 Why are auctions potentially suitable for RES-E?

In the beginning the question arises why auctions are potentially suitable for RES-E at all. Indeed, several answers or good reasons exist for their implementation in that specific context. Note that the following reasons are not unique features of auctions and there might also exist further appropriate RES-E support mechanisms that fulfil certain context specific requirements presented in the following. We are investigating this point further in WP6.

First, an important factor is that project developers usually have more precise information on their expected costs and revenues than the government, i.e. in the RES-E context there exists a situation of information asymmetry (e.g. McAfee, et al. (1986) and IRENA, et al. (2015)). Therefore, project developers should come up with a suggestion of a cost-covering support level – as it is the case in auctions – and not vice versa as for example in case of fixed feed-in tariffs predetermined by government. Hence a decentralisation of information about costs and revenues can be exploited by introducing auction schemes.

Another valid reason for auctions for RES-E is the option of controlling costs, expansion and the technology mix (IRENA & CEM, 2015). That is, the auctioneer can either limit the annual auction budget for RES-E, where the number and total size of awarded projects is uncertain, or restrict the annual number or total size of awarded projects and thereby leave the budget needed uncertain (Latacz-Lohmann & Steven, 2005). Further, the alternatives of conducting technology-neutral or technology-specific auctions enable the regulation of the technology mix in an appropriate manner (Bode & Groscurth, 2013).

Since auctions primarily are an allocation mechanism, the auctioneer aims to ensure allocative efficiency. Namely, if an auction allocates the good or multiple goods efficiently to the bidders, there exist no ex post incentives for resale (Ausubel & Cramton, 1999). Therefore, we will focus on the identification of allocative efficient auctions in our following analysis. However, there might be certain market and framework conditions that rather compromise allocative efficient outcomes than others (see Section 4). Furthermore, well-designed auctions are a competitive market mechanism through which valuable information can be generated. On the one hand, the government collects signals about cost-covering support levels. On the other hand, even project developers can learn from the auction outcome, especially if the award prices are released. Because project developers face competition in an auction in form of award risks, a well-designed auction also generates incentives for innovation (Bode & Groscurth, 2013).

1.3 Classification of auctions relevant for RES-E

An auction is a mechanism (institution) in which a good or several goods (here: the power (MW) or physical work (MWh) of renewable energies) are offered up for bidding. It is a market mechanism with several aims, whereby auction theory mainly focuses on competitive price determination and efficient allocation of one or multiple goods (further aims see WP2[1]). Consequently, auctions for renewable energy support are applied in order to reduce costs of support and identify the "best" (with respect to predefined targets and criteria) suppliers for renewable energy. Since those suppliers will act as bidders (sellers), who offer the auctioned good to the auctioneer, we refer to these auctions as so-called procurement auctions. That is, the auctioneer will buy the good from those bidders offering the best bid, e.g. the lowest price. As the auctioned volume might be split up and delivered by several bidders, our analysis focuses on multi-unit auctions with homogeneous or heterogeneous goods. The homogeneous goods are certain equivalent subsets of the total power offered up for bidding, where the scaling may differ (1MW, 10MW, etc.). The heterogeneous goods are predetermined projects by the auctioneer that are offered for realisation. The bidders (suppliers) will be awarded an amount of the power subsets or projects according to their bids, i.e. the best bids will win as long as the offered amount is less than or equal to the demanded amount. In addition, single-unit auctions may be implemented (see wind offshore auctions in Denmark), which represent a special case of multi-unit procurement auctions with only one single good. Here the same applies as above, the auctioneer can either predetermine the project auctioned and bidders compete for this sole project (intra-project competition) or the each bidder participates with his individual developed project (inter-project competition). The best bid(s) can either be determined based solely on the price (i.e. costs of support) or by multi-attributive criteria such as price, actor diversity, geographical and technological conditions, etc. (see WP2[2]). For reasons of clarity, we will limit our analysis on the former kind of auctions, i.e. homogenous or heterogeneous multi-unit procurement auctions with the bidding price as sole criterion. Note that each multi-criteria auction can be transformed into a single-criterion auction, if the criteria and evaluation approach are

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[1] Please find the corresponding report “Assessment criteria for RES-E auctions” (WP2) on the AURES webpage (http://www.auresproject.eu/publications/assessment-criteria-res-e-auctions)

[2] Please find the corresponding report “Assessment criteria for RES-E auctions” (WP2) on the AURES webpage (http://www.auresproject.eu/publications/assessment-criteria-res-e-auctions

traceable and transparent to all bidders and hence the corresponding bid reflects all criteria (e.g. price-based weighting of all relevant criteria).

1.4 The specifics of RES-E as an auctioned good

1.4.1 What is auctioned?

The question of what is or should be auctioned strongly depends on the preferences regarding the auctioneer's aims. Is his fundamental aim to keep to a predetermined budget? Or is his primary aim to achieve the expansion goal? Hence, we start by attending to the determination of the auction volume, which can either be determined endogenously or exogenously. That is, the auctioneer has two options, where he can either restrict the monetary budget or limit the amount of supported RES-E, e.g. the awarded rating power in MW, the amount of supported MWhs or the number of projects. Latacz-Lohman and Schilizzi (2005) conducted controlled laboratory experiments in order to compare budget-constrained and target-constrained auctions and find that there exist no crucial reasons to favour one approach over the other.

Endogenous auction volume

The first option, that is to limit the budget, strongly focusses on controlling and reducing the support costs and even accepts the risk of not achieving predefined expansion goals. The bids demanding the lowest support levels will be awarded until the total budget is reached. Hence, if bidders submit relatively high bids the total budget is reached early and consequently the expansion goal is missed. However, note that an appropriate reservation price (i.e. maximum price) may reduce the risk of strategically high bids. Finally, this approach only makes sense for multiple and only individually developed projects, i.e. bidder specific projects. An application example of this option can be found in the Dutch SDE+ auction.

Exogenous auction volume

The second option, to limit the supported amount, corresponds to the idea of achieving a predefined expansion target, where the support costs become a secondary goal. Although the government aims to increase the expansion of RES-E, they are interested in a controlled expansion, for example due to grid constraints or public acceptance issues.

In this case, the lowest bids based on demanded support levels will be awarded until the expansion target (MW or MWh) is reached. However, this option leaves the support costs uncertain in favour of a fulfilled expansion goal. Note that the support costs, however, can be limited by setting an adequate reservation price (i.e. maximum price).

Based on the volume dependent approach, there exist several options for “the goods” auctioned in an RES-E auction. Consequently, the auctioneer has to determine beforehand whether a single good, multiple homogeneous goods or multiple heterogeneous goods are offered up for bidding. In the RES-E context, the former option occurs if only the support for one renewable energy project (or one bundle of projects) is awarded per auction. In this case, the project can either be predetermined by the auctioneer or individually developed by each participating bidder. If the support for more than one project should be determined per auction, on the one hand, the auctioneer can demand a certain amount of homogeneous power or energy units that is delivered by several individual projects of the bidders. On the other hand, he can auction the support of particular heterogeneous projects predetermined by himself, e.g. specific projects at different locations.

Depending on what the auctioneer demands and offers up for bidding, different auction formats will be considered relevant in our analysis, as presented in Table 1. The options presented here are based on the auction formats identified in WP2[3]. Moreover, they fulfil specific requirements for suitability in real-world applications as presented in Section 3, where we undertake a detailed analysis of those auction formats.

Table 1: Relevant auction formats according to goods auctioned

	Single good (one good, predetermined or individual)	Homogeneous goods (multiple identical goods, e.g. MW or MWh)	Heterogeneous goods (multiple different goods, e.g. predetermined projects)
Relevant auction formats	- First-price auction - Second-price auction - Dutch auction - English auction	- Pay-as-bid auction - Uniform-price auctions - Vickrey auction - Ascending auction - Descending auction	- Generalised Vickrey auction - Simultaneous multi-round descending auction

1.4.2 Revealed or hidden auction volume

In addition to the choice of auction volume itself (i.e. the monetary budget or the amount to be supported), the question arises if the auction volume should be revealed or hidden.[4] A public auction volume represents a signal that is relevant for the bidders’ estimation of competition. In this regard, a hidden auction volume

[3] Please find the corresponding report “Overview of design elements for RES-E auctions” (WP2) on the AURES webpage (http://www.auresproject.eu/publications/overview-of-design-elements-res-e-auctions)

[4] Note that this question only arises if individually developed projects are auctioned.

incorporates the same effects with regard to uncertainties of the estimated competition level for bidders as an unknown number of participants – from a theoretical point of view.[5] However, from a practical perspective, potential bidders are rather more suspicious of a hidden auction volume, which seems to be consciously undisclosed by the auctioneer potentially for some intransparent reason, than of an unknown number of participants, which in contrast can be taken rather as a given by the participants. For the following argumentation, we will limit the discussion on the question about revealed or hidden auction volumes.

In general, a revealed auction volume provides certainty and represents transparency and reliability for potential bidders in real-world applications. A hidden auction volume in contrast induces high uncertainties for potential bidders and thus may lead to a reduced acceptance of the auction or even lower the participation. In theory, uncertainties generated by a hidden auction volume refer to the bidders' estimation of competition, i.e. the competition they believe to face in the auction. The higher bidders estimate the competition level the more aggressive is their bidding behaviour, i.e. the lower their submitted bids. Especially non-incentive compatible[6] auction formats are sensitive to this effect, since the degree of costs exaggeration strongly depends on the bidders' beliefs about competition. Under certain basic assumptions[7], both alternatives, i.e. revealed or hidden level of competition, generate the same expected auction outcome in first-price and second-price auctions (Harstad, et al., 1990), whereas under modified assumptions of risk averse bidders the auctioneer benefits from a hidden number of bidders in terms of a higher expected auction revenue in the first-price auction (McAfee & McMillan, 1987). However, the unknown competition level because of a hidden auction volume may lead to misestimating in real-world applications. On the one hand, bidders may underestimate the competition level and submit less aggressive, i.e. higher, bids. Supposing all bidders behave according to this, a hidden auction volume increases the expected support costs. However, on the other hand, especially in case of low competition, general overestimating of the competition level might be indeed favourable for the auctioneer in terms of lower expected support costs. To conclude, a hidden auction volume should in practice only be implemented with caution. Misestimating of competition can always happen in both directions, leading to some bidders bidding more and others less aggressively under the assumption of higher or lower competition. Consequently, hidden auction volumes may induce allocative inefficiencies, especially in non-incentive compatible auction formats, which could have been reduced by revealing the monetary budget or amount of RES-E offered up for bidding. Finally, the main argument for a revealed auction volume is the clear and transparent signal provided by the auctioneer, which creates confidence and acceptance among potential bidders, especially in light of a repeated conduction of the auction. Note that for an incentive compatible auction mechanism the weakly dominant strategy to bid one's true costs is preserved for revealed and hidden auction volumes and hence no related inefficiencies may occur in both cases. Further, Damianov et al. (2010) observe in their

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[5] In case of uncertainties, the auction volume as well as the number of participants can be mathematically modelled by appropriate random variables (McAfee & McMillan, 1987).

[6] In non-incentive compatible auction formats bidders have incentives not to reveal their true costs in their bids, i.e. to exaggerate their costs in their bids for example.

[7] Independent private value -approach with symmetric risk-neutral bidders (see Section 2)

experiments that the uniform-price auction outperforms the pay-as-bid auction in terms of higher auction revenues and allocative efficiency under uncertainties regarding the auction volume. Furthermore, Beck, et al. (2001) find that an ex post reduction of the auctioned volume may eliminate collusive strategies for multi-project bidders in uniform-price auctions.

1.4.3 Valuations for RES-E as an auctioned good

In the following we define the valuations for RES-E as an auctioned good from the bidder's perspective as well as from the auctioneer's perspective.

Bidders evaluate the good, i.e. the projects, in two dimensions: On the one hand, they expect a certain project specific energy generation [MWh] over a plant's lifetime which is for instance based on regional conditions and project size. On the other hand, they have certain individual costs to bear over the lifetime [€], e.g. for project development, realisation, operations and maintenance. Assuming that all costs have to be covered by the support of the project, the minimum required support level is defined by the Levelised Cost of Electricity (LCOE). Hence, from now on we refer to a bidder's valuation for a RES-E project as the expected average LCOE, i.e. the project specific cost-covering support level.[8]

Besides achieving the expansion goal and reducing the support costs, the auctioneer may have further aims as, for instance the promotion of domestic industry or a certain regional distribution of RES-E plants (IRENA & CEM, 2015). To analyse those further aims theoretically, they have to be reflected in the auctioneer's individual valuation, e.g. by a monetary quantification. Imagine that two auctions generate the same expected support costs and the same amount of RES-E awarded. If the auctioneer benefits more from the auction that scores better in terms of actor diversity or regional distribution he should consider further appropriate criteria for allocation. Hence, in order to transfer multiple goals of the auctioneer adequately in the auction, so-called multi-criteria auctions can be used. Multi-criteria auctions are auctions in which further (weighted) criteria beyond the bidding price, such as the institutional organisation or project location, are relevant for the award decision, see Che (1993) and Branco (1997). For the implementation of a (multi-criteria) auction that takes the individual valuation of the auctioneer into account, the scoring and evaluation principles of the auctioneer have to be clear and transparently published to all participants. Moreover, see Bushnell, et al. (1994), Bichler (2000), and Smet (2007). Furthermore, there exist specific design options for RES-E auctions as the implementation of contingents within an auction for certain bidder groups that may also serve those requirements (see WP3.3).

[8] We sometimes even just refer to a bidder's individual valuation as individual "costs", which is equivalent in case of a standardized project size, e.g. rating power.

