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Designing auctions for renewable electricity support. Best practices from around the world

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ABSTRACT

Auctions have recently been regarded as a useful alternative to other support schemes for the setting of the remuneration of renewable electricity (RES-E) worldwide. However, whether auctions will fulfill the expectations depends on the choice of design elements. The aim of this article is to analyze the advantages and drawbacks of different design elements according to different criteria. We support our analysis with economic theory and identify best and worst practices in the design of RES-E auctions from around the world. Our findings show that a few design elements score better than the alternatives in some criteria, without scoring worse in others. These "best" practices include a schedule of auctions, volume disclosure, price ceilings, penalties, streamline of administrative procedures and provision of information to potential participants. Design elements usually involve trade-offs between criteria. Overall, these results suggest that the choice of a specific design element is not a win-win decision and depends on the priorities of the respective government.

Introduction

It is widely acknowledged that electricity from renewable energy sources (RES-E) brings many environmental and socioeconomic benefits for society compared to conventional electricity. However, since its costs are still generally higher than those of its conventional counterpart, it could not penetrate the electricity market in the absence of public support. This has been the rationale for the public promotion of RES-E everywhere. However, such support has increased substantially in many countries around the world, raising the concerns of governments about the social acceptability and political feasibility of the policies. These policies have usually been based on administratively-set feed-in tariffs (FITs) or premiums (FIPs), which guaranteed prices for RES-E generators, usually without a cap on the total support costs.

In this context, auctions have recently emerged as a useful alternative for the setting of the remuneration of RES-E projects. The aim is to induce further investments in RES-E without excessively burdening the consumers' pockets.

Some advantages of auctions with respect to administratively-set prices have traditionally been mentioned: they mitigate the information asymmetry problem when setting remuneration levels, they are particularly suitable to control costs, expansion and the technology mix and they are more likely to lead to allocative efficiency (Haufe and Ehrhart, 2015). Support cost savings can be considerable. For example, Del Río et al. (2017) show that a harmonization of support schemes in the European Union (EU) based on a tendering scheme could reduce support costs by 5% in 2030 compared to harmonization based on FITs (16.7€/MWh vs 17.6€/MWh) and by 23% compared to FIPs. However, whether those savings will materialize strongly depends on the market conditions in particular countries for particular technologies and on how auctions are designed. There is some evidence that auctions have led to reductions in support with respect to previous administratively-set FITs in Brazil (Elizondo et al., 2014; Wigan et al., 2016), Ontario (IRENA, 2017) and South Africa (Eberhard et al., 2014), although not in Germany (Tiedemann, 2015). However, Toke (2015) argues that costs reductions that are often associated with renewable energy auctions are not caused by the auctions themselves, but are related with the general declines in costs of renewable energy technologies.

Many countries around the globe have recently implemented auctions for RES-E. According to IRENA (2017), 67 countries had held RES-E auctions as of 2016, up from 6 countries in 2005. In the EU, competitive auctions will have to be implemented in order to provide support to all new installations from 2017 onwards (EC, 2014). As with other support schemes, the devil lies in the details, i.e. whether auctions will fulfill the expectations and result in a successful promotion of RES-E depends on the choice of design elements.

The aim of this article is to analyze the advantages and drawbacks of different design elements according to different criteria. We support our analysis with economic theory and case studies from around the world, identifying best and worst practices in the design of RES-E auctions.

Some analyses of RES-E auctions have been carried out in the literature. The main features of renewable energy auction schemes in five developing countries were described in IRENA (2013). IRENA (2015) aimed to advise policy makers on the implications of different

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approaches to RES auctions, offering choices and recommendations to support optimal decision-making. More recently, IRENA (2017) provides a brief assessment of some recent experiences with auctions from around the world. Ragwitz et al. (2014) examine the key conditions for efficient auctions, reflecting on some international experiences in this area. The authors highlight the most important design features. Some academic work has also been undertaken. Del Río and Linares (2014) analyze the functioning of different design elements in auctions for RES according to several assessment criteria. In addition, academic work on RES-E auction design has been carried out in the context of the EU-funded AURES project.[1]

Compared to the existing literature, this article advances theory and practice in several fronts. First, an overarching and systemic analytical/methodological framework is provided. The relationships between design elements and assessment criteria in order to judge the advantages and drawbacks of different design elements are outlined. These links are mediated by the impacts of design elements on bidders and markets.

Previous work on the topic has either not considered assessment criteria in an explicit manner (IRENA, 2015) and/or included only a narrow set of criteria (IRENA, 2013, 2015; Ragwitz et al., 2014). This article analyzes the strengths and weaknesses of different design elements, using several criteria which are deemed relevant for this assessment from a policy-maker point of view. This approach helps to identify best and worst design practices when a specific goal (criterion) is pursued.

On the empirical front, we draw on more recent studies on the functioning of auctions for RES from around the world than those considered in the literature. Given that this is a highly dynamic field, an update of the more recent experiences provides additional empirical material from which conclusions can be drawn.

Accordingly, the paper is structured as follows. The next section provides the Analytical framework. Section 3 discusses the methodology (see Method). The results of the analysis are provided in Section 4 (see Main results). Section 5 concludes (see Conclusions).

Analytical framework

A crucial starting point in the analysis is that the links between specific design elements and criteria are mediated by the effects on bidders and the market. Therefore, these three components and their interrelationships are described and discussed below.

Design elements in auctions for RES

This section describes the minimum design elements in RES-E auctions.

Volume

There are three main ways to set the volume auctioned: capacity, generation or budget.

- Capacity targets: A total quantity in terms of MW is auctioned.
- Electricity generation targets: There is a goal of a total amount of MWh.
- Budget targets: There is an overall amount of support to be provided. It can be combined with the other two alternatives.

Whether or not to disclose the volumes is also a relevant design choice.

Timing

The length of the period between the announcement of the call for the auction and the time when the actual bidding occurs is a key feature of the auction, and may be set either too long or too short. Most importantly, the existence of regular rounds with a schedule is a critical design element. Setting the number of rounds in a year is a difficult, technology-specific issue.

Diversity

Policy makers may be willing to introduce design elements which increase diversity with respect to technologies, locations, actors and sizes of the installations for a number of reasons (see Del Río et al., 2015b for an extensive explanation). Diversity could be promoted in an auction by organizing different auctions per alternative (e.g., technology-neutral vs. technology-specific), by including minimum quota per alternative, by providing different remuneration levels for different alternatives or by lowering prequalification requirements or penalties for specific categories, i.e., small actors.

Participating conditions: facilitation and requirements

Several elements may facilitate the participation of actors in an auction, while others are rather requirements for this participation:

- Streamlining administrative procedures. Administrative procedures may severely restrict participation in an auction. Therefore, measures to streamline them may facilitate such participation.
- Supporting dialog with stakeholders and information provision. In some countries, policy makers meet with potential bidders to inform them about auction design and to get their feedback for improving such design. Providing information (e.g., renewable energy resource potentials) may also enhance participation in the auction.
- Prequalification requirements. They are required in order to participate in the bidding procedure and are applied in order to prove the seriousness of bids. They can refer to specifications of the offered project (such as technical requirements, documentation requirements and preliminary licenses) or to the bidders (providing evidence of the technical or financial capability of the bidding party) (Held et al., 2014). Financial guarantees by participants are often required. As with other elements, the challenge is to set them at appropriate levels (i.e., neither too stringent nor too lenient).
- Local content rules refer to the requirement to use renewable energy equipment which is manufactured by local firms.

Support conditions: types and forms of remuneration

Remuneration in an auction can be provided for generation (MWh) or capacity (MW). In addition, there are several instruments to set the remuneration for electricity generation, including FITs and FIPs:

- Under FITs, a total payment per MWh of RES-E generated, paid in the form of guaranteed prices and combined with a purchase obligation by the utilities, is provided.
- Under FIPs, a payment per kWh on top of the electricity wholesale-market price is granted. Within FIPs, a main distinction is between fixed and sliding FiPs. Fixed FiPs are set once and do not alter. The total remuneration thus depends on the market prices. Sliding FiPs are set at regular intervals to fill the gap between the average market price perceived by all generators of a given technology and the strike price set in the auction.

Selection criteria

Price-only auctions are organized using only one criterion, i.e., the bid price. In multi-criteria auctions, the price is the main criterion among other criteria which may include local content rules, impact on local R&D, industry and jobs and environmental impacts.

[1] AURES is an on-going project whose main objective is to promote an effective use and efficient implementation of auctions for renewable energy support in the European Union Member States, especially regarding their cost-efficiency. This paper partly draws from work carried by the author in the context of this project.

Table 1
Description of criteria to assess instruments and design elements in auctions for RES-E.
Source: Adapted from Del Río et al. (2015a).

Criteria	Description
Effectiveness	Degree to which RES-E instruments and design elements result in deployment of RES-E projects (% realization rate).
Static efficiency 1 (allocative efficiency, direct generation costs).	Reaching the target at the lowest possible generation costs (€, €/MWh). An auction outcome is efficient if the bidders with the lowest generation costs are awarded. The relevant costs here include generation costs and transaction costs.
Static efficiency 2 (indirect generation costs)	Balancing, profile and grid costs (€, €/MWh) (see footnote 3).
Dynamic efficiency	This refers to long-term technology effects, including impact on innovation and cost reductions over time.
Support costs	Average support level per technology (net of generation costs) (€/MWh), total support costs net of total generation costs (€).
Local impacts	Socioeconomic and environmental effects at the national, regional or municipal level (impacts on the value chain, industry creation, local employment, lower fossil-fuel dependence...).
Actor diversity	The participation of small actors could be encouraged for different reasons (see del Río et al., 2015a).
Sociopolitical feasibility	Degree to which the design elements and the whole support scheme are socially acceptable and politically feasible. This partly depends on other criteria, such as minimization of support costs and local impacts.

