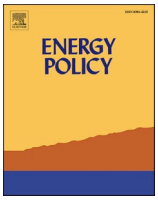
Energy Policy 173 (2023) 113305

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol



Academic research on renewable electricity auctions: Taking stock and looking forward

Pablo del Río [a,*], Christoph P. Kiefer [b]

[a] Institute for Public Policies and Goods (IPP). Consejo Superior de Investigaciones Científicas (CSIC), c/Albasanz 26-28, Madrid, 28032, Spain
[b] Fraunhofer-ISI, Karlsruhe, Germany

ARTICLE INFO

Keywords:
Auctions
Renewable electricity
Systematic review
Support schemes

ABSTRACT

Auctions are currently the dominant and most rapidly expanding form of support for renewable energy project deployment, capturing the interests of policy-makers and academics alike. This article provides a systematic review of the relatively recent but already abundant literature on auctions for renewable energy and proposes a future research agenda on the topic. Major themes, gaps in knowledge, and trends in the literature are highlighted. More research efforts will be needed on the institutional capacity and arrangements, coordination between auctions and other procedures and appropriate inclusion of auctions in policy mixes. The trade-offs between different criteria should be the focus of more rigorous and quantitative marginal analysis, identifying the extent to which improving a given criterion worsens another. The existence, causes and consequences of underbidding, the implications of the just energy transition for the performance of auctions and auction design, the marginal impact of the level of design elements and the interactions between design element choices in "design element packages" merit more attention. There should be a greater focus on the micro-level in the assessment of the success of auctions and auction design. At a methodological level, assessments of auctions with case studies should coexist with more quantitative studies on the topic, using a wide range of methodologies. However, the transferability of lessons on the functioning of design elements across different contexts will be necessarily limited. Finally, a plea is made to national governments and international institutions to facilitate the access to auction data.

1. Introduction

Renewable energy technologies (RETs), and more specifically technologies which generate electricity from renewable energy sources (RES), are a main pillar of the required energy transition towards decarbonisation to meet the Paris Agreement targets (IRENA, 2019a). The diffusion of RETs has been driven by demand-pull policies, with administratively-set feed-in tariffs and feed-in premiums (ASFITs/FIPs) being the most popular instrument in this regard. ASFITs/FIPs have been superseded in the last years by auctions as the dominant scheme for RES deployment worldwide (REN21, 2022). Whereas 6 countries held RES auctions in 2005 (IRENA, 2017), 131 countries held auctions in 2021 (REN21, 2022). 92 countries had ASFITs/FIPs in 2021 (REN21, 2022). In auctions for RES support "a certain amount of power (MW) or energy (MWh) of renewables are offered up for bidding. Bidders compete to be allowed to deliver these volumes on the basis of their required support level (often a premium in €/MWh). The projects with the lowest required support levels typically win the auction" (Mora et al., 2017, p. 1).[1] This is in contrast to ASFITs/FIPs, in which the government sets the support level. Auctions can be designed in many different ways (see section 4.2).

Attention to auctions in the academic literature has gone in pair with its greater policy relevance and there are already many contributions (both academic and non-academic) on this theme. This literature has focused on a wide-array of issues using different methodologies. The aim of this paper is to take stock of this literature through a systematic literature review and propose a research agenda which addresses policy-relevant issues which may not have been sufficiently covered in the

* Corresponding author.
E-mail address: pablo.delrio@csic.es (P. del Río).

[1] In this article, the terms auctions and tenders are used interchangeably. As argued by Gephart et al. (2017, p. 161), "while the term 'tender' refers to the procurement process, the term 'auction' refers to the procedure of selecting competing bids by price. Tenders for renewable energy projects are often organised as reverse auctions".

https://doi.org/10.1016/j.enpol.2022.113305
Received 15 August 2022; Received in revised form 13 October 2022; Accepted 16 October 2022
Available online 28 November 2022

literature.

Up to our knowledge, there isn't a systematic review of the literature on auctions for renewable electricity, although some academic and non-academic contributions have provided a review of RES auctions in the past. These papers have focused on the design of different schemes and their functioning (e.g., del Río and Linares, 2014; IRENA, 2015; Wigan et al., 2016; Winkler et al., 2018, amongst others). However, contributions taking stock of the research done in auctions have not been provided so far. As part of their study on realisation rates in the German PV auction program, Liñeiro and Müsgens (2021) carried out a Scopus search and found that, since 2000, 53 peer-reviewed research articles had addressed the topic of auctions promoting RES expansion. They concluded that the literature largely focuses on auction design. However, their aim was no to provide an in-depth review of this literature. The closest to our paper is Haelg (2020), who carried out a literature review of the impact of design elements on auction outcomes. However, in addition to being more recent, this paper takes a broader view, i.e. it considers many other issues related to RES auctions and not only design elements.

Accordingly, the article is structured as follows. The next section describes the methodology, based on a systematic review with a bibliometric analysis. The results of the review are provided in section 3. Based on this review, section 4 provides a categorization of the main themes in the literature, discusses the state of knowledge in those themes and proposes some avenues for future research. Section 5 concludes and includes some policy implications.

2. Methodology

In order to assess the current state of research in RES auctions, a systematic literature review and bibliometric analysis approach were chosen. Bibliometric analyses build upon systematic literature reviews, yet they are more advanced than those in the sense that a (quantitative) impact and a relationship assessment are possible. This is commonly realized in the form of visual cluster network mapping, which allows highlighting patterns of co-citation, keyword co-occurrences, author or institutional relationships, etc. Such bibliometric analyses are capable of identifying existing and emergent research subtopics in a field, as well as their interrelation, in a number of dimensions.

Therefore, first, a systematic literature review was conducted in order to identify relevant literature and accurately represent the state of academic research in RES auctions. Second, a visual cluster analysis and network mapping was applied to the final sample of identified literature.

2.1. Systematic literature review

Our systematic literature review adheres strictly to the recommended criteria for such a methodology as outlined i.e. by Sovacool et al. (2018), and consisted of 3 sequential steps. First, a comprehensive search strategy was defined and operationalised with three complementary searches based on keywords covering renewable energy auctions generally as well as solar and wind energy auctions specifically. This was necessary given the fragmentation in the existing literature. As solar and wind are the predominating RETs (IRENA, 2021), their explicit inclusion in the keywords seems justified. Since the terms "energy" and "electricity" are often used interchangeably for RETs, and this was also the case for "auction", "tender" and "bidding", they are included in the searches (Table 1).

Secondly, searches in Clarivate's Web of Science (WoS) and Elsevier's Scopus databases were performed and results from them were merged. They include extensive collections of academic literature suitable to conduct systematic literature reviews and bibliometric studies. In the past, researchers mostly used just one database for these kinds of studies due to the technical impossibility to merge the results from WoS and Scopus (Kumar Kar and Harichandan, 2022). However, this would result in the loss of up to 50% of potentially relevant literature (Chistov et al., 2021), jeopardizing the validity of the corresponding studies (Kumar Kar and Harichandan, 2022).

Table 1
Search queries used in the systematic literature review.

Literature field	Operationalisation (search query and keywords)
Renewable energy auctions	*"renewable AND (energy OR electricity) AND (auctions OR tender OR bidding)"*
Solar energy auctions	*"(solar OR photovoltaic) AND (energy OR electricity) AND (auctions OR tender OR bidding)"*
Wind energy auctions	*"(wind OR onshore OR offshore) AND (energy OR electricity) AND (auctions OR tender OR bidding)"*

Source: Own elaboration.

Specifically, the search was carried out in those databases by applying the search terms to title, abstract and keywords in March 2022. Initially, this led to 1441 (WoS) and 526 (Scopus) documents. A language filter (English) was applied. In the case of WoS, an additional filter was set in order to include only results from the Social Sciences Citation Index (SSCI) or Science Citation Expanded Index (SCI-EXPANDED). This led to 410 (WoS) and 303 (Scopus) documents. After manually accounting for overlaps, 106 duplicates were found. The final number of relevant contributions in the sample was 607 (Table 2).

In a third step, exclusion and inclusion criteria were defined and applied to the sample (Table 3).

These exclusion and inclusion criteria were applied to the 607 titles and abstracts by the authors separately. The results matched in the vast majority of papers, and a few non-matching cases were maintained in the sample. In total, the sample was reduced to 97 contributions, which were fully read and carefully examined, and their knowledge contribution was extracted, analysed and discussed in the subsequent content analysis (Sovacool et al., 2018). A weighting on the academic relevance of each paper was not done, as many publications are very recent and, thus, have not been able to accumulate many citations.

2.2. Bibliometric analysis

Additionally, in order to generate an overview of existing and emergent research subtopics in the field of renewable energy auctions and to identify their interrelationships, a bibliometric analysis was performed (Börner et al., 2003; Klavans and Boyack, 2006). Specifically, a visual cluster network mapping based on keyword co-occurrences was carried out. For that, the software "VOSviewer 1.6.16" was used.[2] In a first step, the list of final results from the systematic literature review were formatted, coded and imported into the software.

In a second step, a bibliometric analysis was performed and the

Table 2
Overview of the number of initial and final publications resulting from the search.

Number of results	Web of Science (WoS)	Scopus
Search queries	1441	526
Application of filters (publication type, language, index)	410	303
Aggregated result	713	
Identification of duplicates	106	
Final result (individual publications)	607	

Source. Own elaboration.

[2] VOS stands for "visualisation of similarities". The VOSviewer software is available at www.vosviewer.com VOSviewer performs well for moderately large samples of around 100 items (van Eck and Waltman, 2010), which was the case in this article.

Table 3
Results of the bibliometric analysis (network mapping based on keyword co-occurrences).

ID	Keyword extracted	Occurrences	Links	Total link strength	X	Y	Cluster
1	Auction	331	29	2969	0.1224	−0.089	1
2	auction design	36	28	393	0.5012	−0.3478	4
3	Bid	38	26	419	−0.039	−0.6153	5
4	Bidder	31	21	382	10.662	−0.3923	4
5	Capacity	58	29	656	−0.6074	−0.1123	3
6	Design	31	25	285	0.8336	−0.0442	4
7	design element	29	25	383	0.8524	0.4843	1
8	Effect	25	28	309	0.263	0.2104	1
9	Effectiveness	31	27	427	0.6299	0.2884	1
10	Efficiency	17	27	272	0.5739	0.3892	1
11	Feed	46	26	554	−0.9785	0.3065	2
12	Fit	13	20	207	−1.137	0.0865	2
13	Implementation	15	27	177	−0.0384	0.2341	1
14	Instrument	32	28	376	−0.0219	0.3555	1
15	Investor	21	24	159	0.0001	−0.4736	5
16	local content requirement	11	17	106	0.5696	0.7165	1
17	market concentration	10	8	57	−10.207	−0.7334	3
18	Mechanism	47	25	426	−0.7307	0.2192	2
19	Penalty	14	19	188	12.949	−0.2784	4
20	Policy	39	28	343	−0.314	0.4288	2
21	project developer	12	24	147	−0.4609	−0.4256	5
22	Renewable	17	22	197	−0.6651	0.4078	2
23	renewable electricity	14	24	190	−0.0091	0.5764	1
24	renewable energy source	12	25	139	−0.1473	−0.1864	3
25	renewable energy support	10	19	134	0.9423	−0.1909	4
26	Risk	57	27	607	0.5402	−0.5264	5
27	Support	26	26	313	0.3455	−0.0459	1
28	Tariff	46	26	599	−0.9079	0.1932	2
29	Tender	15	25	144	−0.6063	−0.2995	3
30	Wind	18	25	244	−0.851	−0.1357	3

Note. The number of total mentions of a keyword in the sample is measured by the variable "occurrences". The number of relationships of any given keyword with any other keyword is measured by the indicator "links". This variable indicates with how many other keywords any given keyword is mentioned at least once. The total frequency of co-occurrences of keywords is measured by "total link strength". Higher values in this variable indicate that a keyword is more often co-mentioned with another one (to see the relationships, the network mapping graph must be inspected). "X" and "Y" indicate the position of the keywords in the network mapping graph and "cluster" indicate the cluster or group a keyword belongs to.
Source. Own elaboration based on output from VOSviewer.

Box 1
Inclusion and exclusion criteria used in this review.

1) Only journal articles published in English have been included, and books, book chapters, dissertations/theses, conference papers or working papers were excluded. It is assumed that journal articles are the ones meeting the rigurous peer-review requirement as they have passed the review procedures in the journal/editor board of publication (Peñasco et al., 2021);
2) As in Liñeiro and Müsgens (2021), auctions in the spot market were left out of the review. More specifically, we have not included papers which either provide a method or assess the application of a method in order for RES to optimise their participation in spot or day-ahead markets or focus on the participation of RES bidders in non-RES auctions. Many papers address these topics (Afshar et al., 2018; Aquila et al., 2020; Cheng et al., 2022; Cocchi et al., 2018; Endemaño-Ventura et al., 2021; Fang and Zhao, 2020; Heydari et al., 2021; Khaloie et al., 2020; Khojasteh et al., 2022; Laia et al., 2016; Rayati et al., 2019; Singh et al., 2021; Usaola and Angarita, 2007). However, papers which focus on bidders' behaviour in RES auctions have been included;
3) Articles which comparatively assess different instruments are excluded, even if auctions are included. This is so unless there is a strong focus on auctions (e.g., Butler and Neuhoff, 2008; Huber et al., 2007).

visual network map of keyword co-occurrences was produced (Börner et al., 2003). A similarity matrix based on the co-occurrence matrix of keywords was calculated. The association strength measure[3] was chosen for the normalization process of the co-occurrence data. This is usually recommended for cases such as in this article (van Eck and Waltman, 2009, pp. 1647–1648). Then, a mapping technique was applied to the similarity matrix (van Eck and Waltman, 2009; Zitt et al., 2000). Lastly, the created map was translated (centred at the origin), rotated (maximised variance on the horizontal axis) and reflected (as a function of median values, the solution is reflected on one of the two axes) (Borg and Groenen, 2005; van Eck and Waltman, 2010; Zitt et al., 2000). For the purposes of this study, distance-based mapping was chosen, whereby shorter distances between keywords reflect stronger relationships (higher co-occurrence) (van Eck & Waltman, 2007, 2010). The "VOS mapping technique" was used for scaling, as it generally shows very good performance (van Eck and Waltman, 2010). For the graphical mapping, a minimum of 10 co-occurrences was chosen as a threshold. The resulting 5 clusters are detailed in Table 3 (numerical results) and Fig. 1 (network mapping). Each cluster corresponds to a different

[3] This was a direct probabilistic similarity measure, which "can be interpreted as [a measure] of the deviation of observed co-occurrence frequencies from expected co-occurrence frequencies under an independence assumption" (van Eck and Waltman, 2009, p. 1648).

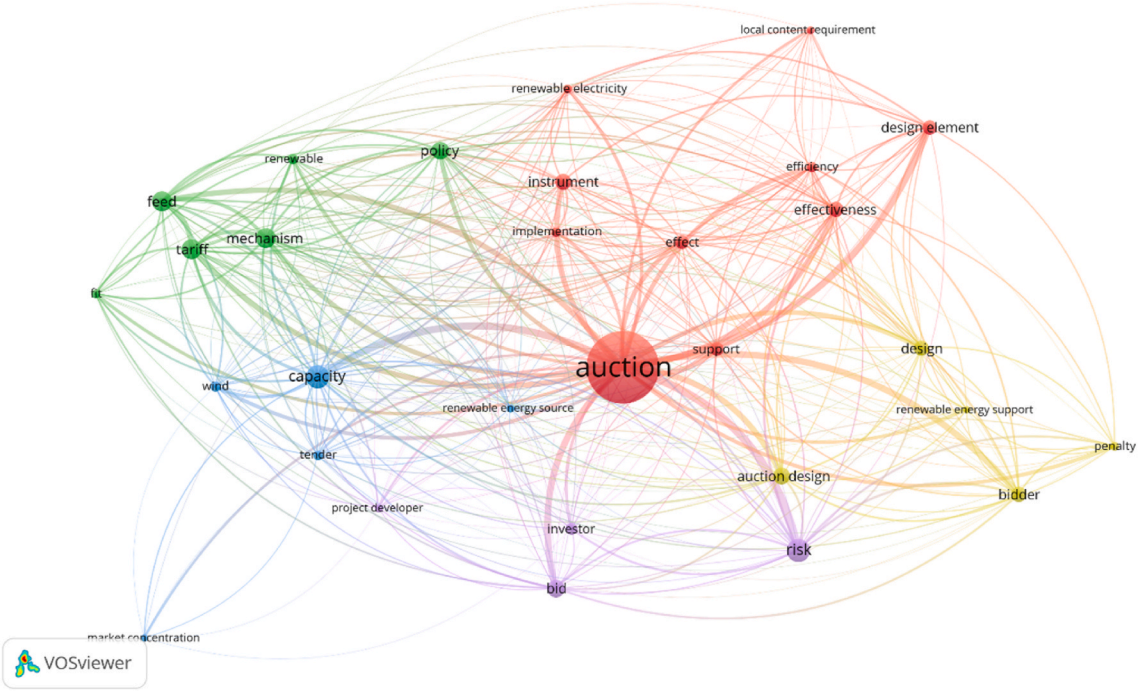


Fig. 1. Network mapping of keyword co-occurrences on the topic of renewable energy auctions.
Source. Output from VOSviewer.

approach. The interpretation of those clusters is as follows: 1) Red: Assessment criteria (effectiveness, efficiency, local content requirement); 2) Green: Auctions versus other mechanisms (administratively-set feed-in tariffs, feed-in premiums); 3) Purple: Auction actors (project developers, investors); 4) Yellow: Auction design; 5) Blue: Technologies participating (wind).

