Renewable Energy 119 (2018) 473–489

Contents lists available at ScienceDirect

Renewable Energy

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

Effectiveness and efficiency of auctions for supporting renewable electricity – What can we learn from recent experiences?

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A R T I C L E I N F O

Article history:
Received 16 November 2016
Received in revised form
7 September 2017
Accepted 22 September 2017
Available online 28 September 2017

Keywords:
Renewable electricity
Support schemes
Auctions
Energy policy
Market-based instruments

A B S T R A C T

The current debate about using auctions to support electricity from renewable sources is very polarised. While their proponents imply that auctions are the universal remedy, their opponents consider them a major threat to other formerly successful policies for renewables. In theory, auctions can improve the effectiveness and efficiency of support. However, the empirical effects of auctions on renewable support have not yet been fully analysed. Here, we use empirical data from Brazil, France, Italy, the Netherlands and South Africa to compare the effectiveness and efficiency of auction-based schemes with previous support schemes. Comparisons with countries that did not switch to an auction scheme in the time period assessed complement the study. The analysis shows mixed results. While auctions can indeed improve efficiency and effectiveness, this cannot be identified as a generic trend. The evidence based on existing data is neither sufficient to recommend the introduction of auctions as a generic instrument, nor does it show that previous support schemes were typically superior. Therefore, policy makers in countries which already have effective and efficient support schemes of any kind need to be very careful when designing auctions in order to achieve the targeted improvements.

1. Introduction

Policies supporting electricity from renewable sources have been in place for more than 20 years in many countries. While in the past, most countries used either fixed feed-in tariffs or quota systems to support renewables, recently more and more countries have introduced auctions[1] as part of their support system [1]. In the European Union (EU), this development will most certainly continue due to the current Guidelines on State aid for environmental protection and energy [2], which prescribe the use of auctions to support renewable electricity with only a few exceptions. Auctions fulfil two main functions in the support system: First, they define support levels[2] in a competitive and market-based way. Second, they serve as a mechanism to control the capacity expansion of renewables as well as the cost of support by setting either a budget, capacity or generation cap.[3] As a consequence, auctions influence both the effectiveness and efficiency of support systems [3–6].

Efficiency and effectiveness are often used as criteria to assess the performance of renewable support schemes [7]. This paper contributes to answering the question of whether recent experiences with auctions support the assumption that auctions outperform other systems in terms of the effectiveness and efficiency of support. The analysis is based on comparing recent auction schemes to other support systems previously used in the analysed countries.

In many countries, the current discussion about auctions is very controversial. Whereas their proponents believe auctions to be the universal remedy [2], their opponents consider them a major threat to formerly successful policies for renewables [8–10]. This paper aims to discover whether it can provide evidence to support either of these extreme positions.

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[1] In the context of renewable policies, the terms tenders and auctions are often used as synonyms. Strictly speaking, tenders are multi-criteria auctions. Throughout this paper only the term auction is used. See Ref. [49] for a more detailed definition.

[2] Throughout the paper, 'support level' corresponds to unit cost subsidy and not to overall support expenditures.

[3] In some countries auctions are also used for other purposes. In Germany, for example, actor diversity is cited as a third objective alongside effectiveness and efficiency [87]. Some countries also use auction mechanisms to increase local economic activity (e.g. France or South Africa, see Section 4.1.2).

https://doi.org/10.1016/j.renene.2017.09.071

The remainder of this paper is structured as follows. Section 2 describes the criteria in more detail and summarises existing results from the literature regarding auction performance. Section 3 explains the methodology used to assess recent auctions. The results are presented and interpreted in Section 4. Section 5 summarises, concludes and discusses policy implications.

2. Effects of auctions on effectiveness and efficiency

Effectiveness corresponds to the degree to which an objective is reached. In the context of renewables, effectiveness refers to the renewable capacity installed or renewable electricity generated in a given period (e.g. one year) because of the support instrument in place [11]. Effectiveness is assessed positively if extension targets[4] are either reached or over-achieved [11]. However, since 2008, unexpectedly high growth rates of solar photovoltaics in a number of countries such as Germany, Italy and Spain resulted in high costs and were one of the reasons in Spain for the moratorium of renewable energy support [12]. Therefore, in this paper, support schemes are deemed effective if the resulting renewable extension does not substantially deviate from the set targets, i.e. there is no or only modest over- or underachievement of these targets.

Auctions influence the effectiveness of support schemes by setting a cap on renewables' extension. Thus, in contrast to support systems without caps, auctions in theory avoid overachieving renewables' extension targets. When compared to the simple capacity or cost caps that can be introduced in systems with administratively set feed-in tariffs or feed-in premiums, auctions have the advantage of allocating scarce funds more efficiently. While simple caps usually distribute support on a first-come-first-served basis, well designed auctions select the projects with the lowest levelised costs of electricity generation (LCOE) [13,14]. However, in order to reach a high level of effectiveness, auctions need to be designed accordingly. First, auction volumes and awarded capacities need to be aligned to extension targets. Second, the auction design must incentivise successful auction participants to realise their projects as awarded. Support scheme effectiveness is high if the renewable extension or generation realised is close to the planned extension (e.g. based on extension targets).

Efficiency is reached when a given target is achieved at lowest cost. In the context of renewable electricity generation, the term efficiency is used in different ways. One definition is the minimization of the overall costs of installing a certain renewable capacity or producing a certain amount of electricity at a given point in time [11]. This kind of efficiency is also called static or macroeconomic efficiency [11,14]. Dynamic efficiency is another aspect. This concept involves the future costs of renewables' extension. It is argued that support schemes incentivizing currently expensive technologies at an early stage contribute to static efficiency in the longer term [11,15]. Efficiency in the context of supporting renewable energy can however also focus on the support costs for renewables and aim at minimizing support costs [14]. In this context, the distribution effects of support schemes play an important role in addition to overall generation costs. Support costs are influenced mainly by the choice of technology, but also by the support levels and risks involved in support systems [16].

Auctions impact the macroeconomic efficiency of support schemes mainly through the chosen technologies and the choice of selection criteria. Additional selection criteria apart from prices tend to decrease macroeconomic efficiency. Otherwise, there are no systematic differences between support systems with and without auctions regarding macroeconomic efficiency. The same is true for the auctions' impact on dynamic and static support efficiency. As for other support schemes, technology-neutral auctions focus on static efficiency, while technology-specific auctions include considerations regarding dynamic efficiency. However, the introduction of auctions can substantially influence the development of support costs. On the one hand, when compared to a system with administratively set support, auctions introduce a competitive, market-based procedure to determine support levels [8,17]. Given sufficient competition on the market, this can reduce support costs. On the other hand, the introduction of auctions also modifies the projects' risk structure because additional risks (especially the risk of penalties for non-realization or delays) are transferred to the plant operator. This involves higher costs as a consequence [6]. Due to these opposing effects of auctions on support costs, their theoretic impact is unclear.