Auction format

Depending on whether the auctioned object can be split between multiple winning bidders, auctions are referred to as single-item or multi-item auctions. In a single-item auction there is a single product which is allocated to a single owner and the product cannot be split. In a multi-item auction the auctioned product is split among different owners and bids are submitted for only part or the total auctioned amount (AURES, 2016).

Auction type

A main distinction is between static (sealed-bids) and dynamic auctions. Under sealed-bid auctions, project developers simultaneously submit their bids with an undisclosed offer of the price at which the electricity would be sold. An auctioneer ranks and awards projects until the sum of the quantities offered covers the volume of energy being auctioned. Under the multi-round descending-clock auction, the auctioneer offers a price in an initial round, and developers bid with offers of the quantity they would be willing to provide at that price. The auctioneer then progressively lowers the offered price in successive rounds until the quantity in a bid matches the quantity to be procured. Hybrid models may use the descending clock auction in a first phase and the sealed-bid auction in a second phase, as in Brazil (IRENA, 2013).

Pricing rules

There are basically two different ways to set support levels in sealed-bid auctions. Under uniform pricing all winners receive the strike price set by the last bid needed to meet the quota or the first bid that does not meet the quota. Thus, either the highest accepted bid (HAB) determines the award price or the lowest rejected bid (LRB) determines the award price. Under the pay-as-bid (PAB) alternative, the strike price sets the amount of generation eligible for support and each winner receives his/her bid.

Price ceilings

In order to limit the costs of support, the auctioneer can set a ceiling price for each technology, above which projects are not considered (IRENA, 2013). Again, setting the ceiling price at an "appropriate" level is not a trivial exercise. A main decision is whether or not to disclose this price.

Table 2
Main indicators for the effects on bidder, market and system level.

Type of effect	Subcategory
Effects on bidder level	Participation risks
	Participation costs
	Expected benefits: bid levels minus generation costs
Effects on market level	Number of bidders
	Diversity of bidders
	Market concentration
Effects on system level	Regional distribution of deployment

Realization period

Deadlines are needed to build the projects which have been awarded contracts. How long this period should last for is a key issue, with a risk of too long or too short periods.

Penalties

Penalties can take different forms: they can forbid participation in successive auctions, reduce the level of support, reduce the length of the support period by the time of the delay, lead to the confiscation of bid bonds and result in penalty payments.

Assessment criteria

Defining "success" in the choice of design elements is certainly not a trivial issue. Assessment criteria are used for this purpose. Our starting point is that these assessment criteria are contained either explicitly or implicitly in policy documents. In addition, other stakeholders have their own views on what are desirable assessment criteria, which are not necessarily contradictory to those of policy-makers. Accordingly, the identification of relevant assessment criteria for RES-E auctions has been based on a combination of different information sources, including official national documents, country case studies published in energy and energy policy journals, which provide a relevant source of information on the challenges perceived by policy-makers, reports from international institutions, EU-funded projects with a specific focus on assessment criteria of energy and climate policies and the gray literature. Although effectiveness and static efficiency are the most common criteria used in the assessments, several contributions expand the set of relevant criteria to include other aspects, such as dynamic efficiency, social acceptability and political feasibility (see Del Río et al., 2012, 2015a; IRENA, 2014). However, there is no a priori unambiguously preferred ranking of criteria in the literature. In principle, a proposed design element is better than the alternative in specific circumstances when it scores better in most of the aforementioned criteria. Table 1 describes the criteria considered in this article and illustrates how they can be measured with relevant indicators.[2]

Static efficiency refers to the minimization of the (system) costs of RES-E generation. System costs can be disaggregated into direct and indirect costs. The former include installation, operation and maintenance of renewable energy technologies. Indirect costs refer to balancing, profile, grid and transaction costs.[3]

[2] Full details on the description of these criteria as well as on how they were derived are provided in Del Río et al. (2015a).

[3] Balancing costs occur due to deviations from schedule of variable RES-E power plants and the need for operating reserve and intraday adjustments in order to ensure system stability. Profile costs are mainly back-up costs, i.e., additional capacity of dispatchable technologies required due to the lower capacity credit of non-dispatchable RES-E. Grid costs are related to the reinforcement or extension of transmission or distribution grids as well as congestion management, including re-dispatch required to manage situation of high grid load (Breitschopf and Held, 2013).

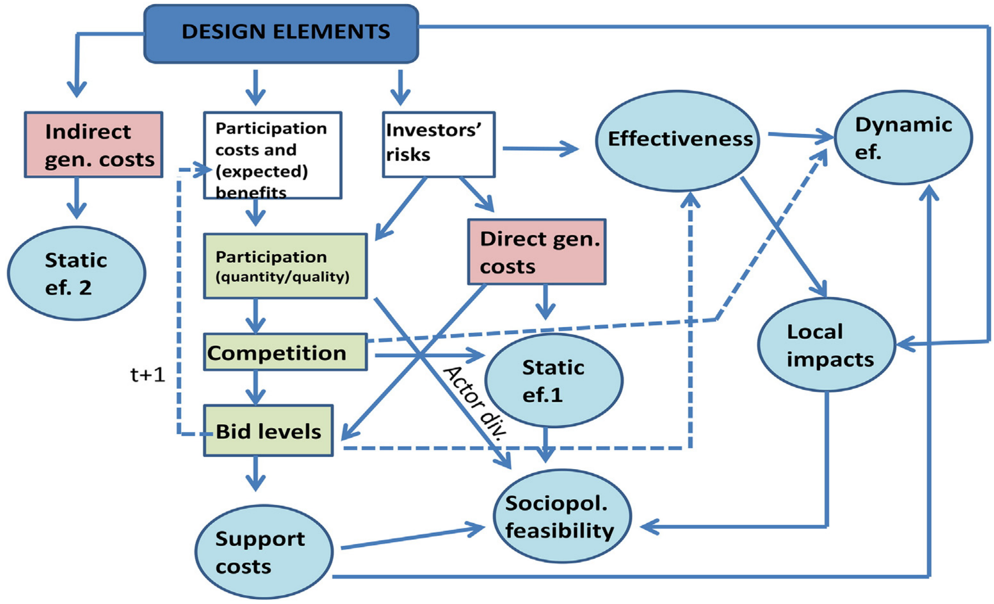

Fig. 1. Relating different components in the assessment of design elements in RES-E auctions.
Source: Own elaboration.

Market, bidders and system effects

The impact of design elements can take place at different albeit interrelated levels, depending on the aggregation considered, from micro (bidders) to meso (system) and macro (regional) (Table 2).

Design elements affect the participation of bidders in the auction by influencing the costs, risks and expected benefits of participation. In general, the higher the costs, the higher the risks or the lower the expected benefits, the lower the number of participants. The impact at bidders' level translates into market effects, which include the number of bidders in the auction, the diversity of those bidders and their market concentration. In turn, these aspects have consequences on the functioning of the auction. Finally, there might be relevant effects at the system level, including impacts on the regional distribution of deployment.

Linking the components

Fig. 1 illustrates the main links between market/bidder/system effects and assessment criteria. The links between components are both empirically-based and theory-based. The incentive to participate in the auction, which depends on the expected benefits, costs and risks, takes a central role in this analytical framework because it affects a critical element, competition, which has both a quantitative and a qualitative aspect. The design element may induce greater participation, making collusion more difficult (positive quantitative impact on competition). But it may also increase the diversity of actors and encourage the participation of stronger bidders instead of weaker ones. These qualitative aspects positively affect competition (Del Río et al., 2015a; Kreiss, 2016). A greater and better competition positively affects static efficiency, since the cheapest technologies/locations are selected and support costs (given lower bid levels). Design elements may also influence investors' risks directly and, thus, generation costs: greater LCOE results from higher capital costs due to greater risks, with a detrimental impact on allocative efficiency and support costs, since higher risks are factored in higher bids. Other criteria are influenced by those mechanisms. Effectiveness, which is affected by those design elements with an impact on investors' risks, competition and bid levels, is a main one. A higher level of competition induces more aggressive bidding and, eventually, underbidding and underbuilding. In turn, effectiveness positively affects other criteria: local impacts and dynamic efficiency. This is so because socioeconomic and environmental benefits depend on the actual deployment of RES-E projects. On the other hand, the prospect of a future market encourages R&D investments, and deployment triggers learning effects and investments in the renewable energy supply chain. Local impacts may be directly influenced by design elements through, e.g., local content requirements. Dynamic efficiency is, in addition to effectiveness, also positively influenced by elements with a positive impact on innovation: a higher competition and a higher support level, since higher profit margins may be partially reinvested on R&D (see Menanteau et al., 2003). Sociopolitical feasibility is positively affected by other criteria: lower support costs, higher static efficiency, higher actor diversity and local benefits. Deployment may also bring negative environmental impacts, and affect social acceptability (NIMBY syndrome). Finally, indirect costs are directly influenced by design elements (e.g., geographical diversity).[4]

Method

The analysis of the advantages and drawbacks of different design elements in RES-E auctions draws on several complementary methods. First, economic theory has been used to assess the impact of different design elements on bidders and the market and, thus, on the assessment criteria. This paper applies economic theory to the analysis of the functioning of auctions in different countries with respect to different design elements. Auction theory is elaborated and summarized in many books and journal papers.[5] In turn, the analytical framework draws heavily on the work of the author and colleagues carried out in the context of the EU-funded AURES project (see Del Río et al. (2015a, 2015b), Del Río (2015) and Haufe and Ehkhart (2015)).