The methodological procedure concluded with an organisation of the content and bibliographic information. Although we do not focus on the non-academic literature, this is a very important part of the literature on RES auctions (Haelg, 2020, p. 2). Therefore, when possible, we have compared our results with those of the non-academic literature, which has partly been revised elsewhere (see del Río, 2020; del Río and Kiefer, 2022; del Río et al., 2020).

3. Results

Supplementary material 1 provides detailed information on the reviewed papers. As it is also the case with other recent reviews in the energy policy realm (e.g., Grubb et al., 2021; Peñasco et al., 2021), and following standard practice (Cohen and Tubb, 2018; Pullin et al., 2018), we provide information on discipline, journal, year, scope (technological, temporal and geographical), aim, approach and method.

Regarding the evolution of papers over time, the results show a slight increase until 2016 and, then, a substantial increase until 2019, when the maximum number of papers per year was reached (Fig. 2). This growth in academic interest is probably related to the strong increase in the implementation of RES auctions worldwide over the period (see, e.g., REN21, 2022).

About 1/3 of papers have been published in a single journal (Energy Policy). Three journals comprise half of the papers. Regarding the disciplines, an overwhelming majority of papers on Economics have been published followed, at a long distance, by papers on Political Science and Sociology. Regarding the geographical areas, there is a clear domination of articles with a focus on the EU and, particularly, on Germany. Many papers provide analyses without focusing on a particular RET. PV and wind are the technologies which are most often being analysed.

Finally, a clear dominance of empirical studies versus theoretical and methodological ones can be observed (Fig. 3). Within those, qualitative analyses, and particularly case studies, prevail with respect to quantitative ones. The initial contributions were almost exclusively based on case studies, but quantitative analyses have been gaining ground. Thematically, there is a clear trend to analyse new topics (impacts of auctions on different aspects/issues).[4]

4. Main themes and future research in the RES auctions literature

The papers included in the previous section have been read and their main themes and results have been coded in a table with the information mentioned in sections 2 and 3 (see Supplementary material 1). This has led to a wide array of themes, which have been categorized in several groups. A discussion of the current state of research is provided (sections 4.1 to 4.4), followed by suggestions on future research (section 4.5).

4.1. Auctions: emergence, preconditions and use in a policy mix

4.1.1. Explaining the fast implementation of auctions

One can wonder about the impressive growth of auctions. There are two alternative explanations, which follow different logics, i.e., the functionalist view according to which it is the advantages of the instrument itself (its alleged greater cost-effectiveness) that led to such adoption, and the structuralist view, which relies on a political-science, sociological or political economy view of instrument choice and stresses the influence of particular interests of policy makers or the pressure of

[4] This includes market concentration (Bayer et al., 2018; Kruger et al., 2021; Shrimali et al., 2016), innovation effects (del Río and Kiefer, 2022), technological diversity (Haelg, 2020), very low auction prices (Martín et al., 2020), the impact of local content requirements (LCRs) (Hansen et al., 2020; Probst et al., 2020; Smeets, 2017), renewable energy community projects (Grashof, 2019; Tews, 2018) and financing conditions, cost of capital and equity costs (Botta, 2019; Dukan and Kitzing, 2021).

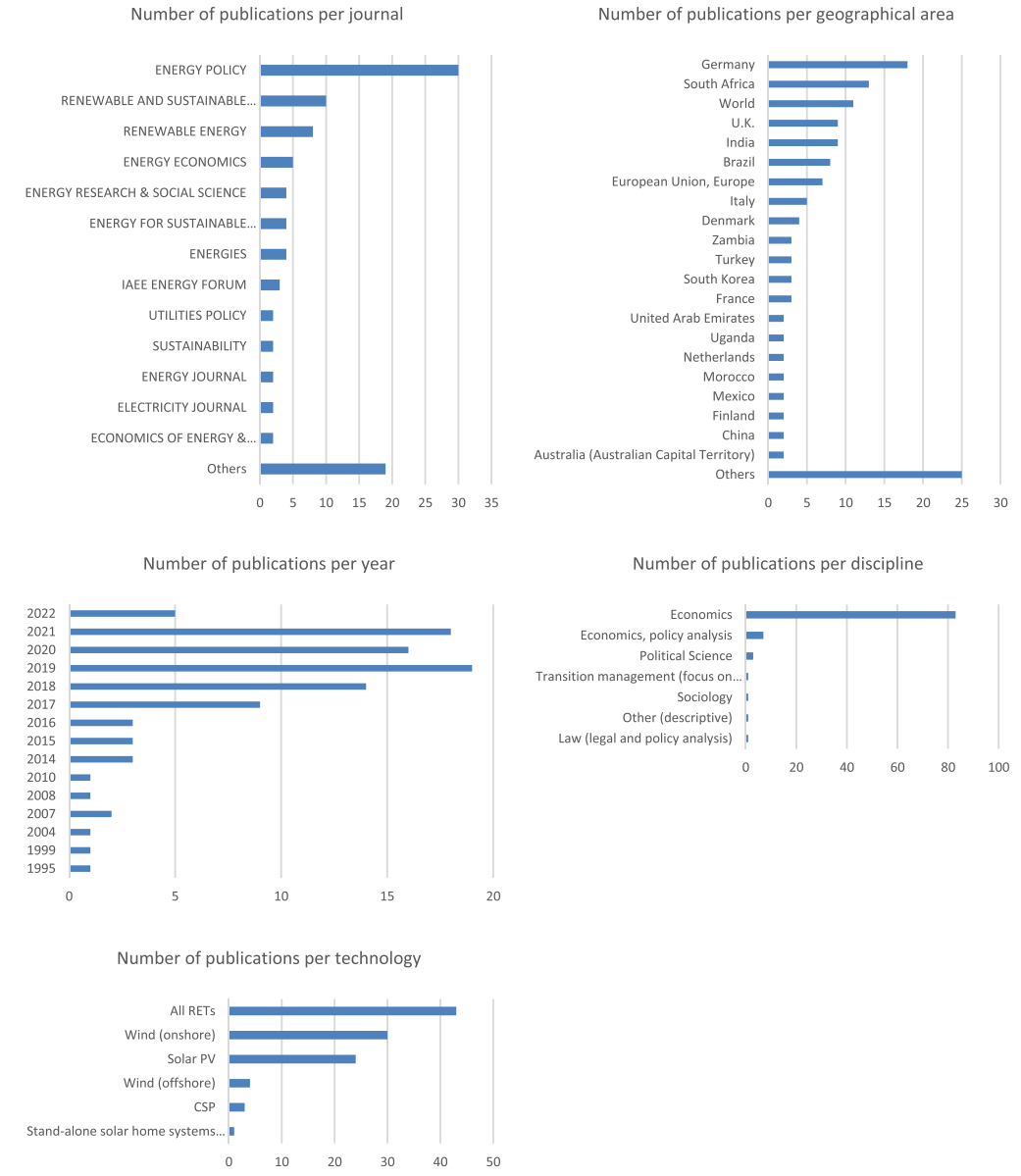


Fig. 2. Overview of the results.
Source. Own elaboration. Notes: 2022 refers to papers published until March only. Some publications analyse several countries and several technologies. Therefore, the sum of the countries or technologies analysed may be greater than the total amount of publications.

given stakeholders behind such adoption. As commented by Grashof (2021) policy instruments are not only chosen because of their expected ability to achieve public goals, but also because they promise to deliver benefits to specific actors. Fitch-Roy et al. (2019), Grashof (2021) and Leiren and Reimer (2018) are examples of this structuralist approach.

4.1.2. Institutional preconditions for the use of auctions: institutional capacity and institutional arrangements

As stressed by Arowolo (2019), moving from auction theory to real-life implementation is not an easy task. This holds true particularly where institutions are not strong enough to support an auction (Maurer and Barroso, 2011). Thus, the implementation of auctions requires a considerable capacity and resources on the part of the auctioneer (Kitzing et al., 2019). Volumes have to be set, auction documentation and information have to be provided and assessed and a decision on the adoption of different design elements has to be taken. Not all countries may have this capacity. Indeed, considerable institutional capacity and resources were a critical factor behind the success of the auctions in South Africa (Eberhard and Naude, 2016; Kruger and Eberhard, 2018), whereas lack of institutional capacity was behind the failure of the government choice of the project site in Zambia (Kruger et al., 2019).

On the other hand, analyses of institutional arrangements and the role played by different public authorities may provide insightful lessons for other countries, although institutional contexts differ and the possibility to transfer those lessons across countries may be limited. The institutional arrangements in RES auctions (design, implementation and control) are discussed with some detail for only a few countries, e.g. South Africa (Eberhard and Naude, 2016) and Brazil (Tolmasquim et al., 2021; Viana and Ramos, 2018).

4.1.3. Technological and market preconditions for the use of auctions

RETs have different features regarding their maturity, complexity, standardisation and modularity. Some of those features may make them less suitable to participate and be awarded in auctions. There is a

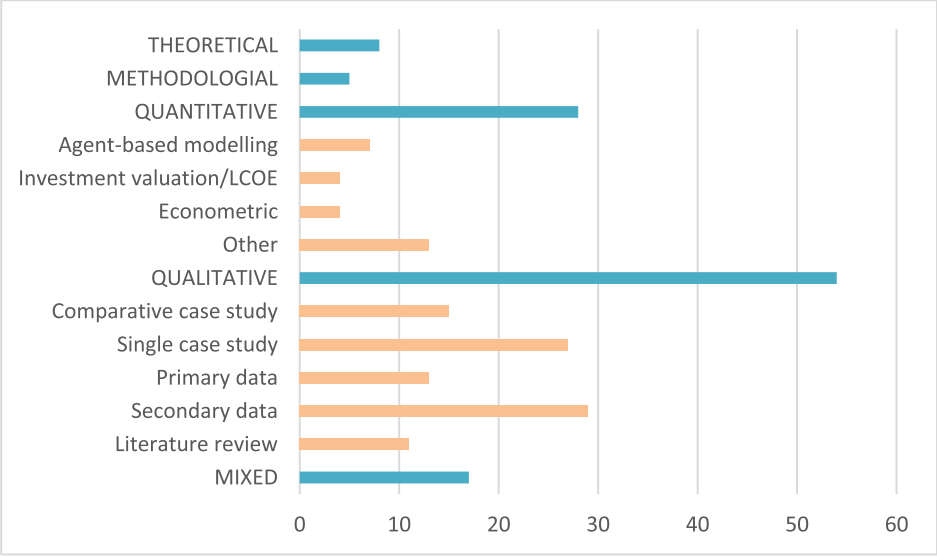


Fig. 3. Number of publications per approach.
Note. Main categories are shown in capital letters and sub-categories in lower-case letters. Within the "qualitative" category, "primary data" refers to the use of data collected through interviews, expert elicitations, etc. and "secondary data" refers to auction outcomes, official data/documents and other publicly available data.
Source: Own elaboration

presumption that this is the case with less mature technologies (del Río and Linares, 2014; Jacobs et al., 2020; Zhu et al., 2021) (see Table 4). Jacobs et al. (2020) argue that auctions may be less suitable not only for less mature technologies, but also for less standardized, complex ones (such as concentrated solar power, CSP).

However, there isn't any strong empirical evidence suggesting that auctions perform worse than ASFITs in promoting the less mature or more complex technologies.

Although most auctions around the world have been conducted for on-grid applications, this does not mean that they cannot be held for off-grid applications. In fact, some auctions for off-grid applications have been conducted (Mali, Sierra Leone and Peru) and, given the lack of access to electricity in rural areas, particularly in less developed economies, they can be a useful instrument to facilitate such access, as shown by Lucas et al. (2020) for Peru.

Given the impressive reduction in the costs of some RETs (PV and wind), a debate has emerged on whether support (e.g., through auctions) is needed for their uptake. Some argue that it is not needed. But, for others, auctions provide the revenue certainty necessary for their uptake (Beiter et al., 2021). A critical risk is the difficulty to finance RET investments with market revenues only, given the volatility of those revenues and, also, the possibility that the merit order effect will lead to very low wholesale electricity prices. These low prices may not be sufficient for all the projects which are needed to comply with the stringent targets in the context of the energy transition towards decarbonisation.[5] Support schemes would still be required for derisking, i.e. to obtain the necessary financing, leading to bankable projects. Auctions would provide a necessary price (revenue) floor in this context (Beiter et al., 2021, p. 1494). Moves in some countries can be observed towards "subsidy free auctions" (e.g., in Germany 2017, the Netherlands in 2018 or Spain in 2016 and 2017) where there is no premium payment (Kitzing et al., 2019, p. 14).[6] These subsidy free auctions have received scarce attention from academia so far.

Table 4
Statements in the academic literature on the suitability of auctions for less mature technologies.

- Zhu et al. (2021, p. 8) argue that "no matter how the mechanism is designed, the investment risks cannot be effectively reduced because of high uncertainty or poor-quality resources. So it is not appropriate for the policy-maker to launch an auction scheme on renewable technologies that are not mature enough or face adverse market conditions".
- Kitzing et al. (2019, p. 12) state that "alternatives to auctions should be considered in situations where 1) reasonable competition cannot be expected, 2) project costs are particularly uncertain due to external factors or 3) secondary policy goals, such as ensuring local added value or actor diversity, are being pursued. These situations occur often when policymakers are seeking to promote immature or innovative RES technologies".
- del Río and Linares (2014, p. 50) find that auctions "have shown a limited ability to promote technologies with different maturity levels".

Source. Own elaboration.

4.1.4. *Auctions in the policy mix*

Auctions have sometimes been used as part of a policy mix with other deployment instruments or other policies. Policy (and instrument) mixes are not a panacea, however. They lead to complementarities and synergies (positive interactions), but also to conflicts (negative interactions) (del Río, 2014; Rogge and Reichardt, 2015).

Analyses on the combination of auctions with other deployment support instruments are scarce. Kwon (2020) and Kwon (2018), who analyse the advantages and drawbacks of adding auctions to a pre-existing scheme (quotas with green certificates), are two exceptions. The authors illustrate the positive interactions between the instruments,

[5] For example, in an analysis of auctions in Germany, Kácsor (2021) finds that according to the modified LCOE calculation around 7–8% of all participants do not need any support because their projects will be economical with revenues from the wholesale market.

[6] In subsidy-free auctions, either awarded bidders bid for zero support (as in some off-shore wind auctions in Germany) or support is not provided, but only the right to build the project is awarded based on non-price criteria (as in the Dutch off-shore wind auctions after 2017).

but also the negative ones.[7] Nevertheless, it is difficult to use a country case (given the particular institutional and policy context and the specific manner in which the policies have been combined) as a lesson for other countries attempting a RES policy mix. This transferability issue is addressed more broadly in section 4.3.

Some contributions also stress the relevance of adding non-deployment instruments to auctions. For example, in their analysis of auctions in emerging economies, Frisari and Stadelmann (2015) suggest adding derisking instruments such as concessional loans and grants to auctions. Ozcan (2021) analyses the combination of auctions and other instruments in Turkey, and recommends combining auctions with a carbon tax.

4.1.5. Coordination of auction and other procedures

In RES deployment, auction procedures are somehow linked to other procedures, including permitting and grid-connection. Lack of coordination between them may lead to unintended consequences, i.e., delays in deployment. This has received some attention in the literature. For example, in their analysis of auctions in Brazil, Bayer et al. (2018) and Viana and Ramos (2018, p. 226) observe that transmission grid issues were the main reason for project delays.

4.2. Assessment of auctions according to goals and assessment criteria

Assessing any policy instrument such as auctions is a complex task, given that policy-makers have different goals and that there are many variables at play (both related and unrelated to policy) which influence those goals apart from the instrument itself. It is thus useful to discuss assessments of auctions within a broad analytical framework which includes the relevant policy elements at different governance levels (Fig. 4).

As shown by several authors (Bayer et al., 2018; del Río and Mir-Artigues, 2019; Matsuo and Schmidt, 2019), high-level energy policy objectives may differ significantly between countries, since governments may like to put more emphasis on having a fast increase in RES deployment, to have low energy prices or to create local industry and employment, for example. Obviously, conflicts between goals are common. These goals translate into policy measures, which comprise several items, organised in a descending order of generality, from broader (framework conditions including targets and policy stability) to more specific applications (instruments and their design elements). Obviously, not only policy aspects influence the fulfilment of policy goals. Some context conditions (socioeconomic and institutional features where the policy measures are applied, including non-energy policies) and external factors are also relevant. A challenge for researchers is to isolate the influence of policies from those external factors.

The evaluation of RES auctions should consider several criteria: effectiveness (the realisation rate of RES projects), static efficiency (minimisation of support costs or total generation costs), dynamic efficiency (impact of innovation and cost reductions), actor diversity (awarding to small actors), local impacts (socioeconomic and environmental) and social acceptability/political feasibility (del Río, 2017).

The evidence on the positive, null (neutral) or negative impact of auctions on the different criteria was coded and summarised in a table (see Supplementary material 2 for details) and the aggregated results were translated to Fig. 5, which suggests several main findings: 1) Effectiveness and efficiency are the two criteria which are mostly assessed; 2) It is broadly agreed that auctions are support-cost efficient; 3) In contrast, the assessment of effectiveness is more ambiguous; 4) Auctions tend to favour the large actors; 5) The results with respect to other assessment criteria are much less clear, and the evidence is too small. These results have been compared to non-academic reports, which broadly confirm these findings.[8]

4.2.1. Analysing the impact on specific criteria

This subsection discusses the aforementioned impacts of auctions on different assessment criteria.