1.4.4 Bid specification

Based on the good specification and the valuations, the auctioneer defines what information bidders have to submit within their bids. We limit our analysis to the following bid specification: If the auctioned project(s) is (are) completely predetermined by the auctioneer, then bidders bid on their requested support level for the realisation regarding the particular project. If bidders participate with their own individually developed projects, they submit bids representing all project specific data relevant for the evaluation of the auctioneer, e.g. size, power rating, region, business form, etc., and the corresponding support level requested. Finally, all (valid) submitted bids are transferred into the award process of the auction, where the auctioneer evaluates them according to the predefined criteria and correspondingly awards them until supply equals demand.

1.5 Criteria to assess different auction types suitable for RES-E

In our subsequent analysis we will assess the relevant auction types identified in WP2[9] with regard to

- Price determination
- Signal generation
- Expected auction revenue (RES-E support costs)
- Incentive compatibility
- Allocative efficiency
- Auctioneer's risks, e.g. risks of unfavourable strategic behaviour (strategic reduction of competition, implicit collusion)
- Bidder's risks, e.g. award risk, award price risk, risk of the winner's curse.

Note that for an overall assessment of an auction, those criteria should not be considered separately but combined and weighted according to the auctioneer's goals.

Price determination

A well-designed auction is a mechanism that serves to generate competitive prices, in particular in markets where the market clearing price is unknown. We distinguish between different forms of price determination, i.e. either a common price for all winning bidders is generated or each bidder receives an individual price. However, all prices are determined through the submitted bids in the auction. Finally, one common price per RES-E auction might be favoured from a political point of view, because a common price represents one

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[9] Please find the corresponding report "Overview of design elements for RES-E auctions" (WP2) on the AURES webpage (http://www.auresproject.eu/publications/overview-of-design-elements-res-e-auctions)

clear price signal. We will go more into detail with the price determination issue in the further work of the project.

Signal generation

If information about the auction outcome, e.g. the award price(s) as the spectrum or average of bids and/or award prices and the awarded volume as well as the submitted volume, is revealed during or after the auction, the auction generates signals for the participating bidders as well as for potential bidders in future auction rounds. That is, project developers receive information from the auction outcome that helps them evaluating their individual risks and chances regarding a future participation in the auction as well as to re-evaluating their strategy in the past round. Provided that the auction is well-designed and generates competitive prices, potential project developers learn about their competitors' support levels and can thus derive which costs and bids are competitive. Although dynamic auctions, for instance, may generate more information during the bidding process than static auctions, the ex post accessible information strongly depends on what the auctioneer reveals after conduction of the auction. In addition, there are auction formats that generate information that is more precise than others. For example, in some auction formats the submitted bids correspond to the expected costs of the particular bidders (see Subsection *Incentive compatibility* below). This fact facilitates the acquisition of information.

Expected auction revenue (RES-E support costs)

The reduction of support costs for renewable energy has become an important goal pursued by the introduction of auctions. Hence, the success of an auction will be evaluated based on the support costs generated through the auction, for instance, in comparison to alternative support level setting mechanisms such as administratively set feed-in tariffs, where further results as the expansion achievement etc. may be considered as well. The expected auction revenue may differ between auction formats, where not only the auction format itself but also the market and framework conditions in which those auction formats are conducted play a crucial role. Assuming the auctioneer is only focused on achieving the expansion goal, he aims to minimise his expected support costs by choosing the corresponding “cheapest” auction format based on the existing market and framework conditions. However, if the auctioneer pursues additional goals, e.g. actor diversity or regional distribution of RES-E plants, by conducting the auction, these goals have to be incorporated in his individual valuation, e.g. by a monetarily quantification. This may lead to the auctioneer benefiting more from an auction outcome that ensures actor diversity than from another that generates lower support costs.

Incentive compatibility

As the auctioneer aims to minimise the expected support costs through the choice of an appropriate auction format, a bidder maximises his expected profit by optimising his bidding strategy in the auction. The incentive compatibility is an important characteristic of bidding induced by certain auction formats and framework conditions. It means that bidders have an incentive to reveal their true costs in their bids. One reason for that is that bidders cannot influence their own support level through their bid in incentive compatible auction formats. They only determine whether they will be awarded or not by bidding. Usually, incentive compatible auctions induce weakly dominant bidding strategies[10]. In non-incentive compatible auctions, bidders determine or at least partly impact their support level in case of being awarded. As a consequence, they usually have an incentive to exaggerate their true costs in their optimal bidding strategies.[11] Hence, bidders submit higher bids in non-incentive compatible auctions than in incentive compatible formats. However, incentive compatible auction formats do not necessarily generate lower support costs. There are also situations in which it is exactly the opposite. Under specific conditions, certain incentive and non-incentive auction formats even generate the same expected support costs (see Section 2). This auction theoretical phenomenon is stated in the so called revenue equivalence theorem. The main advantages of incentive compatibility are that the optimal bid is easy to calculate for the bidders and that incentive compatible auctions result in allocative efficient outcomes, since the truthful (optimal) bid of a bidder is independent of his risk attitude and his beliefs about his competitors. It is a very straight-forward strategy to bid one's own expected costs in contrast to calculate an optimal bid exaggeration in non-incentive compatible auctions. Hence, it is often argued that incentive compatible auctions are easier to understand and to manage, especially for smaller or less experienced bidders (Harrison, 1989). Nevertheless, it is often observed that bidders do not honestly reveal their true costs in incentive compatible auctions in real-world applications. Especially, the practical risk of underbidding is higher in incentive compatible auctions than in non-incentive compatible auctions, see Kagel, et al. (1993) and Cooper, et al. (2008).

Finally, the incentive compatibility only applies under very limited conditions that, however, may not adequately reflect the given reality. For instance, the uniform-price auction with lowest rejected bid is often mentioned as an incentive compatible auction mechanism (Myerson, 1981). Nevertheless, only single-project bidders, who further participate in only one single auction round, have incentives to reveal their true costs in that particular auction. Multi-project bidders would have incentives to exaggerate their costs at least for some of their projects (see Section 4.2). The same applies if bidders have the chance to participate in later auction rounds as well. Then incentives for bidders occur to exaggerate their individual costs in an earlier round, since they anticipate an additional winning probability through their participation in later

[10] Applying a dominant bidding strategy always generates a higher expected profit than playing any other of his possible strategies independent of which strategies the competitors choose.

[11] Bidders optimise their bidding strategy by exaggerating their costs in those non-incentive compatible auctions identified in WP2. Note, that there are also other auction formats and framework conditions where the optimum strategy for bidders may be to bid less than their costs for at least one unit.

rounds. From a theoretical point of view, it can be expected that the bids regarding one project of a particular bidder will decrease continuously over multiple rounds and converge towards the optimum bid in the corresponding one-time auction (Gale & Hausch, 1994).

Allocative efficiency

An auction serves not only as price determination but also as allocation mechanism of goods in case of excess supply. In theory, the question of an optimal allocation generally addresses the aim of Pareto efficiency[12] and of maximising welfare. An allocative efficient auction mechanism maximises welfare by allocating the good to the participant with the highest valuation.[13] Or in other words, the best bidder wins, i.e. the project developer with lowest support costs and/or highest scores in other relevant transparent criteria predetermined by the auctioneer and represented in the corresponding bid. Hence, the aim of allocative efficiency is important in terms of fairness, mitigating resale incentives, see Ausubel, et al. (1999). Allocative efficiency can be at risk due to incentives for unfavourable strategic bidding behaviour, asymmetries regarding valuations and information between bidders, e.g. because of different risk attitudes or planning periods, and the participation of multi-project bidders in the auction. Since the actual or expected costs of project developers are (at least partly) private information, it is not possible to assess an auction outcome in real-world applications as allocative efficient. Consequently, note that though allocative efficiency is an ex post criterion, it cannot be proven ex post in real-world applications but only in theory. However, from an auction theoretical perspective auction formats can also be evaluated ex ante with regard to their expected allocative efficiency. That is, a theoretical efficiency investigation serves at least the purpose of identifying which auction format is expected to be suitable for generating allocative efficient outcomes in practice.

Auctioneer's risks

In the decision of conducting an auction for RES-E the auctioneer has to face and balance certain risks such as excessive prices, insufficient competition and unfavourable strategic bidding behaviour. The latter refers particularly to strategic supply reduction and implicit collusion. Obviously those three categories of risk, the former two in particular, may interact. For instance, decreasing competition increases prices. However, their triggers are complex and in order to identify their original causes, the analysis benefits from a separate consideration.

[12] In a Pareto-efficient outcome, no participant can improve without placing another participant in a less favourable situation. That is, a Pareto-efficient outcome is always stable against incentives for resale.

[13] Note that if we assume that resale is generally allowed, an allocative efficient outcome is always Pareto-efficient as well.

Although the auctioneer can choose the auction format generating the lowest expected support costs under given market and framework conditions, there exist further reasons beyond the auction format that lead to increasing bid prices, e.g. uncertainties regarding high penalties or a high willingness of bidders to take award risks in non-incentive compatible auctions.

Furthermore, potential bidders may distrust an intransparent or too complex auction mechanism. Additional uncertainties which the bidders, such as sunk costs stemming from expenditures for prequalification in unsuccessful bids, may discourage bidders and hence lower the participation in the auction.

Strategic supply reduction is a phenomenon that, on the one hand, can occur if at least one bidder is interested in realising more than one project and consequently submits more than one bid in the same auction. These multi-project bidders consider before as well as during the auction, especially in dynamic auctions, whether it is better for them to bid on all units they are interested in or to withhold some bids in order to generate more profitable support levels for the remaining ones. If a bidder is able to increase his expected rent by waiving additional units, he will reduce his bids accordingly. This behaviour is called strategic supply reduction and leads to a reduced competition in favour of higher support levels. On the other hand, the issue of strategic supply reduction is also relevant before the background of repeated auction rounds, since bidders may have incentives to reduce their supply in particular rounds and instead coordinate their total supply over multiple auction rounds.

Finally, collusion is an unfavourable strategic bidding behaviour that is eventually less tangible and benefits from a transparent bidder structure, meaning that bidders know each other quite well and/or the number of participating bidders is relatively low. Explicit collusion is commonly prohibited by law, but in real-world applications it can be observed that bidders succeed to circumvent the law by implicit collusion. A famous example of implicit collusion is the auction for telecommunication licenses in Germany in 2000, where bidders succeeded to communicate via number combinations in their bids[14] (Klemperer, 2002). Appropriate auction designs, for instance static auctions instead of dynamic auctions or pay-as-bid instead of uniform-price auctions (see Section 3), minimise any incentives for bidders to coordinate as well as hinder the realisation of implicit collusion strategies.

Bidder's risks

The first obvious difference between the more 'traditional' renewable support schemes, such as feed-in tariffs with guaranteed support levels, and competitive auction mechanisms is the award risk. The necessary condition of sufficient competition for a successful auction implies that some bidders have to go away empty-handed. Consequently, whereas project developers often had a guarantee for support in earlier schemes, they now have to handle the risk of not being awarded in an auction mechanism. How the bidders

[14] "Vodafone–Mannesman ended a number of its bids with the digit "6" which, it was thought, was a signal that its preference was to end the auction quickly with six remaining bidders." (Klemperer, 2002)

evaluate/quantify this risk strongly depends on the investments for prequalification, since these costs are sunk and lost in case of not being successful in the auction. The higher the sunk costs, the more are bidders discouraged to bear the award risk and participate in the auction.

Furthermore, there are auction mechanisms in which the award price is uncertain at the time of bid submission.[15] That is the case if a bidder's bid has no influence on the corresponding award price in case of winning, which applies for instance in the uniform-price auction (with lowest rejected bid) and the Vickrey auction. The award risk as well as the award price risk increase uncertainties on bidders' side and might discourage bidders to participate in the auction at all.

Another prevalent phenomenon that may occur under specific assumptions is the risk of the winner's curse. If a bidder suffers from the winner's curse, he realises after being awarded that his actual costs exceed the award price. This phenomenon applies to situations where the individual actual costs are unknown before the auction and bidders can only estimate them, whereas the support costs are either the same for all bidders or at least are interdependent among all bidders. From a theoretical perspective, a rational bidder will ex ante never suffer from the winner's curse as he anticipates this aspect adequately in his bidding behaviour. However, the phenomenon may still occur from an ex post point of view. In general, there are auction mechanisms with higher and lower risks of the ex post winner's curse. For instance, dynamic auctions potentially mitigate this risk as they can facilitate the adequate anticipation of the winner's curse because bidders may obtain valuable information during the auction. This is true if the individual valuation of a particular bidder depends in fact on the signals of the competing bidders, e.g. in case of interdependent valuations, and he can actually observe those during the bidding procedure.

A similar but different risk is the risk of underbidding, i.e. the risk that bidders bid below their costs. We distinguish between conscious underbidding for strategic reasons and unconscious underbidding that may occur if bidders had not calculated their costs appropriately. Whereas a rational bidder would never unconsciously underbid, conscious underbidding may occur in real-world applications due to securing long-term market power through crowding out.

Excursus: Irrational bidding

An auction theoretical analysis is always based on the assumption of rational bidders. A rational bidder maximises his expected profit by submitting an optimal bid according to his available information at the time of bid submission. However, if auctions are implemented in real-world applications the assumption of rationality cannot be taken as a given and irrational bidding behaviour may occur, see e.g. Miller, et al. (1985), Harrison (1989), and Manelli, et al. (2006), i.e. submitting bids that are not expected to be profit maximising according to the information available. There exist several reasons for irrational bidding in

[15] In pay-as-bid auctions, for example, the bidders know their award price (= their bid) at the time of bid submission.

practice. First, the auction format can be misunderstood by the participants and it can be an overly high burden for bidders to develop an optimised bidding strategy (e.g. Uniform-price auctions, see Section 3). Besides, bidders may incorporate the available information incompletely and/or incorrectly in their bidding strategies. Finally, the insufficient anticipation of the winner's curse may provide another reason for underbidding in case of an interdependent value approach (see Section 2).