In addition, those theoretical relationships have been supported by empirical findings. The empirical assessment of the strengths and weaknesses of different design elements for RES-E auctions has been

[4] A detailed discussion on the interrelationships, overlaps and links between those components is provided in Del Río (2015).

[5] Interested readers are directed to Klemperer (1999, 2004), Cramton (2009), Menezes and Monteiro (2005), Milgron (2004), for an overview of auctions theory and to Maurer and Barroso (2011) for a more energy-sector-specific analysis.

based on several sources of information of past and current schemes from around the globe:

1. Top academic energy, energy policy and climate policy journals.[6] Terms such as "tender", "auction" or "bidding" were inserted in the journals' internal search engines. The corresponding articles were filtered manually in order to discard those which were not directly related to RES-E auctions. Thirty articles on auctions for RES-E support were initially selected. However, most of these articles did not focus on the design of auctions for RES-E but focused on the comparison between auctions and other alternatives for RES-E support, namely administratively-set support such as FITs or FIPs. Indeed, only 6 articles addressed the issue to some extent, focusing on old experiences with auctions for RES-E in the U.K. (Mitchell, 1995; Mitchell and Connor, 2004) and China (Yu et al., 2009; Wang, 2010) and prequalifications (Kreiss et al., 2016). A review of best practices before 2012, which did not cover all the schemes, was carried out by Del Río and Linares (2014).
2. Reports with an extensive coverage of auctions for RES-E from international institutions such as IRENA (IRENA, 2013, 2015) or the World Bank (Maurer and Barroso, 2011), EU projects (Held et al., 2014) and others (Ragwitz et al., 2014; De Lovinfosse et al., 2013; Factor, 2017).
3. Gray literature. In addition, a Google search has been performed, using relevant terms, including "tenders for renewable energy", "auctions for renewable energy" or "bidding for renewable energy". Documents on the design of auctions in particular countries were identified.
4. The paper also draws heavily from empirical research on auctions for RES carried out in the EU-funded AURES project. Sixteen country case studies on auctions from around the world were undertaken in this project, some of them by the author of this article. They are publicly available at the AURES project website (http://www.auresproject.eu). These case studies were carried out using a combination of data sources, including official documents and interviews with key stakeholders in each country.

The analysis has considered 30 international experiences from around the world, with different temporal and technology scopes (Table 3).

Main results

This section reports the results of the analysis of the advantages and disadvantages of different design elements according to different criteria, identifying best and worst practices from around the world. Fig. 2 indicates which design element has been most often used.

Volume

If the emphasis is put on *effectiveness* and renewable energy targets are set in relative terms (i.e., as a percentage of electricity demand), then a generation-based volume target would be preferable, since compliance would be more predictable. However, ensuring that a generation target is exactly met becomes more difficult than with the other two alternatives (capacity-based or budget-based). Although a level of generation cannot be ensured under capacity-based targets, because this depends on the quality of the renewable energy resource, effectiveness could be assessed at an earlier stage, i.e., when the plants are deployed, rather than having to wait until the end of the remuneration period, as with generation-based targets (Del Río et al., 2016). Capacity-based auctions are the most widespread option (Fig. 2). The amount of capacity installed or electricity generated is uncertain under budget-based volumes. For example, in Poland, the budget caps may result in low levels of generation (if there is a large share of high bids) (Kitzing and Wendring, 2016) and, in the Netherlands, the budgets are structurally underused (Noothout and Winkel, 2016). Notwithstanding, the different metrics do not affect the realization rate of projects effectively winning in the auction.

If the goal is to minimize *support costs*, then a budget-based volume would be preferable since it ensures a given level of support costs. Capacity-based volumes would be the least recommendable in this regard, since support costs (which depend on the amount of generation times the winning price) would be uncertain.

While no discernible differential impact can be expected on *allocative efficiency*, grid management would be easier under generation-based targets (lower *indirect generation costs*). Capacity-based volumes are preferable for *dynamic efficiency* since they provide the strongest signal to equipment manufacturers on the relevant market size for the future, which may encourage innovation and supply chain improvements (Del Río et al., 2016). The incentive for innovation by technology and equipment suppliers partly depends on the size of the market where they can sell their products (Del Río et al., 2015b). The market for equipment manufacturers would be uncertain in generation-based targets and a proper signal for equipment manufacturers would be absent in budget-based targets.

The *sociopolitical acceptability* of the three metrics depends on which is the main political priority; if support costs, then a budget-based target would make more sense; if effectiveness, then a generation-based target would be better. Capacity-based targets would be preferable if building a local supply chain is the main goal.

Setting the appropriate volume level represents a main challenge. If it is set too high, as in Italy (Tiedemann et al., 2016) and France (Förster, 2016), lack of competition and high bids are more likely, although this problem can be mitigated with a ceiling price.[7] The size and readiness of the local renewable energy market in the first round of the auction in South Africa, in 2011, were initially overestimated, resulting in too large volumes, limited competition and high bids (Eberhard, 2013; IRENA, 2015). In Peru, the volume auctioned for biomass in the first auction was 813 GWh/year and only 143 GWh were awarded, i.e., it was too large from a static efficiency and a support cost perspective (Del Río, forthcoming-c).

If volumes are too small, then more aggressive bidding, underbidding and ineffectiveness may result. In Spain, a moratorium on RES-E support since 2012 led to a pipeline of 10 GW of wind projects. This was 20 times higher than the 500 MW which were auctioned in the first auction, probably leading to underbidding and, thus, ineffectiveness (Del Río, 2016c). Volume reductions can be considered when a specific design element lowers competition.

A main issue is whether the volume, which is a main variable to estimate competition, should be disclosed. Revealing the auction volume provides certainty, transparency and reliability for potential bidders, leading to lower risks and, thus, higher participation and competition and lower bids and *support costs*. A hidden volume may induce *allocative inefficiencies* due to the higher risks (higher financing and capital costs) and also if bidders underestimate the competition level and submit less aggressive bids. Equipment manufacturers benefit from information on the market volume, which encourages innovation and would be beneficial for *dynamic efficiency*. However, some countries decided not to disclose volumes in order not to provide too much information and discourage strategic behavior and collusion. This was the case in Brazil (Förster and Amato, 2016). In South Africa, not revealing the volumes was thought to encourage competition since it prevented the strategic behavior which could have led the auction to end up prematurely with high *support levels* (Del Río, 2016a).

[6] We identified top academic journals in the energy, energy economics, energy policy and climate policy areas with an impact factor in the Joint Citation Reports (JCR) of Thompson-Reuters.

[7] Also note that a higher volume increases the probability of winning and makes it more attractive for potential bidders to participate. This higher incentive to participate would increase competition levels (Kreiss, 2016).

Table 3
RES-E auctions around the world considered in this study.
Source: own elaboration.

Europe	America	Africa	Asia	Oceania
Spain 2016-WN, B	BRAZIL 2007–2009, W, H, B,	South Africa 2011–2014 all RES	India 2010–2014 PV, CSP	Australia (Australian Capital Territory, ACT) 2012–2016, PV, W
Denmark 2005–2015, WF, W nearshore	California 2011–2015, all RES	Zambia 2016 PV	China 2003–2007 WN	
France 2012–2014, PV	Peru 2009–2015 all RES	Morocco 2011–2013 WN, PV, CSP	UAE (Dubai) 2012–2016 PV	
Germany 2015-ground-mounted PV	Chile 2015—all RES	Uganda 2015—small PV (<5 MW)		
Ireland 1995–2003. W, H, B	Argentina 2016—all RES	Ghana 2015–2016 PV		
Italy 2013–2015, W, H, G, B.	Mexico 2016—all RES (nuclear and cogeneration). In reality, solar PV and wind won.			
Netherlands 2011–2016, all RES (also RES H&C)	Quebec 2005–2009 W			
Portugal 2006–2008 W, B	Panama 2011–2014 wind hydro, PV			
U.K. NFFO 1990–1998, all RES	Uruguay 2006–2013 WIND, biomass, hydro, PV			
U.K. CfD 2015—all RES				
Poland 2016—all RES				
Russia 2013—small H, W, PV				

W: wind; WN: Wind on-shore; WF: Wind off-shore; PV: solar photovoltaics; CSP: concentrated solar power; B: biomass; H: hydro; G: geothermal; H&C: Heating and cooling.

Timing

A too short period between the announcement of the auction and the deadline for bid submission may restrict participation and negatively affect competition. This has been the case in several countries. In Portugal, the lead time has been deemed a short one (Del Río, 2016b). Short time spans between the auction announcement and the deadlines for bid submissions discouraged competition in South Africa (Montmasson-Clair and Ryan, 2014; Yuen, 2014). Lower competition leads to higher *support costs*.