4.2.1.1. Effectiveness. Many studies show that auctions have led to delays, undersubscription or low realisation rates (below the volume awarded) (see Supplementary material 2 for details). An important distinction is between ex-ante (in)effectiveness (undersuscription) and ex-post (in)effectiveness (low realisation rates and delays in building the projects). Although some papers can only measure the first one, given that the deadline for commissioning projects has not been closed at the time of writing (e.g., Shrimali et al., 2016), the evidence shows that ex-post effectiveness has been much more addressed.

4.2.1.2. Efficiency. Despite the considerable methodological difficulties (see section 4.2), there is a wide agreement that auctions are efficient regarding awarded bids and resulting support costs (so-called "support cost efficiency"). However, *strictu sensu*, efficiency should refer to the minimisation of total (or system) generation costs, which include direct (fixed and variable, usually measured by the LCOE) and indirect generation costs (balancing, profile and grid costs) (see Breitschopf and Held, 2013), whereas the focus on support costs is rather a distributional issue (see Cerdá & del Río, 2015). Thus, the small attention to generation costs when analyzing efficiency is striking from an academic point of view. The reason for the focus on support costs is triggered by the concern of policy makers about the impact of RES support on the electricity bill.

An interesting research topic is the possible trade-off between direct and indirect generation costs. This trade-off is partly related to geographical diversity. Auctions encourage the choice of the best sites in terms of resources by bidders/investors (lower LCOEs), but this may lead to project locations far from consumption centers, which may require e.g. grid extensions or grid reinforcements, i.e. higher indirect costs. To our knowledge, only Farrell et al. (2018) have partly addressed this issue, showing that such trade-off exists. Which design elements (DEs) can be adopted to encourage project dispersion has received some attention (IRENA, 2019b; Kruger et al., 2019), but how auction DEs can minimise the overall costs (direct + indirect) has been an unexplored topic.

Some cost components have received scant attention in the past. One important component of LCOE is capital costs. Only two papers have analysed the impact of auctions on the cost of capital (Botta, 2019; Đukan and Kitzing, 2021) with ambiguous results (Table 5). In addition, research on administrative costs in auctions and their level with respect

[7] Basically, auctions have sales risk but not price risk, a renewable portfolio standard (RPS) has price risk but not sales risk. If both could be combined, each type of risk would be reduced. Kwon (2020) identifies a negative interaction caused by auctions in this mix: adding auctions to renewable energy certificates (RECs) leads to an incentive for small and medium solar PV generators to produce more electricity. In turn, this reduces REC prices and results in a lower level of effectiveness in renewable electricity generation, which in turn makes it necessary to increase renewable electricity targets to make up for this shortfall.

[8] These reports are from IRENA (2013, 2015, 2017, 2019b), the Interamerican Development Bank (Viscidi and Yepez, 2019), United States Agency for International Development (USAID, 2017, 2019), the results of the case studies carried out in the EU-funded AURES and AURESII projects, which are specifically dedicated to RES auctions (see del Río, 2017; Wigan et al., 2016 and the project websites http://www.auresproject.eu/and http://aures2project.eu/), the World Bank (Azuela et al., 2014; Khana and Barroso, 2014; Wang et al., 2014) and the Council of European Energy Regulators (CEER, 2018), among others.

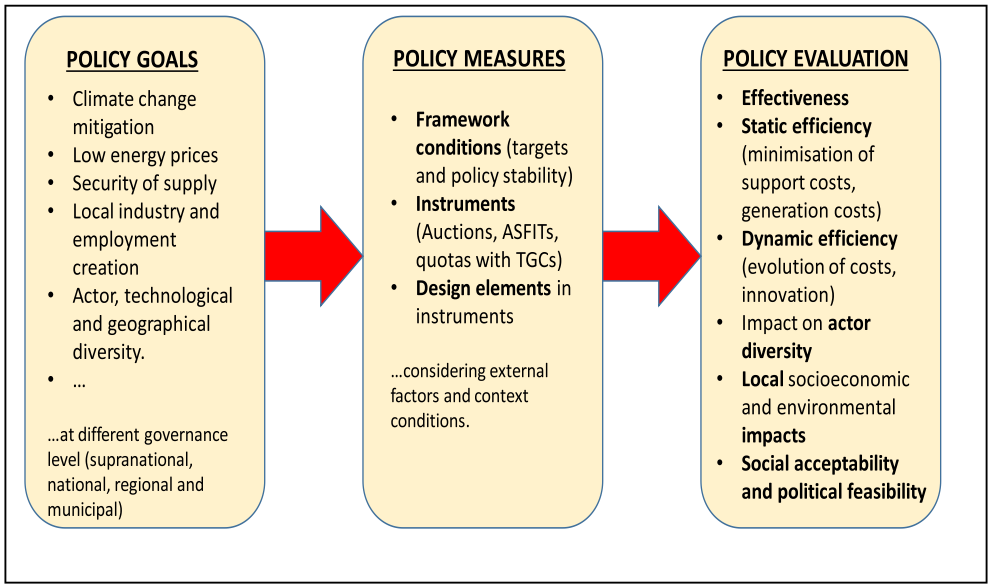


Fig. 4. Illustrating the analytical framework to assess auctions.
Source: Own elaboration.

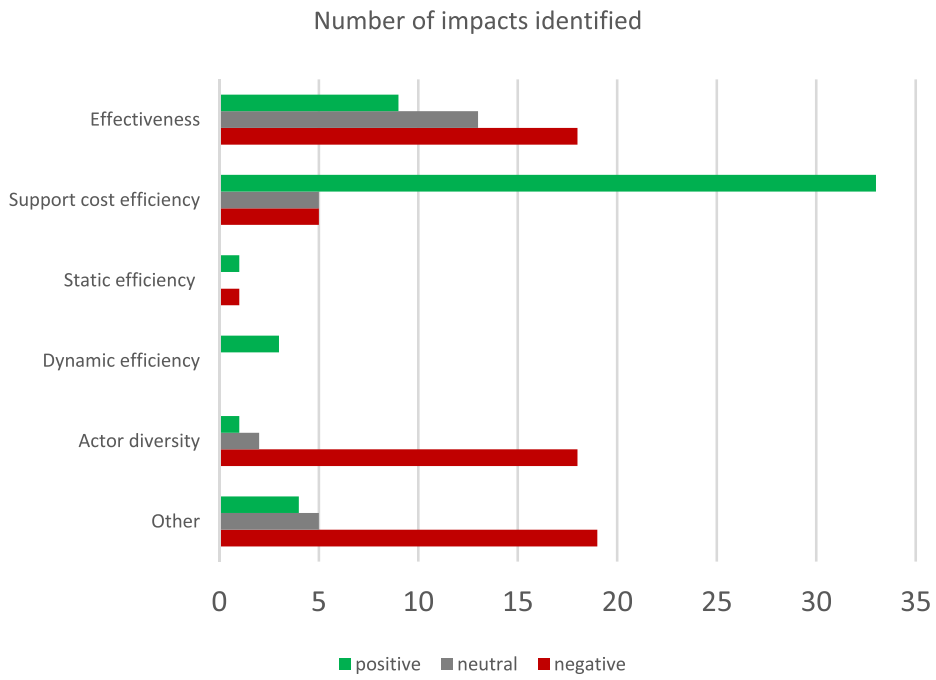


Fig. 5. Results of the outcome of auctions per assessment criterion.
Source: Own elaboration.
Source: Own elaboration. Note: Not all the reviewed articles provide results on the outcomes of the auctions, since many of them focus on the design elements. Outcomes generally refer to the results of auctions compared to other schemes (e.g. previous ASFITs in the country or ASFITs in other countries).

to ASFITs has been scarce.[9]

4.2.1.3. Dynamic efficiency. In contrast to static efficiency, dynamic efficiency evaluates whether a policy instrument helps drive down the costs of RETs (Wigan et al., 2016). There has been little focus on dynamic efficiency in the literature (Münch and Marian, 2022), which may be related to difficulties in obtaining the appropriate data (Wigan et al., 2016).

A controversial topic is the discussion on the extent to which auctions are actually a main source of cost reductions in RETs. Many articles claim so, but for others those cost reductions mostly reflect technological improvements, i.e. they are not caused by RES auctions themselves (Table 6). However, auctions have shown the capacity to translate those cost reductions of the technology to lower support costs (bid prices) (Bayer, 2018; Bayer et al., 2018), which has not always been the case with alternative instruments (del Río and Mir-Artigues, 2012).

4.2.1.4. The impact of auctions on innovation. This is an unexplored and closely related topic to dynamic efficiency. In their review on the tiny

[9] This debate remains open, with Eberhard and Kåberger (2016) arguing that ASFITs lead to higher administrative costs than auctions, and Huber et al. (2007) and Mitchell (1995) arguing the opposite.

Table 5
Academic articles on auctions and the cost of capital.

- Dukan and Kitzing (2021) investigate the effects of the shift to auctioning on costs of capital and financing conditions in wind energy in Europe through 43 interviews. The authors find that auctions create a competitive environment that pressures the industry into accepting higher risks and lower returns. To reduce negative impacts on cost of capital and financing, the authors recommend that policymakers adopt remuneration schemes that stabilise revenues and support smaller actors through removing participation hurdles.
- Botta (2019) analyses how policy induced uncertainty affects the cost of capital of renewable energy power plants with the help of a questionnaire to 38 representatives of different firm types (project developers, utilities, cooperatives, venture capital, private equity or hybrid, infrastructure fund, pension fund and insurance company, bank and private investor) and show that improved auction design can help to lower the equity cost between 0.5% and 1.5%. Three design elements reduce the costs of financing (costs of equity): shifting from technological-neutral to technology-specific auctions, from one-off auctions to auctions with an schedule and from non-monetary to moderately large bid bonds.

Source. Own elaboration.

Table 6
Studies mentioning the link between auctions and cost reductions.
Source: Own elaboration.

Auctions lead to cost reductions…

- Lackner et al. (2020, p. 142) argue that Germany and Mexico "show large price drops over the span of months, which suggests that competition and learning by doing, rather than longer-term trends such as technology improvements, are driving prices down".
- Kylili and Fokaides (2015, p. 229), referring to Taiwan, argue that "the fact that the tariff rates dropped by 38% from 2010 levels by the third round of auctions that occurred within the same year before the introduction of the auction mechanism is a distinctive proof of the high effectiveness of incorporating the auction mechanism into the FiT scheme".
- For IRENA (2017, p. 17), "the competition in the market that is created by a properly designed auction can bring down the price of renewable energy projects more efficiently than other support mechanisms".

Cost reductions are not caused by auctions …

- "Cost reductions that are associated with renewable energy auctions are not caused by the auction systems themselves, but rather are associated with general declines in the costs of renewable energy technologies" (Toke, 2015, p. 43).
- **"**both reduced panel costs and increased competition have contributed to low bids in PV auctions—but panel costs have had a more pronounced impact**"** (Liñeiro and Müsgens, 2021, p. 16).
- **"**Some of these reductions are due to the drop in hardware costs of these technologies between 2011 and 2014**"** (Matsuo and Schmidt, 2019, p. 21).
- **"**In all four countries examined, auction prices declined over time (…). One important cause of the declines in prices for photovoltaic projects was the global price drops for PV modules (…). The decreasing costs for project developers are reflected in falling auction prices**"** (Bayer et al., 2018, p. 312).
- Grashof et al. (2020) analyse the price outcomes of the first two years of onshore wind power auctions in Germany both over the course of the seven auction rounds and in comparison to the simultaneously applicable FIT. The authors find that "auction results below the level of a previously applicable FIT may possibly be due to the competitive pressure of the instrument, but also to a general decline in the costs of technology**"** (Grashof et al., 2020, p. 2).

Source. Own elaboration.

literature on the comparative innovation effects of auctions (only four papers on the topic), del Río and Kiefer (2022) find that auctions have generated lower incentives to innovate in RETs than ASFITs/FIPs. They argue that, although the literature assumes that auctions should lead to innovation through their impacts on competition (Bento et al., 2020; Haufe and Ehrhart, 2018), there might be other mechanisms at play which explain why auctions may provide a limited impact on innovation: some inherent features of auctions (the capacity caps and lower support due to competitive pressure) may lead to detrimental effects on innovation as mediated by their negative impact on market creation, reinvestment of profits into R&D and learning effects. As with other themes, the impact of auctions on innovation is likely to be mediated by the choice of DEs.

On the other hand, there is a concern that auctions have had a negative impact on the quality of the adopted RES equipment (Table 7). DEs can also have a relevant impact on the features of the adopted innovations. This was the case with technical standard requirements in India (Münch and Marian, 2022) and geographical correction factors, which favoured lower hub heights in the German scheme, since higher hub heights would lead to higher electricity production, but also the reference yield would be higher, decreasing the quality factor and thus, increasing the correction factor (Croonenbroeck and Hennecke, 2020, p.10). Surprisingly little research has been devoted to these issues in the past.

4.2.1.5. Actor diversity and market concentration. Actor diversity has received considerable attention in the literature, either renewable energy communities (Grashof, 2019) or small actors in general (e.g., Álvarez & del Río, 2022; del Río and Linares, 2014). There is a wide agreement that auctions have detrimental effects on actor diversity (see del Río et al., 2020 for an in-depth review of the topic), although some contributions do not find a relation between auctions and the participation of small actors (Bayer et al., 2018; Cassetta et al., 2017; Liñeiro and Müsgens, 2021)[10].

A topic related to actor diversity, which has received much less attention, is market concentration. This is encouraged by auctions, although it is strongly dependent on auction design (see also del Río et al., 2020 for a review). Kruger et al. (2021) have recently shown that, while there has been some degree of market concentration, it did not have an adverse impact on project pricing or market development.

4.2.1.6. Impacts on local industry creation. Some papers have shown negative effects of auctions on local industry creation (Butler and Neuhoff, 2008; Matsuo and Schmidt, 2019), particularly when the government has "low award prices" as its single priority, because investors may prefer to import cheaper equipment from abroad to meet their obligations (Sirin and Sevindik, 2021). Again, the impacts of auctions on the local value chain are contingent upon the choice of DEs (Matsuo and Schmidt, 2019), but this has largely been an unexplored topic.

4.2.2. Analysing the trade-offs between goals in auctions

Achieving one goal or criterion may be at the expense of worsening another and, thus, the choice of instruments may depend on government priorities. Table 8 provides examples of the trade-offs reported in the

Table 7
Statements on the impact of auctions on the quality of adopted equipment.

- Kylili and Fokaides (2015) argue that the low bids in auctions have led to the adoption of low-quality equipment. Referring to China, they comment that "the winning bids of these auctions, ranging from 0.081 to 0.121 €/kWh, were ultimately proven to be much too low for the project to be economically feasible. Subsequently, not only were the actual installations much lower than the contractual capacities but they were also commonly found to suffer low quality" (Kylili and Fokaides, 2015, p. 229).
- Similarly, for the case of India, Münch and Marian (2022, p. 10) find out that "given that fierce price competition from cheap, imported components erodes profits, it is unlikely that project developers will invest in research and development and quality upgrading".
- Balfour (2017) also argues that low profit margins could have a negative impact on the technical quality and reliability of projects.

Source. Own elaboration.

[10] The literature mentions several reasons why small actors have a hard time in auctions: large bidders have a higher capacity to cope with the transaction costs, the uncertainty on future remuneration before the actual bidding takes place and the requested guarantees in auctions. They may also have lower costs (due to economies of scale), easier access to finance, more power to negotiate lower prices with equipment manufacturers and a greater ability to spread their risks (see Álvarez & del Río, 2022).

literature. The most usually-mentioned trade-off is between efficiency and effectiveness.

4.2.3. Underbidding

Some authors have argued that awarded bid prices in auctions may have been too low, leading to underbidding (awarded bid prices being lower than deployment costs), with detrimental effects on several criteria, especially on effectiveness (i.e., underbuilding, Table 9). Bidders could make wrong assumptions about the future costs, and bid aggressively, ending up with bid prices lower than those costs at the time of building the project, because the costs were not reduced as expected due to unforeseen events (e.g., increase in interest rates, raw material prices, etc …).

Underbidding has received some attention in the literature, but in-depth studies on their occurrence are scarce. It is extremely difficult to detect because there are several factors at play and the impact is also mediated by auction design. Comparing awarded bids with the LCOEs in the respective locations, Martín et al. (2020) found possible underbidding in auctions in 10 countries from America and Europe. Some authors argue that common financial models/NPV models are not appropriate to identify underbidding (Stetter et al., 2020; Voss and Madlener, 2017). For this task, real options analysis (ROA) has been proposed, as in Voss and Madlener (2017) and Matthäus et al. (2021).

4.2.4. Effects on social acceptability

Two main sources of negative impacts of auctions on social acceptability have been identified in the literature: geographical concentration of projects in given locations, leading to NIMBY effects, and procedural justice concerns (when local actors do not participate in the auction process). However, auctions could also positively affect social acceptability if they would lead to local industry creation or if support costs are reduced with respect to previous schemes. In this context, a relevant distinction is between local acceptance (local residents and stakeholders agreeing with a specific project) and social acceptability as such (the wider socio-political acceptance of certain RETs or policies by the public) (Grashof, 2019).

These issues have received some attention in the past. Regarding geographical concentration, Agnolucci (2007) and Mitchell and Connor (2004) found that the high level of competition in the U.K. NFFO led to geographical concentration, sometimes in scenic areas, leading to NIMBY effects. This was also the case in Australia (Buckman et al., 2014). This NIMBY problem may be exhacerbated in the future, as ambitious RES targets need to be met, at least in the EU, which require a much greater installation of new solar and wind generation capacities and probably higher (more visible) turbines closer to residential areas (Grashof, 2019).