However, the risks caused by auctions are usually lower than those under quota schemes where plant operators need to handle the twofold price risk on both the regular electricity and the certificates market [8]. Both price components are uncertain and depend on future market developments whereas, under auction schemes, income is usually fixed over the plant's lifetime [8,11,18–22].

So far, a number of authors have assessed the performance of auctions as an element of support schemes for electricity generation from renewables in a qualitative manner [4,6,23–26]. There are also some more detailed analyses of individual countries [8,10,27–30]. In general, these assessments show a mixed picture of the success of past experiences with auctions regarding both effectiveness and efficiency. Particularly, in some countries where low support levels were reached, many projects were not realised [30].

A comparative data-based assessment of different countries concerning the performance of auctions has been missing to date. This paper contributes to filling this gap by assessing the auction systems of five selected countries. The assessment compares them to both the system previously in placein each country before the tender scheme was introduced, and to three countries that retained the same non-auction support system over the entire evaluation period.

3. Methodology

Adequate support levels for renewable energy vary between countries and over time. There are cost differences between countries due to differing resource endowments, but also due to planning procedures, land availability and financing conditions. Over time, the costs of renewables tend to decrease due to technological learning, but changes in the prices for raw materials or in global demand also influence the costs of renewable energy projects.

A panel analysis is the most appropriate methodology to analyse the effects of auctions on the effectiveness and efficiency of renewable energy support. Panel analysis is a statistical method used to analyse two dimensional data, typically cross sectional and longitudinal. The support scheme performance in countries with and without auctions could be analysed and compared using panel analysis, regarding both the effectiveness of auction schemes and their efficiency.

However, such a panel analysis requires 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.[5]

[4] By extension targets, we mean the targets for deploying renewables. These can be formulated as installed capacities, electricity generated or percentage shares of total energy consumption or electricity generation.

[5] To assess the scheme's effectiveness, the realization period needs to be completed to enable an evaluation of realization rates.

Thus, the assessment is based on a small number of countries. In order to handle this small-N problem, a twofold approach is selected in this paper in order to represent both dimensions. First, cross-country analyses are undertaken comparing countries that have introduced auctions with those that are still using other support schemes. The countries without auction schemes were selected to match the auction-using countries in as many characteristics as possible (e.g. political risk, resource endowment etc.). The cross-country comparison is used to control for developments over time like technology cost decreases. In addition, longitudinal within-country assessments are made using data from countries that switched from a different support scheme to auctions in recent years in order to control for country-specific characteristics such as resource endowment.

In order to obtain robust results despite the small number of years and countries, the two assessments are then combined. In a first step, the cross-country analysis serves to identify the main deviations between the assessed auction and non-auction schemes. In a second step, the reasons for the identified deviations are investigated by within-country assessments including quantitative and qualitative information.

In general the results are not based on statistical analysis due to limited data availability, but rather use the available data as empirical evidence. 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. Nevertheless, these existing observations provide the first quantitative evidence to inform policy making.

Offshore wind and concentrated solar power (CSP) are typically auctioned in one-unit auctions where projects are predetermined by central authorities and bids are compared for one specific location. As such one-unit auctions differ substantially from the multi-unit auctions used for other technologies, offshore wind and CSP are excluded from the analysis.

3.1. Country selection

Ideally, case study countries should be randomly selected from a large number of candidate countries. However, there are only a few eligible candidates when comparing auctions to non-auction-based support schemes. These countries need to have introduced auctions not too recently in order to enable the assessment of results (i.e. in 2013 at the latest). Furthermore, the auctions in these countries should be used as a tool for the effective and efficient allocation of support funds and not mainly for other purposes such as distributing grid capacity. Finally, the selected countries need to have used a different support system before introducing auctions in order to enable within-country comparisons. Based on these criteria, Brazil, France, Italy, the Netherlands and South Africa were chosen as suitable case study countries.

In addition to the countries that switched to auction-based support schemes, countries that continued to use a non-auction-based support scheme were selected for cross-country comparisons. Auction-using countries differ substantially regarding the degree of economic development and financial stability as well as resource endowment and electricity market design. In order to enable a meaningful cross-country assessment of auctions compared to other schemes, the second group of countries selected should be a good match for the first group in as many characteristics as possible. For the EU countries of France, Italy and the Netherlands, other EU member states provide such a fit. Germany, Austria and Luxembourg were identified as suitable countries using the following criteria: First, the selected countries have used the same support scheme without retroactive changes or regime switches since at least 2004 as the first auctions included in the analysis took place in 2004. Second, the countries use a uniform technology-specific support scheme for PV, onshore wind and biomass. For Italy, Southern European countries might provide a better fit. However, none of these countries fulfils the selection criteria. For the emerging markets of Brazil and South Africa, other emerging markets, ideally in regional proximity, would enable a comparison. However, both countries are leaders with regard to renewable support policies and expanding renewables and it was not possible to identify a suitable match not using auctions.[6] As a consequence, these two countries are included in the cross-country comparisons with EU countries. This divergence is handled in the interpretation of the results.

The auction designs as well as the design of previous support systems and of support systems used in countries that did not switch are briefly described in Section 4.1 as a basis for determining and interpreting the performance of auctions compared to other support systems.

3.2. Time horizon

Fig. 1 shows in which years and for which technologies auctions were conducted in the selected countries. The start of each line corresponds to the auctioning date, the line represents the time period after which successful auction participants had to realise their projects.

The figure illustrates a number of problems regarding the assessment of auction performance. First, the differing duration of realization rates complicates the assessment of auction effectiveness. Further challenges are posed by the overlap of realization periods between different auctions for one technology in some countries. Second, the assessment of auction efficiency and effectiveness is also influenced by external developments taking place over the period considered.

In this period, there were far-reaching economic and political developments due to the financial crisis. Simultaneously, there was substantial deployment of renewable technologies leading to a very dynamic price development, especially regarding photovoltaics. In Germany, for example, the average prices for PV decreased by 70–80%, while those for biomass and onshore wind remained relatively stable between 2006 and 2014 [43–46]. Because of these external developments, a reduction in support levels cannot be clearly attributed to the introduction of auctioning, but may also be caused by the general downward trend in plant prices or sinking capital costs. In addition, variations in support effectiveness are not only caused by the choice and design of the support scheme, but also by the availability of capital in a given year. The comparison of countries that have introduced auctions with those using other support systems is meant to partly account for these external developments.