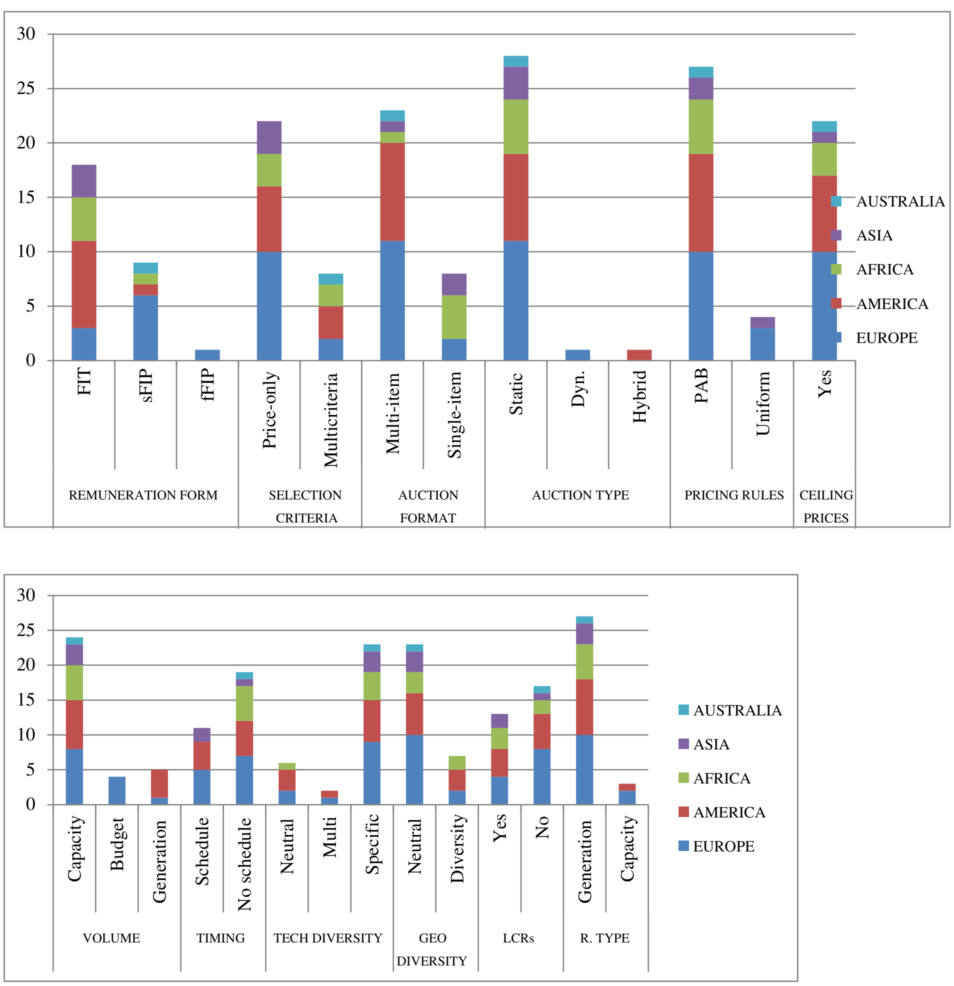

Fig. 2. Frequency of the different design elements in the analyzed experiences. Note: numbers refer to the amount of RES-E auctions which have adopted the design element. In a few cases, two alternatives have simultaneously been used.
Source: Own elaboration.

Most importantly, a long-term schedule for regular auctions published with sufficient anticipation (i.e., 3 years, depending on the technology) decreases investor risks and encourages participation in the auction. Frequency at fixed dates in California led to high participation (Fitch-Roy, 2015). The lower risk improves financing conditions and reduces generation costs (higher *static efficiency*). Furthermore, the expectation that there will be more rounds mitigates the risk of underbidding since bidders do not need to bid so aggressively in a given round, with a positive impact on *effectiveness*. In addition, a schedule facilitates the development of a robust supply chain because equipment manufacturers can plan their investments accordingly. The certainty given to technology developers regarding the existence of a future market for their technology encourages technological progress (Del Río and Linares, 2014). For example, with periodic auctions providing a steady stream of newly contracted wind power projects in Brazil, the wind equipment industry flourished (Elizondo et al., 2014). This leads to a higher *dynamic efficiency*.

There are numerous examples of the detrimental consequences of auctions at irregular intervals or infrequent ones. The low frequency of auctions in Poland has probably led to underbidding since losing in an auction means a long waiting time (Kitzing and Wendring, 2016). The irregular intervals in Ireland, without a long-term schedule, led to high investor risks and financing costs and low effectiveness (Steinhilber, 2016a). The lack of a schedule led to only one participant in the Danish Anholt tender (Kitzing and Wendring, 2015), to underbidding in the recent U.K. auction (Fitch-Roy and Woodman, 2016) and to the absence of a competitive market in the U.K. NFFO in the 1990s (Butler and Neuhoff, 2008; Del Río and Linares, 2014). The lack of a schedule in Spain has led to high risks for investors and has negatively affected effectiveness and the supply chain (Del Río, 2016c). If the priority of the government is to have a control on the *costs of support*, then the choice for regular or stand-alone auctions is not so clear. Although regular auctions are likely to reduce the risks for investors (lower bids), stand-alone auctions would allow governments to retain flexibility to adjust the auctioning schedule in response to changes in market conditions (IRENA, 2015).[8] This might explain why they are more widespread (Fig. 2).

Diversity

Policy makers may be willing to introduce design elements which increase diversity with respect to technologies, plant sizes, actors and locations for several reasons (see Del Río et al., 2015a). In general, a problem with increasing diversity in RES-E auctions is market segmentation, which could lead to few bidders and low competition in a given contingent, resulting in higher bids and higher generation costs (lower *allocative efficiency* and *support costs*). We focus on technology and geographical diversity.

Technological diversity

Technology-differentiated support, which is more widespread than technology-neutral support (Fig. 2), aims to encourage the local industrial value chain (an argument in China, Brazil, France, Portugal and South Africa), system integration (California, France) and participation of small actors/social acceptance (Denmark, France). Technology-neutral auctions would lead to stronger competition than technology-specific auctions due to a potentially higher number of participants. Projects with lowest costs would be awarded a contract and lower bids and *support costs* would result. This was the expectation in the technology-neutral auction in the Netherlands, where technological diversity and, thus, *dynamic efficiency*, have been negatively affected (Wigan et al., 2016). Similarly, the more expensive technologies were not promoted in the UK, where waste-to-energy and onshore wind dominated (Mitchell and Connor, 2004; Lipp, 2007). Biomass-anaerobic digestion or offshore wind projects were not commissioned in the Irish AER (Finucane, 2005).

Geographical diversity

A priori, compared to geographically-neutral auctions, geographical diversity would lead to higher generation costs and, thus, a lower *allocative efficiency* and higher *support levels*. It could also involve additional government resources in order to identify appropriate sites. For example, the project sites were pre-selected by the government in China, with a lower static efficiency than in a geographical-neutral auction (Steinhilber, 2016b). In Mexico, the locational signal in the first auction did not encourage the location of projects in the places with the best solar or wind resources (Del Río, forthcoming-b).[9] However, although the aforementioned signals had a negative effect on allocative efficiency, they tried to encourage the location of new projects where they would most benefit the power system, as indicated by expected congestion prices obtained from a long term system simulation. Every package bid was adjusted: the "good" locations (where nodal prices are high) were rewarded and the "bad" ones (those with lower nodal prices) were discouraged for bid comparisons in the auction (IRENA, 2017, p.14). Therefore, from an overall efficiency (system cost) perspective, the locational signal may not be so detrimental. Furthermore, the reduction of the risks of administrative permits under geographical diversity would reduce the risk of non-compliance by freeing the investors from the liability of securing land, obtaining environmental permits, carrying out resource assessments and securing access to the grid (IRENA, 2013). The lower participation costs and risks increase participation and competition (lower bids and support costs), (partially) offsetting the higher bid prices from market segmentation and the non-minimization of generation costs.

Geographical diversity may increase social acceptability, as in Portugal (Del Río, 2016b), lower the risk of excessive remuneration in the best sites, ensure proximity to the grid and/or loads, leading to fewer grid restrictions, and reduce the risks of administrative permits. When the grids are underdeveloped, as in many countries in Africa, it makes sense to organize auctions for projects at preselected sites in order to minimize system costs, even if the location of those projects is not optimal from an allocative efficiency perspective. This has been the case in Uganda and Zambia (Eckhouse and Hirtenstein, 2016; Del Río, forthcoming-a).

Participation conditions: requirements and facilitation

Streamline of administrative procedures

Burdensome administrative procedures can lead to lower levels of participation and, thus, competition, higher bids and *support costs* but also to a lower *effectiveness*. For example, project realization was severely reduced in Ireland due to a misalignment between spatial planning and the auction scheme (Steinhilber, 2016a). Acknowledgement of the high transaction costs stemming from burdensome administrative requirements in South Africa led to streamlined procedures in round 4 (Allen and Overy, 2015; Eberhard et al., 2014). Streamlined procedures, one-stop-shop for permits and an integration of the permitting

[8] A different, yet challenging issue is to determine the optimal number of rounds and the volumes. More rounds may create a "narrow market" problem in one round. Large volumes auctioned in one specific round would stifle completion in that round. The "optimal" number of rounds depends on the technology and situation of the market. In general, fewer rounds would be more suitable for technologies with potentially fewer actors (offshore wind) and more frequent rounds could be recommended for technologies/bands with more participants (roof-top solar PV). Thus, volume and frequency are related to some extent.