Regarding procedural justice, this refers mostly to the lack of participation and awarding of small actors and the local communities where the projects will be located in the auction process. The connection between actor diversity and social acceptability is made by some authors in the literature (Agnolucci, 2007; Côté et al., 2022)(Table 10). A more proactive role of citizens in decarbonisation efforts to foster the acceptance and deployment of RES infrastructure will be needed, particularly with a strong climate ambition (European Commission, 2015; Côté et al., 2022).

4.2.5. Interactions/interrelation of auctions with the just energy transition (JET)

Auctions have and will be implemented in the context of the JET, together with other policies. The JET basically means strong ambition in RES deployment and addressing the "just" part of decarbonisation, i.e., that no one is left behind (Wang and Lo, 2021). The JET represents a challenge for the design of auctions, since they require healthy competition levels (volumes awarded should be lower than volumes submitted), which could be hampered by the high ambition of the JET, as this would entail large auction volumes. Social acceptability would be

Table 8
Examples of trade-offs between goals in auctions taken from the literature.

Trade-off between goals in auctions	Examples from the literature
Between effectiveness and support cost efficiency …	"When aiming for high effectiveness, regulators need to keep in mind that there is a substantial trade-off with efficiency. Pushing bidders towards realisation of the projects comes at the cost of a risk premium for projects. Participants in the auction require compensation for excluding strategies from their decision space" (Matthäus, 2020, p. 8). "Policy makers face several trade-offs, particularly between higher project implementation rates and possibly increased prices" (Gephart et al., 2017, p. 159). "Note that the auctioneer's goals of minimal procurement cost and high post-auction realisation rates are partially conflicting as lower award prices lead, ceteris paribus, to lower realisation rates" (Matthäus et al., 2021, p. 1098). These authors show that longer realisation periods and lower prequalification requirements lead to lower bids but also lower realisation rates.
Between effectiveness and local impacts …	"In this case, policy makers would need to decide which objective – on-time implementation or the local production of components – is the major aim in economic and energy policy" (Bayer et al., 2018, p. 106).
Between support cost efficiency and actor diversity (AD) …	The results in Álvarez and del Río (2022) show that a greater diversity of bidders' sizes increases the probability that the auction will not be efficient. In other words, promoting small actors with respect to large ones comes at a cost in terms of a lower allocative efficiency i.e., that the lowest-cost bidders will not be awarded
Between efficiency and local industry creation …	Matsuo and Schmidt (2019) have found a trade-off between low-cost renewable energy deployment and local industry development, by comparing the renewable energy auctions in Mexico and South Africa. They find that "the prioritization of low-cost RE generation can result in a greater reliance on existing foreign value chains and capital, without building the local capabilities that could result in greater long-term benefits for the market" (Matsuo and Schmidt, 2019, p. 11).
Between effectiveness and AD …	**"**There is thus a trade-off in achieving the lowest-cost option and in maintaining actor diversity and accomplishing the capacity expansion goals envisaged" (Welisch, 2019, p. 379).
Between direct costs and indirect costs …	Farrell et al. (2018) show that there is a trade off between congestion and site-specific economics of scale: places with good economies of scale and renewable resources lead to high congestion costs (since projects are concentrated there).
Between lower generation costs and lower support costs (allocative efficiency and support cost efficiency) …	**"**Non-discriminatory auctions allocate support to projects with the lowest generation costs (LCOE). However, these auctions neither necessarily prevent windfall profits nor consider integration costs. Policy makers have to consider these trade-offs when designing auctions for RE support" (Kreiss et al., 2021, p. 197). "Although it is not the projects with the lowest costs that are awarded, the total support costs decrease"" (Kreiss

(*continued on next page*)

Table 8 (*continued*)

Trade-off between goals in auctions	Examples from the literature
	et al., 2021, p. 201). "The National REM auction design yields a higher allocative efficiency compared to the National auction at the expense of a higher average remuneration per kWh" (Bichler et al., 2020, p. 2).

Source. Own elaboration.

Table 9
Examples on the link between underbidding and underbuilding taken from the literature.

- Referring to China, Kylili and Fokaides (2015, p. 229) comment that "The winning bids of these auctions, ranging from 0.081 to 0.121 €/kWh, were ultimately proven to be much too low for the project to be economically feasible". They conclude that "the most important challenge of the auction mechanism was found to be the extremely low bids issued by the investors that ultimately prove the projects to be financially unviable" (op.cit. p.233).
- Agnolucci (2007, p. 477) acknowledged "that the NFFO competitive bidding process led to some renewables projects bidding too low. Coupled with a challenging planning environment, this caused the low deployment rate mentioned above".
- In their study on Brazil, Viana and Ramos (2018, p. 226) argue that "concerns have been raised regarding the long-term sustainability of projects because of the low prices that were bid".
- In his analysis of the German auctions, Lundberg (2019, p. 450) comments on the "high risks of projects not being realized due to aggressive bidding and special rules for cooperatives".
- Zhu et al. (2021) find that too much competition may not be good since it may lead to underbidding, which may result in cash-flow problems during project operations or delay the project.

Source. Own elaboration.

negatively influenced by the high bid prices in a low competition environment. Such high ambition would also mean that many places would need to host the deployment of RES projects, possibly leading to their geographical concentration and negatively affecting the social acceptability of RES (NIMBY). These effects may not be directly related to auctions, but to the high ambition of the RES targets in the context of the JET. The extent to which auctions could be designed to mitigate them may be the subject of further research.

Up to now, the treatment of JET issues in the auction literature has been limited. Some papers have indirectly addressed distributional and procedural justice, for example when discussing the participation and award of small actors (particularly RES communities), or market concentration. To our knowledge, only Müller and Claar (2021) have analysed how auctions have privileged certain RES project constellations and investment patterns and how these may bear concrete implications for energy justice and a just transition, with a case study of South Africa.[11]

4.3. Focus on design elements

Design elements are a main factor influencing the success of the auctions (IRENA, 2015, 2019b; Nasirov et al., 2019). Policy makers have several DEs to choose from (Table 11).

Table 10
Examples on the connection between actor diversity and social acceptability in the literature.

- Regarding local involvement, Mitchell (1995, p. 1082) concluded that "in particular, as several wind farms began to be commissioned at the same time, mainly in Wales, it was felt by some that wind energy development was happening too quickly, with too limited a local involvement".
- Also referring to the NFFO, Agnolucci (2007, p. 484) states that "if local people had been consulted, opposition to wind would have been less intense".

4.3.1. Impacts of design elements

Those DEs can be expected to affect different aspects, issues and criteria. There is already an abundant literature on auction design, both academic and non-academic (see, e.g., IRENA, 2013; IRENA, 2015, 2017; 2019b). The academic literature has analysed theoretically and empirically the impact of different DE choices on different issues (Table 12).

Whereas the impacts of specific design elements within the auction in a country have dominated the discussion, there are also some papers which take a broader perspective, and analyse the impact of different DEs in different countries (i.e., del Río, 2017; del Río and Linares, 2014; Gephart et al., 2017; Haelg, 2020). Haelg (2020) provides a very insightful and complete review of these impacts. However, our review allows us to provide some insight on the outcome of the following design elements, either because they have not been sufficiently covered in Haelg (2020) (multicriteria auctions, transferability of rights), because new evidence has appeared which was not included there (LCRs) or because the impacts of the instrument on a specific criterion were not conclusive (pricing rule on bid prices, transferability of rights).

- **Multicriteria auctions.** Governments may want to include non-price criteria in the auctions for several reasons (e.g., local employment and local industry creation, community engagement, system integration costs etc …).[12] With the exception of the South African case, there isn't an in-depth analysis of the implications of those multicriteria auctions (for prices and the other criteria), and the extent of the trade-offs between them. In addition, how auction theory can contribute to the design of RES multicriteria auctions has not been well researched. The underlying auction-theoretic principle is the concept of scoring auctions (Che, 1993) but it has so far not been analysed for RES auctions, with the exception of Ciaccia et al. (2010) .[13]
- **Pricing rule.** Haufe and Ehrhart (2018) discuss the implications of pay-as-bid (PAB) versus uniform pricing (UP) for RES auctions. The basic idea is that UP is more incentive-compatible than PAB, but only under very restrictive assumptions (single-project bidders). "As soon as bidders participate with more than one bid, in more than one auction round or their costs have some common components (e.g., PV-module prices), UP is no longer incentive compatible, and thus cannot be expected to automatically lead to superior results as compared to PAB" (Kitzing et al., 2019, p. 13).[14]

A critical issue is the impact of the pricing rule on support costs and

[11] The authors proposed that, to further the goals of a JET regarding distributive justice, the government should organize a regional bidders' round in particular provinces, provide higher rewards in the auction for the inclusion of local actors beyond the minimum, increase the domestic capacities for renewable energy research funding and complement the auction programme with local content requirements. In terms of procedural energy justice, they claim that "a close collaboration between project developers, local government and civil society, for example through stakeholder dialogue, would enhance public participation. Local trustees could greatly benefit from training in community development" (Müller and Claar, 2021, p. 14).

[12] Some governments have already done so: South Africa (Eberhard and Naude, 2016; Kruger and Eberhard, 2018), Australia (Buckman et al., 2019) and Turkey (Sirin and Sevindik, 2021).

[13] "In a scoring auction, the buyer announces a scoring rule and commits to award the contract to the firm with the highest score. The scoring rule ranks bids according to prices, quality attributes and, sometimes, the characteristics of supplying firms" (Huang, 2019, p.1).

[14] As shown by Ausubel et al. (2014) in the general auction literature, bidders have an incentive to bid strategically in UP auctions if they can submit multiple bids.

Table 11
Auction design elements: description of options.

Design element categories	Description of alternatives
1.Metrics for volume setting and disclosure	The volume in renewable electricity auctions can be set in terms of capacity (MW), generation (MWh) or budget (e.g., million €).
2. Schedule	A schedule of auctions implies a commitment to launch an auction at regular intervals. The alternative is to organize ad-hoc auctions, i.e. set at irregular intervals. Even if there isn't a schedule of auctions, these may be organized on a regular basis (i.e., with a high frequency).
3. Diversity (technological, geographical, actor and size)	Auctions can be organized which are neutral with respect to the participation or awarding of technologies, locations, actors and project sizes. In contrast, a specific sort of those categories can be promoted through several options. All electricity generation technologies (renewable or non-renewable) are in principle eligible to participate and be awarded in technology-neutral auctions. Only one technology is eligible to participate in technology-specific auctions, or several of them in multi-technology auctions. Auctions can also be geographically neutral (no requirement to deploy the project in a given location) or geographically-diverse (the location is either pre-selected by the government or an incentive to locate in given places is provided).
4. **Participating conditions**	-Information provision: Governments may support participation in the auction through the provision of information to potential bidders (e.g., measurement of resource potentials). -Seller concentration rules (SCRs): In order to ensure competition, the auction may be cancelled if there is not a minimum number of participants. -Material or financial prequalification requirements. They may fall on the bidder (e.g., previous experience, a good financial record or economic guarantees) or on the project (e.g., pre-development of sites or possession of administrative permits) and mitigate the risk of non-realisation. -Local content rules (LCRs). Some countries require that the equipment used in the projects awarded in the auction is manufactured domestically.
5. Remuneration type	Either generation (MWh) or capacity (MW) may be remunerated in RES auctions
6. Remuneration form.	Awarded bidders may receive a full payment (feed-in tariff, FIT) or a premium which is additional to the market price (feed-in premium, FIP). Under fixed FIPs, a constant amount of support which complements the spot market price is granted. Thus, the total remuneration in this case depends on the evolution of the market price. Sliding FIPs cover the difference between the average market price and the strike price set in the auction. Sliding FIPs can be one-side or two-side (commonly known as contract-for-differences).
7. Selection criteria	The award criterion may be only the lowest price (price-only auctions) or the lowest price and other criteria, such as local industry or employment creation (multi-criteria auctions).
8. Auction format	Auctions can be single-item or multiple-item ones. In the former, a single bidder is awarded a single product, i.e., the product cannot be divided into several units. In the latter, several bidders may be awarded the total amount of the auctioned volume.
9. Auction type	Auctions can be dynamic or static. In dynamic auctions, bidders interact with each other when submitting their bids, and can adjust them accordingly. In static (also called sealed bid) auctions, bidders provide undisclosed bids to the auctioneer, who then ranks the projects accordingly.
10. Pricing rules	Awarded bidders in auctions can either receive their bid (pay-as-bid, PAB) or the bid of the last accepted bidder or the first rejected bidder (uniform pricing).
11. Existence and disclosure of ceiling prices.	A ceiling on bid prices means that bids above such price are not considered in the bidding procedure.
12. Realisation periods.	The awarded projects should be built by a given date

Source: Own elaboration based on del Río (2017). See del Río (2017) and IRENA (2015) for further details.

Table 12
Analysis of the impact of DE choices on different issues in the academic literature (selected examples).

- Prequalifications and penalties (Kreiss et al., 2017; Welisch, 2018). Impact of the stringency of prequalification requirements and schedule on efficiency and effectiveness (Welisch and Poudineh, 2020). Impact of prequalification requirements and penalties on effectiveness (Matthäus, 2020).
- Project site selection by the government (Kruger et al., 2019).
- Different pricing rules (pay-as-bid vs uniform pricing) (Anatolitis and Welisch, 2017).
- Auction formats (Bichler et al., 2020)
- Design of auctions for a specific technology: CSP (del Río and Mir-Artigues, 2019).
- Impact of three design elements (hourly supply blocks, realisation periods and contract duration) on RES in electricity auctions (Nasirov et al., 2019).
- Impact of special provisions for renewable energy communities on auction results (Tews, 2018).
- How to integrate technical requirements into auction design (Münch and Marian, 2022).
- Technologically-neutral vs. technology-specific auctions (Kreiss, 2019).

Source. Own elaboration.

irrational bidding. The issue on the effects on support costs is far from closed. Whereas model results in Anatolitis and Welisch (2017) and Matthäus et al. (2021) show that PAB lead to lower prices and support costs, Kreiss et al. (2017) and Kácsor (2021) reach the opposite conclusion.

On the other hand, Haufe and Ehrhart (2018) claim that there is a higher risk of irrational underbidding by inexperienced bidders in UP. Matthäus et al. (2021) also argue that UP auctions foster more aggressive bidding than PAB auctions. Governments are also concerned about this risk. For example, Bose and Sarkar (2019) report that a reason for the choice of PAB in India was the lower risk of irrational bidding compared to UP. Indeed, an overwhelming majority of governments around the world have chosen the PAB rule (del Río and Kiefer, 2021). This may also be due to its ability to adjust the level of remuneration to the marginal cost of different bidders (Stetter et al., 2020).

- **Local content requirements (LCRs).** Some countries have included LCRs in auctions to boost local industries (i.e. Brazil, China, India, Russia and South Africa). With the disruption in supply chains caused by recent events (e.g., COVID-19), more countries may want to include those LCRs in order to increase their security of supply, although probably at the expense of higher bid prices. The success of LCRs in encouraging local industries and their negative impact on bid prices has not been systematically researched in the literature, with the notable exceptions of Hansen et al. (2020), Smeets (2017) and Probst et al. (2020) (Table 13). There is some evidence that LCRs have led to an increase in auction support costs and an increase in

domestic manufacturing capacity (Probst et al., 2020). However, whereas Probst et al. (2020) find that projects subject to LCRs had the same realisation rate as all other projects, Smeets (2017) shows that LCRs in the auction had a negative impact on effectiveness. Notwithstanding, the evidence is short.

An important challenge is measuring success, i.e., local industry creation. Hansen et al (2020) criticise the quantitative metrics used in the literature to measure the local impacts of LCRs.[15]

- **Transferability of rights.** The consequences of awarded bidders being able to transfer their building rights to other actors have not been analysed in-depth. This issue is obviously policy-relevant in the context of the JET: Given the ambitious RES targets, if awarded bidders decide, for some reason, not to build the projects, then the JET would be slowed down, unless those bidders were allowed to transfer their rights to someone else who could build the project. To the best of our knowledge, only Gephart et al. (2017) provide a (general) analysis of the issue and discuss different options.[16] However, Gephart et al. (2017, p. 154) also warn that "the transferability of support rights/contracts may also lead to unintended effects and speculation".

4.3.2. What is the motivation behind the choice of DEs?

To analyse the drivers of the choice of DEs, the functionalist vs. structuralist perspectives of Grashof et al. (2020) are useful to structure the discussion (see 4.1.1). The term "goals" under the functionalist approach refers to public goals, whereas under the structuralist approach it refers to selective benefits to specific actors or groups (Grashof et al., 2020). In fact, the choice of design elements is probably influenced by the context conditions in a country, the government goals and the influence of pressure groups.[17] Obviously, we can also assume that different policy goals of governments translate into a different auction design. This has been an unexplored issue, with the exception of del Río (2017) and Matsuo and Schmidt (2019). Finally, how context conditions influence auction design directly and indirectly (through their impact on goals) and have affected the design in given countries has not been analysed in a systematic manner so far.

4.3.3. Challenges in auction design and in research on auction design

4.3.3.1. The level of design elements. Research in the past has focused on whether a given design element (DE) should be adopted and, in the econometric models, whether the DE has been adopted or not (with a dummy variable). But insights on the level at which DEs should be set (i.e., their intensity) are less common. One exception is Haufe and Ehrhart (2018) who claim that the costs of physical prequalification requirements should not be above 3–5% of the capital expenditures.

4.3.3.2. Marginal analysis of trade-offs. When designing an auction, policy makers face several trade-offs, particularly between higher project implementation rates and possibly increased prices. There is a scarcity of articles on this topic. A notable exception is Matthäus et al. (2021), who show the extent of the trade-offs between DEs. They find that more stringent prequalification requirements increase deployment costs only moderately, whereas realisation rates increase drastically. They also show that, with respect to PAB, UP leads to higher deployment costs but also higher realisation rates.