3.3. Assessment of effectiveness

As described above, a two-step approach is applied to determine the effectiveness of auctions compared to other support schemes.

[6] Potential candidates with sufficiently stable markets for renewables would be Russia, China, India or Indonesia. However, China used auctions for onshore wind until 2007 and for PV until 2010; in India, national and state level schemes interact in a complex manner with competitive bidding used in some regions and tax exemptions playing a major role; Russia uses an unsuccessful capacity payment for supporting renewables; and Indonesia uses auctions for PV while wind tariffs are set based on bilateral negotiations. Therefore none of these countries can serve as a "non-auction reference".

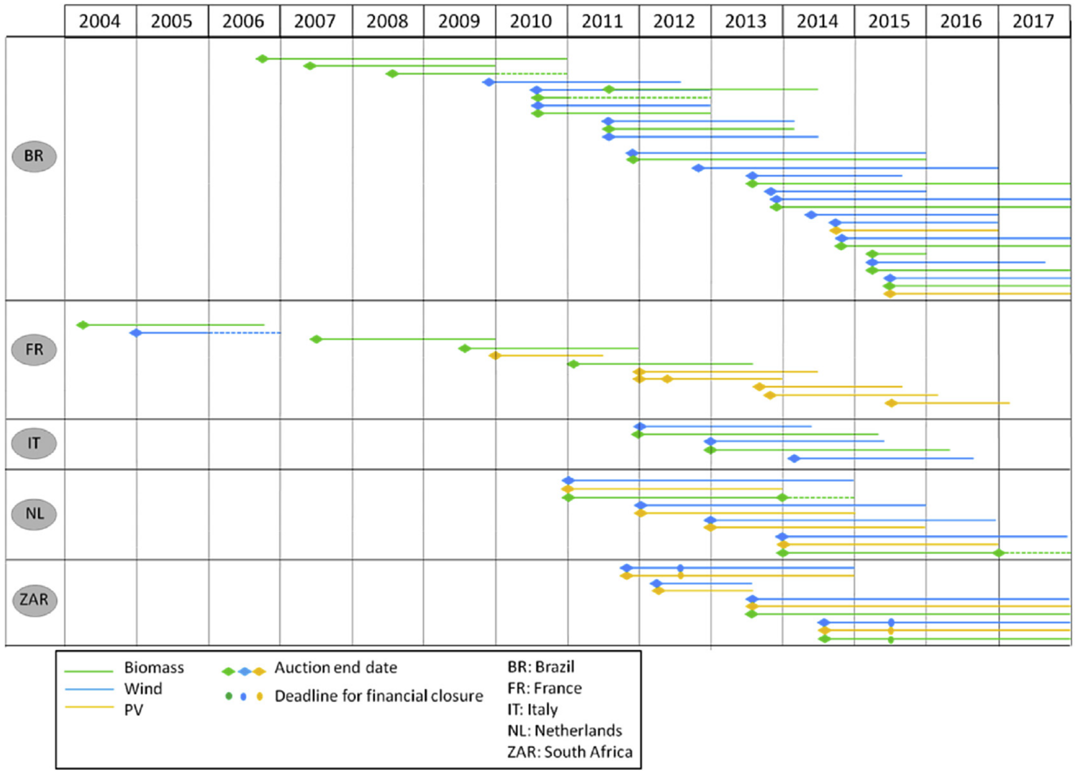

Fig. 1. Timeline of auctions considered in the analysis.
Sources: [31–42].

The cross-country analysis is used in a first step to determine general differences regarding support scheme effectiveness. For this purpose, targeted and actual deployment is compared and deviations between the two are assessed. This evaluation is only conducted for EU member states and for the period from 2011 to 2014 as EU member countries have technology-specific renewables extension targets clearly defined for this period in their National Renewable Energy Action Plans (NREAPs) [47].

In the second step, the effectiveness of auction schemes is assessed in more detail in order to determine possible reasons for the deviations. For this purpose, only countries with auction schemes are included. Again, targeted and realised volumes are compared but this time not on a yearly basis. Instead, in order to handle the overlap of auction periods, the specific auction rounds in the case study countries are grouped into auction and non-auction periods (see Table 1). The year in which the auction was held is not taken into consideration as projects are usually realised later.[7] In some cases, periods with parallel availability of a different support scheme are included in the analysis. This is the case for early auction periods in France and Brazil and needs to be considered when interpreting the results. Using the same auction periods, the adequacy of auction volumes is evaluated by comparing the auction volume to the targets. However, there are problems in some countries as the auctions only apply to a subgroup of a technology, e.g. depending on installed capacity, but the targets are defined for the technology as whole. This is considered in the interpretation of results.

[7] Installed capacity statistics are available until 2014 only in most cases. Therefore, if commissioning deadlines are not reached by 2014, the auctioned or awarded capacity is distributed evenly across the years of the realization period for the assessment. This leads to potentially higher deviations than in reality.

Table 1
Auction periods considered in the analysis of support scheme effectiveness.

Technology	Country	Time frame
Biomass	Brazil	2006–2010
		2011–2014
	France	2004–2006
		2012–2014
	Italy	2013–14
	Netherlands	2011–14
	South Africa	2012–2014
PV	France	2013–14
	Netherlands	2012–14
	South Africa	2012–2014
Wind	Brazil	2011–2014
	France	2005–06
	Italy	2013–2014
	Netherlands	2012–2014
	South Africa	2012–2014

Furthermore, the feasibility of auction volumes is assessed by matching auction and awarded volumes. Finally, the realization rates of awarded projects are analysed. This more detailed investigation of auction schemes makes it possible to draw conclusions regarding auction design.

3.4. Assessment of efficiency

The assessment of efficiency focuses on the analysis of support level developments. These incorporate both the effect of competition as well as the changes in project risk structure. A two-step approach is taken.

First, the development of support levels in countries with auctions and in those with other support schemes is compared. Administratively set support levels used in a certain year are compared to auction results of the same year. This approach does not take into account the fact that auction participants realise their projects later due to realization periods in auctions, although this time lag might lead to lower support levels resulting from auction schemes. Due to the lack of available data on realization dates for most of the awarded projects, it is not currently possible to improve the approach taken. The abstraction from the time lag seems legitimate because realization dates differ between successful auction participants in each round, auction participants might also misjudge future developments, and technologies with steep learning curves (e.g. PV) typically have relatively short realization periods. However, this aspect needs to be taken into account when interpreting the results. The comparison is made considering the entire range of support levels because average or mean values would distort the results due to the small number of countries involved.