[9] Regional adjustment of bid prices (hourly adjustment factors per zone) were included. These adjustments rewarded or penalized those zones where new capacity is needed or where production overcapacity exist, respectively. The locational signal was weakened in the second auction as the auction focused instead on the quality of the resources (IRENA, 2017).

procedure, as in Denmark (Held et al., 2014), can increase participation and the effectiveness of the auction. They also reduce costs for investors, which leads to a higher allocative efficiency. Those winning in the first auction in Mexico did not have the certainty that they would obtain the interconnection (Del Río, forthcoming-b; POYRY, 2016). Since players are not obliged to demonstrate acquired land rights, there is a risk that not all projects will be implemented as planned (IEA, 2016, p.51). Both have a detrimental impact on effectiveness. This suggests that the auction procedure and the interconnection process should be homogenized, as recommended by Del Río and Linares (2014).

Supporting dialog with stakeholders

Supporting the dialog with stakeholders would increase participation and competition and reduce bid levels (lower *support costs*). For example, an open dialog with stakeholders has led to broad support for the program in California (Fitch-Roy, 2015). Investors were not able to discuss the auction conditions before submitting the final offer in the Danish Anholt auction, which was a factor behind low participation in this auction (Kitzing and Wendring, 2015). The Danish Energy Agency has organized meetings with pre-qualified bidders to discuss auction conditions before submitting their bids. While this reduced investors' risks, it also weakened the competitive nature of auctions (Wigan et al., 2016, p.15). In South Africa, a conference is initially organized, allowing the government to communicate any changes to all market agents equally (Del Río, 2016a; Toke, 2015).

Transparency, clear rules, information provision and stakeholder dialog have been clear facilitators of participation in Mexico, by reducing the risks and costs of participation. In turn, this has had positive effects on competition and bid prices (Del Río, forthcoming-b). Simplicity and transparency are considered main strengths of the auctions in Peru by many stakeholders (Del Río, forthcoming-c). Different types of actors have been attracted, particularly foreign ones, leading to healthy levels of competition. Risk reduction has to be weighted with reductions in the competitive character of auctions and the potential *allocative inefficiencies* that may result. For example, project sites were preselected by political actors in China, with detrimental effects on *allocative efficiency* (Steinhilber, 2016b).

Prequalification requirements

Prequalification criteria are crucial for *effectiveness*. They aim to ensure the seriousness of bids and sort out projects with low realization probability (see Kreiss et al., 2016 for a theoretical analysis). But they may discourage the participation of actors by increasing the costs of participation, leading to lower levels of competition and higher bids and policy costs. On the other hand, they increase the probability that stronger bidders participate, leading to higher quality of bids (Kreiss, 2016). Competition in the auction increases also if weaker bidders are replaced by stronger ones (Haufe and Ehrhart, 2015; Kreiss, 2016). In particular, strong requirements can deter smaller participants (Moore and Newey, 2013), negatively affecting actors' diversity.

As with other design elements, setting them at appropriate levels represents a crucial challenge. Too strong prequalification requirements reduce participation and, thus, competition, leading to higher bids and *support levels* and a lower *allocative efficiency*. For example, in France, only 60% of the submitted bids were eligible, likely due to unclear and/or inadequate documentation requirements (Förster, 2016), leading to lower competition and higher bids. In Peru, strict compliance rules severely limited participation in the 2009 auction (IRENA, 2015; Del Río, forthcoming-c). In Uganda, technical specifications have been too strict. Narrow requirements for individual components, rather than for the quality of power produced, have prevented developers from choosing the least cost option to meet requirements (Castalia, 2016). Although prequalification requirements can help reduce the risk of underbidding (IRENA, 2015), too strong requirements may lead to too aggressive bidding behavior, i.e. underbidding, because some costs of prequalification will be lost if the bidder is not successful in the auction and winning becomes more important to the bidder (Rosenlund, 2016).

If they are too weak, ineffectiveness may result, as in Ireland and Panama. After high non-realization rates in the initial rounds in Ireland, bidding projects were required to have secured planning permission. Later auction rounds also required bidders to provide cash flow statements showing that the proposed project could break even (DMNR, 2003; Steinhilber, 2016a). In Panama, low financial guarantees and the absence of other prequalification requirements has led to weak bidders participating in the auction and low effectiveness (Factor, 2017). In Chile, guarantees pledged have been deemed rather insufficient (Muñoz and Galetovic, 2017) and the financial guarantees will increase from 14,800 to 29,600€/GWh in the next auction (EnergyNews, 2017).

Local content rules (LCRs)

LCRs are aimed at enhancing the local economic development opportunities in the country, which may increase the *local impacts* and the *social acceptance* of the scheme. For example, government officials in South Africa see LCRs as a way to boost local manufacturing in an underdeveloped sector (Eberhard et al., 2014). Proponents of the policy claim that significant socioeconomic benefits are derived (South African Government, 2015). However, McDaid (2014) argues that the impact on local manufacturing and sustainable local economic development have been modest. This has also been the case with LCRs in Uruguay (Factor, 2017). In general, while it is true that the local innovation-supply chain would be supported, it is unclear if this is beneficial from a wider perspective (Del Río and Linares, 2014), i.e., the impact on *dynamic efficiency* is unclear.

The drawbacks of LCRs might be the reason for their limited implementation (Fig. 2). They include fewer bidders, given the higher costs and risks for investors, lower levels of competition and higher administrative costs due to monitoring and verification of the local content. This would end up in higher *generation costs*, bid prices and *policy costs*. For example, there were two auctions in India, one with LCRs and the other without. The local content sub auction received half as many bids as its open counterpart (700 MW vs. 1470 MW) and resulted in significantly higher bids (Khana and Barroso, 2014). In Russia, onerous LCRs were one of the reasons for the low interest of project developers in the auction (Rice et al., 2014). In South Africa, opponents of the LCRs argued that they resulted in higher bids because local components were not cost-competitive with those sourced abroad (Del Río, 2016a). The Portuguese case shows that the creation of a local wind industrial cluster took place at the expense of greater support costs and a lower allocative efficiency (Del Río, 2016b).[10] LCRs led to higher costs for RES-E projects in Uruguay (Factor, 2017).

In addition, the projects can be delayed if LCRs are too stringent, negatively affecting the *effectiveness* of the scheme. For example, delays in the first wind auction in Brazil were caused by the requirement to have 60% of the cost of equipment spent locally, as only one manufacturer was operating at the time (IRENA, 2013). The lack of a competitive domestic RES-E industry and manufacturing capacity in South Africa made the LCR a bottleneck for projects, and increased the costs and risk of failure in the construction phase (De Lovinfosse et al., 2013). However, there has been considerable competition in South Africa despite the implementation of LCRs (Del Río, 2016a). Likewise, in China, competition has not been negatively affected by LCRs because China is large enough to have some competition even among its domestic industry players (Steinhilber, 2016b). Therefore, the situation of the local market with respect to the technology in question should be considered when implemented LCRs. Non-existent or low-quality local

[10] One of the most important selection criteria was the development of a wind industrial cluster. This did not guarantee that the sites selected by the wind developers were optimal, but that the chosen developers had the economic capability to create a large industrial investment (Del Río, 2016b).

manufacturers would result in a bottleneck for the successful completion of projects.

Finally, LCRs may violate the World Trade Organization (WTO) rules. This issue was a major point of contention in India, as the United States filed an official complaint with the WTO against India's LCRs (Khana and Barroso, 2014). This was also the reason that China ceased to apply LCRs since 2009.

Information provision

Providing information to potential participants (e.g., resource assessments) can be justified for *effectiveness* because lack of information on the characteristics of the resource may lead to excessively optimistic bids and underbidding. Information provision would encourage *actor diversity* since smaller actors are likely to suffer more from this information problem. Information provision would reduce the risks and costs for bidders, which would encourage higher participation and competition and lower bids (lower *support costs*), as it has been the case in Uruguay (Factor, 2017). It would also improve *allocative efficiency* if it contributes to deploy RES-E in the best sites, although this would be (partly or totally) offset by the higher administrative costs.

Support conditions

Remuneration type (energy or capacity-based)

The remuneration granted and the functioning of the plant are not connected under capacity-based remuneration and, thus, there isn't a lower incentive to run the plant efficiently.[11] Therefore, generation-based remuneration increases the incentive for a better design and functioning of plants (better *allocative efficiency*) and provides better system integration (lower *indirect costs*). Capacity-based metrics can lead to greater certainty on *support costs* since support is paid upfront. However, the net impact on support costs is uncertain since the greater allocative efficiency with generation-based remuneration would lead to lower bids. An overwhelming majority of countries has adopted generation-based remuneration (Fig. 2).

No clear differences can be observed regarding *dynamic efficiency*. A generation-based metric may induce more competition between equipment suppliers to innovate and provide technologies that maximize the revenue of RES-E generators. But equipment suppliers would have an incentive to sell technologies that are cheaper than their competitors', and this incentive exists whichever metric is used.

Energy remuneration form

The three alternatives in this category (FITs, fixed and sliding FIPs) differ in two main dimensions: market integration and investors' risks. FITs, which is the most widespread, provide very stable revenues with very low investment risks and therefore low risk premia with respect to RES financing. Under FIPs, and in contrast to FITs, plant operators need to market the electricity generated directly at the electricity market. The main advantage of FIPs is their market orientation, as the electricity price is part of the overall remuneration for RES-E plants. In this way, decentralized direct marketing of RES-E is encouraged and incentives to feed-in electricity in times of negative prices are reduced, i.e., RES-E is made more responsive to price signals. A greater market exposure, however, comes with a higher investment risk and higher financing and, thus, capital costs. The lower risks under FITs would translate directly into lower bids (Del Río and Linares, 2014) and may also attract potential bidders, which increases competition and further reduces bid prices.