In general, each auction format involves a different risk of irrational bidding behaviour and hence auction formats have to be evaluated separately in that context. However, the auctioneer could reduce the general risks of irrational bidding by providing appropriate information and/or trainings for potential participating bidders, as the experiences of participating bidders regarding the implemented auction format plays a crucial role. That is, if bidders are rather experienced with auctions or particularly the specific auction format, the risks of irrational bidding behaviour can be mitigated.

2 Theoretical framework: Independent private value model or interdependent value model

In auction theory, two approaches are distinguished in order to model bidders' valuations (costs and revenues, see Subsection 1.4.3) of the good (Krishna, 2009). Both approaches are relevant for the RES-E context depending on the specification of the auctioned good: On the one hand, all bidders can participate with their individually developed projects in the auction and only be awarded with their own project. On the other hand, one or several project(s) can be predetermined and offered up for bidding by the auctioneer, where multiple potential project developers compete for the award of those predetermined project(s). Whereas the so-called independent private value approach lends to model the former case, the interdependent value approach can serve to abstract the latter case. Consequently, we will look at two different value models here in order to distinguish between individually developed projects by bidders and predeveloped projects by government. This will form the basis for understanding the auction formats which are introduced in the next section.

2.1 The independent private value model (IPV)

The independent private value approach (IPV) is often used as a starting point because of its simplifying theoretical properties. This model assumes that each bidder exclusively knows his own costs[16] and only has certain beliefs about the other bidder's costs, where the costs of all bidders are independently drawn from a

[16] In the IPV model we use costs as a synonym of signal. Because, in contrast to the IV approach, here a bidder's actual valuation corresponds exactly to his individual signal. That is, a bidder's valuation is not affected by the other bidders' signals or any other external signals.

known distribution. All that is common knowledge to all participants, meaning that all bidders and the auctioneer have the same information.

From a theoretical point of view, there exists a unique symmetric Nash-equilibrium in pure strategies in the IPV model under the assumption of symmetric, risk-neutral, single-project bidders for the following multi-unit auction formats introduced in WP2[17]

- Static auctions: pay-as-bid auction, uniform-price auctions and Vickrey auction
- Dynamic auctions: ascending and descending clock auction

Hence, let us have a first look at these auctions under those assumptions. In the corresponding equilibria, all multi-unit auction formats are expected to be allocative efficient as well as revenue equivalent (Engelbrecht-Wiggans, 1988). That is, although bidders submit different bids depending on the auction format, all auctions end with the same expected result (Maskin, et al., 1989). In each auction, a bidder chooses the strategy that maximises his expected rent (profit). The expected rent is computed from all possible rents, which can be achieved by the strategy, weighted by their corresponding possibilities of winning. In all auction formats bidders will submit bids equal to or greater than their costs in order to ensure a positive profit in case of winning.
The uniform-price auction with lowest rejected bid, the Vickrey auction, and the descending clock auction are incentive compatible under above mentioned assumptions, which means, that bidders have an incentive to bid their true costs. One reason for that is that bidders cannot influence the award price through their bids in case their bids are awarded and consequently bid exactly their true costs.
The pay-as-bid auction and the uniform-price auction with highest accepted bid as well as the ascending clock auction, in contrast, are not incentive compatible, since the bid determines the award price, i.e. the award price is equal to the bid in the pay-as-bid auction and is determined by the bid with positive probability in the uniform-price auction or the ascending clock auction. As a consequence, bidders exaggerate their true costs in order to balance the trade-off between increasing their rent in case of winning (higher bidding) and increasing their winning probability (lower bidding).
Nevertheless, the higher bids in the non-incentive compatible auctions are balanced in the corresponding equilibria and all above mentioned auction formats result in the same efficient allocation as well as in the same expected award price (Engelbrecht-Wiggans, 1988). Because of the revenue equivalence, the IPV approach provides an appropriate starting point for further analyses and a profound understanding of the particular auction formats as well as for carving out differences between them.

Note that this result also applies for single-unit auctions, i.e. first-price auction and second-price auction. But whereas the second-price auction is incentive compatible, bidders have the incentive to exaggerate their true costs in the first-price auction (Myerson, 1981).

[17] Please find the corresponding report “Overview of design elements for RES-E auctions” (WP2) on the AURES webpage (http://www.auresproject.eu/publications/overview-of-design-elements-res-e-auctions)

How does the IPV approach apply to the RES-E context?

We consider the option for RES-E auctions where each bidder participates with one or several individual projects that differ e.g. by their particular locations. Each project developer knows his individual project-related costs but not those of his competitors. The reason is that, on the one hand, individual cost structures per se are usually not public and, on the other hand, bidders often do not know who else participates in the auction. Nevertheless, project developers may have certain estimations about the competition level as well as their competitors' costs, e.g. based on earlier experiences in the particular industrial sector or respective market analyses. That is, project developers have only certain beliefs about their competitors' costs, but do not know them exactly. Further, the competitive costs are widely irrelevant for their own cost calculation as projects differ significantly, e.g. depending on the location. Another aspect is that project developers often have to face long development periods and thus uncertainties regarding their individual costs estimations may occur as well. That is, potential bidders have not only limited information on their competitors' costs but sometimes even with regard to their own costs. However, since they can undertake assessments of their own particular situation as for example quantify the potential of wind or solar power for their individual project and know their planned power rating and construction type, bidders can estimate their individual costs quite well (Bofinger, 2013).

Assuming the bidders know their individual costs exactly, uncertainties regarding the competitor's costs are mathematically modelled by random variables. In these models, the spread of the expected cost outcomes decreases as information about the competitors' costs structures improves, i.e. the more precise the approximations of their competitors' costs structures become. Note, for example, that bidders in technology-specific auctions may have quite similar costs structures, whereas in technology-neutral auctions costs can vary significantly between bidders. In case there are also uncertainties regarding the individual costs of a bidder, the IPV approach has to be extended correspondingly. Therefore, the individual costs can also be modelled by random variables that represent the expected individual costs including all relevant uncertainties. However, the success of an adequate mapping from real costs (competitive and/or individual) into a theoretical distribution is limited. Nevertheless, the abstraction of the real situation for RES-E described above into the IPV model involves only very small natural trade-offs and hence serves as a suitable theoretical approach.

2.2 The interdependent value model (IV)

The interdependent value approach (IV) includes private value components as well as common value components. That means that the individual valuation of a bidder depends not only on his own signal but also on other (unknown) signals as for example those of his competitors or even further external signals. A pure common value approach, as an extreme case of the interdependent value approach, acts on the assumption that all bidders have the same valuation for the good. This applies if the individual valuations of all bidders are affected equally by the same signals, e.g. if the actual valuation of the good is represented by the sum or average of all signals. In contrast, the individual valuation of the good may also be primarily influenced by the bidder's individual signal, for example, which leads to different actual valuations among bidders. However, in all cases the exact valuation of the good is uncertain for all participants at the time of the auction. That is, although bidders have a private signal regarding the value of the good, they can only estimate the exact value based on their individual signal plus common information such as the distribution functions of the other relevant signals or the scope of the value distribution of the good. In general, the value estimation would be facilitated if bidders also received the other relevant signals, e.g. those of their competitors. That is, the more signals a bidder would receive the more accurate becomes his estimation about the value of the good. At this point, the question may arise why it is actually important for the bidder to make his valuation as accurate as possible at the time of the auction. The reason is that bidding without knowing one's actual valuation carries a general risk of under- and overbidding based on erroneous valuations. Especially underbidding may represent a serious risk for bidders in procurement auctions, since a non-cost award price may be the consequence. In auction theory, we refer to this phenomenon as the winner's curse. We suppose that the bidder submitting the lowest bid wins, who is in the extreme case of a common value model probably exactly the bidder who unfortunately underestimated the costs of the good the most. Hence, it is apparent that in an interdependent value model, bidders benefit from learning about other bidders' signals, e.g. in dynamic auctions, in order to reduce their risk to suffer from winner's curse. In general, the higher the common value component in an interdependent value model, the higher is the risk of the winner's curse (Krishna, 2009).

How does the IV approach apply to the RES-E context?

If one (or several) particular project(s) is (are) offered up for bidding to several potential project developers, there exist common value aspects, e.g. represented by the potential of wind or solar power in the region of the corresponding project(s). Before the auction, bidders may have different estimations about this potential and only in case of being awarded they will learn the actual potential of the project. Particularly, all bidders will realise the same potential over time if they have been awarded. Consequently, this is a common value dimension. In addition, there remain bidder specific private value aspects as for example operating and investment costs. Hence, if bidders compete for identical projects the, IV approach is suited as a theoretical model. The more project features such as power rating, equipment manufacturers and others are predetermined by the auctioneer, the higher the common value component.

3 Auction formats suitable for RES-E

As auction mechanisms are not a panacea, there are several requirements to fulfil in order to ensure the suitability in general and for RES-E in particular. First and foremost, a necessary condition is sufficient competition, i.e. supply must exceed demand in procurement auctions, in order to avoid excessive prices. Hence, the auctioneer needs to determine the auction volume (supply) in an appropriate manner, e.g. ensure excess of supply based on recent market analyses.

A suitable auction design reflects adequately the predetermined policy goals as well as the bidder's calculus (Bode & Groscurth, 2013). First, that means that each specific design element is implemented in the auction so as to trigger a specific behaviour or situation that can be directly linked to the policy goal it was aimed at. The adequate reflection of bidders' calculus by a corresponding bidding structure can for example be implemented with quantity price-bids, since for a bidder's calculation the power rating of the project [MW] and the related support level [€ per MWh] is decisive. Further, a suitable auction mechanism should minimise bidders' risks as well as specific risks of the auctioneer. Note that these risks are likely to occur particularly under certain market and framework conditions (see Section 4).

For multi-unit procurement auctions a broad variety of auction formats exists and has already been introduced in WP2[18]. There we distinguish between static and dynamic auctions as well as hybrid auction formats.

Our analysis here will be limited to auctions in which the following three basic principles are met:

- Bids are binding
- The best bids (according to a pre-specified evaluation rule considering all relevant criteria) will win
- The winning bidders will at least receive their bid price

These principles are motivated by the aim of a transparent and fair auction mechanism that induces high acceptance among project developers and hence a high level of participation, especially against the background of repeated auctions. First, the option to crowd out other projects within the auction, e.g. the submission of relatively low bids that are withdrawn in case of award, should be avoided by binding bids and awards that are combined with withdrawal penalties. Second, an allocation which is subsequently considered fair should award the best bids according to relevant criteria, with the criteria having been revealed before the auction to the participating bidders. Finally, bidders have to face award price risks in some auction formats, i.e. they do not know their future award price as they have no influence on their price in case of winning. Hence, a bidder friendly auction should at least guarantee a minimum award price for each bidder based on his corresponding bid. Namely, in light of bidders already having to cope with award volume risk, it might lead to excessively high risk for investors if they also should face award price risk in an auction design that does not guarantee them at least receiving their bid level when being awarded. Another

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[18] Please find the corresponding report "Overview of design elements for RES-E auctions" (WP2) on the AURES webpage (http://www.auresproject.eu/publications/overview-of-design-elements-res-e-auctions)

reason for the third principle is, that auctions in which bidders may receive less than their bid set strong incentives for unfavourable bidding behaviour.

Although these basic principles seem very intuitive, there exist auction formats, not only in theory but also in practice, which do not meet all of them. For instance, the median price auction, which was implemented to auction durable medical equipment in the U.S.in 2009 and failed in many respects, does not meet the third criterion, as the following example illustrates (Cramton, et al., 2015).

<ins>Example: Unfavourable characteristic of the median-price auction</ins>

We assume, that 3 goods are auctioned and i= 1,…,5 potential suppliers, where each supplier can only deliver one good, submit the following bids in monetary units: $b_1 = 10$; $b_2 = 12$; $b_3 = 13$; $b_4 = 15$; $b_5 = 16$. Then the auction allocates the 3 goods to Bidder 1, 2 and 3. The award price p is the median of the winning bids, i.e. $p = b_2 = 12$. Consequently, Bidder 3 gets less than his bid, $p = 12 < 13 = b_3$. This characteristic sets strong incentives for unfavourable bidding behaviour as strategically high bids, for example, and hence should be avoided.

In the following we will focus on suitable auction mechanisms for RES-E that fulfil those three basic principles.