In a second step, developments in individual countries with auctions are analysed in order to draw conclusions regarding auction schemes in general as well as specific auction designs or individual circumstances. Although limited data availability inhibits a full panel assessment, the combination of both approaches yields useful empirical evidence in an emerging policy field. The cross-country analysis partially controls for external developments during the assessment period, for example the cost reduction of PV or the financial crisis. The within-country assessments take into account differences between countries, such as resource endowment, availability of land or other barriers to expanding renewables.

4. Results

It is frequently stated that the exact design of a support scheme is as important as the choice of a specific instrument [48,49]. In a real world context, neither the analysed auction schemes nor the pre-auction schemes can be assumed to be optimally designed but often include national preferences, e.g. in terms of technology specifics or project sizes. Some of these elements remain constant when switching support schemes; others are changed. In order to provide a transparent picture of these design elements, this section includes both a short description of the support systems in all the selected countries and the results concerning effectiveness, efficiency and project characteristics.

4.1. Support scheme design in case study countries

The auction and non-auction support schemes used in case study countries are described in the following.

4.1.1. Non-auction support mechanisms

Table 2 gives an overview of pre-auction support systems as well as existing non-auction support schemes in selected countries.

Before introducing auctions, Italy used a system of tradable green certificates with technology banding for supporting wind with a capacity above 0.2 MW and biomass with a capacity of more than 1 MW. The obligation was fulfilled by buying tradable green certificates of 15 years duration issued by the Italian Energy Service Provider (GSE) to renewable plant operators [58]. A certificate system usually implies a rather high risk for plant operators as they have to sell their electricity as well as the certificates on markets with volatile prices [59]. However, in Italy, GSE had to sell certificates at the difference between 180 €/MWh and the annual average market price of electricity in case of an undersupply of certificates and to buy certificates at 78% of this price in case of an oversupply of certificates. Thus, the volatility of the overall income was comparatively low for renewable plant operators in Italy [58].

All other countries used or use a feed-in system with administratively set technology-specific support levels. Support schemes differ especially regarding the support period, which ranges between 12 and 20 years. Furthermore, some systems include a cap on budget or yearly installed capacities and, in these cases, different criteria are in place to select projects.

4.1.2. Auction design in case study countries

Auction designs also differ between countries as shown in Table 3[8]. Auctions are partially technology-neutral in Brazil[9] and the Netherlands. In Brazil, different auctions are used to procure general capacity, reserve capacity and to specifically support renewable electricity. The first two types are mostly technology-neutral, the latter is technology-specific. While biomass and wind have been successful in all auction types, PV has only been supported by one special renewable support auction so far[10]. The Brazilian system is criticised for including a plethora of auction schemes as transaction costs are deemed too high [52]. In the Netherlands, all technologies participate in the same auction process. However, price caps differ between technologies to avoid windfall profits for cheaper technologies. In Italy and South Africa, auctions are technology-specific. France even uses subcategories for solar energy depending on plant size and technology.

Brazil and the Netherlands also differ from the other case study countries as there are no size restrictions for participating in the auction process. In the other countries, small plants (with differing definitions) are excluded from auction schemes. In South Africa, smaller plants are not supported at all, while in France and Italy, alternative support schemes exist for these plants.

The case study countries also use different pricing rules. In South Africa and France, pay-*as*-bid pricing is implemented. Italy uses descending-clock auctions and Brazil combines both types in a hybrid system. In the Netherlands, the maximum price for each technology is fixed depending on the bidding round in which a plant participates, and bids only include capacities. Apart from the price, South Africa and France apply additional selection criteria including environmental aspects and local economic development. Auction awards can be traded in some countries but not in others.

Deployment deadlines are between one and five years. In Brazil, the deadlines depend on the auction type. In South Africa, deadlines are the same for all technologies. The Netherlands, France and Italy apply technology-specific deadlines. Interestingly, technology-specific deadlines differ, e.g. biomass has a longer realization time than onshore wind in France, but a shorter one in Italy, while in the Netherlands deadlines for biomass vary between 1.5 and 4 years and depend strongly on the type of technology.

Table 4 gives an overview of the most important design elements for securing plant realization, i.e. prequalification requirements, guarantees and additional penalties. Guarantees are usually paid before participation in the auction and/or after funding approval and are only reimbursed if and when the plant is commissioned. When assessing the designs, one needs to keep in mind the trade-off between complexity and harsh penalties which might reduce competition, and between low requirements and penalties that might reduce realization rates. The lack of penalties and resulting low realization rates were one of the main criticisms of early UK auctions [8]. However, Table 4 shows that prequalification requirements, guarantees and penalties still vary widely

[8] An overview of terms and definitions related to renewable energy auctions is provided by the EU-funded project AURES (http://auresproject.eu/about-auctions).

[9] In Brazil, wind and biomass were even successful in tenders for general capacity extension where they competed with conventional technologies.

[10] The results of this auction are not included in the analysis as no developments can be seen from one auction round.

Table 2
Overview of pre-auction support systems in case study countries.

Country	Time frame	Type of support	Determination of support level	Duration of payment (years)	Technology-specific?	Cap
Brazil	2002–2008	Feed-in tariff	Administrative	20	Capacity caps per technology	First-come-first-served based on date of environmental permit
France	2000 - now	Feed-in tariff	Administrative	15 to 20	None	Not applicable
Italy	2002–2012	Tradable green certificates	Market-based with administratively set cap and floor	15	None, excess certificates bought by GSE at floor price	Not applicable
Netherlands	2003–2010	Sliding feed-in premium	Administrative	12 to 15	Budget caps per technology	First-come-first-served
South Africa	2009–2011	Feed-in tariff	Administrative	15 to 20	None	Not applicable
Austria	Since 2003	Feed-in tariff	Administrative	13 to15	Budget cap	First-come-first-served
Germany	Since 2000	Feed-in tariff and sliding feed-in premium	Administrative	20	Support levels depending on previous extension rates ("Breathing cap") for PV and onshore wind	Not applicable
Luxembourg	Since 2002	Feed-in tariff	Administrative	20	None	Not applicable

Sources: [23,50–58].

Table 3
Overview of auction design elements in case study countries.