Sliding FIPs provide a good balance between low investment risks (highest under fixed FIPs and lowest under FITs) and high market integration of RES-E generation (highest under fixed FIPs and lowest under FITs). Under sliding FIPs, RES-E plant operators are not exposed to the overall risk of trends in electricity prices, as with fixed FIPs. Compared to FITs, investment risks are higher, since RES-E has to be marketed. The strike price is determined in the auction procedure. The public has to bear higher risks regarding the policy costs, since these depend on the development of the market price of electricity.

Interestingly, some auctions explicitly include the "value" of electricity in their design, trying to encourage electricity generation at times of higher demand, i.e., providing a bonus (Mexico, California and Abu Dhabi). In México, electricity from variable RES-E will be paid at the price included in the seller's bid as adjusted up or down by "hourly adjustment factors". More will be paid for the electricity at times of higher demand and less at times of lower demand (Mayer Brown, 2016). In California, operators are paid higher prices at times of higher system demand (Fitch-Roy, 2015). In Abu Dhabi, electricity fed into the grid from June to September (when demand for air conditioning is greatest) is remunerated at prices which are 60% higher than energy delivered from October to May (IRENA, 2017).

Selection criteria: price-only/multicriteria auctions

Price-only auctions would result in the lowest bidders being awarded contracts, whereas multicriteria auctions allow for the achievement of multiple policy objectives (e.g. local employment, local environmental impacts, industrial development, social acceptance etc.) (Del Río et al., 2015b). Since the least cost bidders might not be selected in multicriteria auctions, a *lower allocative efficiency* and *higher support costs* would result compared to price-only auctions. The extra cost has to be weighted with the benefits of the other policy objectives (*local impacts* and *dynamic efficiency*) which nevertheless could be more effectively tackled with measures outside the auction scheme. In Portugal, the multicriteria auction did not guarantee that the sites selected by the wind developers were optimal (Del Río, 2016b). Multicriteria auctions are far less common than price-only auctions (Fig. 2).

Auction format

If the priority of the government is on *allocative efficiency*, then single-item auctions would be preferable. If *effectiveness* or *actor diversity* are the main goals, then multi-item auctions could be recommended. Allocating the volume to be contracted to more than one project developer reduces non-compliance risks (better *effectiveness*). Economies of scale could be higher under single-item, since one single winner could better reduce some fixed costs (i.e., higher *allocative efficiency*). *Actor diversity* would be higher under multi-item auctions, as different bidders are awarded contracts instead of a single one. Other criteria would not be significantly affected. Note that, for some technologies and project types (e.g. off-shore wind), splitting the volume auctioned in several units would be difficult. Thus, in practice, the choice for one or the other alternative is limited.

Auction type

Auctions can be organized in a static (sealed bid) or a dynamic manner (descending or ascending clock). Sealed bids are simpler than dynamic ones. Thus, participation costs are lower (Maurer and Barroso, 2011). In addition, when competition in an auction is weak, not revealing any information during the auction process becomes an advantage of sealed-bid auctions. Static auctions are less vulnerable to implicit collusion than dynamic ones (Haufe and Ehrhart, 2015). Virtually all countries analyzed have adopted static auctions (Fig. 2). The descending clock auction design allows for strong price discovery, which is particularly relevant when there is uncertainty on the costs of renewable energy projects, mitigating the risk of winners' curse, which occurs when bidders do not know their actual valuation for the good. Therefore,

[11] This is so because power generation with investment-based support is incentivized only by the hourly electricity market price. Kitzing et al. (2016) argue that a possible advantage is the distortion-free participation in all segments of the electricity market.

sealed bids are recommendable when the main priority is to reduce the administrative costs and the risk of implicit collusion (*support costs*). If the priority is *effectiveness*, then dynamic auctions are preferable, since the risk of underbidding (and, thus, underbuilding) is lower.

Pricing rules

There are basically two pricing alternatives in sealed-bid auctions: pay-as-bid (PAB) or uniform (either highest-accepted-bid, HAB or lowest-rejected-bid, LRB).

PAB is preferable for *effectiveness* reasons, whereas uniform pricing is better to minimize the *costs of support,* since it is theoretically more incentive-compatible and has led to aggressive bidding in practice (see below). In contrast to PAB, uniform pricing with LRB is incentive compatible, e.g., cost exaggeration is discouraged and, thus, a lower bid (and lower *support costs*) can be expected because, in the LRB, the bidders' own prices do not influence the price they will be paid in case of winning (see Haufe and Ehrhart, 2015 for further details). Thus, participants bid their true cost[12] and a common price signal is provided. Although uniform pricing is often viewed as fair since all winners receive the same price (which is not the case with PAB), it may sometimes be difficult to justify having bidders with very different cost structures receiving an identical price for the energy sold (unclear *political feasibility*).

Compared to PAB, uniform pricing leads to uncertainties regarding award prices for winners and, in practice, it creates a risk of irrational behavior, underbidding, underbuilding and ineffectiveness. Some bidders bid below their costs, hoping that the marginal bidder will set an attractive price for all winning projects (Steinhilber, 2016c). This has been the case in Spain (Del Río, 2016c) and U.K. (Fitch-Roy and Woodman, 2016). In Spain, uniform pricing has contributed to many firms offering very low prices, believing that the cut-off point would be higher (Del Río, 2016c). Few countries have adopted it (Fig. 2).

Price ceilings

Ceiling prices limit the risk of high support costs, for example in case of low competition. This was the reason they were set in Italy (Tiedemann et al., 2016). Determining appropriate ceiling prices is challenging, however. They can be set too low, as in Brazil in 2013 (Elizondo et al., 2014) and in Peru's first round, contributing to *ineffectiveness* (IRENA, 2013; Del Río, 2017forthcoming-c). Low ceiling prices would have detrimental effects on technological diversity in technology-neutral auctions and probably on actors' diversity if mature technologies and large players are the only ones able to bid at prices lower than the ceiling (IRENA, 2015). In contrast, too high ceiling prices were set in South Africa's first round (Montmasson-Clair and Ryan, 2014; Yuen, 2014). Higher ceiling prices have a positive quantitative but a negative qualitative effect on competition: higher number of participants but weaker ones.

A different issue is whether those prices should be disclosed. This has ambiguous effects on support costs. Disclosure would increase transparency, investor confidence, participation and competition (e.g., lower *support costs*) but it may bias the results of the auction if the bidders propose relatively high bids marginally close to the ceiling price ("anchoring") as was the case in Peru (IRENA, 2013), South Africa (Eberhard, 2013) and India (IRENA, 2015).

[12] With the exception of multi-project (since bidders may behave strategically, bidding their true costs with some projects while trying to drive up the price with secondary projects) and uniform pricing with highest accepted bid (Haufe and Ehrhart, 2015).

Realization period

Appropriate deadlines for constructing the projects need to be set for *effectiveness* and *support costs* reasons. However, the challenge is precisely to set them at levels which are neither too long nor too short. Too short periods lead to higher risks for investors, low participation and competition and higher bids, as in the recent U.K. (Fitch-Roy and Woodman, 2016) and Danish Anholt auctions (Kitzing and Wendring, 2015). Long grace periods give temporal flexibility to bidders in achieving compliance but too long periods increase the risks of an excessive remuneration (compared to technology costs). In the U.K. NFFO, project developers had a 5-year "grace period" in order to initiate their projects and some of them based their bids on the expected cost reductions in the following 5 years. Since costs did not decrease as expected, and penalties for failing to develop the project had not been implemented, many developers failed to build the project (Ackermann et al., 2001; Edge, 2006). Likewise, speculation on falling prices during the allowed construction period may have led to unrealistically low bids in Poland (Kitzing and Wendring, 2016) and Chile (Manancourt, 2016). Therefore, if *support costs* are the main goal, then the government should avoid setting the deadlines too long. If *effectiveness* is the main priority, then they should not be too short.

Penalties

Effectiveness requires the implementation of penalties. Their absence is likely to lead to ineffectiveness, as in India's PV state auctions (Khana and Barroso, 2014). They were considered to be critical to the success of the auction in China (Wang et al., 2014). The low penalties contributed to underbidding in Poland and the U.K. In the recent U.K. auction, the penalty for failing to build the projects (exclusion from any future auctions within 13 months) is insignificant because other bidding rounds have not been announced (Fitch-Roy and Woodman, 2016). In the U.K. NFFO, the absence of penalties was behind the poor installation rate (Ackermann et al., 2001; Edge, 2006). In Poland, the low penalty for non-compliance is one of the factors leading to underbidding and, thus, underbuilding (Kitzing and Wendring, 2016). In Denmark, penalties had not been adopted initially (Rødsand 2), but this was later corrected for purposes of effectiveness (Kitzing and Wendring, 2015).

Again, the key issue is how to implement penalties and their level. Too low (or non-existent) penalties would lead to *effectiveness*. If they are set too high, then lower levels of participation and competition, higher bids and *support costs*, lower *allocative efficiency* and lower *actor diversity* can be expected.