No-regret DEs have also been found. For example, Welisch (2018) shows that penalties positively influence effectiveness without negatively affecting bid prices. Welisch and Poudineh (2020) found that a regular schedule (vs. a one-shot auction and a stringent penalty) are good for effectiveness and also for lower support costs.

4.3.3.3. Have auctions been designed differently for different technologies/applications?. Most papers on RES deployment provide a general analysis for all RETs and all applications (i.e., on-grid/off-grid). Case studies on a single country usually focus on a single technology and, when several technologies are included, the differences in design might be mentioned but not systematically analysed. An exception is del Río and Mir-Artigues (2019), who provide an in-depth analysis of auctions for CSP, suggesting differences with respect to other RETs and Lucas et al. (2020), who analyse off-grid auctions for stand-alone PV systems in Peru and highlight the differences with respect to on-grid applications.

4.3.3.4. The difficult transferability of results on auction design. A main finding in the literature is that one-size-does-not-fit-all and that the design of auctions should consider the particularities of the countries where they are implemented (i.e., the "context") (Gephart et al., 2017; Mora et al., 2017). This limits the extent of generalizability of findings and restricts the transferability of results of the DEs across countries. However, this should not mean that the lessons learned from one particular country are meaningless. They can be locally adapted and tailor-made designs could be defined (Arowolo, 2019). Some country characteristics may be taken into account when designing auctions, for instance developing country vs. developed country (Matthäus, 2020), small vs. large country (Welisch, 2019) or the specially high cost of capital in given countries (Frisari and Stadelmann, 2015; Lucas et al., 2017).

4.3.3.5. The micro-level in the analysis of the impact DE on specific firms. The innovation economics and management literatures suggest that different firm characteristics could modulate the effects of a DE on a particular firm. This is relevant with respect to several thematic areas of auction design. For example, in the realm of community RES projects, Grashof (2019, p. 27) argues that "RE investors have, until recently, been pictured as a rather homogeneous group resembling electric utilities". However, this micro-level impacts of DEs have received scant attention in the literature.

[15] These include welfare, wages and employment effects, number of jobs created, number of new local manufacturing firms established after LCR implementation, the expansion of the number of projects or sales in existing firms or the number of activities subcontracted to existing local producers (Hansen et al., 2020).

[16] They include allowing bidders to return the support right/contract earlier in exchange for a smaller penalty so that the auctioneer can re-auction the right, an automatic replacement system where the support right/contract is automatically transferred to the next highest bid, allowing the transfer of the support right/contract to other projects of the same bidder or the sale of support rights to other market actors (Gephart et al., 2017).

[17] One illustrative example would be the choice for technology-neutral vs. technology-specific auctions, which cannot be expected to depend only on "technical" arguments, but also on the pressure of given actors.

Table 13
Research on LCRs in RES auctions.

- Probst et al. (2020) provide an empirical assessment of the short-term costs of LCRs in PV auctions in India, finding that they led to a 6% increase in the cost of solar photovoltaic power generated from those projects, and a parallel short-term increase in domestic manufacturing capacity.
- Based on a review of the literature, Hansen et al. (2020) analyse the determinants of the effectiveness of LCRs. They find that "The variation in the effectiveness of LCRs can be explained by a framework that combines the following four determining factors: (i) market size and stability; (ii) policy design and coherence; (iii) the restrictiveness of the LCRs; and (iv) the domestic industrial base. The paper highlights a lack of systematic approaches and rigour in existing research, thus proposing the development of a common framework and set of indicators to assess the efficiency of LCRs" (Hansen et al., 2020, p.1).

Source. Own elaboration.

4.3.3.6. Interactions/interrelations/interlinkages/interdependencies between different DEs. It is often assumed that the effect of a DE is isolated from the impact of other DEs, i.e., that the addition of DEs to other DEs is a 1 + 1 sum. Research on policy mixes has shown that this does not need to be the case (del Río, 2014) and this may also not be the case regarding the aggregation of different design elements. On the contrary, different DEs can be expected to interact between each other in either positive or negative ways, leading to complementarities, synergies and conflicts. These interlinkages, interdependencies and interactions between DEs have not been the focus of past research (Haelg, 2020).

4.3.4. The limits of design: consideration of other policy and non-policy factors

Despite a consensus on the importance of DEs for auction success, some problems in auctions may not be fixed through a better auction design. There might be three reasons for this. First, conflicts and trade-offs between energy policy objectives/goals (see section 4.2.2) make it likely that improving one criterion with a given DE is achieved at the expense of worsening another criterion. Second, there might be other policy-related factors outside auctions design which influence such success, including those pertaining to the aforementioned framework conditions (ambition of RES targets and policy stability, see section 4.2).[18] Third, there are external factors to auction design (see Table 14).

Thus, there is a risk of overstating the role of design in auctions, since this design may not be able to address all problems or it can only do so in a less than optimal manner. Some issues (e.g., poor conditions to obtain financing, or some risks for investors) would require more than targeted auction design. It would rather ask for complementary policies to auctions (i.e., derisking instruments, such as low-interest loans, for example). In addition, there is a risk of attributing failure in RES deployment to those external factors (the other extreme). In fact, the three elements (auctions, non-auction policy aspects and external factors) are inextricably linked, i.e. country characteristics interact with auction design. The implications for auction design are evident: the choice of DEs should take into consideration those external effects and adapt design accordingly. In addition, other policies need to be implemented to address the potential barriers caused by those external factors.

However, it can be very hard to disentangle the influence of DEs from the external factors on the success of the auction,[19] which creates a challenge when assessing the success of auctions attributable to auction design. Bento et al. (2020) carry out an econometric analysis which isolates the effects of auctions from the impact of contextual factors. They find out that those other factors are not more relevant than auctions in explaining RET investments.

Table 14
Examples of external factors to auction design.

Bayer et al. (2018) and Bayer (2018) mention various country-specific external factors: wind potential, financing, risks for externally caused delays, infrastructure (are additional investments in infrastructure necessary?, learning curve (how advanced is the industrial development of the respective technology in the particular country?) and exchange rates. Bayer et al. (2018) found that, in Brazil, delays were caused by factors beyond the control of the project developers. Attractive business conditions (economic stability) in Chile have been recognized as a key factor for large-scale investments in renewable energy according to Nasirov et al. (2019).

Source. Own elaboration.

Table 15
Several examples of authors who mention the data unavailability problem in the literature.

"So far, our little experience of RES auctions has limited opportunities for comprehensive studies based on empirical analysis" (Cassetta et al., 2017).
"The case study findings show that it is not yet possible to conduct an overall evaluation of auctions used to support renewables due to the very limited experience with well-designed auctions and restricted data availability" (Winkler et al., 2018, p. 477).
"It is not currently feasible to conduct a complete analysis on the effect of introducing auctions because the number of countries that introduced auctions sufficiently long ago or that have a stable alternative support scheme to form a reliable reference case is very limited" (Winkler et al., 2018, p. 475).
"The short time span since most RES auction schemes are in place and the limited data availability renders an empirical evaluation of different RES auction designs infeasible" (Bichler et al., 2020, p. 2).
"Opportunities for empirical assessments are restricted by the limited use of auctions for renewable electricity support and the lack of suitable data on tenders" (Cassetta et al., 2017, p. 664). "few articles quantify project realisation rates. This discrepancy largely stems from the lack of appropriate auction data. First, the quantification of realisation rates requires waiting for construction deadlines to be met. Second, once a deadline is met, information about the project's construction status is often difficult to access or simply unavailable." (Liñeiro and Müsgens, 2021, p. 2).

Source. Own elaboration.

4.4. Focus on data and methods

4.4.1. Data availability

Due to the few auctions that were conducted until recent times and the lag between the auction and the commissioning dates (which particularly influences the analysis of effectiveness), hard data on auction outcomes have often not been available (Table 15).

Although the widespread implementation of auctions has increased the amount of data available, we support the call to national and international regulators made by Liñeiro and Müsgens (2021, p. 16) "to improve and facilitate the access to disaggregated data on auction results".

While data on awarded bids and bidders have usually been publicly available, data on non-awarded bids and bidders have not. There might be reasons why these data are not published (e.g., restricting their disclosure may mitigate strategic bidding in future auctions), but researchers would clearly benefit from their publication, as they would allow them to analyse the main features and strategies of non-awarded bidders and their reaction to different DEs. In turn, this may lead to useful recommendations for auction design (i.e., systematic non-awarding of small actors, given technologies etc …).

On the other hand, data on auction outcomes are often provided in a too aggregated manner (Bichler et al., 2020). It would be desirable to have consistent data on single awarded projects.

4.4.2. Difficulties in measuring success

A critical problem in the empirical analysis of auctions in the past has been to correctly choose the metrics to measure their outcome regarding a specific assessment criterion. This problem has been particularly serious when assessing efficiency. Two approaches have been followed in this context: analysing the impact of auctions on the evolution of support costs overtime or comparing auctions with ASFITs, either for the

[18] For example, Kruger et al. (2021, p.7) argue that, regarding MC, "continued policy uncertainty played a much bigger role in limiting market development and bidder diversity than the auction process or its design". In the analysis of off-shore wind in Denmark, Toke (2015, p. 51) mentions that "in practice we can see in both cases that a high degree of regulatory certainty is important" and that "the success of the Danish offshore wind programme in delivering several offshore windfarms through its auction/tender process is much concerned with the degree of regulatory certainty given to the developers" (Toke, 2015, p. 48).

[19] As put by Bayer (2018, p. 2649) "the regulatory conditions and external factors cannot be clearly differentiated in scientific terms, and it would require considerable effort to calculate their quantitative effect on auction prices".

same country (in two consecutive periods) or for different countries. Both types of analysis are problematic.

Too often, researchers have equated a given percentage reduction in awarded prices in a country's auction overtime with its success in terms of efficiency. This is clearly insufficient, since percentage reductions may not be attributable only to the choice and design of the support scheme (auctions), but also to reductions in technology costs and external developments (i.e, lower capital costs) (Bayer et al., 2018; Winkler et al., 2018, see also section 4.2).

On the other hand, the differences in auction prices between countries are attributable to a multitude of factors[20]. Sometimes, authors use the ceiling price and the discount that awarded bids represent with respect to such ceiling price to argue that auctions have led to strong price reductions (e.g., Viana and Ramos, 2018; Wigan et al., 2016).[21] Obviously, such reductions depend on the level of the ceiling price and cannot be argued to be cost-efficient by themselves. Comparing awarded bids with the LCOE (as done in IRENA, 2019b) also represents a considerable challenge, since the LCOE of specific projects is an unobservable variable for researchers, bidders project LCOEs for the future year of building the project (and the current LCOE is thus not so relevant) and not taking into account the time varying nature of revenue streams can be misleading (see Beiter et al. (2021); Martín et al. (2020) and IRENA (2019b) for a deep discussion on the drawbacks of this approach).

Comparing support prices in auctions with those in ASFITs faces the problem of setting a counterfactual. Here also, simplistic analyses have been performed, whereby the results of auctions today are compared to past results in ASFITs, leading to the aforementioned issue regarding technology cost reductions. By definition, a counterfactual subsidy does not exist (Shrimali et al., 2016) but "only few authors were cautious enough to underline that there is no rigorous, counterfactual-based, causal identification of the effect of public auctions on electricity price" (Münch and Marian, 2022, p. 2). In addition, Gephart et al. (2017) and Grashof et al. (2020) argue that the results of auctions are not directly comparable to those of ASFITs because, in ASFITs, only the support granted to built projects is considered whereas, in auctions, the awarded bid prices of all projects are included in the assessment, regardless of whether those projects have been built or not. Another problem is that instruments are compared without taking into account that an instrument (ASFITs) with particular DEs is compared to another (auctions) with other DEs. Thus, we are not comparing generic instruments.

4.4.3. Methods: beyond qualitative case studies

As shown in section 3, qualitative studies have dominated quantitative ones. Qualitative studies are mostly based on case studies. They have generally used official data and documents to analyse the design and/or outcome of auctions. Sometimes this has been complemented with interviews to key stakeholders on their perception of how the auction has worked. The initial case studies in the late 1990s-early 2000s were almost exclusively focused on single countries (e.g., Laali and Benard, 1999; Mitchell, 1995; Mitchell and Connor, 2004) and on the functioning of these schemes rather than on design.

Later on, comparative case studies emerged in the academic literature (del Río and Linares, 2014), as well as in the non-academic one (IRENA, 2015; Viscidi and Yepez, 2019; Wigan et al., 2016). These analyses emphasised the role of auction design.

Case studies have a main advantage: they are able to capture relevant information regarding qualitative details which would be relevant in the first stages of the analysis of a topic, since they contribute to identify their main aspects and dimensions. They are particularly well suited to identify alternative causal mechanisms in order to build well-founded theory (Eisenhardt, 1989). However, even if they are done in a rigorous manner, they do not allow their results to be generalizable and hypothesis-testing is limited. Furthermore, transferability of findings to other contexts is difficult. Some of them are subjective, based on perceptions and opinions, i.e., not real data. They may be used to propose hypotheses, but not to test them. Of course, this subjectivity can be mitigated through triangulation with other sources (e.g., secondary information or own data). Notwithstanding, studies on RES auctions will continue to rely on case studies in the future, given data limitations, the existence of many confounders, the qualitative dimension of many of the relationships and the importance of context-specific factors which are difficult to grasp in quantitative studies.

In order to mitigate the problems of qualitative case studies and combine the strengths of qualitative and quantitative methods, some papers follow a sequential exploratory/explanatory mixed methods research design, which is based on quantitative data collection followed by a second stage of qualitative data collection and analysis (e.g., Grashof, 2019; Kruger et al., 2021).

4.4.4. Econometric modeling

Given the inherent limitations of case studies, but also the fact that case studies have already played their role in contributing to the growing maturity of the topic, quantitative analyses have been gaining ground over time. The first quantitative studies, such as Shrimali et al. (2016), Dobrotkova et al. (2018) and Winkler et al. (2018) started to emerge as more auctions were conducted and data on those auctions were disclosed. Papers trying to use alternative methodologies to case studies included comparative analysis of auctions based on metrics which use real data for different countries (e.g., Shrimali et al., 2016; Winkler et al., 2018), comparisons between auction data and LCOEs (e.g., Dobrotkova et al., 2018), simulations (e.g., Anatolitis and Welisch, 2017) and econometric studies (e.g., Bento et al., 2020; Matthäus, 2020).

Econometric modelling is also faced with practical challenges: 1) Availability of auction data. For example, Bento et al. (2020) use data until 2014, but auction implementation skyrocketed after that year; 2) Econometric models may not be able to capture the complex auction environment and they are prone to issues of reverse causality and omitted variable bias. In particular, it is difficult to include relevant drivers of RET investments in addition to the auction, which helps to isolate its effects (see 4.11). This is partly related to data availability, which may prevent the inclusion of other factors. For example, Matthäus (2020) only includes two controls in his model which, as admitted by the author himself, might be insufficient; 3) Identify causality between the explanatory (auctions) and dependent variables; This can be done when using panel data (e.g., Bento et al., 2020). However, panel analyses "require a relatively large sample size to obtain significant results. Currently, there are only a few countries that have switched to an auction scheme and whose auctions' effectiveness can be evaluated" (Winkler et al., 2018, p. 474); 4) Include the intensity of the DEs. DEs have been included as a dummy variable in the past (e.g., Matthäus, 2020).

4.4.5. Agent-based modelling (ABM)

Some papers use ABM to model RES auctions, addressing different themes (Table 16). However, ABM has its pros and its cons (Table 17).

4.4.6. Other potentially useful methodologies for future studies

Recently, more and more methodologies and approaches are being used to address different themes in RES auctions, adapted to their research needs. Only some of those which have been used in the past are

[20] Therefore, "it is thus not possible to draw a conclusion regarding the capacity of the country-specific financing instrument to minimise support costs on the basis of auction prices alone. Instead, an additional detailed cost analysis would need to be conducted" (Bayer et al., 2018, p. 314).

[21] With respect to support cost efficiency, Viana and Ramos (2018) claim that the auction system in Brazil was successful because it led to reductions of 17% with respect to the initial price.

Table 16
Different themes addressed with ABM in the academic literature.

• A comparison of the results of the pricing rules in onshore wind power in Germany (Anatolitis and Welisch, 2017).
• Assessing how pre-qualifications and penalties affect the U.K. Contract-for-Differences (CfD) auction outcomes in terms of effectiveness and efficiency (Welisch, 2018).
• An assessment of the design of the U.K. CfDs for off-shore wind (Welisch and Poudineh, 2020).
• Investigating how setting the auction schedule and the auctioned volume per round impacts the auction outcomes in the multi-technology auction in Denmark in 2018 (Welisch, 2019).
• Analysing bidder behaviour in the German photovoltaic auction pilot, taking into account different price rules (Welisch and Kreiss, 2019).
• Analysing how the special rules for RES cooperatives in the German auction in 2017 affected actor diversity and the risk of winning projects not being realized (Lundberg, 2019).

Source. Own elaboration.

Table 17
The pros and cons of ABM applied to RES auction research.