Country	Technology	Project size	Pricing rule	Selection criteria	Trading of auction awards permitted	Deadline for deployment
BR	Technology-neutral and technology-specific	No restrictions	Hybrid: descending clock followed by sealed pay-*as*-bid	Price only	Yes	1-5 years
FR	Onshore wind	>12 MW	Pay-*as*-bid (sealed bid)	price 60%, other: installed capacity 10%, environment and local acceptance 20%, technical + financial capacity	Yes (with permission of minister of energy)	14 months
	Biomass	>12 MW		price 30–50%, other: purchase of biomass, location, energy efficiency, technical + financial capacity		30 months
	PV	100-250 kW		until 2012 only price, since 2013 CO2-balance 1/3		20 months
	PV	>250 kW		price 40%, other: environmental impacts, industrial risks, CO2-balance, feasibility, R&D		24 months
IT	Onshore wind Biomass	>5 MW >5 MW	Descending clock	Price only	No	28 months 16-28 months
NL	Technology-neutral	No restrictions	Sequential bidding rounds with predetermined maximum prices by technology (first come, first served basis)	Price only	No provisions found	1.5–4 years depending on technology and subcategory
ZAR	Onshore wind Biomass PV	5-140 MW >5 MW	Pay-*as*-bid (sealed bid)	Price 70%, other: job creation, local content, preferential procurement, enterprise development, socioeconomic development	Yes	3 years, since 2013 4 years (after bid submission), additional deadline for financial closure

Sources: [6,29,32–34,37,38,40,42,53,60–62].

with France and the Netherlands at one extreme applying very low financial penalties and Italy at the other end of the spectrum implementing a guarantee of 10% of investment combined with reduced support if projects are delayed.

4.2. Results regarding effectiveness

As described above, a two-step approach is used to assess support schemes' effectiveness. First, the results of the cross-country analysis are presented. This assessment includes only EU countries and compares NREAP targets to the actual capacity expansion.

Tables 5–7 show the extension targets, real capacity extensions and the relative and absolute deviations for PV, onshore wind and biomass, respectively. As the targets differ substantially among countries, the relative deviation is of special interest when assessing support scheme effectiveness.

In the case of PV, targets were surpassed in all countries and most years. The exceptions are Germany and Luxembourg, where targets were not reached in 2014. The lowest deviation from the target was 6%, which occurred in Germany in 2013; the highest deviation in the same year was in Austria with an installed capacity almost 15 times above the set target. Surprisingly, targets were also

Table 4
Prequalification criteria, guarantees and penalties in case study countries' auctions.

Country	Technology	Financial viability	Location access	Grid access	National/ regional development	Environmental aspects	Guarantees	Penalties
BR	All technologies	✓ Participant's net worth ≥10% of investment	→ ✓ Land use rights	✓ Approval	✓ Wind: 60% local content	✓ License	1st: 1% of estimated project costs, 2nd: 5%	✓ reduced contract price during period of delay (10–50%), contract termination possible
FR	Onshore wind	✓		✓ Report		✓ EIA, CO2 assess-ment		
	Biomass	✓ Tax records				✓ Evaluation		intended, but not defined support period shortened by months of delay
	PV < 250 kW	✓ Evidence of equity capital/loan offer	✓ Bidder has to be owner			✓ CO2 balance		intended, but not defined
	PV > 250 kW	✓ Evidence of equity capital/loan offer, tax records	✓ Bidder has to be owner			✓ Environ-mental evaluation, CO_2 balance	until 2011: 50,000€/MW (≈5% of investment[a])	Before commissioning permit: 5000€/MW/100000€; after commissioning: intended, but not defined
IT	Onshore wind, biomass	✓ Bank guarantee		✓ Connection offer, approved budget for connection		✓ Wind: EIA	✓ 1st: 5% of investment, 2nd: 10%	✓ support is reduced by 0.5% for every month of delay
NL	Technology neutral	✓ Financial plan, for large projects: bank statement, realization contract	✓ Permission of land owner			✓ License		✓ exclusion of the project from SDE + for 5 years in case of delay, penalties for large projects
ZAR	Onshore wind, biomass, wind	✓ Minimum thresholds are required	✓ Prove of access		✓	✓	✓ 1st: 100,000 ZAR/MW (≈1% of investment[a]), 2nd: 200,000 ZAR/MW (≈2%[a])	✓ Contract may be terminated

[a] Assumption: investment 1000 €/kW, exchange rate ZAR/€ = 14.3266 (1.8.2014).
Sources: G. [28,29,33,34,37,38,40,42,53,60–62].

Table 5
Relative and absolute annual deviations between actual and targeted PV deployment in EU countries with and without auctions.

Non-auction countries	2011	2012	2013	2014	Auction countries	2011	2012	2013	2014
Austria					**France**				
Target (MW)	14	16	18	19	Target (MW)	274	302	322	350
Realised (MW)	163	46	263	145	Realised (MW)	1752	1169	687	1002
Relative deviation (%)	1064	188	1361	661	Relative deviation (%)	539	287	113	186
Absolute deviation (MW)	149	30	245	126	Absolute deviation (MW)	1478	867	365	652
Germany					**Netherlands**				
Target (MW)	4500	3499	3499	3499	Target (MW)		36	44	44
Realised (MW)	7485	7604	3694	1966	Realised (MW)		220	377	302
Relative deviation (%)	66	117	6	−44	Relative deviation		511	757	586
Absolute deviation (MW)	2985	4105	195	−1533	Absolute deviation (MW)		184	333	258
Luxembourg									
Target (MW)	0	12	6	21					
Realised (MW)	12	34	20	15					
Relative deviation	∞	183	233	−29					
Absolute deviation (MW)	12	22	14	−6					

Sources: [47,63].

substantially exceeded in countries with auction schemes. This is probably due to plants that were built outside the auction scheme based on self-consumption or schemes with administratively set tariffs existing in parallel to the auction scheme. From these observations, there is no clear indication that auctions or a market-based determination of support levels help to increase support scheme effectiveness.

In the case of onshore wind, the relative deviations from targets are generally lower than for PV. However, the data confirms the concern that auction schemes often reduce extension rates so that targets are not achieved. Some countries with auctions remained below their extension target for onshore wind in all the years analysed. However, this can be attributed to the fact that, in Italy, the auction volumes were lower than the target and, in the Netherlands, the technology-neutrality of the auction scheme led to a focus on other technologies. Furthermore, the problem of not reaching extension targets for onshore wind is not confined to countries with auction schemes. In Luxembourg, no wind installations were built in 2013 and 2014 even though targets foresaw capacity expansion for these years. At the same time, Germany and

Table 6
Relative and absolute annual deviations between actual and targeted onshore wind deployment in EU countries with and without auctions.