Table 4 summarizes the results of the assessment per design element and criterion. The signs (+, =, −) indicate whether the design element scores better than the alternative in the considered criterion. In some cases, the comparison is between a too high/low level of the design element and the alternative (appropriate, medium level). Finally, in other cases, there are three alternatives, which are compared to each other. It can be observed that, if the focus is put on a specific criterion, then some design elements are more suitable than others. For example, generation-based volumes, a schedule of auctions, improving administrative procedures, prequalification requirements and penalties and a FIT would be particularly recommendable for reasons of effectiveness, whereas, if minimization of support costs is the policy priority, then budget-based volumes, a schedule of auctions, geographically and technologically neutral auctions, improving administrative procedures and low ceiling prices should be implemented.

An interesting finding is that some criteria usually go in the same direction (support costs and allocative efficiency), while others seem to be in conflict, either always (support costs and allocative efficiency on the one hand and local impacts and dynamic efficiency on the other) or often (e.g., effectiveness and support costs, allocative efficiency and

Table 4
Summary of the impact of the design elements on the criteria.
Source: Own elaboration.

Design elements		Effect	Support costs	Alloc. EF	Indirect costs	Local impacts	Dyn EF	Actor DIV	Social accept.
1. Volume	Generation-based	+	=	=	+	=	=	=	?
	Budget-based	−	+	=	−	−	−	=	?
	Capacity-based	=	−	=	−	=	+	=	?
	Level too high	+	−	−	=	+	+	+	?
	Level too low	−	+	+	=	−	−	−	?
	Disclosure (vs. non-disclosure)	=	+	=	=	=	+	=	=
2 Periodicity	Long lead times	=	+	+	=	=	=	=	=
	Short lead times	=	−	−	=	=	=	=	=
	Schedule (vs. no schedule)	+	+	+	=	=	+	=	=
3 Diversity (vs. its absence)	Technology-neutral	=	+	+	−	−	−	−	?
	Geographically-neutral	=	+	+	−	?	=	−	?
4 Participation conditions	Improving administrative procedures*	+	+	+	+	+	+	+	+
	Supporting dialog with stakeholders*	+	?	?	=	=	=	=	+
	Prequalification requirements*	+	−	−	=	=	=	−	?
	Prequalification too strong	+	−	−	=	=	=	=	=
	Prequalification too weak	−	+	+	=	=	=	=	=
	LCRs*	=/−	−	−	=	+/=	+	=	?
	Information provision*	=	?	+	=	=	=	+	=/+
5 Support cost conditions	Generation-based (vs. investment-based)	=	−	+	+	=	=	=	=
	FIT	+	+	+	−	=	+	+	+
	FIP fixed	−	−	−	+	=	−	−	−
	FIP sliding	=	=	=	=	=	=	=	=
6 selection criteria	Multicriteria (vs. price-only)	=	−	−	=	+	+/=	=	?
7 auction format	Single-item (vs. multi-item)	−	=	+	=	−	=	−	?
8 auction type	Static (vs. dyn.)	−	+	?	=	=	=	+	+
9 pricing rules	PAB (vs. uniform)	+	−	−	=	=	=	=	?
10 pricing rules	Ceiling prices (vs. their absence).	=	+	+	=	=	=	=	+
	High ceiling prices	+	−	=	=	=	=	=	?
	Low ceiling prices	−	+	=	=	=	=	=	?
	Disclosed (vs. non-disclosed)	=	?	?	=	=	=	=	+
11 Realization period	Too short	+	−	−	=	=	=	=	?
	Too long	−	+	+	=	=	=	=	?
12 penalties	Too high	+	−	−	=	+	=	−	?
	Too low	−	+	+	=	=	=	+	?

Note: The design element scores (+) better than the alternative in the considered criterion; (=) similarly to the alternative (or no change can a priori be expected); (−) worse than the alternative; (?) refers to opposing effects, with an unclear net effect.
* vs. their absence.

indirect costs…). There might also be conflicts within a given criterion, since the design element induces opposing forces. This is often the case with support costs.

Conclusions

RES-E auctions have increasingly been perceived worldwide as a good alternative to other instruments to control the costs of RES-E support. However, whether auctions will live to expectations will depend on their appropriate design. This article has focused on the micro-conditions of effective design, providing an overarching analytical framework and evidence-informed guidelines of the advantages and disadvantages of different design elements, taking into account different mechanisms activated by the design elements and their impact on different assessment criteria.

Our findings show that a few design elements score better than the alternatives in some criteria without scoring worse in others. These can be regarded as "best" practices and include a schedule of auctions, volume disclosure, price ceilings, penalties, streamline of administrative procedures and provision of information to potential participants.

However, most design elements involve trade-offs between criteria, i.e., their choice may improve one criterion at the expense of worsening another and, thus, their choice depends on the priorities of the government. In particular, conflicts between effectiveness and support costs/allocative efficiency and between support costs/allocative efficiency and other criteria (system costs, local impacts, dynamic efficiency and actor diversity) are common. Our results suggest that, when designing auctions for RES, there are only a few alternatives which should be implemented irrespectively of governments' priorities. Therefore, the idea that there is an unambiguously preferred way to design auctions for RES is only partly true.

Three issues should be taken into account when interpreting the impact of design elements on criteria and also suggest fruitful avenues for further research. First, some of those elements work in tandem and one may amplify or mitigate the impact of the others. There are several empirical examples of this. For example, different design aspects are mentioned as reasons behind underbidding and possibly underbuilding in Poland, namely the low expected frequency of auctions, the low penalties and the relatively long realization period (Kitzing and Wendring, 2016). Further research should analyze the interactions and interdependencies of design elements and disentangle their individual influence. The synergies and conflicts between design elements should be addressed from a theoretical point of view.

Second, design elements are only one of the factors affecting those criteria. There are some external factors at play in all auctions for RES. For example, in addition to program design, other factors had an impact on the success of the auction program in South Africa, including program management factors, market factors, favorable characteristics of the banking sector and the existence of advisory services (Eberhard et al., 2014). In addition, some complementary policies have coexisted with auctions and have had an influence on the outcome of these auctions. For example, countries may provide soft loans for participants in the auctions (as in Brazil). Auctions in Zambia, Uganda and Ghana are part of a broader mix of instruments, implemented with the support of international organizations, such as the World Bank, which are aimed at de-risking and providing technical support. These policies reduce the financing costs and participation risks and, thus, increase participation (Lucas et al., 2017). This leads to higher competition levels and lower bid prices. The relative influence of those other factors and policies on the success of auctions should be the focus of future research.

Finally, the fact that one design element scores well in one or another criterion may not necessarily mean that it can be applied everywhere. Thus, the extent to which "best practices" can be implemented in countries with different regulatory cultures is worth analyzing.