With respect to other modeling techniques, ABM is an appropriate modeling tool to simulate complex systems and real-word phenomena, it is flexible with respect to changes and can establish sufficiency theorems (Anatolitis and Welisch, 2017).
On the negative side, some real DEs are difficult to include. For example, Lundberg (2019, p. 450) argues that the exemption clause for the citizens' energy cooperatives in Germany was not included in Anatolitis and Welisch (2017). In addition, ABM assumes rational agents, and one can wonder whether actors always participate in auctions in a rational manner (Grashof, 2019; Lundberg, 2019). Furthermore, learning effects cannot be easily captured in the ABM (Welisch and Kreiss, 2019). Finally, it may not be able to take into account external factors such as the evolution of electricity prices or the political and economic situation, which have an important influence on actual auction outcomes (Anatolitis and Welisch, 2017). Lundberg (2019, p. 456) notes that his ABM has several important limitations: 1) the model doesn't include the choice to enter the auction in the first place, instead the number of participants is kept constant; 2) Agents do not consider the level of the highest bid in the previous auction, when they plan their bids.

Table 18
Methodologies used in the past which could be possibly relevant for future studies on RES auctions.

• Multicriteria decision-making models to analyse the key factors that drove the significant rise of renewable technologies in Chilean energy auctions (Nasirov et al., 2019),
• Conjoint analysis to assess how policy design and the uncertainty regarding the future arrangements between the UK and the EU contribute to determine the cost of equity for renewable energy (Botta, 2019),
• Choice experiments to investigate risk-return preferences for different onshore wind energy auction designs by European project developers (Côté et al., 2022),
• Objectivist grounded theory approach to assess the impact of auctions on financing conditions and cost of capital for wind energy projects in Europe (Đukan and Kitzing, 2021).

Source. Own elaboration.

mentioned here (Table 18), whereas discussing their pros and cons is beyond the scope of this paper.

4.4.7. More focus on bidders

Several authors analyse bidder behavior in RES auctions or try to determine the optimal bidding strategy in RES auctions. In addition to ABM, a variety of methodologies have been used in this context, including LCOE models (Dobrotkova et al., 2018; Kácsor, 2021), discounted flow (DCF) metrics such as net present value (NPV) (Frisari and Stadelmann, 2015; Martín et al., 2020), real-options analysis (ROA) (Matthäus et al., 2021; Voss and Madlener, 2017), modified ROA (Zhu et al., 2021) and other (advanced) financial modeling (Stetter et al., 2020).

LCOE and DCF were the initially applied models. The LCOE method has important limitations in this context. For example, it does not include market-entry strategies or other motivations of developers that influence the levels of bids in auctions (Dobrotkova et al., 2018) and does not account for investment requirements (Stetter et al., 2020). The limited ability of the LCOE for assessing the viability of winning bids requires the use of discounted cash-flow metrics such as NPV for reliable project appraisal (Martín et al., 2020). DCF models allows getting initial rough estimates for the non-strategic bid price. But they also have some drawbacks. Most insufficiently account for risk and uncertainty and, thus, tend to overestimate a project's value and underestimate its required level of remuneration (Stetter et al., 2020, p. 2).

ROA models have emerged, trying to make up for some of the defficiencies observed in those initial models. NPV approaches do not take into account the inherent option values of projects. In ROA models, the awarded right to build subsidized renewable energy capacity is viewed as a real option, i.e. bidders assign a positive option value to the possibility to default on the project. According to Voss and Madlener (2017), ROA is better than NPV in this regard, since it considers the flexibility value. Whereas Matthäus et al. (2021) do not include risk-aversion or strategic bidding in their model, the models of Stetter et al. (2020) and Voss and Madlener (2017) include strategic bidding (in an effort to include the real-world elements that bidders have to take into account) and provide insight on the dynamics of repeated bidding strategies and interdependent bids.

Stetter et al. (2020) try to make up for the defficiencies observed in LCOE and DCF models. They design an advanced financial modeling approach that integrates with strategic bidding optimization in order to determine competitive and risk-adequate auction bids. With respect to Voss and Madlener (2017), who account for a basic present value model, Stetter et al. (2020) use the adjusted present value (APV), which they deem more appropriate for project finance. The APV allows the authors to determine the risk-adequateness of equity investors. This is obviously not the place to discuss those models and their limitations in depth.[22]

4.5. Suggestions for future research

The previous sections have provided insights on the state of the art on RES auctions regarding several themes. This review has identified gaps in knowledge, which suggest several avenues for future research (Table 19).

5. Conclusions and policy implications

This article has provided an extensive and in-depth review of the literature on RES auctions, which has grown alongside the real-world implementation of the instrument around the world. This literature is relatively recent but already abundant, and has addressed many different policy-relevant topics, albeit with one discipline clearly dominating (Economics). A clear evolution in the treatment of themes can be observed (from the analysis of functioning of auctions in single countries to cross-country analyses and from the analysis of functioning of auctions with respect to other schemes to the influence of design elements on the performance of auctions). The applied methodologies have also changed overtime (from an exclusive use of qualitative case studies to more quantative techniques).

The results of our review show that auctions are generally support cost-efficient, although their performance in terms of effectiveness is more mixed. Their impact with respect to promoting actor diversity is clearly negative. Nevertheless, the literature shows that the success of auctions strongly depends on how they are designed.

However, many research gaps remain. More multidisciplinarity in the analysis of auctions is recommendable, particularly regarding what is expected to be a key bottleneck to RES deployment in the next years,

[22] For the limitations of each study, see Voss and Madlener (2017, p. 35) and Stetter et al. (2020, p. 11).

Table 19
Recommendations on future research organised per theme, section and subsection.

Theme (subsection)	Recommendations for further research
4.1. Auctions: emergence, preconditions and use in a policy mix.	
4.1.1. Explaining the fast implementation of auctions.	Further research should focus on identifying the drivers of auction implementation around the world and in specific regions and whether these drivers are different across different countries.
4.1.2. Institutional preconditions for the use of auctions: institutional capacity and institutional arrangements.	More research on institutional capacities, resources and arrangements is needed. Analyses should be extended to other countries, and cross-country comparisons of commonalities and differences in institutional arrangements should be carried out. More analysis should be devoted to policy learning in auction design overtime, specially for auctions with a long history (e.g., Brazil). What design elements changed and why (i.e., as a result of the identification of perceived problems and/or political economy issues)?
4.1.3. Technological and market preconditions for the use of auctions.	Apart from analysing how auctions for less mature RES have worked, future research should also identify which design elements would be more appropriate in technology-specific auctions for these technologies and which other technology features would make them more suitable for the use of auctions and which wouldn't. For example, the dispatchability of CSP is not appropriately valued in price-only technology-neutral auctions (see del Río and Mir-Artigues, 2019). Further research should further investigate the functioning of off-grid auctions in countries where they have been implemented. More attention should be paid to subsidy free auctions (i.e., under what circumstances and for which technologies they would be most appropriate).
4.1.4. Auctions in the policy mix.	Policy mixes must be carefully designed so that each instrument is complementary to others. Further research should be devoted to the advantages and disadvantages of combining auctions with other deployment instruments (e.g., soft loans), i.e. adding auctions to a preexisting instrument and adding non-deployment policies to auctions. Which other policies lead to complementary or synergistic effects when combined with auctions? Which design elements in auctions mitigate the possible conflicts between auctions and other instruments?
4.1.5. Coordination of auction and other procedures.	Since auction procedures (and RES expansion more generally) need to be integrated with transmission expansion planning (Farrell et al., 2018) and the interconnection issue needs to be simultaneously considered in the auction process (Moon and Jung, 2020), how the coordination between the different procedures has been operationalised in the past and what policy actions need to be adopted to favour it should be the focus of future research.
4.2. Assessment of auctions according to goals and assessment criteria.	
4.2.1. Analysing the impact on specific criteria.	*Effectiveness.* Future research should be devoted to the analysis of ex-ante effectiveness by carrying out a worldwide analysis of its occurrence, also analyzing the factors (and DEs) that drive it, i.e. the factors discouraging potential bidders from participating in the auction. Such analysis would also allow identifying if effectiveness is different for different regions or countries (e.g., OECD vs. non-OECD). For example, Matthäus (2020) shows that auctions in OECD countries have been less effective. *Efficiency* Identifying the impact of auctions on total generation costs is a research effort worth undertaking in the future. The possible trade-offs between direct and indirect generation costs should be explored. How DEs can minimise the overall generation costs (direct + indirect) should be investigated. The contribution by Bichler et al. (2020) on combinatorial auctions to encourage system-optimal allocation of capacity is a very promising proposal in this regard. Given the limited samples in both Botta (2019) and Đukan and Kitzing (2021), future research is needed to quantify the impacts of auction designs on the costs of capital and financing, and to establish firm cause-effect relations (Đukan and Kitzing, 2021). Whether auction induces project developers to shift between different types of financing, and whether those decisions are more likely to occur in some types of countries compared to others should also be investigated, extending the analyses beyond Europe. Further research on administrative costs in auctions and their level with respect to ASFITs is welcome. *Dynamic efficiency* Further research on dynamic efficiency is needed. In particular, the statement from Grashof et al. (2020, p. 1) that "there is to date insufficient empirical analysis providing evidence in favour or against the general cost-cutting strength of auctions, partly due to methodological difficulties" still holds, suggesting an important avenue for future research. *Impact on innovation* Further research, at both the theoretical and empirical level, is needed to identify the determinants of innovation as influenced by auctions and auction design elements. The impact of auctions or auction DEs on the quality of the adopted equipment merits more attention. *Actor diversity and market concentration* Further research should delve into the circumstances under which auctions have a detrimental effect on the participation of small actors, including the DEs which encourage such participation. It should also analyse the trade-offs between promoting actor diversity and other assessment criteria. Further research should deepen our knowledge of the impact of market concentration on the outcome of the auctions with respect to different criteria. It should also focus on the manufacturing equipment stage, which has received limited attention compared to the project ownership and project development segments. *Local industry creation* Future research should pay attention to those DEs and the trade-offs of increasing local manufacturing capacity and other criteria.
4.2.2. Analysing the trade-offs between goals in auctions.	Future research should focus on the short-term vs. long-term effects of auctions. The existence and extent of trade-offs should be identified in a more systematic manner (i.e., through a review with an explicit focus on those trade-offs and through simulation models). In addition, the extent of the trade-offs may depend on the choice of design elements (see 4.2).
4.2.3. Underbidding.	Further research should respond three main questions: 1) Has there really been underbidding?; 2) How can underbidding be mitigated through a better design without severely affecting the efficiency of the support scheme?; 3) What has been its consequences on effectiveness and other criteria?
4.2.4. Effects on social acceptability.	Further research could delve into how DEs can increase social acceptability, the trade-offs between increasing social acceptability and other goals and criteria and how this trade-off can be mitigated through an appropriate auction design. In addition, research on facilitating local involvement in the auction process, in order to increase the local and social acceptability of the scheme and renewables more broadly, is recommendable.
4.2.5. Interactions/ interrelation of auctions with the just energy transition (JET).	Auctions could be designed to mitigate the impact of auctions and the JET on acceptance and, particularly, to enhance the local acceptability of RES projects, for example by including compensations to local neighborhoods where projects are located and by favouring spatial dispersion. Also, a locational signal may be provided in RES auctions to encourage the uptake of RES projects in regions affected by the closure of the fossil fuel plants that the JET involves. Further research could focus on other issues: auctions in policy mixes, auction design and trade-offs. First, as a key policy to encourage the uptake of RES, it should analyse how auctions could contribute to the JET, complementing other policies. Second, designing auctions with explicit considerations of justice and fairness can contribute to

(*continued on next page*)

Table 19 (*continued*)

Theme (subsection)	Recommendations for further research
	speed up the energy transition and make it more ambitious. Therefore, it should identify DEs which could be adopted and have been adopted to enhance JET concerns and, particularly, social acceptability in the location of RES projects. Research on the design of auctions and their performance in countries (particularly those in Europe) which have explicitly included social acceptability considerations in their auctions should be undertaken. Third, the possible trade-offs of the inclusion of DEs which address the "just" part of the JET with other goals and criteria, including effectiveness and minimisation of support costs, should be assessed.
4.3. Focus on design elements.	
4.3.1. Impacts of design elements.	Some DEs deserve more attention in future research: *Multicriteria auctions*. How should they be properly designed? (methodological and empirical research). *Pricing rule (PAB vs. UP)* Future analysis should focus on an extension of the models to other situations. This is challenging since "it is impossible to derive a theoretical comparison between PAB and UP outcomes in terms of multi-unit, repeated auctions" (Welisch and Kreiss, 2019, p. 26) because, theoretically, both pricing rules are inefficient in the case where bidders can supply multiple units. More generally, further research should investigate the consequences when moving from single-unit, single project bidders, one-off auctions to multi-unit, multi-round auctions and multi-project bidders (e.g., Kreiss et al., 2017 extend their analysis from single-item to multi-item auctions). Further research on the impact of the pricing rule on support costs and irrational bidding is needed. In particular, future investigations should provide more empirical insights on the reasons for irrational bidding under UP (and the extent to which this is also the case in PAB). *Local content requirements (LCRs)* Further systematic research to analyse the success of LCRs in encouraging local industries and their negative impact on bid prices is needed. The thin evidence on the impact of LCRs on effectiveness calls for future research on the topic. The existence and extent of possible trade-offs should also be further investigated. Hansen et al. (2020) and Probst et al. (2020) propose several avenues for future research, such as including other influential factors (exchange rate fluctuations, changing financing conditions, levels of poverty and inequality, customs procedures, corruption, and the protection of intellectual property rights), devoting more attention to the importance of the level of institutional capacity in the involved government agencies to design and implement LCR systems, analysing how the determining factors in the framework operate at the microlevel (through in-depth research at the firm level), focusing on non-manufacturing sectors (services), expanding the geographical coverage beyond the aforementioned countries and analysing long-term effects. *Transferability of rights* Future research should explore why the transferability of rights has not been used much, despite its potential benefits in terms of effectiveness. In addition, more formal analyses on this topic (e.g., with ABM simulations) are highly welcome.
4.3.2. What is the motivation behind the choice of DE?	Further research should analyse the incentives and rationale driving the auction design choices made by policymakers (Münch and Marian, 2022), how different stated policy goals translate into different DE choices and the other way around, i.e., what the choice of a given set of DEs tells us about the real policy goals of governments and the influence of pressure groups. Future research should pay attention to how context conditions influence auction design directly and indirectly (through their impact on goals) and how these conditions have affected the design in given countries.

Table 19 (*continued*)

Theme (subsection)	Recommendations for further research
4.3.3. Challenges in auction design and in research on auction design.	*The level of design elements.* Future research should be devoted to the analysis of the impact of the levels of DEs on given assessment criteria, i.e., whether there are linearities, threshold effects etc … *Marginal analysis of trade-offs.* Further research on the trade-offs and no-regret DEs is welcome. How does a given DE improve one criterion at the expense of worsening another? Are there no regrets DEs (that is, DEs which improve one criterion without worsening another)? *Have auctions been designed differently for different technologies/applications?* Further research should focus on how auctions have been designed differently in the past for different technologies/applications. *The difficult transferability of results on auction design.* As argued by Matthaus (2020, p.6), "future research could disassemble country categories into single factors-such as regulatory quality, political stability, and amount of foreign direct investment-and study interactions with auction design". After understanding the underlying mechanisms of renewable energy auctions, auction design should be tailored to the specific circumstances in each country. *The micro-level in the analysis of the impact DE on specific firms.* More micro-level analysis of the impact DE on specific firms is welcome. In particular, referring to further research on LCRs, Hansen et al. (2020) mention that this could benefit from analysing how individual companies respond to the LCRs from a management perspective (Hansen et al., 2020, p. 10). *Interactions/interrelations/interlinkages/interdependencies between different DEs.* Future investigations should be dedicated to assess which packages of DE choices are best from a given assessment criterion point of view, and which DEs minimise the level of trade-offs between the different assessment criteria. This would help governments decide which DEs they should choose if a given criterion is prioritised over others.
4.3.4. The limits of design: consideration of other policy and non-policy factors.	More studies are needed, particularly econometric ones, on the influence of DEs on key assessment criteria (efficiency and effectiveness) with respect to the external factors.
4.4. Focus on data and methods	
4.4.1. Data availability.	It would be desirable to have consistent data on single awarded projects, for example for a more complete assessment of the determinants of deployment effectiveness (Cassetta et al., 2017). Liñeiro and Müsgens (2021) show that such data can be obtained by merging different databases.
4.4.2. Difficulties in measuring success.	Rigour in the assessment of auction on efficiency is required. More elaborated metrics and counterfactuals are needed.
4.4.3. Methods: beyond qualitative case studies	Although mixed methods are not without challenges (such as "the identification of the quantitative results to further explore and the choice of the appropriate sample size for each phase" (Grashof, 2019, p. 24)), they may be an interesting methodological approach to follow in the future analyses of RES auctions.
4.4.4. Econometric modeling.	Measurement of DEs in levels, not as dummies, should be done in the future to account for DE intensity (see 4.3). Furthermore, including dummies for the DEs may lead to potential multicollinearity problems (e.g., between material and financial prequalifications). As mentioned in 4.4.2, a critical problem in econometric studies, especially when comparing auctions to ASFITs, is the absence of a counterfactual.
4.4.5. Agent-based modelling (ABM)	Further research should try to extend the models by adding several issues mentioned in 4.4.5. For example, Anatolitis and Welisch (2017, p. 402) propose to improve the agents' utility functions by implementing more parameters (e.g. predicted electricity prices or the location and wind speed of a project), agents' reaction to disruptive changes in the

(*continued on next page*)

Table 19 (*continued*)

Theme (subsection)	Recommendations for further research
	market environment and the outcomes of auction experiments aiming to better approximate human behavior in the tendering process.
4.4.6. Other potentially useful methodologies for future studies.	Consider the use of several methodologies in future research, including multicriteria decision-making models, experimental approaches (conjoint analysis) and choice experiments (see also 4.4.6).
4.4.7. More focus on bidders.	A greater focus on the bidders' level in future auction research would be useful in order to identify the impact of auctions and auction design on bidders in general and on particular types of bidders, fine-tuning auction design to facilitate the participation of a wide diversity of bidders. More research in this context would also respond to the need for practical assistance for project developers in bid price quantification (Stetter et al., 2020). Two specific recommendations for future research can be provided: 1) some of the initial models were relatively simple, but did not include basic elements of bidders strategies in auctions. This has improved in more recent models and further efforts should be made to mimic the real-world elements faced by bidders when participating in RES auctions. This would be particularly beneficial to those bidders, as useful information would be provided to facilitate such participation; 2) Since bidders may not be so rational (Grashof, 2019; Lundberg, 2019), non-rational bidding should be included, which allows to explain some types of underbidding. Including non-rational bidding in bidders' models is a difficult task, as auction theory itself is based on the assumption of rational actors. Could models deviate somehow from the assumption of bidder rationality? How would the introduction of non-rational bidders, or at least boundedly rational bidders, change the results? What would be the consequences for auction design? Future research should try to answer these questions.