Non-auction countries					Auction countries				
	2011	2012	2013	2014		2011	2012	2013	2014
Austria					**Italy**				
Target (MW)	221	203	186	172	Target (MW)			620	620
Realised (MW)	99	236	329	441	Realised (MW)			440	141
Relative deviation (%)	−55	16	77	2	Relative deviation (%)			−29	−77
Absolute deviation (MW)	−122	33	143	269	Absolute deviation (MW)			−180	−479
Germany					**Netherlands**				
Target (MW)	1930	1751	1616	1829	Target (MW)		732	415	801
Realised (MW)	1860	2136	2761	3096	Realised (MW)		117	280	152
Relative deviation (%)	−4	22	71	70	Relative deviation		−84	−33	−81
Absolute deviation (MW)	−70	385	1145	1267	Absolute deviation (MW)		−615	−135	−649
Luxembourg									
Target (MW)	5	14	17	18					
Realised (MW)	1	13	0	0					
Relative deviation	−80	−7	−100	−100					
Absolute deviation (MW)	−4	−1	−17	−18					

Sources: [47,63].

Table 7
Relative and absolute annual deviations between actual and targeted biomass deployment in EU countries with and without auctions.

a					Auction countries				
	2011	2012	2013	2014		2011	2012	2013	2014
Austria					**France**				
Target (MW)	2	2	4	4	Target (MW)	88	88	223	223
Realised (MW)	30	71	−471	−202	Realised (MW)	262	−195	−25	119
Relative deviation (%)	1408	3450	−11867	−5141	Relative deviation (%)	200	−323	−111	−47
Absolute deviation (MW)	28	69	−475	−206	Absolute deviation (MW)	175	−283	−247	−104
Germany					**Italy**				
Target (MW)	308	314	280	261	Target (MW)			190	191
Realised (MW)	605	460	532	631	Realised (MW)			133	5
Relative deviation (%)	96	47	90	142	Relative deviation			−30	−98
Absolute deviation (MW)	297	146	252	370	Absolute deviation (MW)			−57	−186
Luxembourg					**Netherlands**				
Target (MW)	2	5	5	5	Target (MW)		328	311	139
Realised (MW)	1	0	2	−1	Realised (MW)		−41	−140	−129
Relative deviation	−48	−102	−59	−114	Relative deviation (%)		−112	−145	−193
Absolute deviation (MW)	−1	−5	−3	−6	Absolute deviation (MW)		−369	−451	−268

Sources: [47,63].

Austria clearly surpassed their targets. This result suggests that other factors such as land availability are a major driver for wind installation deployment rates. As explained above, in the countries with auctions, the delay between the auction date and the implementation date complicates detailed planning of target achievement and might be an additional explanation for target deviations in countries with auction schemes.

In the case of biomass, net installed capacities were negative in some years in Austria, Luxembourg, France and the Netherlands, leading to excessive negative deviations from the targets, especially in Austria. Of the countries using auctions, only France reached its target in 2011. Countries with other support systems, however, also show high deviations from targets in both directions. It can be concluded that auctions for biomass in the observed countries and years decrease target overachievement but do not improve support scheme effectiveness in general in this comparison.

Based on the cross-country comparisons, there is no evidence that auctions increase the effectiveness of support compared to other schemes. Target achievement depends not only on the support system but also on other factors, especially non-economic barriers.

A more detailed analysis of the reasons for deviations in auction systems follows in the next section. As described above, apart from hard to plan delays in project realization, deviations in auction schemes can be caused either by a mismatch between target and auction volumes, a discrepancy between auction volumes and awarded projects, or unexpectedly low or high realization rates.

The analysis first assesses whether auction volumes were adequate for target achievement in the countries assessed. A suitable auction volume can be slightly above the targeted capacities to take into account possible project defaults. In the absence of other support schemes or technology categories to meet the target, however, the auction volume must not be below the target volume. In countries with technology-specific targets but technology-neutral auctions, planning the technology mix is less straightforward [52]. For these countries, the analysis compares targets with awarded capacities. Auction periods instead of yearly targets are analysed to determine realization rates. For Brazil and South Africa, annual extension targets similar to those in the NREAPs are used [47,64,65].

Fig. 2 depicts the range of percentage deviation from targets of auction volume (for countries with technology-specific auctions) or awarded capacities (for countries with technology-neutral auctions). Results are shown separately for all case-study countries and for EU countries (see Table 3 for a list of countries and technologies). In most countries, auction or awarded volumes do not match the targets. The only exception is French PV. In some cases, this might be due to the existence of parallel support systems for other

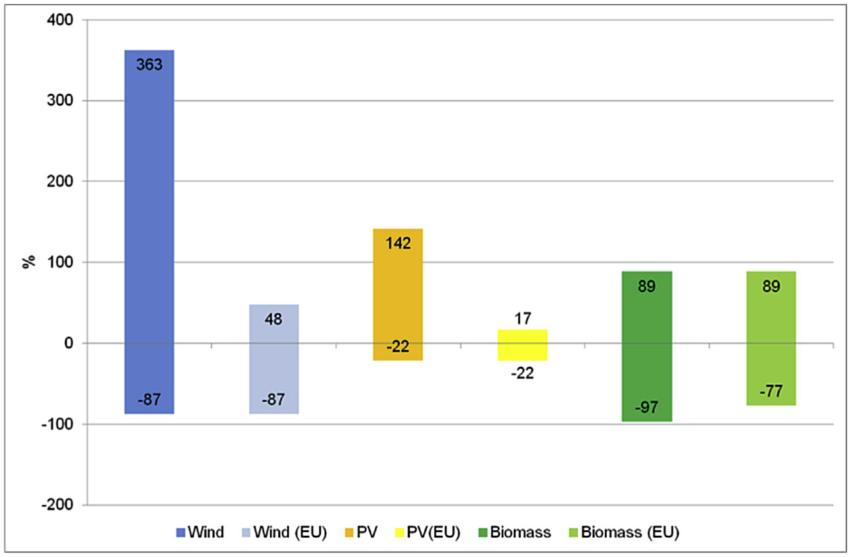

Fig. 2. Ranges of percentage deviation of auction volume/awarded capacity from targeted volume by technology; countries included as listed in Table 3. Sources: [33,34,40,47,64–69].

technology subgroups, e.g. in the case of Italian biomass, where plants under 12 MW are supported by a fixed feed-in tariff. However, Italy still failed to reach its biomass extension target in 2013 and 2014. In countries with technology-neutral auction systems, it is of course more challenging to influence the match between target and awarded capacities, but the most extreme values occur in systems with technology-specific support schemes. The results of the analysis therefore indicate that a mismatch between auction volumes and targets can be one reason for low auction effectiveness.