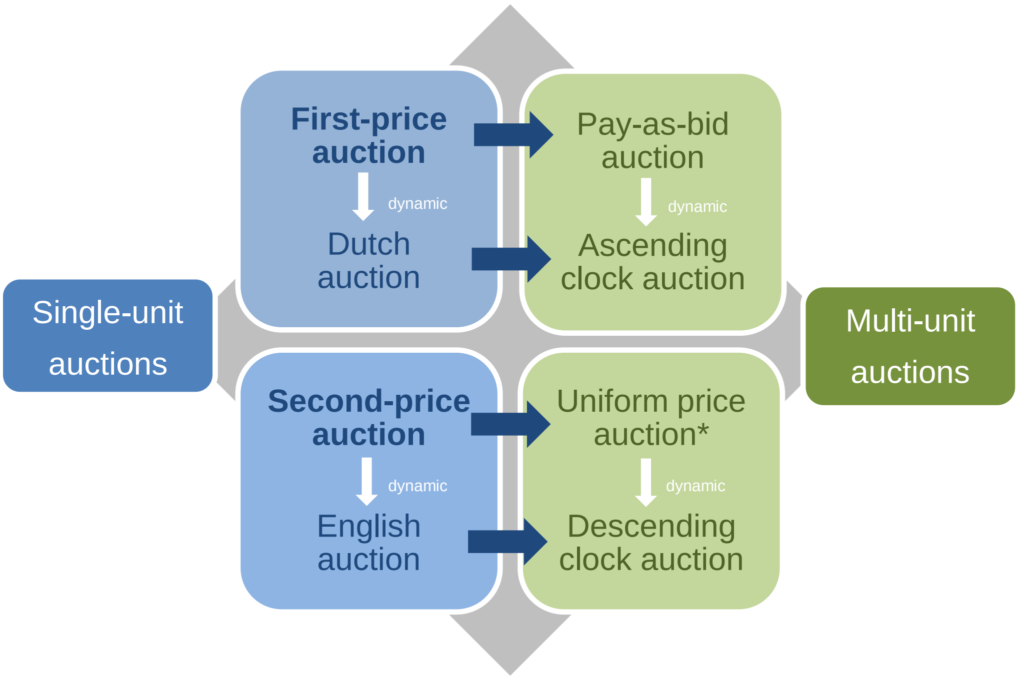
If not mentioned separately, we will as a starting point base our analysis on the following *simplifying assumptions*: We investigate relevant auction formats under the standard assumptions of an independent private value (IPV) model with symmetric, risk-neutral single-project bidders. Further, we start by assuming that in this case there are no prequalification or penalty measures, but they will be discussed later in WP3.3. Hence, for now we limit our investigation to these basic assumptions without further restrictions in order to understand and emphasise essential characteristics of the relevant auction formats for RES-E as well as identify fundamental differences between them. Furthermore, we will discuss suitable auction systems under specific market conditions deviating from these basic assumptions in Section 4.

Finally, in the following the auction formats identified in WP2[19] are analysed and evaluated regarding their suitability for RES-E. Based on our simplifying assumptions, Figure 1 divides the relevant auction formats in single- and multi-unit auctions for homogenous goods, where the static auctions (first- and second-price auction, pay-as-bid and uniform-price auction) are represented with their dynamic counterparts (Dutch and English auction, ascending and descending clock auction). To avoid redundancy, the subsequent assessment in Section 3.1 covers single-unit auctions as a special case of multi-unit auctions for homogenous goods with only one unit, where bidders participate with their individual projects. Furthermore, multi-unit auctions for heterogeneous goods are analysed separately in Section 3.2. Note that single-unit

[19] Please find the corresponding report “Overview of design elements for RES-E auctions” (WP2) on the AURES webpage (http://www.auresproject.eu/publications/overview-of-design-elements-res-e-auctions)

auctions in which the auctioned project is predetermined by the auctioneer have to be analysed under common value assumptions and are hence considered in Section 4.3 rather than in this section.

Figure 2: Single-unit auctions and their corresponding extensions to homogenous multi-unit auctions



**only UP with lowest rejected bid*

3.1 Multi-unit auctions for homogenous goods

3.1.1 Static auction formats

The most common static auction formats of multi-unit auctions for homogenous goods are the pay-as-bid auction, both variants of the uniform-price auction and the Vickrey auction.

Pay-as-bid auction

First note that the pay-as-bid auction corresponds to the first-price auction if only one good is auctioned. In a pay-as-bid auction, bidders determine their winning probability as well as their award price through their submitted bid. That is, they have an incentive to exaggerate their costs in order to benefit from a higher rent in case of winning, however, at the expense of a lower winning probability (Krishna, 2009). Note that a bidder realises only a positive profit in case of winning, if his bid exceeds his costs. Hence in other words, the higher the bid the higher the profit in case of winning, but also the lower the probability to be successful at all. In balancing this trade-off a bidder’s risk attitude plays a decisive role, because the higher the risk

aversion of a bidder, the smaller the exaggeration of his costs (Myerson, 1981). In laboratory experiments it is often observed that human beings rather behave in a risk-averse manner (Harrison, 1989).
The main advantage of the pay-as-bid auction is that bidders have no uncertainties about their award price in case of winning, since they receive exactly their bid. Further, the pay-as-bid auction is relatively stable against unfavourable bidding behaviour even under specific market conditions as we will see in Section 4. However, the main disadvantage of the pay-as-bid auction is the risk of generating very different award prices among bidders as the following example illustrates.

> Example: Different award prices in the pay-as-bid auction
> We assume that three homogeneous goods are offered up for bidding and four potential suppliers with single-unit supply submit the following bids: b_1=7MU, b_2=9MU, b_3=14MU, b_4=15MU. Consequently, the bids of Bidder 1, 2 and 3 are awarded and the highest awarded bid (b_3=14) is two times higher than the lowest awarded one (b_1=7).

Uniform-price auctions

The two variants of the uniform-price auction differ in regard to the pricing rules, which induce different incentives for bidders and hence affect the bidders' individual bidding behaviour in different ways. The uniform-price auction with lowest rejected bid (LRB) is incentive compatible (at least for single-project bidders as assumed here). In contrast, the bidders have incentives to exaggerate their true costs by bidding in the uniform-price auction with highest accepted bid (HAB) (Krishna, 2009). One reason (i.e. necessary condition) for the incentive compatibility in the former case is that bidders who only submit one bid never determine their award price in case of winning, whereas in the second variant a positive probability exists to determine the award price through the submitted bid. An obvious disadvantage of the uniform-price auction, especially in contrast to the pay-as-bid auction, is that bidders have to face uncertainties at the time of bid submission regarding their award price in case of winning, see example.

> Example: Award price risk in the uniform-price auction
> We assume that three homogeneous goods are offered up for bidding and four potential suppliers with single-unit supply submit the following bids: b_1=6MU, b_2=9MU, b_3=10MU, b_4=15MU. Hence, the bids of Bidder 1, 2 and 3 are awarded at a price of 15MU if the uniform-price variant of the lowest rejected bid applies.
> If Bidder 4 submitted a bid of b_4=11MU, the award price of bidder 1, 2 and 3 would have been 11MU.

Consequently, the awarded bidders have no influence on their price at all in case the award price solely depends on the lowest rejected bid. However, bidders know beforehand that the award price is at least equal to their bid or even higher. Based on this fact, another disadvantage of the uniform-price auction is the increased risk of irrational underbidding. This is obviously caused by mistaking the auction form by inexperienced bidders (Miller & Plott, 1985). Namely, in case of underbidding, bidders basically follow the idea of increasing their winning probability by an excessively low bid. At the same time they seem not to recognise that they only increase their winning probability compared to a cost-covering bid by the cases of being awarded with a not cost-covering support level. That is, they do not take into account that a bid below their (expected) costs might lead to a not cost-covering award price in case of winning. Finally, the main advantage of the uniform-price auction, in both variants, is the common award price, which from a political perspective may be favoured in contrast to different award prices in an auction due to a clear and common price signal. The vulnerability of unfavourable strategic behaviour strongly depends on further market conditions (see Section 4).

Note that if only one good is auctioned, the uniform-price auction with lowest rejected bid corresponds to the second-price auction and the uniform-price auction with highest accepted bid turns into a first-price auction.

Vickrey auction

The Vickrey auction for homogenous goods exactly corresponds to the uniform-price auction with lowest rejected bid if all participating bidders are only interested in one unit and consequently submit only one single bid.

Excursus: Submitting multiple bids in static multi-unit auctions

If bidders are interested not only in one unit but in multiple ones, they will consequently submit multiple bids in the auction. This is a general option to be considered in the context of auction mechanisms for RES-E, since a project developer may plan several projects at the same time and hence also participate with multiple projects in an auction round.

We assume that four homogeneous goods are offered up for bidding and three potential suppliers participate in the auction, which is either conducted as a pay-as-bid, uniform-price or Vickrey auction. One supplier is interested in two units, we will refer to him as Bidder 1, and the two others, Bidder 2 and 3, are each interested in three units. They submit the following bids:

- Bidder 1 bids for the first unit b_1^1=6MU and for the second unit b_1^2 = 8MU,
- Bidder 2 bids b_2^1=12MU, b_2^2 =12MU and b_2^3 =14MU,
- Bidder 3 submits b_3^1 =7MU, b_3^2 =9MU and b_3^3 =10MU.

Since the lowest bids are awarded in the pay-as-bid, uniform-price and Vickrey auction, both bids of Bidder 1 and the two lowest bids of Bidder 3 are awarded in every auction. Bidder 2 is not successful with any of his bids.

Pay-as-bid auction: Each successful bid determines the corresponding award price, hence Bidder 1 is awarded two units at a price of 6+8=14MU and Bidder 3 receives two units at a price of 7+9=16MU.

Uniform-price auction (highest accepted bid): If the highest accepted bid, here b_3^2 =9MU, is price-determining, Bidder 1 and 3 receive each two units at a price of 2*9=18MU.

Uniform-price auction (lowest rejected bid): If the lowest rejected bid, here b_3^3 =10MU, is price-determining, Bidder 1 and 3 receive each two units at a price of 2*10=20MU.

Vickrey auction: If Bidder 1 had not participated in the auction, all bids of Bidder 3 and the lowest bid of Bidder 2 would have been awarded. That is, instead Bidder 1 with his two bids, Bidder 3 would have been awarded with b_3^3 =10MU and bidder 2 with b_2^1=12MU. Consequently, the award price of Bidder 1's two units is 10+12=22MU.

If Bidder 3 had not participated in the auction, all bids of Bidder 1 and the two lowest bids of Bidder 2 would have been awarded. That is, instead Bidder 3 with his two lowest bids, Bidder 2 would have been awarded with b_2^1 =12MU and b_2^2=12MU. Consequently, the award price of Bidder 3's two units is 12+12=24MU.

Please note that the different auction formats induce different incentives and, thus, the submitted bids will differ between auction formats. Hence, the examples above serve solely for illustration. Conclusions regarding a comparison of auction revenues or efficiency are not representative. Since under different auction formats different incentives regarding the bidding behaviour occur and consequently the existence of multi-project bidders has to be considered carefully in auction format specific analyses, which will be done adequately in Section 4.2.

3.1.2 Dynamic auction formats

In contrast to the sealed-bid one-shot situation in static auction formats, in dynamic auctions bidders have the chance to observe the development of the auction price and other bidders' bids and to adapt their bidding strategies during the auction process. Thus, as already mentioned in WP2[20], dynamic auctions reveal more information than static ones, but are also more complex to implement as well as more vulnerable to implicit collusion (Cramton, 1998). However, since bidders can observe their competitor's bidding behaviour and adapt their strategies accordingly, dynamic auctions reduce the risk of winner's curse in case of common value situations (McMillan, 1994).

Ascending clock auctions

Clock auctions are quite established because of their fast realization. For instance, in the Netherlands, flowers are sold via clock auctions within seconds (Van Heck & Ribbers, 1997). In case of multi-unit procurement auctions the procedure is as follows: The clock starts with a support level that is low enough that no participant is willing to accept. Then the price is increased continuously within predefined fractions of time and bidders signalize successively their acceptance of the recent price. That is, bidders are awarded one after another by dropping out of the auction until the demanded amount of RES-E is reached. The award price will be determined by the last awarded bidder. Hence, this auction format is equivalent to the uniform-price auction with highest awarded bid. If only a single unit is auctioned the auction corresponds to the dynamic counterpart of the first-price auction, the Dutch auction.

Descending clock auctions

The descending clock auction is incentive compatible for single-project bidders. Furthermore, from a theoretical perspective, the descending clock auction then corresponds to the static uniform-price auction with lowest rejected bid under simplifying basic assumptions. However, in the dynamic descending clock auction the participating bidders can observe exactly their competitors dropping out at the corresponding award prices, if this information is revealed in the auction. Consequently, even though the descending clock auction is strategically equivalent to the uniform-price auction with lowest rejected bid, the dynamic auction generates weigh more information during the auction procedure than its static counterpart. Note, that the descending clock auction can also be implemented with the highest accepted bid (last auction price) variant.

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[20] Please find the corresponding report "Overview of design elements for RES-E auctions" (WP2) on the AURES webpage (http://www.auresproject.eu/publications/overview-of-design-elements-res-e-auctions)

Nevertheless, the auctioneer has to deliberate carefully on the implementation of descending clock auctions under certain market and framework conditions, see Section 4.

3.2 Multi-unit auctions for heterogeneous goods

For the purpose of a comprehensive analysis of multi-unit auctions with heterogeneous goods we extend the aforementioned simplifying assumptions insofar as bidders can also be interested in multiple goods. The essential difference of heterogeneous goods, in contrast to homogenous goods, is that they differ from each other. In case of single-project bidders these differences between heterogeneous goods are just disregarded in bidders' valuations as they are only interested in one of the goods anyway. Hence a separate analysis for single-unit bidders is not necessary. Finally, in case of multi-project bidders for heterogeneous goods not only the number of units awarded might be relevant for bidders but also which unit or combination of units they will be awarded with. For example, a bidder who participates with two projects in the auction may be only interested in realising both projects simultaneously due to economies of scale. Consequently, he focusses on the award of both projects at a certain price. Otherwise, he would not realise any of his projects or at least only at a significantly higher price. With the objective of an efficient auction outcome, the bidder should have the option to reflect his (complementary) valuations regarding the realisation of his projects adequately in his bids. That is, in a well-designed auction, he should be allowed to submit a combinatorial bid for the realisation of both projects as well as two exclusive bids for the separate realisation of each project. In case of substitutive valuations (costs) the combinatorial bid is lower than the sum of the exclusive bids. In addition, substitutive valuations (costs) exist if the combinatorial bid is higher than the sum of the exclusive bids. This is the case, if a bidder favours a separate realisation of his multiple projects over the simultaneous one, for example due to financial or capacity constraints. If the combinatorial bid equals the sum of exclusive bids, we refer to this as additive valuations.
To integrate complementary, substitutive and additive valuations (costs) adequately in the auction mechanism specific auction formats are considered in the following. This includes the static generalised Vickrey auction and the dynamic simultaneous multi-round descending auction. In both auction formats bidders have the option to submit combinatorial as well as non-combinatorial bids according to their individual valuation.