Source: Own elaboration

at least in leading European countries: social acceptability. The contribution of non-economic disciplines, including sociology and political science will be much needed in this regard. However, within the economics discipline, the research has been quite diverse in the use of different economic approaches. In addition, the focus has strongly been on non-dispatchable technologies (solar PV and wind), on a pair with their impressive cost reductions and deployment worldwide. However, dispatchable RETs will also be needed in order to decarbonize electricity systems, contributing to the flexibility and manageability of electricity systems. More research effort will be needed, especially at the empirical level, to identify how auctions will need to be designed to encourage the uptake of those RETs. Which specific elements of institutional capacity are particularly beneficial and which institutional arrangements are needed to favour the successful implementation of auctions is a policy-relevant topic worth addressing. Further research should also delve into how auctions and other procedures (administrative permitting and grid access) should be coordinated to avoid delays in building the projects. Furthermore, how auctions can contribute to the overall performance of instrument mixes, how other instruments can improve the performance of auctions in those mixes and how auction design could balance and mitigate the conflicts between auctions and other instruments in the policy mix are clearly policy-relevant research gaps.

At a thematic level, the trade-offs between different criteria should be the focus of more rigorous and quantitative marginal analysis, identifying the extent to which improving a given criterion worsens another, and how design elements may mitigate those trade-offs, achieving a good balance between the assessment criteria. Further research should also pay more attention to underbidding: its real-world existence, its consequences and causes, particularly those related to auction design. The implications of the JET for the performance of auctions and auction design is also a policy-relevant topic. How the ambition in RES deployment required by the JET will impact social acceptability and competition in auctions through potentially high auction volumes and how these detrimental effects can be mitigated with other policies and innovative auction designs are research questions worth answering. Multicriteria auctions can play a relevant role in this context since they include non-price elements, but they require careful design in order not to spoil the positive price features of the instrument. Other gaps in the analysis of design elements (such as the consequences of the transferability of project building rights) will need to be addressed.

Also regarding design, key research questions refer to the marginal impact of the level of design elements i.e., to which extent a change in their level affects different assessment criteria and whether "no-regret" design elements exist, what interactions between choices in different design element categories can be expected with respect to specific criteria and what "design element packages" can be recommended if governments prioritise a given criterion over others. A greater focus on the micro-level (i.e., on bidders) and on the firm-level features and factors (including those related to company management and strategy) which are likely to influence the impact of design elements in particular companies is recommendable, as well as more research on the relative importance of auction design with respect to other elements, i.e., external factors and non-auction policies and instruments, in the assessment of the success of auctions.

At a methodological level, the era of assessments of auctions with case studies is not over, but it should coexist with more quantitative studies on the topic, using a wide range of methodologies. However, some methodological difficulties remain in the comparative assessment of auctions, particularly with respect to efficiency (both static and dynamic). In addition, the transferability of lessons on the functioning of design elements from one context to another is likely to be limited. This provides a note of caution to simply take design elements which have worked well in given contexts and adopt them in other contexts. However, we should not fall into pure relativism: what has not worked somewhere else may not work in another setting unless an appropriate adaptation of design elements to the local context conditions is made (which requires a previous analysis of those conditions).

Finally, addressing this policy relevant topic, and particularly how to improve auction design, requires good research. And good research requires good data. We make a plea to national governments and international institutions to facilitate the access to auction data.

As any other study, this one has two main limitations. First, only academic papers have been included, excluding policy reports which make up an important share of the auction design literature (Haelg, 2020, p. 2). Second, a limitation of our research may be related to the method used (a systematic review). Systematic reviews are the gold standard in literature reviews (only behind meta-analyses) according to Sovacool et al. (2018) and "reviews should never be done in any other way (Khan et al., 2003, p. 118). Although systematic reviews provide a strict and robust literature review protocol, which is likely to minimise the subjectivity in carrying out such reviews, subjectivity cannot be ruled out.

CRediT authorship contribution statement

Pablo del Río: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Christoph P. Kiefer:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data are provided in the supplementary material (Supplementary material 1 and Supplementary material 2)

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2022.113305.

References

Afshar, K., Ghiasvand, F.S., Bigdeli, N., 2018. Optimal bidding strategy of wind power producers in pay-as-bid power markets. Renew. Energy 127, 575–586.

Agnolucci, P., 2007. The importance and the policy impacts of post-contractual opportunism and competition in the English and Welsh non-fossil fuel obligation. Energy Pol. 35 (1), 475–486.

Álvarez, F., del Río, P., 2022. Is small always beautiful? Analyzing the efficiency effects of size heterogeneity in renewable electricity auctions. Energy Econ. 106 https://doi.org/10.1016/j.eneco.2021.105698.

Anatolitis, V., Welisch, M., 2017. Putting renewable energy auctions into action – an agent-based model of onshore wind power auctions in Germany. Energy Pol. 110, 394–402. https://doi.org/10.1016/j.enpol.2017.08.024.

Aquila, G., de Queiroz, A.R., Junior, P.R., Rocha, L.C.S., de Oliveira Pamplona, E., Balestrassi, P.P., 2020. Contribution for bidding of wind-photovoltaic on grid farms based on NBI-EFA-SNR method. Sustain. Energy Technol. Assessments 40, 100754.

Arowolo, W., 2019. Designing reverse auctions for solar power as a potential energy access solution for the Nigeria power sector. Electr. J. 32 (8), 106635.

Ausubel, L.M., Cramton, P., Pycia, M., Rostek, M., Weretka, M., 2014. Demand reduction and inefficiency in multi-unit auctions. Rev. Econ. Stud. 81 (4), 1366–1400.

Azuela, G.E., Barroso, L., Khanna, A., Wang, X., Wu, Y., Cunha, G., 2014. Performance of Renewable Energy Auctions: Experience in Brazil. The World Bank, China and India.

Balfour, J., 2017. The race to the bottom - accelerating PV insolvency. Renew. Energy World. Retrieved from. https://www.renewableenergyworld.com/solar/the-race-to-the-bottom-accelerating-pv-insolvency/.

Bayer, B., 2018. Experience with auctions for wind power in Brazil. Renew. Sustain. Energy Rev. 81, 2644–2658. https://doi.org/10.1016/j.rser.2017.06.070.

Bayer, B., Schäuble, D., Ferrari, M., 2018. International experiences with tender procedures for renewable energy – a comparison of current developments in Brazil, France, Italy and South Africa. Renew. Sustain. Energy Rev. 95, 305–327. https://doi.org/10.1016/j.rser.2018.06.066.

Beiter, P., Kitzing, L., Spitsen, P., Noonan, M., Berkhout, V., Kikuchi, Y., 2021. Toward global comparability in renewable energy procurement. Joule 5 (6), 1485–1500. https://doi.org/10.1016/j.joule.2021.04.017.

Bento, N., Borello, M., Gianfrate, G., 2020. Market-pull policies to promote renewable energy: a quantitative assessment of tendering implementation. J. Clean. Prod. 248, 119209.

Bichler, M., Grimm, V., Kretschmer, S., Sutterer, P., 2020. Market design for renewable energy auctions: an analysis of alternative auction formats. Energy Econ. 92, 104904.

Borg, I., Groenen, P.J., 2005. Modern Multidimensional Scaling: Theory and Applications. Springer Science & Business Media.

Börner, K., Chen, C., Boyack, K.W., 2003. Visualizing knowledge domains. Annu. Rev. Inf. Sci. Technol. 37 (1), 179–255.

Bose, A.S., Sarkar, S., 2019. India's e-reverse auctions (2017–2018) for allocating renewable energy capacity: an evaluation. Renew. Sustain. Energy Rev. 112, 762–774. https://doi.org/10.1016/j.rser.2019.06.025.

Botta, E., 2019. An experimental approach to climate finance: the impact of auction design and policy uncertainty on renewable energy equity costs in Europe. Energy Pol. 133, 110839.

Breitschopf, B., Held, A., 2013. Guidelines for assessing costs and benefits of RET deployment. Report in the framework of the EU-funded DIACORE project. Retrieved from. http://diacore.eu/.

Buckman, G., Sibley, J., Bourne, R., 2014. The large-scale solar feed-in tariff reverse auction in the Australian Capital Territory, Australia. Energy Pol. 72, 14–22. https://doi.org/10.1016/j.enpol.2014.04.007.

Buckman, G., Sibley, J., Ward, M., 2019. The large-scale feed-in tariff reverse auction scheme in the Australian Capital Territory 2012, to 2016. Renew. Energy 132, 176–185. https://doi.org/10.1016/j.renene.2018.08.011.

Butler, L., Neuhoff, K., 2008. Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. Renew. Energy 33 (8), 1854–1867. https://doi.org/10.1016/j.renene.2007.10.008.

Cassetta, E., Monarca, U., Nava, C.R., Meleo, L., 2017. Is the answer blowin' in the wind (auctions)? An assessment of the Italian support scheme. Energy Pol. 110, 662–674. https://doi.org/10.1016/j.enpol.2017.08.055.

CEER, 2018. Tendering procedures for RES in Europe: state of play and first lessons learnt. CEER Public Document. Retrieved from. https://www.ceer.eu/documents/104400/-/-/167af87c-5472-230b-4a19-f68042d58ea8.

Cerdá, E., del Río, P., 2015. Different interpretations of the cost-effectiveness of renewable electricity support: some analytical results. Energy 90, 286–298.

Che, Y.-K., 1993. Design competition through multidimensional auctions. Rand J. Econ. 668–680.

Cheng, Q., Luo, P., Liu, P., Li, X., Ming, B., Huang, K., Gong, Y., 2022. Stochastic short-term scheduling of a wind-solar-hydro complementary system considering both the day-ahead market bidding and bilateral contracts decomposition. Int. J. Electr. Power Energy Syst. 138, 107904.

Chistov, V., Aramburu, N., Carrillo-Hermosilla, J., 2021. Open eco-innovation: a bibliometric review of emerging research. J. Clean. Prod. 311 https://doi.org/10.1016/j.jclepro.2021.127627.

Ciaccia, G., Doni, N., Fontini, F., 2010. Auctioning wind power sites when environmental quality matters. Energy Pol. 38 (4), 1734–1740.

Cocchi, G., Galli, L., Galvan, G., Sciandrone, M., Cantù, M., Tomaselli, G., 2018. Machine learning methods for short-term bid forecasting in the renewable energy market: a case study in Italy. Wind Energy 21 (5), 357–371.

Cohen, M.A., Tubb, A., 2018. The impact of environmental regulation on firm and country competitiveness: a meta-analysis of the porter hypothesis. J. Assoc. Environ. Resourc. Econ. 5 (2), 371–399.

Côté, E., Đukan, M., Pons-Seres de Brauwer, C., Wüstenhagen, R., 2022. The price of actor diversity: measuring project developers' willingness to accept risks in renewable energy auctions. Energy Pol. 163 https://doi.org/10.1016/j.enpol.2022.112835.

Croonenbroeck, C., Hennecke, D., 2020. Does the German renewable energy act provide a fair incentive system for onshore wind power?—a simulation analysis. Energy Pol. 144, 111663.

del Río, P., 2014. On evaluating success in complex policy mixes: the case of renewable energy support schemes. Pol. Sci. 47 (3), 267–287.

del Río, P., 2017. Designing auctions for renewable electricity support. Best practices from around the world. Energy Sustain. Dev. 41, 1–13. https://doi.org/10.1016/j.esd.2017.05.006.

del Río, P., 2020. Tendencias internacionales en el diseño apropiado de subastas para renovables. Funseam. Retrieved from. https://funseam.com/wp-content/uploads/2020/10/082020_InformeFunseamDisenoApropiadodeSubastasparaRenovables.pdf.

del Río, P., Kiefer, C.P., 2021. Analysing patterns and trends in auctions for renewable electricity. Energy Sustain. Dev. 62, 195–213. https://doi.org/10.1016/j.esd.2021.03.002.

del Río, P., Kiefer, C.P., 2022. Which policy instruments promote innovation in renewable electricity technologies? A critical review of the literature with a focus on auctions. Energy Res. Social Sci. 89 https://doi.org/10.1016/j.erss.2022.102501.

del Río, P., Kiefer, C.P., Menzies, C., Marquardt, M., Fitch-Roy, O., Woodman, B., 2020. Effects of Auctions on RES Value Chains. Deliverable 4.1 of the EU-Funded AURES II Project. CSIC, Madrid. Retrieved from. http://aures2project.eu/wp-content/uploads/2020/10/AURES_II_D4_1_effects_value_chain_upt.pdf.

del Río, P., Linares, P., 2014. Back to the future? Rethinking auctions for renewable electricity support. Renew. Sustain. Energy Rev. 35, 42–56. https://doi.org/10.1016/j.rser.2014.03.039.

del Río, P., Mir-Artigues, P., 2012. Support for solar PV deployment in Spain: some policy lessons. Renew. Sustain. Energy Rev. 16 (8), 5557–5566.

del Río, P., Mir-Artigues, P., 2019. Designing auctions for concentrating solar power. Energy Sustain. Dev. 48, 67–81. https://doi.org/10.1016/j.esd.2018.10.005.

Dobrotkova, Z., Surana, K., Audinet, P., 2018. The price of solar energy: comparing competitive auctions for utility-scale solar PV in developing countries. Energy Pol. 118, 133–148. https://doi.org/10.1016/j.enpol.2018.03.036.

Đukan, M., Kitzing, L., 2021. The impact of auctions on financing conditions and cost of capital for wind energy projects. Energy Pol. 152 https://doi.org/10.1016/j.enpol.2021.112197.

Eberhard, A., Kåberger, T., 2016. Renewable energy auctions in South Africa outshine feed-in tariffs. Energy Sci. Eng. 4 (3), 190–193. https://doi.org/10.1002/ese3.118.

Eberhard, A., Naude, R., 2016. The South African renewable energy independent power producer procurement programme: a review and lessons learned. J. Energy South Afr. 27 (4) https://doi.org/10.17159/2413-3051/2016/v27i4a1483.

Eisenhardt, K.M., 1989. Building theories from case study research. Acad. Manag. Rev. 14 (4), 532–550.

Endemaño-Ventura, L., González, J.S., Fernández, J.M.R., Payán, M.B., Santos, J.M.R., 2021. Optimal energy bidding for renewable plants: a practical application to an actual wind farm in Spain. Renew. Energy 175, 1111–1126.

European Commission, 2015. Communication from the COMMISSION to the EUROPEAN PARLIAMENT, the COUNCIL, the EUROPEAN ECONOMIC and SOCIAL COMMITTEE, the COMMITTEE of the REGIONS and the EUROPEAN INVESTMENT BANK. A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. Retrieved from. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2015:80. FIN.

Fang, Y., Zhao, S., 2020. Look-ahead bidding strategy for concentrating solar power plants with wind farms. Energy 203, 117895.

Farrell, N., Devine, M.T., Soroudi, A., 2018. An auction framework to integrate dynamic transmission expansion planning and pay-as-bid wind connection auctions. Appl. Energy 228, 2462–2477.

Fitch-Roy, O.W., Benson, D., Woodman, B., 2019. Policy instrument supply and demand: how the renewable electricity auction took over the world. Polit. Govern. 7 (1), 81–91. https://doi.org/10.17645/pag.v7i1.1581.

Frisari, G., Stadelmann, M., 2015. De-risking concentrated solar power in emerging markets: the role of policies and international finance institutions. Energy Pol. 82, 12–22. https://doi.org/10.1016/j.enpol.2015.02.011.

Gephart, M., Klessmann, C., Wigand, F., 2017. Renewable energy auctions–When are they (cost-) effective? Energy Environ. 28 (1-2), 145–165.

Grashof, K., 2019. Are auctions likely to deter community wind projects? And would this be problematic? Energy Pol. 125, 20–32. https://doi.org/10.1016/j.enpol.2018.10.010.