In the next step, auction volumes are compared to awarded volumes. Brazil and the Netherlands are excluded from this analysis due to their partially technology-neutral auction design.

Fig. 3 shows that the awarded volumes often deviate substantially from auction volumes. The highest deviation occurred in the French biomass auction of 2010, when more than double the auction volume was awarded. The other extreme is the 2011 South African biomass auction, where no project could be awarded. In general, awarded volumes in South Africa were notably below auction volumes due to low competition and the fact that the entire target volume for the period 2011 to 2014 was auctioned in this year. In later rounds however, more capacity than auctioned was assigned to auction participants. Italian wind auctions performed better regarding the fit of auction volume to awarded capacities. In the first auction in 2012, competition was slightly too low to reach the auction volume. In 2013, however, auctions were oversubscribed. The final awarded amount included two projects more than planned due to legal disputes. In general, as in the previous section, the performance of the auctions included in the analysis is ambiguous. To conclude, in some cases, the cap on installed capacities in auctions was not interpreted as strictly as expected. In addition, installed capacities will not reach target levels if

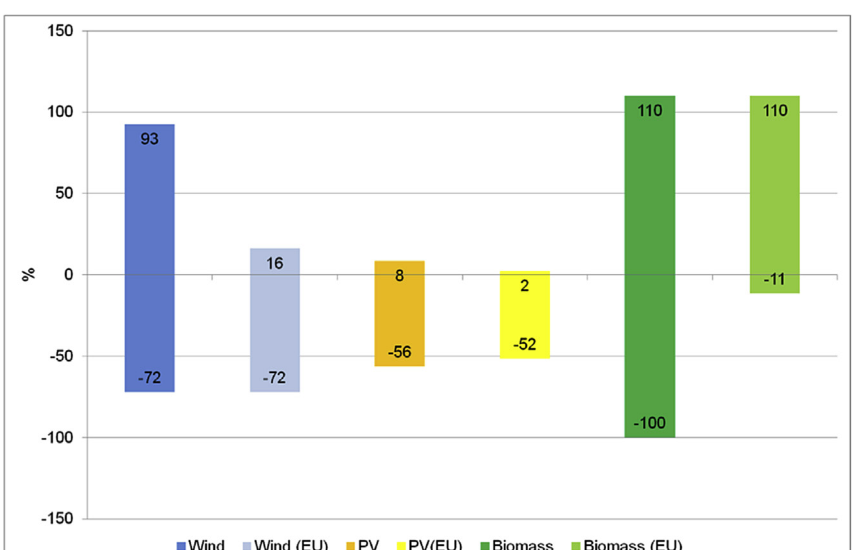

Fig. 3. Range of percentage deviations of awarded capacity from auction volume; countries included as listed in Table 3. Sources: [33,34,40,67].

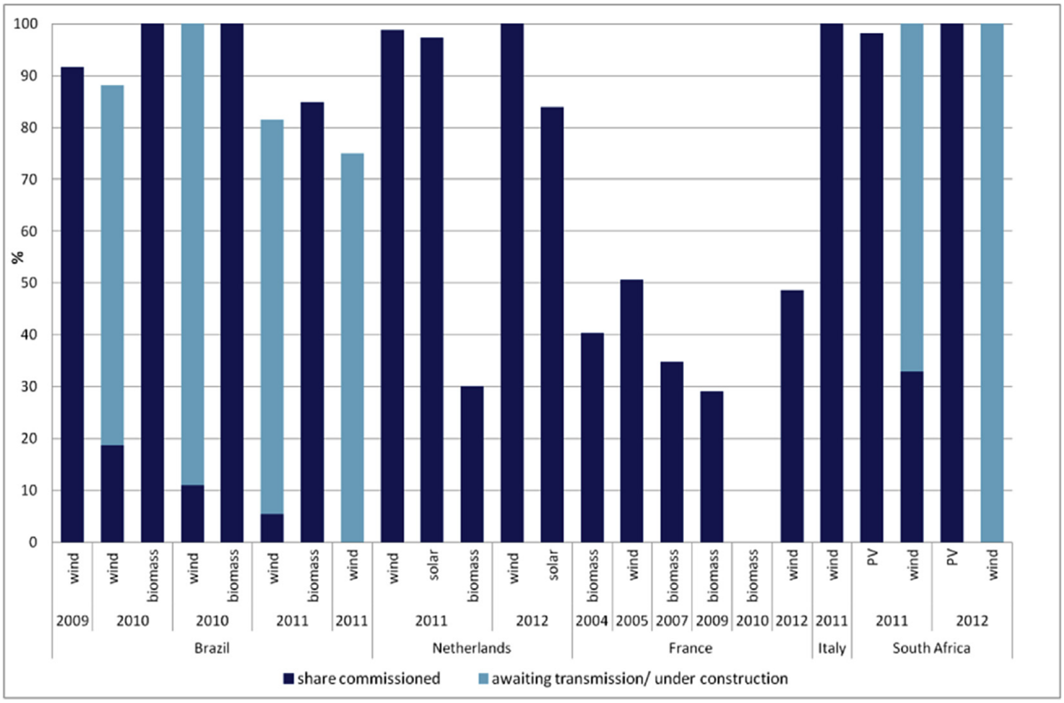

Fig. 4. Realization rates by auction round. Data includes projects until 2015; BNEF data includes projects under construction and awaiting transmission (Brazil/South Africa); French projects until 2014 (after deadline); no data available for French PV auctions; data for Brazil only includes five auction rounds: (2LER, 2 LFA, 12 LEN, 3 LER, 4 LER).
Sources: [33,40,66,69,70].

competition in the auction is too low due to auction design or other parameters such as land or capital availability.

The last central issue regarding the effectiveness of auction schemes is the degree to which projects awarded in the auctions are actually commissioned.

Fig. 4 shows the realization rates achieved in the case study countries. Projects under construction or awaiting transmission are also included as there is a high probability that these projects will be realised. Realization rates for auctions taking place after 2012 are not included as the deployment deadlines for the respective projects have not yet been reached. Observed realization rates are very high in Brazil and South Africa.[11] In Italy, all the projects awarded in the 2011 wind auction were realised. Wind and PV projects in the Netherlands also had high realization rates, while biomass projects were implemented to a lesser degree. In France, realization rates were generally quite low (between 0% and 50%). No data was available for French PV auctions – but the evaluation assessment [71] mentions rates of 50% for this technology as well. The differing realization rates might be an indication of the importance of material prequalification requirements, guarantees and penalties, because guarantees and penalties are comparatively small or even undefined in France (see Table 4). However, the Netherlands reach acceptable realization rates for wind and PV in a comparable setting. In general, the data indicates that high realization rates are possible and therefore that low realization rates do not necessarily limit auction effectiveness. The results show that auctions promise to be an effective support scheme provided that important design elements are properly implemented, e.g. auction volumes are sufficiently high and reasonable penalties are set. However the empirical data basis is still too small to conclude whether auctions will outperform other support schemes with respect to effectiveness.