3.2.1 Static auction formats

Generalised Vickrey auction

The generalised Vickrey auction is an extension of the Vickrey auction to heterogeneous goods.
Here, bidders are allowed to submit exclusive bids for single units as well as bids for any combination of units. Finally, those bids are awarded that minimise the total award costs (RES-E support costs) of the auctioneer under the conditions that all units are allocated, each unit is only allocated to one bidder and

each bidder is only successful with one of his bids. We refer to this allocation as the optimal allocation. The award price of a bidder is the difference of virtual award costs in case the particular bidder had not participated in the auction and the award costs of all other bidders in the optimal allocation. Or in other words, a successful bidder receives the opportunity costs of society of his participation in the auction. As a consequence, award prices may differ among winning bidders.

From a theoretical perspective, the main advantage of the generalised Vickrey auction is its incentive compatibility. This should especially be emphasised in the context of heterogeneous goods, because most appropriate combinatorial auction formats generate complex incentives for bidders and are not incentive compatible at all (Ausubel & Milgrom, 2004). As a consequence, the generalised Vickrey auction possesses the advantageous characteristic of generating allocative efficient outcomes.
Nevertheless, although the generalised Vickrey auction has favourable theoretical properties such as incentive compatibility and allocative efficiency, it is rarely found in real-world applications (Ausubel & Milgrom, 2004). One potential reason is that the procedure is very elaborate from a bidder's perspective regarding the possible number of up to $2^k - 1$ bids, if k units are auctioned. Further, the determination of the optimal allocation is a NP-complete problem[21]. Besides the argument of being too complex especially for unexperienced bidders, the auction format is very vulnerable to collusion and to multiple bidding identities by a single bidder. Furthermore, a risk of very high award prices arises, which is often mentioned as show stopper (Ausubel & Milgrom, 2004).

[21] A NP-complete problem is a problem where no fast solution can be found despite today's advanced algorithms of computer science.

Example: High award prices in the generalised Vickrey auction

Two goods A and B are offered up for bidding to three potential suppliers whose bids or costs (because of incentive compatibility) for good {A} or {B} as well as for both {A, B} are presented in monetary units (MU) in the following table.

Table 2: Exemplary bids in the generalised Vickrey auction

Bidders	Goods		
	{A}	{B}	{A,B}
Bidder 1	10	10	15
Bidder 2	5	10	15
Bidder 3	10	5	15

The optimal allocation is x= (x_1; x_2; x_3) = ({}; {A}; {B}), i.e. Bidder 1 receives nothing, Bidder 2 receives A, and Bidder 3 receives B. Thus the auction outcome is efficient. The corresponding sum of winning bids (total award costs) is B(N) = 0 + b_2({A}) + b_3({B}) = 0 + 5 + 5 = 10MU. The sum of winning bids without Bidder 2 is given by B_{-2}(N) = 5MU and without Bidder 3 by B_{-3}(N) = 5MU. Because Bidder 1 is not successful, he does not receive any payments (p_1 = 0). If Bidder 2 did not participate, the optimal allocation would have been (x_1; x_3) = ({A}; {B}) and the corresponding sum of winning bids (total award costs of virtual allocation) for this allocation is B(N \ {2}) = 15MU. Consequently, the payment for Bidder 2 is the following: p_2 = B(N \ {2}) – B_{-2}(N) = 15 – 5 = 10MU.

Analogous to this, Bidder 3's payment is p_3 = B(N \ {3}) – B_{-3}(N) = 15 – 5 = 10MU. Consequently, the total payment by the auctioneer is p = p_1 + p_2 + p_3 = 20MU, although all three bidders could have delivered A and B at support levels (far) below 20MU.

The above mentioned example illustrates the disadvantage of high award prices in the generalised Vickrey auction in the specified situation of two bidders with additive costs and another with complementary costs. In the following we compare the exemplary results, i.e. the total award costs of 20MU and the allocative efficiency in the generalised Vickrey auction, with potential results of a pure combinatorial option in the same situation. For reasons of simplicity, we assume that bidders also submit the same incentive compatible bids. In an auction mechanism, where solely combinatorial bids for {A, B} are allowed, the total award costs would be 15MU. However, the allocation would not be efficient. That is, with this option lower support costs could have been generated, however, at the expense of an inefficient allocation.

Consequently, the advantageous characteristic of allowing both combinatorial and exclusive bids in a generalized Vickrey auction may generate an allocative efficient outcome due to incentive compatibility, but may at the same time lead to high award prices. To conclude, the generalised Vickrey auction serves rather as a theoretical benchmark for multi-unit auctions for heterogeneous goods because of its advantageous theoretical properties than as a promising option for real-world applications, e.g. in the context of RES-E.

3.2.2 Dynamic auction formats

Simultaneous multi-round descending auctions

The simultaneous multi-round descending auction, which is considered relevant for the RES-E context in case of auctioning heterogeneous goods, is often called the multi-unit analogue to the well-known English auction. However, the strategic incentives for bidders generated by the simultaneous multi-round descending auction are much more complex than those in the English auction for a single good. Often, it is even not possible to make statements regarding an optimal bidding strategy since e.g. multiple bidding equilibria may exist.

A simultaneous multi-round descending auction consists of multiple bidding rounds. In each bidding round, bidders can simultaneously submit bids for a number of auctioned units according to the activity rules[22]. At the end of each bidding round, the standing best bids per unit are announced and bidders have the chance to underbid in the subsequent round. The particular auction for a unit ends if no more bids are submitted for this unit in the recent bidding round. Then the bidder who submitted the last best standing bid for this unit is awarded at the price of his bid.
Since the simultaneous multi-round descending auction represents a dynamic mechanism it is in particular suitable if bidders have interdependent valuations for the heterogeneous goods. This is motivated by the fact that bidders with interdependent valuations may benefit from learning about their competitors' costs signals during a dynamic auction process since this may reduce the risk of the winner's curse (see Section 2).

However, even in the case of private valuations bidders may have incentives not to reveal their true costs in the auction but drop out already at higher prices which increases the award costs of the auctioneer. If bidders have complementary valuations for the goods, another disadvantage may occur. Because complementary valuations cannot be reflected adequately in the bidding in a simultaneous multi-round descending auction, bidders with complementary valuations often suffer from the so-called regret or exposure problem, see Cramton (2010) and Goeree, et al. (2006). Furthermore, the procedure of the simultaneous multi-round descending auction may lead to very long delays. Based on that, this auction format can be hardly suitable for RES-E, where continuous support and expansion represent essential goals. Another unfavourable practice in simultaneous multi-round descending auctions is strategic supply

[22] Activity rules, e.g. bidding rights, are often implemented by the auctioneer in order to avoid unfavourable strategic bidding behaviour. These bidding rights, that are valid for certain units, can for instance be gained by submitting bids on those units in the first round and avoid that bidders who already dropped out of the auction can get in again (Cramton, 2004). Or in other words, bidders can only reduce their demanded amount of power supported, but never increase it. Thus activity rules can for example ensure that bidders who did not submit a bid for a certain unit in the previous round bid on that unit in the next round.

reduction, which leads to lower competition and hence should be avoided by the auctioneer (Cramton, 2010). Thereby, the German auction of telecommunication licences in 1999 often serves as a famous example of strategic supply reduction in practice (e.g. Klemperer, 2002 and Grimm, et al. 2003). In the following example the basic principle of strategic supply reduction is illustrated. Assume that the support of two projects is auctioned and two bidders A and B participate, where both can either realise one project or two projects. The example emphasises the risk of strategic supply reduction in simultaneous multi-round descending auctions.

Example: Strategic supply reduction in simultaneous multi-round descending auctions

Table 3: Example: Strategic supply reduction in simultaneous multi-round descending auctions

	Assumptions The cost-covering support level of A is 10MU per project and that of B is 12MU per project. Both bidders are interested in realising both projects. The starting price (reservation price) is 15MU per project.
Case I **No coordination / no strategic supply reduction**	A and B both bid straightforward for both projects until their individual minimum support level is reached. That is, B bids 12MU for each of the both units and drops out afterwards. A would stay further in the auction since he would bid 10MU for each of the two units. Then both bids of bidder A are awarded and A receives a support of 12MU per project. The rent of A is 2 * (12-10) MU = 4MU. The rent of B is zero. The total award costs of the auctioneer are 2*12MU=24MU. The auction outcome is allocative efficient.
Case II **Coordination / strategic supply reduction**	A and B both bid straightforward for one project each until their individual minimum support level is reached. That is, B bids 12MU for one project and A bids 10MU for the other. Then one bid of each bidder, A and B, is awarded and both receive the starting price of 15MU per project. The rent of A is 5MU and the rent of B is 3MU. The total award costs of the auctioneer are 2*15MU=30MU. The auction outcome is not allocative efficient.
Conclusion	Both bidders increase their rent with strategic supply reduction to the disadvantage of the auctioneer, who suffers from higher award costs. Further, in case of strategic supply reduction, allocative inefficiency occurs.

The risk of strategic supply reduction can be reduced by an ambitious reservation price. For example, if the starting price (reservation price) was 13MU, bidder A would not have increased his rent by strategic supply reduction and hence not use this option. However, although an ambitious reservation price may reduce the risk of strategic supply reduction, it is an additional design element needed to maintain the success of the auction in the exemplary case. In addition, the determination of an appropriate reservation price is another challenge: A low reservation price may reduce the number of bidders and hence involves the risk of insufficient competition, whereas a high reservation price still sets incentives for strategic supply reduction. The risk of strategic reduction of competition or implicit collusion is aggravated by the situation of repeated auctions and a relatively low number of bidders or bidders who know each other very well (see Section 4.5). Hence, the suitability of simultaneous descending multi-round auctions for RES has to be treated with caution and based on an in-depth analysis of the corresponding national or international market.

3.3 Hybrid auction formats

Hybrid auctions consist of a combination of different auction mechanisms. Prevalently, static and dynamic auction formats are combined in a multi-stage auction process. For instance, in the first stage bidders participate in a dynamic auction and the winning bidders qualify for the second stage, i.e. the award stage, which is conducted as a static auction. The idea behind is to concentrate competition in the final phase via suspending weaker bidders already in an earlier stage. If there are high discrepancies among bidders' strengths and uncertainties regarding the level of competition, a hybrid mechanism may increase transparency by structuring the allocation process in multiple stages. On the one hand, bidders in an advanced stage know that they belong to the stronger participants but also that strengths have increased among their competitors. The latter may lead to a more aggressive bidding behaviour, i.e. decreased bids. However, note that a rational bidder takes the existence of multiple bidding stages already into account when bidding in an earlier stage, e.g. for example by relatively higher bids in the beginning. Consequently, a general conclusion regarding the expected support costs in a hybrid auction compared to a non-hybrid one cannot be drawn. On the other hand, implementing a dynamic auction, where bidders can observe their competitors' bids, may reveal valuable information about competition. This information can especially be helpful for the bidding behaviour in subsequent stages. This is why the conduction of a dynamic auction is particularly reasonable in earlier stages. In Brazil, a two-stage hybrid auction mechanism was implemented, in which a descending-clock auction was conducted in the first stage and a pay-as-bid auction in the second stage. Furthermore, hybrid formats are also planned or already implemented in further countries as the UK, Mexico or Morocco (see WP4).

3.4 Summary: Evaluation of suitable auctions formats for RES-E and conclusion

The first analysis based on simplifying assumptions presented in the beginning of Section 3 enables us to draw a first summary for auction formats suitable for RES-E. The following table provides a first assessment of relevant auction formats for RES-E according to the general auction theoretical criteria introduced and discussed in detail in Subsection 1.5.

Tables 4 and 5 compare the auction formats individually discussed above for multi-unit auctions for homogeneous and heterogeneous goods with regard to those criteria. Thereby, we distinguish for the price determination whether a common award price for all successful bidders per auction is generated, which we evaluate as advantageous (+) or several individual award prices are determined, which is consequently evaluated as rather disadvantageous (-) – the argumentation behind that can be found in Subsection 1.5. Regarding the signal generation, auction formats in which participating bidders may learn during the auction procedure about their competitors' valuations are considered positive (+). However, please note here, that learning about competitive signals is only relevant in case of interdependent valuations. Further, the signal generation of an auction, especially not only for participating but also potential bidders and the public, strongly depends on what information the auctioneer reveals afterwards. This aspect we denote by (). As we stated in Section 2, all auction formats mentioned in Table 4 generate the same expected auction revenue (=) under our simplifying assumptions. Further, we evaluate in Table 4 and 5 if the listed auction formats are incentive compatible (+) or not (-) and if they end in an allocative efficient outcome (+) or not (-) from a theoretical perspective. Further, if there may exist specific risks for the auctioneer as well as for bidders we mention those explicitly. Since auctions are a competitive mechanism, the award volume risk for bidders is inevitable and consequently not mentioned here. In practice, the risk of irrational bidding may occur, which can have negative impacts on the auction outcome (see Subsection 1.5). If incentives for irrational bidding behaviour are high, we mark this with (-). If they are rather low, we mark this with (+).