Grashof, K., 2021. Who put the hammer in the toolbox? Explaining the emergence of renewable energy auctions as a globally dominant policy instrument. Energy Res. Social Sci. 73 https://doi.org/10.1016/j.erss.2021.101917.
Grashof, K., Berkhout, V., Cernusko, R., Pfennig, M., 2020. Long on promises, short on delivery? Insights from the first two years of onshore wind auctions in Germany. Energy Pol. 140 https://doi.org/10.1016/j.enpol.2020.111240.
Grubb, M., Drummond, P., Poncia, A., McDowall, W., Popp, D., Samadi, S., Pavan, G., 2021. Induced innovation in energy technologies and systems: a review of evidence and potential implications for CO2 mitigation. Environ. Res. Lett. 16 (4) https://doi.org/10.1088/1748-9326/abde07.
Haelg, L., 2020. Promoting technological diversity: how renewable energy auction designs influence policy outcomes. Energy Res. Social Sci. 69 https://doi.org/10.1016/j.erss.2020.101636.
Hansen, U.E., Nygaard, I., Morris, M., Robbins, G., 2020. The effects of local content requirements in auction schemes for renewable energy in developing countries: a literature review. Renew. Sustain. Energy Rev. 127 https://doi.org/10.1016/j.rser.2020.109843.
Haufe, M.-C., Ehrhart, K.-M., 2018. Auctions for renewable energy support – suitability, design, and first lessons learned. Energy Pol. 121, 217–224. https://doi.org/10.1016/j.enpol.2018.06.027.
Heydari, A., Memarzadeh, G., Astiaso Garcia, D., Keynia, F., De Santoli, L., 2021. Interval prediction algorithm and optimal scenario making model for wind power producers bidding strategy. Optim. Eng. 22 (3), 1807–1829.
Huang, Y., 2019. An empirical study of scoring auctions and quality manipulation corruption. Eur. Econ. Rev. 120, 103322.
Huber, C., Ryan, L., Gallachóir, B.Ó., Resch, G., Polaski, K., Bazilian, M., 2007. Economic modelling of price support mechanisms for renewable energy: case study on Ireland. Energy Pol. 35 (2), 1172–1185.
IRENA, 2013. Renewable energy auctions in developing countries. Retrieved from. https://www.irena.org/documentdownloads/publications/irena_renewable_energy_auctions_in_developing_countries.pdf.
IRENA, 2015. Renewable energy auctions: a guide to design. Abu Dhabi, United Arab Emirates. Retrieved from. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/Jun/IRENA_Renewable_Energy_Auctions_A_Guide_to_Design_2015.pdf.
IRENA, 2017. Renewable energy auctions : analysing 2016 (9789295111080). Abu Dhabi. Retrieved from. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Jun/IRENA_Renewable_Energy_Auctions_2017.pdf.
IRENA, 2019a. Global Energy Transformation. A Roadmap to 2050. IRENA, Abu Dhabi. Retrieved from. https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition.
IRENA, 2019b. Renewable Energy Auctions: Status and Trends beyond Price. International Renewable Energy Agency, Abu Dhabi. Retrieved from. https://www.irena.org/publications/2019/Dec/Renewable-energy-auctions-Status-and-trends-beyond-price.
IRENA, 2021. IRENA statistics. Retrieved from. https://www.irena.org/Statistics/Download-Data.
Jacobs, D., Grashof, K., del Río, P., Fouquet, D., 2020. The Case for a Wider Energy Policy Mix in Line with the Objectives of the Paris Agreement. Shortcomings of Renewable Energy Auctions Based on World-wide Empirical Observations. Energy Watch Group, World Future Council/Global Renewables Congress and Haleakala Stiftung. Retrieved from. https://www.renewablescongress.org/2020/12/study-on-re-auctions-the-case-for-a-wider-energy-policy-mix-in-line-with-the-objectives-of-the-paris-agreement/.
Kácsor, E., 2021. Modelling bidding behaviour on German photovoltaic auctions. Energies 14 (2), 516.
Khaloie, H., Abdollahi, A., Shafie-Khah, M., Siano, P., Nojavan, S., Anvari-Moghaddam, A., Catalão, J.P., 2020. Co-optimized bidding strategy of an integrated wind-thermal-photovoltaic system in deregulated electricity market under uncertainties. J. Clean. Prod. 242, 118434.
Khan, K.S., Kunz, R., Kleijnen, J., Antes, G., 2003. Five steps to conducting a systematic review. J. R. Soc. Med. 96 (3), 118–121.
Khana, A., Barroso, L., 2014. Promoting Renewable Energy through Auctions: the Case of India. The World Bank. Retrieved from. https://olc.worldbank.org/content/promoting-renewable-energy-through-auctions-case-india.
Khojasteh, M., Faria, P., Vale, Z., 2022. A robust model for aggregated bidding of energy storages and wind resources in the joint energy and reserve markets. Energy 238, 121735.
Kitzing, L., Anatolitis, V., Fitch-Roy, O., Klessmann, C., Kreiß, J., Río, F.W., Woodman, B., 2019. Auctions for renewable energy support: lessons learned in the AURES project. In: IAEE Energy Forum. Paper presented at the.
Klavans, R., Boyack, K.W., 2006. Quantitative evaluation of large maps of science. Scientometrics 68 (3), 475–499.
Kreiss, J., 2019. Challenges in designing technology-neutral auctions for renewable energy support. Paper presented at the. In: Transforming Energy Markets, 41st IAEE International Conference. Jun 10-13, 2018.
Kreiss, J., Ehrhart, K.-M., Haufe, M.-C., 2017. Appropriate design of auctions for renewable energy support – prequalifications and penalties. Energy Pol. 101, 512–520. https://doi.org/10.1016/j.enpol.2016.11.007.
Kreiss, J., Ehrhart, K.-M., Haufe, M.-C., Soysal, E.R., 2021. Different cost perspectives for renewable energy support: assessment of technology-neutral and discriminatory auctions. Econ. Energy Environ. Pol. 10 (1).
Kruger, W., Eberhard, A., 2018. Renewable energy auctions in sub-Saharan Africa: comparing the South African, Ugandan, and Zambian programs. Wiley Interdisciplin. Rev.: Energy Environ. 7 (4) https://doi.org/10.1002/wene.295.
Kruger, W., Nygaard, I., Kitzing, L., 2021. Counteracting market concentration in renewable energy auctions: lessons learned from South Africa. Energy Pol. 148, 111995.
Kruger, W., Stritzke, S., Trotter, P.A., 2019. De-risking solar auctions in sub-Saharan Africa – a comparison of site selection strategies in South Africa and Zambia. Renew. Sustain. Energy Rev. 104, 429–438. https://doi.org/10.1016/j.rser.2019.01.041.
Kumar Kar, S., Harichandan, S., 2022. Green marketing innovation and sustainable consumption: a bibliometric analysis. J. Clean. Prod. 361 https://doi.org/10.1016/j.jclepro.2022.132290.
Kwon, T.-h., 2018. Policy synergy or conflict for renewable energy support: case of RPS and auction in South Korea. Energy Pol. 123, 443–449.
Kwon, T.-h., 2020. Policy mix of renewable portfolio standards, feed-in tariffs, and auctions in South Korea: are three better than one? Util. Pol. 64, 101056.
Kylili, A., Fokaides, P.A., 2015. Competitive auction mechanisms for the promotion renewable energy technologies: the case of the 50 MW photovoltaics projects in Cyprus. Renew. Sustain. Energy Rev. 42, 226–233.
Laali, A., Benard, M., 1999. French wind power generation programme EOLE 2005 results of the first call for tenders. Renew. Energy 16 (1-4), 805–810.
Lackner, M., Koller, S., Camuzeaux, J.R., 2020. Policy brief—using lessons from reverse auctions for renewables to deliver energy storage capacity: guidance for policymakers. Rev. Environ. Econ. Pol.
Laia, R., Pousinho, H., Melíco, R., Mendes, V., 2016. Bidding strategy of wind-thermal energy producers. Renew. Energy 99, 673–681.
Leiren, M.D., Reimer, I., 2018. Historical institutionalist perspective on the shift from feed-in tariffs towards auctioning in German renewable energy policy. Energy Res. Social Sci. 43, 33–40. https://doi.org/10.1016/j.erss.2018.05.022.
Liñeiro, T.B., Müsgens, F., 2021. Evaluating the German PV auction program: the secrets of individual bids revealed. Energy Pol. 159, 112618.
Lucas, H., del Río, P., Cabeza, L.F., 2020. Stand-alone renewable energy auctions: the case of Peru. Energy Sustain. Dev. 55, 151–160. https://doi.org/10.1016/j.esd.2020.01.009.
Lucas, H., del Río, P., Sokona, M.Y., 2017. Design and assessment of renewable electricity auctions in sub-saharan Africa. IDS Bull. 48 (5-6).
Lundberg, L., 2019. Auctions for all? Reviewing the German wind power auctions in 2017. Energy Pol. 128, 449–458. https://doi.org/10.1016/j.enpol.2019.01.024.
Martín, H., Coronas, S., Alonso, À., de la Hoz, J., Matas, J., 2020. Renewable energy auction prices: near subsidy-free? Energies 13 (13), 3383.
Matsuo, T., Schmidt, T.S., 2019. Managing tradeoffs in green industrial policies: the role of renewable energy policy design. World Dev. 122, 11–26. https://doi.org/10.1016/j.worlddev.2019.05.005.
Matthäus, D., 2020. Designing effective auctions for renewable energy support. Energy Pol. 142 https://doi.org/10.1016/j.enpol.2020.111462.
Matthäus, D., Schwenen, S., Wozabal, D., 2021. Renewable auctions: bidding for real options. Eur. J. Oper. Res. 291 (3), 1091–1105.
Maurer, L., Barroso, L., 2011. Electricity Auctions: an Overview of Efficient Practices. The World Bank, Washington. Retrieved from. http://documents.worldbank.org/curated/en/114141468265789259/pdf/638750PUB0Exto00Box0361531B0PUBLIC0.pdf.
Mitchell, C., 1995. The renewables NFFO: a review. Energy Pol. 23 (12), 1077–1091.
Mitchell, C., Connor, P., 2004. Renewable energy policy in the UK 1990–2003. Energy Pol. 32 (17), 1935–1947. https://doi.org/10.1016/j.enpol.2004.03.016.
Moon, J., Jung, T.Y., 2020. A critical review of Korea's long-term contract for renewable energy auctions: the relationship between the import price of liquefied natural gas and system marginal price. Util. Pol. 67, 101132.
Mora, D., Kitzing, L., Rosenlund, E., Steinhilber, S., del Río, P., Wigand, F., Woodman, B., 2017. Auctions for renewable energy support - taming the beast of competitive bidding. Final report of the EU-funded AURES project. Retrieved from. http://aures2project.eu/2021/07/06/auctions-for-renewable-energy-support-taming-the-beast-of-competitive-bidding/.
Müller, F., Claar, S., 2021. Auctioning a 'just energy transition'? South Africa's renewable energy procurement programme and its implications for transition strategies. Rev. Afr. Polit. Econ. 48 (169), 333–351. https://doi.org/10.1080/03056244.2021.1932790.
Münch, F.A., Marian, A., 2022. The design of technical requirements in public solar auctions: evidence from India. Renew. Sustain. Energy Rev. 154, 111713.
Nasirov, S., Cruz, E., Agostini, C.A., Silva, C., 2019. Policy makers' perspectives on the expansion of renewable energy sources in Chile's electricity auctions. Energies 12.
Ozcan, M., 2021. Renewable energy auctions in Turkey: auction design based on stakeholder opinions. Renew. Energy 169, 473–484.
Peñasco, C., Anadón, L.D., Verdolini, E., 2021. Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments. Nat. Clim. Change 11 (3), 257–265.
Probst, B., Anatolitis, V., Kontoleon, A., Anadón, L.D., 2020. The short-term costs of local content requirements in the Indian solar auctions. Nat. Energy 5 (11), 842–850.
Pullin, A., Frampton, G.K., Livoreli, B., Petrokofsky, G., 2018. Guidelines for authors environmental evidence. Retrieved from. www.environmentalevidence.org/information-for-authors.
Rayati, M., Sheikhi, A., Ranjbar, A.M., 2019. Optimal contract design for purchasing from frequency regulation service providers with private information. IEEE Trans. Power Syst. 34 (3), 2445–2448.
REN21, 2022. Renewables global status report. REN21 Secretariat. Paris. Retrieved from. https://www.ren21.net/wp-content/uploads/2019/05/GSR2022_Full_Report.pdf.
Rogge, K., Reichardt, K., 2015. Going beyond Instrument Interactions: towards a More Comprehensive Policy Mix Conceptualization for Environmental Technological Change. SPRU Working Paper Series. University of Sussex. Retrieved from.

Shrimali, G., Konda, C., Farooquee, A.A., 2016. Designing renewable energy auctions for India: managing risks to maximize deployment and cost-effectiveness. Renew. Energy 97, 656–670. https://doi.org/10.1016/j.renene.2016.05.079.
Singh, S., Fozdar, M., Malik, H., Khan, I.A., Al Otaibi, S., Albogamy, F.R., 2021. Impacts of renewable sources of energy on bid modeling strategy in an emerging electricity market using oppositional gravitational search algorithm. Energies 14 (18), 5726.
Sirin, S.M., Sevindik, I., 2021. An analysis of Turkey's solar PV auction scheme: what can Turkey learn from Brazil and South Africa? Energy Pol. 148, 111933.
Smeets, N., 2017. Similar goals, divergent motives. The enabling and constraining factors of Russia's capacity-based renewable energy support scheme. Energy Pol. 101, 138–149. https://doi.org/10.1016/j.enpol.2016.11.037.
Sovacool, B.K., Axsen, J., Sorrell, S., 2018. Promoting novelty, rigor, and style in energy social science: towards codes of practice for appropriate methods and research design. Energy Res. Social Sci. 45, 12–42. https://doi.org/10.1016/j.erss.2018.07.007.
Stetter, C., Piel, J.-H., Hamann, J.F., Breitner, M.H., 2020. Competitive and risk-adequate auction bids for onshore wind projects in Germany. Energy Econ. 90, 104849.
Tews, K., 2018. The crash of a policy pilot to legally define community energy. Evidence from the German auction scheme. Sustainability 10 (10), 3397.
Toke, D., 2015. Renewable energy auctions and tenders: how good are they? Int. J. Sustain. Energy Plan. Manag. 8, 43–56, 10.5278.ijsepm.2015.8.5.
Tolmasquim, M.T., de Barros Correia, T., Porto, N.A., Kruger, W., 2021. Electricity market design and renewable energy auctions: the case of Brazil. Energy Pol. 158, 112558.
USAID, 2017. Designing renewable energy incentives and auctions: lessons for Asean. Retrieved from. https://pdf.usaid.gov/pdf_docs/PA00SVK9.pdf.
USAID, 2019. Designing renewable energy auctions: a policymaker's guide. Scaling up renewable energy project - July 2019. Retrieved from. https://www.usaid.gov/sites/default/files/documents/1865/USAID-SURE_Designing-Renewable-Energy-Auctions-Policymakers-Guide.pdf.
Usaola, J., Angarita, J., 2007. Bidding wind energy under uncertainty. In: International Conference on Clean Electrical Power. Paper presented at the 2007.
van Eck, N.J., Waltman, L., 2007. Bibliometric mapping of the computational intelligence field. Int. J. Uncertain. Fuzziness Knowledge-Based Syst. 15, 625–645, 05.
van Eck, N.J., Waltman, L., 2009. How to normalize cooccurrence data? An analysis of some well-known similarity measures. J. Am. Soc. Inf. Sci. Technol. 60 (8), 1635–1651.
van Eck, N.J., Waltman, L., 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84 (2), 523–538. https://doi.org/10.1007/s11192-009-0146-3.
Viana, A.G., Ramos, D.S., 2018. Outcomes from the first large-scale solar PV auction in Brazil. Renew. Sustain. Energy Rev. 91, 219–228. https://doi.org/10.1016/j.rser.2018.04.003.
Viscidi, L., Yepez, A., 2019. Clean Energy Auctions in Latin America. Inter-American Development Bank. Retrieved from. https://publications.iadb.org/publications/english/document/Clean_Energy_Auctions_in_Latin_America.pdf.
Voss, A., Madlener, R., 2017. Auction schemes, bidding strategies and the cost-optimal level of promoting renewable electricity in Germany. Energy J. 38. KAPSARC Special Issue.
Wang, X., Barroso, L., Elizondo, G., 2014. Promoting Renewable Energy through Auctions: the Case of China. The World Bank. Retrieved from. https://openknowledge.worldbank.org/bitstream/handle/10986/18676/886970BRI0Live00Box385194B00PUBLIC0.pdf?sequence=7.
Wang, X., Lo, K., 2021. Just transition: a conceptual review. Energy Res. Social Sci. 82, 102291.
Welisch, M., 2018. The importance of penalties and pre-qualifications. Econ. Energy Environ. Pol. 7 (2), 15–30.
Welisch, M., 2019. Multi-unit renewables auctions for small markets - designing the Danish multi-technology auction scheme. Renew. Energy 131, 372–380. https://doi.org/10.1016/j.renene.2018.07.044.
Welisch, M., Kreiss, J., 2019. Uncovering bidder behaviour in the German PV auction pilot: insights from agent-based modeling. Energy J. 40 (6).
Welisch, M., Poudineh, R., 2020. Auctions for allocation of offshore wind contracts for difference in the UK. Renew. Energy 147, 1266–1274.
Wigan, F., Förster, S., Amazo, A., S, T., 2016. Auctions for renewable energy support: lessons learnt from international experiences. Report of the EU-funded AURES project. Retrieved from. https://auresproject.eu/publications/auctions-renewable-energy-support-lessons-learnt-from-international-experiences.
Winkler, J., Magosch, M., Ragwitz, M., 2018. Effectiveness and efficiency of auctions for supporting renewable electricity – what can we learn from recent experiences? Renew. Energy 119, 473–489. https://doi.org/10.1016/j.renene.2017.09.071.
Zhu, L., Li, L., Su, B., 2021. The price-bidding strategy for investors in a renewable auction: an option games–based study. Energy Econ. 100, 105331.
Zitt, M., Bassecoulard, E., Okubo, Y., 2000. Shadows of the past in international cooperation: collaboration profiles of the top five producers of science. Scientometrics 47 (3), 627–657.