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References

Ackermann T, Andersson G, Söder L. Overview of government and market driven programs for the promotion of renewable power generation. Renew Energy 2001;22:197–204.
Allen and Overy. South African Renewable Energy Independent Power Producer Procurement Programme (REIPPPP): salient features of and changes to the bid window 4 RFP for purposes of the 1800 MW expedited bid submission window. http://www.jdsupra.com/legalnews/southafrican-renewable-energy-80365/, 2015.
AURES. Website of the EU-funded AURES project. http://www.auresproject.eu, 2016.
Breitschopf B, Held A. Guidelines for assessing costs and benefits of RET deployment. Report in the framework of the EU-funded DIACORE project; 2013. [http://diacore.eu/].
Butler L, Neuhoff K. Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. Renew Energy 2008;33:1854–67.
Castalia. First performance review and baseline report for GET FiT Uganda; 2016 [May 2016].
Cramton P. How best to auction natural resources. In: Philip Daniel, Goldsworthy B, Michael K, McPherson C, editors. Handbook of oil, gas and mineral taxation. Washington, DC: IMF; 2009.
De Lovinfosse I, Janeiro L, Gephart M. Lessons for the tendering system for renewable electricity in South Africa from international experience in Brazil, Morocco and Peru. Commissioned by: Deutsche Gesellschaftfür Internationale Zusammenarbeit (GIZ) GmbH. South African — German Energy Programme (SAGEN); 2013.
Del Río P. A methodological note on the links between components for the assessment of design elements in auctions for RES. Report for the AURES project; 2015.
Del Río P. Auctions for renewable energy support in South Africa: instruments and lessons learnt. AURES report D.4.1-ZA, March 2016; 2016a.
Del Río P. Auctions for renewable energy support in Portugal: instruments and lessons learnt. AURES report D.4.1-PT, March 2016; 2016b.
Del Río P. Implementation of auctions for renewable energy support in Spain: a case study. AURES report D7.1-ES, March 2016; 2016c.
Del Río P. Auctions for renewable support in Zambia: instruments and lessons learnt. Report of the EU-funded AURES project; 2017a. [forthcoming].
Del Río P. Auctions for renewable support in Mexico: instruments and lessons learnt. Report of the EU-funded AURES project; 2017b. [forthcoming].
Del Río P. Auctions for renewable support in Peru: instruments and lessons learnt. Report of the EU-funded AURES project; 2017c. [forthcoming].
Del Río P, Linares P. Back to the future? Rethinking auctions for renewable electricity support. Renew Sustain Energy Rev 2014;35:42–56.
Del Río P, Ragwitz M, Steinhilber S, Resch G, Busch S, Klessmann C, et al. Assessment criteria for identifying the main alternatives. D2.2 report under the beyond 2020 project, funded by the intelligent energy—Europe program; 2012. [http://www.res-policy-beyond2020.eu/].
Del Río P, Wigan F, Steinhilber S. Assessment criteria for RES-E auctions. Report D2.2 (b) for the project AURES (promoting effective renewable energy auctions), funded under the EU H2020 program; 2015a. [Available at http://auresproject.eu/].
Del Río P, Haufe MC, Wigan F, Steinhilber S. Overview of design elements for RES-E auctions. Report D2.2 (a) for the project AURES (promoting effective renewable energy auctions), funded under the EU H2020 program; 2015b. [Available at http://auresproject.eu/].
Del Río P, Fitch-Roy O, Woodman B. Identification of alternative options. Report 6.1 AURES project; 2016.
Del Río P, Resch G, Ortner A, Liebmann L, Busch S, Panzer C. A techno-economic analysis of EU renewable electricity policy pathways in 2030. Energy Policy 2017;104:484–93.
DMNR. Alternative energy requirement (AER VI — 2003) a competition for electricity generation from biomass, hydro, and wind. Available from: http://www.dmnr.ie, 2003.
Eberhard A. Feed-in tariffs or auctions? Procuring renewable energy supply in South Africa. The World Bank; 2013 [Note Number 338. April].
Eberhard A, Kolker J, Leigland J. South Africa's renewable energy IPP procurement program: success factors and lessons. Public-Private Infrastructure Advisory Facility (PPIAF) and World Bank; 2014.
Eckhouse, B., Hirtenstein, A. 2016. Cheapest Solar in Africa Comes to Zambia Through World Bank Plan. Bloomberg, June 13, 2016.
Edge G. A harsh environment: the non-fossil fuel obligation and the U.K. renewables industry. In: Mallon K, editor. Renewable energy policy and politics: a guide for decision-making. London: Earthscan; 2006. p. 163–84.
Elizondo G, Barroso L, Cunha G. Promoting renewable energy through auctions: the case of Brazil. The World Bank; 2014.
EnergyNews. Tercera subasta eléctrica en Chile por 4.200 GW anuales Publicado el 31/01/2017; 2017.
European Commission (EC). Guidelines on state aid for environmental protection and energy 20142020, COM (2014) 2322, 2014; 2014.
Factor. Subastas de energía renovable en Latinoamérica y Caribe; 2017 [Bilbao].
Finucane M. Ireland-RE Support. "Mecanismos de Retribución y Desarrollo de las Energías Renovables". Madrid: Club Español de la Energía; 2005 [May 18th 2005].
Fitch-Roy O. Auctions for renewable support in California: instruments and lessons learnt. AURES report D4.1-CAL, December 2015; 2015.
Fitch-Roy O, Woodman B. Auctions for renewable energy support in the United Kingdom: instruments and lessons learnt. AURES report D4.1-UK, March 2016; 2016.
Förster S. Small-scale PV auctions in France: instruments and lessons learnt. AURES report D4.1-FR, March 2016 report D4.1-FR, March 2016; 2016.
Förster S, Amato A. Auctions for renewable energy support in Brazil: instruments and lessons learnt. AURES report D4.1-BRA, March 2016; 2016.
Haufe M-C, Ehrhart K-M. Assessment of auction formats suitable for RES-E, s.l. AURES, report D3.1; 2015.
Held A, Ragwity M, Gephart M, de Visser E, Klessmann C. Design features of support schemes for renewable electricity. A report within the European project "cooperation between EU MS under the renewable energy directive and interaction with support schemes". Netherlands, Utrecht: Ecofys; 2014.
IEA. Mexico energy outlook; 2016.
IRENA. Renewable energy auctions in developing countries; 2013.
IRENA. Evaluating renewable energy policy: a review of criteria and indicators for assessment. Abu Dhabi: IRENA; 2014.
IRENA. Renewable energy auctions: a guide to design; 2015.
IRENA. Renewable capacity statistics 2017; 2017 [Abu Dhabi].
Khana A, Barroso L. Promoting renewable energy through auctions: The case of India. The World Bank; 2014.
Kitzing L, Wendring P. Auctions for renewable support in Denmark: instruments and lessons learnt. AURES report D4.1-DK, December 2015; 2015.
Kitzing L, Wendring P. Implementation of auctions for renewable energy support in Poland: a case study. AURES report D7.1-PL, March 2016; 2016.
Kitzing L, Islam M, Rosenlund E, Held A, Ragwitz M, Winkler J, et al. Recommendations on the role of auctions in a new renewable energy directive. Report of the EU-funded AURES project. October 2016; 2016. [http://auresproject.eu/sites/aures.eu/files/media/documents/redii_memo_final.pdf].
Klemperer. Auction theory. A guide to the literature. J Econ Surv 1999;13(3):227–86.
Klemperer P. Auctions: theory and practice. Princeton University Press; 2004.
Kreiss J. The effect of competition levels on auction outcomes. Policy memo 4, AURES project; 2016.
Kreiss J, Ehrhart K, Haufe MC. Appropriate design of auctions for renewable energy support — prequalifications and penalties. Energy Policy 2016;101:512–20.
Lipp J. Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. Energy Policy 2007;35(11):5481–95.
Manancourt V. Winners of Chile's record electricity auction may not be bankable, say lawyers. Monday, 19 September 2016 by Vincent Manancourt. Cariola Diez Perez Cotapos Abogados; 2016.
Maurer L, Barroso L. Electricity auctions: an overview of efficient practices. Washington: World Bank; 2011.
Mayer Brown. Mexico's clean energy auction: material provisions of the power purchase agreements; 2016 [Legal Update March 31, 2016].
McDaid L. Renewable energy independent power producer programme review 2014. Electricity Governance Initiative of South Africa downloaded from the EGI website (Tools and Downloads) at: http://www.egi-sa.org.za/downloaded-documents, 2014.
Menanteau P, Finon D, Lamy M. Prices versus quantities: choosing policies for promoting the development of renewable energy. Energy Policy 2003;31(8):799–812.
Menezes F, Monteiro P. An introduction to auction theory. Oxford University Press; 2005.
Milgron P. Putting auction theory to work. Cambridge University Press; 2004.
Mitchell C. The renewables NFFO.A review. Energy Policy 1995;23(12):1077–91.
Mitchell C, Connor P. Renewable energy policy in the UK 1990–2003. Energy Policy 2004;32(17):1935–47.
Montmasson-Clair G, Ryan G. Lessons from South Africa's renewable energy regulatory and procurement experience. J Econ Financ Sci 2014;7(S):507–26.
Moore S, Newey G. Going, going, gone. The role of auctions and competition in renewable electricity support. London: Policy Exchange; 2013.
Muñoz C, Galetovic A. Energy auctions in Chile: guarantees and leverage. http://www.brevesdeenergia.com/blog/posts/energy-auctions-in-chile-guarantees-and-leverage/, 2017.
Noothout P, Winkel T. Auctions for renewable energy support in the Netherlands: instruments and lessons learnt. AURES report D4.1-NL, March 2016; 2016.
POYRY. A review of the second long-term auction note from Poyry Management Consulting; 2016 [October 2016].
Ragwitz M, Held A, Winkler J. Auctions for renewable energy in the European Union: questions requiring further clarification. Study on behalf of Agora Energiewende. www.agora-energiewende.de, 2014.
Rice B, Blomfield A, Rotar A. Russia's second renewable energy auction gives both glimmer of hope and cause for concern. King & Spalding Energy Newsletter; 2014. [http://www.kslaw.com/library/newsletters/EnergyNewsletter/2014/July/article1.html].
Rosenlund E. Pre-qualifications and penalties. Policy memo 2, October 2016. Report for the AURES project; 2016.
South African Government. Independent Power Producers Procurement Programme (IPPPP). An overview. As at 30 June 2015. TEM Bonn – June 2015; 2015.

Steinhilber S. Auctions for renewable energy support in Ireland: instruments and lessons learnt. AURES report D4.1-IE, March 2016; 2016a.
Steinhilber S. Onshore wind concession auctions in China: instruments and lessons learnt. AURES report D4.1-CN, March 2016; 2016b.
Steinhilber S. Implementation of auctions for renewable energy support in Slovakia: a case study. AURES report D7.1-SK, March 2016; 2016c.
Tiedemann S. Auctions for renewable energy support in Germany: instruments and lessons learnt. AURES report D4.1-GER, March 2016; 2015.
Tiedemann, S. Förster, S., Wigand, F. 2016. Auctions for renewable energy support in Italy: instruments and lessons learnt. AURES report D4.1-IT, March 2016.
Toke D. Renewable energy auctions and tenders: how good are they? Int J Sustain Energy Plan Manag 2015;8:43–56.
Wang Q. Effective policies for renewable energy – the example of China's wind power – lessons for China's photovoltaic power. Renew Sustain Energy Rev 2010;14(2):702–12.
Wang X, Barroso L, Elizondo G. Promoting renewable energy through auctions: the case of China. The World Bank; 2014.
Wigan F, Förster S, Amazo A, Tiedemann S. Auctions for renewable energy support: lessons learnt from international experiences. Report D4.2 of the EU-funded AURES project, June 2016; 2016.
Yu J, Fuxing J, Zhang L, Chen Y. An overpainted oriental arts: evaluation of the Chinese renewable market. Energy Policy 2009;37:5221–5.
Yuen KSE. REIPPP - a new dawn for South African renewables? An analysis of renewable energy prices in the South African renewable energy independent power producer procurement programme [Master Thesis] International Energy Sciences Po, Paris School of International Affairs; 2014 [June 2014].