Table 4: Comparison of multi-unit auctions for homogeneous goods under simplifying assumptions

		Price determination (common)	Signal generation	Expected auction revenue	Incentive compatibility	Allocative efficiency	Auctioneer's risks	Bidder's risks	Risk for irrational bidding behaviour in practice
Multi-unit auctions for homogeneous goods	Pay-as-bid auction	-	()	=	-	+	none	-	+
	Uniform-price auction (HAB)	+	()	=	-	+	none	Award price risk	-
	Uniform-price auction (LRB)	+	()	=	+	+	none	Award price risk	-
	Vickrey Auction	-	()	=	+	+	none	Award price risk	+
	Ascending clock auction	+	+,()	=	-	+	none	Award price risk	+
	Descending clock auction	+	+,()	=	+	+	none	Award price risk	+

For a comparative conclusion of the auction formats for homogenous goods, the criteria of expected auction revenue, allocative efficiency and auctioneer's risks can be neglected since all auction formats perform equally in this regard. According to Table 4 the dynamic ascending and descending clock auctions are slightly advantageous over their static counterparts, the uniform-price auctions (HAB and LRB), due to a stronger signal generation during the auction. However, as already mentioned, this is only relevant in case of interdependent valuations. Further, dynamic auctions are in their practical implementation usually more complex and expensive than static ones. The pay-as-bid auction outperforms both variants of the uniform-price auction in terms of no award price risk and lower risk of irrational bidding behaviour. However, the pay-as bid auction generates a different award price for each successful bidder, whereas the uniform-price auction defines a common one for all successful bidders. Consequently, under simplifying assumptions, a ranking of the three options for a practical implementation depends on the individual weighting of the above discussed aspects by the auctioneer. We will learn in the following Section 4 that under RES-E specific market and framework conditions, such ranking is subject to further ambiguity. Therefore, we will briefly discuss the clock auctions as the dynamic parts of the multi-unit auctions for homogeneous goods under specific market conditions in more detail below.

Table 5: Comparison of multi-unit auctions for heterogeneous goods

		Price determination (common)	Signal generation	Expected auction revenue	Incentive compatibility	Allocative efficiency	Auctioneer's risks	Bidder's risks	Risk for irrational bidding behaviour in practice
Multi-unit auctions for heterogeneous goods	Generalised Vickrey auction	-	()	Bench-mark case	+	+	Complexity, high prices, collusion	Award price risk	-
	Simultaneous multi-round auction	-	+, ()	Since there exists no unique equilibrium, no statements can be made.			Strategic supply reduction, long delays	Award price risk	-

For the heterogeneous goods, we analysed the Generalised Vickrey auction as a static format and the simultaneous multi-round auction as a dynamic format. The latter format slightly outperforms the former in terms of signal generation in case of interdependent valuations among bidders. Admittedly, both auctions generate different award prices for bidders in an auction round. However, the main disadvantage of both auction formats is that they involve high risks for the auctioneer, which are presented in detail in Subsection 3.2. This is why the practical implementation is very sensitive to given market conditions and requires besides a profound understanding of the market almost individually perfect conditions, which is usually not the case in reality.

The hybrid auction formats in the combinations as described above represent a specific class of auction formats that can be split up in his individual combined parts, i.e. auction formats, for which the corresponding evaluation above applies as well. However, the specific characteristic of a hybrid mechanism to concentrate competition in the final phase via suspending weaker bidders in earlier stages may play a crucial role in some situations. Consequently, it may be worthwhile to keep hybrid formats in mind even though they are more complex and time-consuming to implement in real world applications.

3.5 Applicability to RES-E support instruments

Any auction format has to be embedded in a RES support scheme, which can make use of different instruments such as tariffs or premiums (see WP2[23]). Hence, in the following paragraphs potential interactions between chosen auction formats and support instruments will be discussed with regard to general impacts on strategic incentives for project developers in an auction, expected auction outcomes and the resulting achievement of policy goals. For that purpose, we distinguish for the subsequent analysis between support instruments with external dependence, i.e. support levels are partially derived from other market prices, e.g. spot market prices and support instruments without external dependence, see also Menanteau, et al. (2003), Couture, et al. (2010), and Klein, et al. (2010).

RES-E projects are characterised by a high share of fixed costs for project development and implementation and usually have relatively low variable costs. This characteristic requires relatively high upfront investments of project developers and consequently induces the need to recover investment costs by an adequate remuneration over the project lifetime. However, the electricity rates on the electricity market are neither cost-covering for RES-E yet nor stable as electricity markets feature a high price volatility. Consequently, support instruments have been implemented by the government in the past to balance price differences to provide long-term financial security to project developers in order to increase the expansion of renewable energies.

Whereas support schemes solely based on instruments without external dependence (such as tariffs) are often criticised in terms of lacking competitive incentives, they represent high investment security for project developers thanks to the predictability of future cash flows that they provide, see Mitchell et al. (2006) and Couture et al. (2010). The predefined support levels are oriented at the specific generation costs and differ e.g. according to technologies or locations. As a consequence, they further attract especially smaller and rather risk-averse bidders and hence may increase expansion, see Mitchell et al. (2006) and Couture et al. (2010). For example, feed-in-tariffs (FITs) without external dependence were successfully implemented with regard to an increased deployment in Germany (Butler & Neuhoff, 2008). However, predetermined support levels in FITs may lead to an uncontrolled and inefficient expansion of RES-E technologies in a non-competitive context and hence in particular lead to excessive support costs (Butler & Neuhoff, 2008).

If instruments without external dependence are combined with auctions, bidders demand their optimal cost-covering support level individually by bidding in the auction. Thereby, a rational bidder bases his optimal bid on the expected total costs and energy generation over project lifetime, as well as on his beliefs about competition[24]. That is, electricity market specific conditions can be disregarded by bidding, which may facilitate the bid calculation for less experienced project developers. Furthermore, the allocation via auctions is expected to be allocative efficient from a theoretical point of view under simplifying assumptions.

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[23] Please find the corresponding report “Overview of design elements for RES-E auctions” (WP2) on the AURES webpage (http://www.auresproject.eu/publications/overview-of-design-elements-res-e-auctions)

[24] Note that beliefs about competition are only crucial for bidding in non-incentive compatible auction formats.

However, the suitability of combining instruments without external dependence and auctions with regard to policy goals is ambiguous. On the one hand, an individually demanded market-independent instrument ensures to cover individual investment costs and consequently may be advantageous for high participation and/or realisation rates. On the other hand, incentives for bidders based on other relevant markets, as the spot market for example, are only limited. Although they will face competition in terms of outbidding their competitors, their bidding strategies can be developed completely isolated from external markets as the electricity market. This fact may hinder a smooth integration of RES-E into the electricity market which is planned by many policy makers for the long term. With instruments without external dependence, project developers may not have the chance to learn about electricity market specific fluctuations and how to develop an adequate strategy according to the market.

An instrument with external dependence (such as premiums) in which project developers receive support on top of the electricity market price, in contrast, already postulates the anticipation of electricity market specific uncertainties. Because the premium will only partly cover the individual costs, project developers are incentivised, for instance, to generate RES-E in time of high demand, see Klein et al. (2010) and Couture et al. (2010). However, instruments with external dependence increase several risks for bidders (Klein et al., 2010 and Mitchell et al., 2006) and hence perform worse than those without external dependence in terms of providing investment security for project developers, which may lead to lower participation (Couture et al., 2010).

Thus, if bidders in an auction submit bids for their individual cost-covering premium over project lifetime, they bear the risk of non-cost-covering total support levels in case of underestimating future revenues at the electricity market. These uncertainties regarding the total support level can be theoretically abstracted by common value aspects (see Section 2) since the uncertainties of future electricity prices apply to all project developers equally. This fact may affect the bidding behaviour in the way that bidders (with interdependent valuations) may suffer from the risk of winner's curse (see Subsection 4.5) due to non-sufficient anticipation of the particular situation (see Section 2). Since, as a consequence, awarded bidders may not finalise their projects due to not-cost covering support levels, the political expansion target may be at risk. However, bidders would learn to anticipate future market developments and related uncertainties adequately in their bids in order to exist in a competitive market over the long term. This would finally facilitate to integrate large shares of RES-E in the electricity market (Klein et al., 2008).

4 Chances and risks of the identified auction types in the context of specific market conditions

The suitability of the auction format depends on various framework and market conditions such as level of competition, participation of multi-project bidders, uncertainty of bidders regarding project costs and energy generation, predictability of project costs and energy generation by the auctioneer, transparency of bidders, asymmetric beliefs, repeated conduction of the auction and last but not least default risks. The impacts of those factors on the before identified auction types are discussed in the following.

The previous simplifying assumptions are now relaxed in order to model relevant aspects and settings for real-world applications in the RES-E context. We emphasise related chances and risks for each auction type and conclude with a suggestion for which auction format might be most suitable under given conditions. In each subsection only one assumption is neglected, all others are maintained as in the simplifying case. Note that in reality a mix of several conditions might be most applicable and hence the auctioneer needs to decide which corresponding chances and risks are most relevant to him in the particular situation. Finally, we conclude our results in a market and framework conditions specific evaluation.

4.1 Level of competition

Sufficient competition is a necessary condition for the success of any auction. Klemperer (2002) mentions high participation as a key element of successful auctions. However, this condition is difficult to quantify and there exists no best practice of how to ensure high participation rates in an auction per se. It is obvious that the question of who and how many bidders will probably participate in the auction is crucial here. The answer strongly depends on the specific market situation and is very sensitive to auction related risks for the bidders. Basically, competition is increased by a higher number of bidders as well as by replacing weaker bidders by stronger ones.

Assuming low competition, Klemperer (2002) states that weaker bidders prefer the pay-as-bid auction over the uniform-price auction because they benefit from a positive probability to be awarded. Unfortunately, this fact is due to inefficiencies occurring under low competition in pay-as-bid auctions.
In fact, all auction formats suitable for RES-E benefit from a higher level of competition in terms of reduced expected support levels and increased allocative efficiency. However, allocative efficiency is hardly traceable in real-world auctions and very sensitive to asymmetries regarding information and cost structures among bidders. Consequently, an auctioneer focussing on reduction of support costs as well as achieving allocative efficiency should always aim at finding appropriate measures beyond the auction format to ensure both results at the same time. For that reason, the auctioneer should aim at increasing participation in the auction by reducing bidders’ risks adequately, for instance, by a transparent and simple auction design with

low participation barriers, which enjoys high acceptance among all potential bidders. Furthermore, appropriate measures to integrate asymmetric bidder groups, e.g. bidders with essential costs differences, might be helpful to increase participation, see e.g. establishment of boni and mali or contingents in auctions that are analysed in detail in WP3.3.

Number of bidders

Whereas the number of bidders has no impact on the optimal bidding behaviour of a single-project bidder in a uniform-price auction with highest rejected bid and the descending clock auction, the optimal bidding strategy, in particular the degree of cost exaggeration, strongly depends on the number of bidders in a pay-as-bid auction and a uniform-price auction with highest accepted bid, supposed that the auction volume is constant. Since single-project bidders have a weakly dominant strategy to bid truthfully their costs in a one-time uniform-price auction with lowest rejected bid and descending clock auction, their bidding behaviour is independent of the beliefs about their competitors, e.g. number and strengths. In a pay-as-bid auction bidders exaggerate their true costs less strongly if more bidders participate. That is, higher competition because of an increased number of bidders induces more aggressive bids. The same results occur for uniform-price auctions with highest accepted bid, where the impacts are even aggravated by the reduced probability of bids to be price-determining when more bidders participate. Nevertheless, from a theoretical point of view, expected revenue equivalence and allocative efficiency of all four auction formats apply independent from the number of bidders. Note that this result presuppose that the (expected) number of participating bidders is common knowledge in all auction formats.

Asymmetric bidders

As bidders' strengths are modelled by distribution functions, symmetric and asymmetric bidders differ in the way that symmetric bidders draw their individual cost signals from the same distribution function, whereas asymmetric bidders draw them from different ones. If bidders are symmetric, all bidders have ex ante the same expected strength, where the particular signals may differ and are private information. Whereas we focused on symmetric bidders in our simplifying assumptions, we now investigate the consequences of asymmetric bidders, i.e. bidders that ex ante have different cost expectations. Consequently, for asymmetric bidders not only the private cost signals may differ but also the expected strengths, i.e. asymmetric bidders are ex ante distinguishable from each other by their expected strengths. In order to assess bidders' strengths, we assume that different distribution functions can be ranked, for instance by concepts of stochastic dominance such as first-order stochastic dominance (Maskin & Riley, 2000). That is, a stronger bidder's cost signal is more likely to fall below a certain value than that of a weaker bidder. Or in other words, a stronger bidder is expected to have lower costs than a weaker one.

Because of the existence of a weakly dominant strategy for single-project bidders in the uniform-price auction with lowest rejected bid and the descending clock auction, the incentive compatibility persists. Thus allocative efficiency is maintained in these auction formats under asymmetric bidders. However, in the pay-as-bid auction inefficiencies may occur due to asymmetries among bidders: weaker bidders submit more aggressive bids than stronger ones as they face higher competition.

Maskin and Riley (1998) show for the first-price and second-price auctions that expected revenue equivalence no longer holds by neglecting the assumption of symmetric bidders. However, neither the first-price nor the second-price auction is per se superior in generating lower expected support costs under asymmetric bidders. The auction format favoured by the auctioneer in terms of minimisation of support costs depends strongly on the specific “form” of asymmetry, i.e. for instance if the distributions are shifted or stretched. Since in real-world applications, e.g. the RES-E auctions, it might be difficult to capture and describe the form of asymmetry in an appropriate manner, the condition of asymmetric bidders should not be taken as crucial factor when searching for the most suitable auction format in a specific situation.

The bidding behaviour in first-price and second-price auctions can be transferred to its multi-unit extension in case of single-project bidders. Hence, there exists no ranking of pay-as-bid and uniform-price auctions regarding expected support costs as well, if bidders are asymmetric.

4.2 Participation of multi-project bidders

Since project developers may plan and realise several projects simultaneously, they may also submit multiple bids in the same auction. To start with, we assume that each bidder has additive costs for multiple projects, i.e. the cost of simultaneously developing multiple projects equals the cost of developing each project separately. Hence, neither economies of scale nor additional costs due to simultaneous project developments exist.
We assume that each bidder may apply with more than one project and submit multiple bids accordingly, i.e. for each project one bid is submitted.

The participation of multi-project bidders induces the risks of strategic supply reduction and allocative inefficiencies, see Noussair (1995) and Ausubel, et al. (2002). If a bidder is interested in participating with multiple projects, ha may have the incentive withhold some projects in favour of a higher award price for the remaining ones. Multi-project bidders balance the trade-off between realising more projects at lower support levels and realising fewer projects in favour of higher support levels. Note that supply reduction can either be reached by submitting relatively high bids on additional projects or by not submitting any bids on additional projects at all in an extreme case. However, incentives for strategic supply reduction for multi-project bidders particularly occur in certain auction formats, especially in auctions where additional bids may influence the award price for another bid of the same bidder.

Hence, in a pay-as-bid auction, where a bid only impacts its own winning probability as well as its own award price in case of being successful, bidders cannot benefit from strategic supply reduction in case of

binding bids. This is, because a bidder only increases his award price and simultaneously lowers his award probability in case of submitting strategically higher bids. As a result, the pay-as-bid auction even allocates the goods efficiently under the assumption of additive valuations of the multi-project bidders[25].
Nevertheless, assuming that awards are not binding, i.e. bidders can withdraw their award without additional costs, incentives occur to exaggerate supply and submit multiple bids that differ slightly. This bid diversification serves as an optimisation of cost exaggeration and hence as an optimised bidding strategy (Belica, et al., 2015). Note that this situation is rather theoretical as in reality, project developers usually have to apply for the auction with concrete specified projects.

Whereas there exists a weakly dominant strategy to bid truthfully ones' costs in case of single-unit supply in a one-time uniform-price auction, the situation is different if a bidder is interested in more than one unit and submits multiple bids: the additional bids, i.e. the higher ones, determine with a certain probability the award price of the previous bids, i.e. the lower ones. This fact induces incentives to bid relatively higher on additional bids in order to gain a higher award price in case the additional bids are price-determining (Engelbrecht-Wiggans & Kahn, 1998). Of course, this effect strongly depends on the probability of determining the award price with such additional bids, i.e. the fewer bidders participate or the lower the ratio of number of bidders to number of auctioned goods the higher is the chance to determine the price. Consequently, in both variants of the uniform-price auction the risk of unfavourable bidding strategies, i.e. supply reduction, exists if bidders are interested in more than one unit. This is illustrated in the following example.

<u>Example: Incentives for supply reduction for multi-project bidders in the uniform-price auction with lowest rejected bid</u>
We assume that three homogeneous goods are offered up for bidding to three potential Bidders 1, 2 and 3 in a uniform-price auction with lowest rejected bid. Bidder 1 is interested in two goods, Bidder 2 and 3 only have a single-unit supply. The following bids are submitted: b_1^I=5MU, b_1^{II}=6MU, b_2=8MU and b_3=10MU. Hence, the bids of Bidder 1 and 2 are awarded and the award price is 10MU.
Alternative behaviour of Bidder 1 (strategic supply reduction): Bidder 1 bids b_1^I=5MU and b_1^{II}=20MU. Then all winning bidders receive one good at a price of 20MU. Consequently, Bidder 1 increases his award price of the first good by refusing the second good.

Hence the favourable characteristic of incentive compatibility only applies for the specific case of single-project bidders and the first bid of multi-project bidders who only participate in one single auction. In all other cases there exist incentives for bidders to exaggerate their true costs in the bids. Consequently, even in a uniform-price auctions inefficiencies are likely to occur in case of multi-project bidders.

[25] Otherwise, i.e. in case of sub- or super-additive costs due to economies of scale or capacity constraints, inefficiencies may occur because of interdependencies between a bidder's valuations of the multiple goods.

In a descending clock auction the risk of strategic supply reduction is even aggravated for multi-project bidders compared to the static counterpart, the uniform-price auction. Because multi-project bidders can observe the bidding procedure, they can optimise their decision of dropping out of the auction process early with one bid for the benefit of a higher award price of the other bids.

By relaxing the assumption on additive costs, i.e. supposing bidders have sub- or super-additive costs for multiple projects, the impacts discussed above remain the same, except when synergies (economies of scale) between multiple projects of a bidder become too strong. In that case, combinatorial auctions are considered more appropriate.

4.3 Uncertainties of bidders' valuations (IV approach)

In this subsection we move away from the IPV model and consider the IV model, i.e. uncertain and interdependent values (costs). This model applies to the case that the auctioned projects are predetermined by the auctioneer (see Section 2). In this case, we assume that bidders are more uncertain about their actual costs for realising the projects than in the case of individually developed projects, for which we consider the IPV approach appropriate. Therefore, bidders have to build beliefs about their uncertain costs based on the information provided by the auctioneer as well as their private costs signals. Here, the other bidders' private costs signals may help a bidder in estimating his cost estimation more precisely. As mentioned in Section 2, these properties are captured by the interdependent value (IV) model. In this context, the main risk is that those bidders will win who have estimated the costs as being the lowest - the risk of the winner's curse. Misestimating of costs, however, can be reduced by the auctioneer as the level of uncertainties depends on the information that the auctioneer reveals. Thus, the auctioneer may reduce the risk of winner's curse by publishing valuable information about the project(s) before the auction. However, the information communicated should be transparent, traceable and reliable, otherwise potential bidders could be discouraged to participate in future auction rounds or they might base their expected valuation on inadequate information again leading to misestimations.

In an IV framework, bidders benefit from auction formats that reveal information during the auction, so that they can learn from their competitors about the actual costs, which allows them to adapt their costs estimations and bidding strategies, respectively. This induces that dynamic auction formats as the descending clock auction or the reverse English auction in the single-unit case should be favoured over their static counterparts. Nevertheless, the increased transaction costs of dynamic auctions have to be weighed against the advantages of information acquisition. Regarding the uniform-price auction and the pay-as-bid auction, so far no essential differences have been found with respect to the risk of the winner's curse.

4.4 Uncertainties of auctioneer's valuation

Since information asymmetries between auctioneer and bidders are characteristic for the RES-E context, it is a relevant issue to address the consequences of uncertainties regarding the auctioneer's valuation. Assuming that project developers participate with their individual planned and developed projects in the auction, they usually are the better informed party with respect to expected costs and revenues. Nevertheless, why is it crucial for the auctioneer to have precise information about expected support levels? Besides increased uncertainties in estimating future support costs, he will have difficulties to determine an adequate reservation price. If he sets a too ambitious (low) reservation price, he will risk missing his expansion goal. However, a too high reservation price may lead to excessive prices. Consequently, valuable and accurate information on expected support levels will help to balance this trade-off.

The auctioneer benefits in all auction formats from an optimal reservation price in terms of reduced expected support costs. However, allocative inefficiencies may occur in case the lowest valuation (costs) of all bidders exceeds the reservation price but not the auctioneer's valuation.

As ex ante uncertainties in the auctioneer's valuation persist independently of the auction format, there is no auction format that is per se more suitable than another in order to reduce negative consequences in this particular situation. However, if there exist further incentives for unfavourable strategic bidding behaviour because of specific market and framework conditions, an adequate reservation price gains in importance: For instance, in situations where the risk for strategic supply reduction is relatively high (due to participation of multi-project bidders in certain auction formats for example), an ambitious reservation price is a unique measure to avoid unfavourable strategic behaviour.

4.5 Transparency of bidders

If project developers know their competitors in the auction very well, stronger incentives occur to coordinate with each other in all auction formats. Especially in repeated auctions bidders might learn about their competitors. The risk of collusion increases especially with frequent auction rounds as here the coordination is easily continued and transferred to the next rounds. A high transparency of bidders is favoured additionally by a relatively low number of project developers in the market. Whereas it might be difficult to eliminate the incentives for collusion per se, the auctioneer can at least hinder the continuing of collusive strategies. Consequently, if a high transparency of bidders exists the auctioneer should choose an auction format that is less vulnerable to collusion.

As a rule of thumb, static (sealed bid) auction formats are considered as more appropriate to avoid collusion than dynamic auction formats as the latter facilitate implicit collusion strategies during auction process. In contrast, the sealed-bid auction formats, i.e. both variants of the uniform-price auction and the pay-as-bid auction, rather prevent collusive bidding behaviour since bidders cannot observe their competitors' bids. Here, the risk for collusion is considered higher under uniform-pricing than under pay-as-bid. Klemperer (2002) emphasises that there exist incentives for bidders to coordinate on particular shares of the auctioned volume in favour of a common high award price. Note that in uniform-price auctions, award and award price are (at least with a positive probability) decoupled by bidding, whereas in a pay-as-bid auction each awarded bidder receives his corresponding bid. Consequently, there exists a positive probability that a bidder's bid is awarded in a uniform-price auction with a relatively high award price even if the bid itself is relatively low.

4.6 Asymmetric beliefs

We denote beliefs as a participant's expectation about competition or, in particular, his expectations about the (competitive) bidder's strengths. Each bidder has a concrete signal about his own strength but only beliefs about the other participants' strengths. In the beginning, we acted on the simplifying assumption that all participants, i.e. auctioneer and bidders, have the same beliefs about each other before the auction. Relaxing this assumption yields the case that participants may have different information about each other. In particular, asymmetric beliefs imply that at least one participant has wrong beliefs about reality. The higher the number of misinformed participants and the more fallacious the misinformation, the greater is the effect of asymmetric beliefs regarding the auction outcome. However, asymmetric beliefs can be advantageous and disadvantageous as well as effectless for the auction outcome. This depends on the type of misinformation and the implemented auction format. The crucial question is if the prevailing misinformation leads to beliefs of higher or lower competition as compared to reality.
For instance, let us assume that all bidders believe that their opponents are relatively strong, whereas all bidders in fact are rather weak. Then, competition is overestimated. If those bidders participate in a pay-as-bid auction, the auctioneer will benefit from lower support costs generated by the auction compared to the case where all bidders know that they are all weak in reality. In contrast, if all bidders act on the assumption of weaker competitors (misinformation), exactly the opposite applies: The auction generates higher support costs. The reason for that is that bidders exaggerate their costs in pay-as-bid auctions based on their beliefs about competition. Therefore the higher bidders expect the competition to be, the lower are their submitted bids in a pay-as-bid auction, independent if their beliefs are correct or based on misinformation. A similar result follows for the uniform-price auction with highest accepted bid, where the optimised bid also incorporates an exaggeration based on beliefs about competition as there exists a positive probability to be price determining in case of winning. In the uniform-price auction with lowest rejected bid, it is obvious that the weakly dominant bidding strategy remains unaffected even under asymmetric beliefs. Consequently, the pay-as-bid auction and the uniform-price auction with highest accepted bid generate lower (higher) expected support costs than the uniform-price auction with lowest rejected bid in case of overestimation (underestimation) of competition. In dynamic auctions bidders may recognise their asymmetric beliefs and adapt them according to their observations during the auction process, e.g. the incentive compatible descending clock auction reveals bidders' actual cost estimations sequentially.

4.7 Repeated conduction of the auction

In order to ensure a continuous expansion of RES-E, several auction rounds have to be conducted during a year. One motivation behind this is that bidders should have the opportunity to participate in an auction round whenever their project status fulfils the prequalification criteria and hence avoid delays caused by the new system. However, repeated auctions have specific properties that induce specific risks which may be disadvantageous for the auctioneer. Since a bidder can take the repeated conduction into consideration by determining his optimised bidding strategy, he can incorporate the option to be awarded in a future round, if not being successful in the current round.

To start with, we suppose that the volume of supply is a fixed amount for each year and all projects participate in the auction rounds until they are awarded. Then incentives for bidders occur to bid higher in earlier rounds than in later ones in all four auction formats (pay-as-bid, uniform-price (LRB and HAB), descending clock auction). The reason for this is that in the beginning the bidders face the additional chance to be successful in upcoming rounds. Note that even the weakly dominant strategies in the uniform-price auction with lowest rejected bid and the descending clock auction are not preserved in this case. If no new projects are added to the supply over time, these effects are, from a theoretical perspective, compensated over time and the expected total support costs equal those that would have been generated by a single auction with the same amount of supply and aggregated awards.

In the RES-E context, however, it is more appropriate to assume that there accrue new projects to the amount of supply over time. Hence, if the expected level of competition is the same in each auction round, the optimal bid will be the same, i.e. the optimal bidding strategy will be constant over rounds, if the number of auction rounds is uncertain.

Nevertheless, the argument that bidders may speculate of being awarded in a later round may persist from a psychological point of view and induce relatively higher bids in earlier rounds (McAfee & Vincent, 1993). In that context, expected costs of delays regarding project development and realisation play a crucial role, because the lower the costs are the stronger is the incentive to wait for being awarded in later rounds.

The experimental analysis by Abbink (2001) states that less experienced bidders submit more aggressive bids in a pay-as-bid auction. Consequently, the pay-as-bid auction is supposed to generate lower support costs than the uniform-price auctions in an early phase. However, as bidders will learn about the competition and adapt their bidding strategies respectively, these differences of expected support costs will converge over time.

Moreover, it has to be taken into account that the repeated conduction of auctions increases the chance and, thus, the incentives for multi-project bidders to successfully implement strategic supply reduction at the expense of higher prices and, thus, higher support costs. The reason for this is that repeated conduction eases (implicit) collusion.

To conclude, there is no essential reason to favour a certain auction format over another against the background of repeated auctions. However, it might be reasonable to choose an auction format that is relatively stable against collusion, since the repetition may increase transparency between project developers and hence facilitate collusive strategies.

4.8 Default risks

The adequate integration of default risks plays a crucial role for the design of a suitable auction mechanism for RES-E, if project developers participate in the auction before their projects are completely finalised. In that case, already awarded bidders may not succeed to realise their corresponding projects in time or even not at all. There can be several reasons for a default, such as insufficient support, missing approvals or force majeure (act of nature beyond control) that all refer to uncertainties for bidders at the time of bid submission. Hence, the auctioneer may benefit by reducing these uncertainties for the bidders' project planning and realisation phase, e.g. through variable support levels, appropriate prequalification measures or adequate penalties. First, through variable support levels (such as sliding feed-in premiums), specific uncertainties regarding actual costs and energy generation are transferred from the project developer to the auctioneer. Second, the auctioneer may demand specific prequalification requirements, where bidders have to ensure a predetermined project planning status involving the most important approvals for their project or other appropriate proofs of suitability.

Penalties may encourage bidders to pursue their projects although their realisation may not be profitable in itself. Unfortunately, all the aforementioned default risks persist in all auction formats suitable for RES-E. Hence, in order to accommodate these default risks, a standard auction format has to be complemented by further appropriate RES-specific design options in addition to the auction format, e.g. prequalification and penalty measures. The chances and risks of these particular options are discussed more detailed in the following report of WP3.3.

5 Experiences with auctions from other industries

Besides the RES-E context, auctions are already a well-established tool for various sectors in industry and policy. For instance, auction mechanisms have already been and recently are used for industrial procurement processes, the sales of telecommunication licences, the refinancing operations, or the sales of oil and gas leases, to name just a few. In the following we will highlight differences between those and the RES-E sector, discuss potential lessons learnt in the particular examples and the options to transfer them into the RES-E context. The subsequent analysis is focused on the aforementioned cases of auction implementations since those possess relatively high similarity to RES-E auctions regarding goals, market conditions and/or implementation.

5.1 Industrial procurement auctions

In industrial procurement auctions, usually long-term contracts for high volumes of a product are auctioned. That is, the participation in the auction represents an existential decision for most of the suppliers, especially for those suppliers whose core business is based on the auctioned contracts. This may induce a high serenity of participating bidders as well as incentivise aggressive bidding behaviour. The auctions are mostly conducted as multi-unit auctions, i.e. the overall volume can be split among bidders and delivered by multiple suppliers. Furthermore, most contracts contain the supply of highly innovative products. Therefore, the choice of an auction as a suitable mechanism is reasonable in terms of price discovery by exploiting information asymmetries between auctioneer and bidders. The usage or production of the products can either be supplementary or complementary, which should be adequately reflected in the bid specification. For instance, the auctioneer may offer the option to submit combinatorial bids, i.e. bids for single units as well as for combinations of several units, in order to achieve optimal allocations and award prices. Another crucial characteristic of industrial procurement auctions is that the quality of the offered good(s) may differ between suppliers. Consequently, the submitted bids have to be evaluated not only with respect to prices but also to quality criteria as product conformity, conditions of delivery and further service and product related parameters relevant for the auctioneer’s award decision, see Beil, et al. (2003), Bichler, et al. (2005), and Perrone, et al. (2010). This is why well-designed industrial procurement auctions are always tailor-made and hence very much limited to the given goals and conditions in one particular situation. The main goals are price discovery and reduction as well as the selection of appropriate suppliers. Often only a relatively small number of well-known suppliers participate in the auction, so that a high market transparency may be given among bidders, which increases the risk of collusive behaviour. Furthermore, asymmetric synergies between several goods among bidders may exist and require special design elements as for example bidder specific bid specifications, i.e. one bidder is allowed to submit combinatorial bids whereas another is not.

Industrial procurement auctions are usually implemented as a one-shot auction with multiple criteria relevant for the award in order to map the auctioneer's valuation. Often multi-stage auctions are implemented to concentrate competition in later stages by eliminating weaker bidders already in earlier stages. Furthermore, a special bidder may be favoured for several reasons, e.g. a long-term supplier receives an exceptional position in the bidding process. In the past, auction mechanisms have increasingly been used for industrial procurement processes, see Jap (2002) and Elmaghraby (2007).

What do industrial procurement auctions have in common with RES-E auctions?

In some countries (including Germany) there has evidently been a mismatch of predetermined support level and technology cost development, at least for certain technologies and certain time periods, which has led to a faster than anticipated RES-E expansion. Here, there are obviously existing information asymmetries between government and project developers, which can motivate the implementation of auctions also in the RES-E context. In RES-E auctions also long-term contracts will be awarded as the support for RES-E will be paid by the government for a predetermined time. Additionally, the "project quality" regarding the expected energy performance may significantly differ between applying projects because of different geographical potentials. In contrast, a controlled geographical distribution of projects may be optimal in terms of network expansion. So, the auctioneer in the RES-E context may also benefit from an auction mechanism that considers and integrates those quality and network expansion differences adequately, e.g. by using multi-criteria auctions but also by implementing other appropriate design elements as contingents (see WP3.3) for example. The goals of price discovery and reduction as well as the selection of appropriate suppliers can also be mentioned as the two most relevant ones in the RES-E context. However, the auctioneer for RES-E may pursue additional goals as actor diversity etc. as well.

What are differences between industrial procurement auctions and RES-E auctions?

Whereas industrial procurement auctions are tailor-made one-shot auctions, RES-E auctions will typically be conducted several times a year. This fact changes the requirements to avoid collusion and other unfavourable strategic bidding behaviour in an important way. The repeated conduction of an auction for RES-E requires a stable design that is also able to persist under changing market conditions. For that reason, a rather simple auction mechanism satisfying a variety of requirements should be favoured over a rather complex tailor-made mechanism for one situation but that may be very vulnerable to changing conditions. Finally, the market participants may be rather more unknown in the RES-E context compared to the potential suppliers in an industrial procurement auction. This fact reduces the chance to find an appropriate tailor-made auction mechanism, but also reduces the risk of collusive bidding behaviour.

5.2 Auctions for telecommunication licenses

Since the 1990s licences for telecommunication are sold via auctions by many governments all over the world, see McMillan (1995) and Klemperer (2002). The licenses differ by predetermined frequencies and are auctioned in long-term contracts. Bidders may have supplementary or complementary usage of the licences. The government's goals of the auction are efficient allocation, i.e. the selection of appropriate buyers, price discovery and (eventually) maximisation of revenue. Usually only a small number of bidders participates, which is due to very strong prequalification criteria. Since those participants are usually established telecommunication firms with long-term experience in the market, a high market transparency exists. However, asymmetric information between auctioneer and bidders motivates the implementation of an auction (McMillan, 1995). Meanwhile, auctions for telecommunication licences are international standard, where different formats are used between countries (Klemperer, 2002). Usually, dynamic auctions are implemented and although the licenses are reallocated after 15 years, the auctions for telecommunication licenses have to be considered as one-time auctions rather than as repeated auctions. The reason for that is that bidders may not be able to wait for being awarded until the next auction round in 15 years and hence the future reallocation auctions have no relevance for bidding in the current auctions.

What do sales auctions for telecommunication licenses have in common with RES-E auctions?
The telecommunication licences are auctioned as long-term contracts as the support levels for RES-E projects as well. Furthermore, the auction goals of efficiency and price discovery are similar in both cases. The information asymmetry between auctioneer and bidder also exists in both contexts. Finally, we have state-run auctions for the allocation of telecommunication licenses as well as of RES-E support.

What are differences between sales auctions for telecommunication licenses and RES-E auctions?
In contrast to the sales auctions for telecommunication licenses, the RES-E auctions are repeated auctions, which induces essential differences for the optimal design and implementation. In addition, a small number of bidders and high transparency among them as the case in sales auctions for telecommunication licenses may not be given in the RES-E context.

5.3 Auctions for refinancing operations

In auctions for refinancing operations liquidity is auctioned in form of homogenous goods, i.e. money, via short-term contracts for 2 weeks (Ehrhart, 2001). Before 2000, fixed-rate tenders were implemented which led to massive overbidding and consequently the auction design was changed to variable rate tenders, see (Nautz & Oechssler, 2003). The central bank, who runs the auction, pursues several aims by its implementation. They signal the minimum interest and further control the volume of money offered via the auction, where the volume can either be revealed or hidden. Besides signalling and controlling, allocative efficiency is an important goal as well as the discovery of liquidity needs (Ehrhart, 2001). The market situation is highly competitive, since a very large number of bidders from the international financial sector participates in those auctions. It is a repeated auction that is conducted on a weekly basis as a sealed-bid auction with interest-volume bids. The auction format changes between pay-as-bid and uniform pricing auction (Ausubel & Cramton, 2002).

What do auctions for refinancing operations have in common with RES-E auctions?

In both cases the bidders are the better informed party and hence an auction represents an appropriate measure to exploit existing information asymmetries. Both auctions are conducted repeatedly, whereas the auctions for refinancing operations is even conducted on a weekly basis, the RES-E auctions may be held several times, e.g. 3-4 times, a year. The auctioneer's goals strongly resemble those in the RES-E context. Not only an allocative efficient outcome and price discovery, but also the aim of signalling and controlling, plays a crucial role in the RES-E context. Potential bidders and the auctioneer, i.e. the government, may learn from previous auction rounds through revealed information. Furthermore, the government can control the expansion of RES-E by an appropriate determination of the auctioned volume. Finally, in both cases the bid is two-dimensional as bidders submit interest-volume bids in the auction for refinancing operations and support level-volume bids in the RES-E auction.

What are differences between auctions for refinancing operations and RES-E auctions?

Especially the high competition in the auctions for refinancing operations represents an essential difference to the RES-E context, where the competition level is mainly uncertain or even expected to be low for several technologies.

5.4 Auctions for oil and gas leases

First auctions for oil and gas leases in the U.S. took place in 1954 and became a prevailing instrument (Porter, 1992). In these auctions, bidders do not exactly know the value of the auctioned oil and gas leases at the time of sale, although they are allowed to carry out seismic investigations before the auction. In addition, the actual value is the same for all interested parties (Hendricks, et al., 1993). Consequently, the situation can be theoretically modelled with a common value approach (see Section 2). The auctions are implemented as first-price sealed bid auctions, where multiple (heterogeneous) tracts are offered up for bidding simultaneously and bidders submit bids for each tract they are interested in (Hendricks, et al., 1993). Further, reserve prices are announced that are constant for all tracts within one particular auction but may vary between several auctions. After the auction the winning bids as well as the identities of the corresponding bidders are published (Hendricks, et al., 1993). Besides price discovery, the main goals of the auction are allocative efficiency and maximising the auctioneer's revenue (Cramton, 2007).

What do auctions for oil and gas leases have in common with RES-E auctions?

The common value approach also applies to the RES-E context, if projects predefined by government, i.e. predeveloped wind-offshore parks, are planned to be auctioned. Wind measurements could be undertaken in order to achieve a more concrete value estimation of the project, similar to the seismic investigations for oil and gas tracts.

What are differences between auctions for oil and gas leases and RES-E auctions?

In order to highlight any differences a more detailed market-analysis for oil and gas leases has to be considered. However, it is obvious that the common-value approach is only relevant for RES-E auctions if projects are predeveloped by the auctioneer and not in case project developers participate with their individual projects in the auction.

Since auctions are very sensitive to given market and framework conditions, identical auction formats may lead to completely different auction outcomes under changing situations (Klemperer, 2002). Consequently, well-designed auctions adequately incorporate individual market-specific aspects and therefore lessons learnt can only be drawn with caution and under very strict limitations.

6 Conclusions

In the beginning of the report a general classification of relevant auction formats for RES-E was presented and a comprehensive introduction to their general characteristics was provided under simplifying assumptions. The main result of this first approach is that the considered auction formats perform equally well regarding expected auction revenue (i.e. support costs) and allocative efficiency in theory, even if the optimal bidding behaviour differs in the particular auctions. However, since auctions for RES-E as real-world applications have to be evaluated before the background of specific market and framework conditions, we extended our analysis by relaxing those simplifying assumptions. As a result our analysis revealed a certain ambiguity of auction formats under changing market conditions. Hence, a profound market analysis is necessary before the implementation of auctions in order to find potential chances and risks with regard to relevant auction formats. To emphasise how sensitive the implementation of a specific auction format may be, we have presented several examples from other industries. Although lessons learnt can only partly be drawn from these other industries, they offer a valuable first starting point for RES-E auctions in case of similar conditions.

This report will form the basis for further auction theoretical analyses with regard to additional RES-E specific design elements as well as for experimental investigations, where selected auction formats are tested with students in a controlled laboratory experiment. Regarding the former the next step will be to focus on the potential problem of low realisation rates in the RES-E context. Low realisation rates may be due to the fact that bidders face several uncertainties by participating in an auction, e.g. risk of not winning, prequalification requirements, penalties etc. Mitigation measures for a low realisation rate can include measures such as prequalification criteria, bid bond guarantees and penalties in case of non-delivery or delays. However, introducing these measures can increase the overall risk for the bidders and have adverse effects, e.g. on competition. Further we will discuss other specific additional design options for RES-E with regard to regionalisation or actor diversity as for example the introduction of contingents for a certain group of bidders (weak bidders, e.g.), the homogenisation of bidders or a bonus malus system, to name just a few.

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AURES is a European research project on auction designs for renewable energy support (RES) in the EU Member States.

The general objective of the project is to promote an effective use and efficient implementation of auctions for RES to improve the performance of electricity from renewable energy sources in Europe.

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