4.3. Efficiency

As described above, the assessment of efficiency focuses on the development of support levels. Comparing countries that introduced auctions and those that did not is complemented by within-country comparisons over time in those countries that switched to an auction scheme.

Figs. 5–7 show the development of support level ranges for PV, onshore wind and biomass, respectively, and compare auction results with support levels of countries not using auctions. For each range, the more comparable EU countries are also shown separately. For all technologies, the year-wise comparison with non-auction schemes shows that auction ranges are generally at the lower end of non-auction ranges. This indicates that auctions do indeed contribute to saving support costs. Even when the time lag between the auctioning date and project realization is taken into consideration, auctions led to lower support levels in many cases. However, the fact that mainly large projects participate in auctions qualifies auction performance.

For PV, support levels decreased substantially between 2010 and 2014 in non-auction schemes corresponding to the cost decline of PV since 2008. This is also the case for auctions in South Africa, where increasing competition was the main cause the price reduction there [53]. The generally lower support level in South Africa corresponds to the higher solar irradiation in this country. European auction results do not follow this trend. Instead, they start from a low level in 2011 and stay roughly at this level until 2014. This result may be due to the fact that auction participants in 2011 already foresaw the impending price decrease and acted accordingly. Thus, auctions might avoid delays in adjusting support levels to changing costs. However, lower support levels in auction

[11] This might be due to the used data source – South African realization rates are calculated based on BNEF data, which only includes between 78% and 88% of the capacity awarded in the auctions. The actual realization rates might be slightly lower.

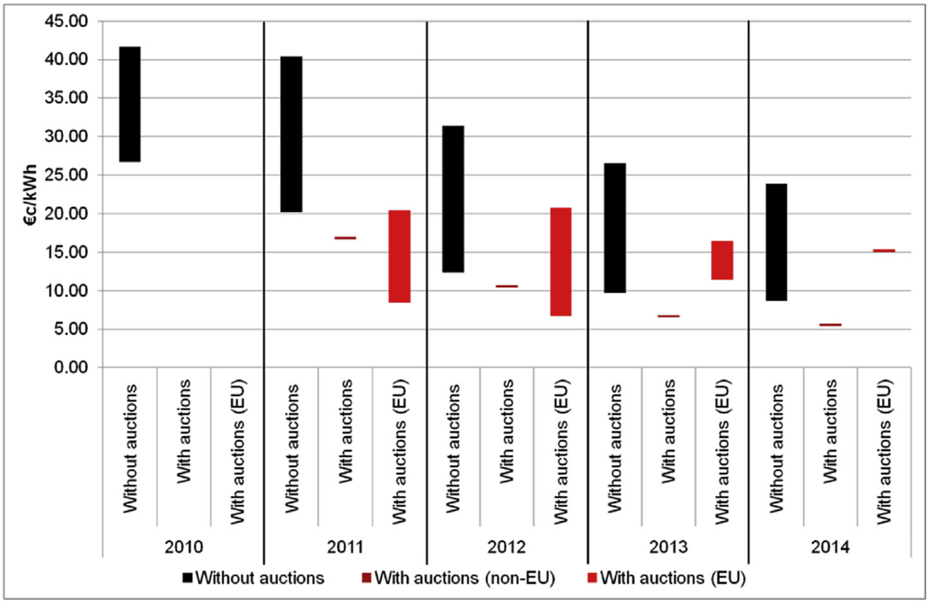

Fig. 5. Development of support levels for photovoltaics in countries with and without auction systems (2014 real values).
Sources: [33,34,37,38,40–42,66,67,72–85].

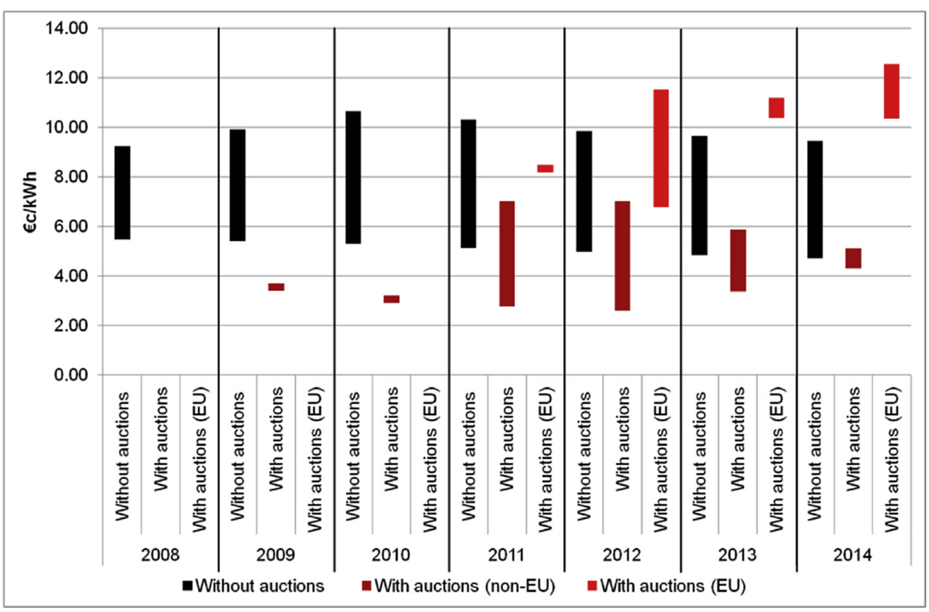

Fig. 6. Development of support levels for onshore wind in countries with and without auction systems (2014 real values).
Sources: [33,34,37,38,40–42,66,67,72–85].

schemes in Italy and France could also be due to better resource endowment in these countries compared to Germany, Austria and Luxembourg. In the Netherlands, only a few PV projects were successful in the auction and there are speculations that non-economic benefits were one reason for the low bidding.

In the case of onshore wind, support levels resulting from auctions are partly above those in other support schemes, especially in European countries. Deviations between Brazil, South Africa and Europe are probably due to differences in resource endowment. In Europe, auctions took place in Italy and the Netherlands. Wind resources are comparable in Italy and Austria as well as in Germany and the Netherlands so that the use of auctions for onshore wind in the European context has not had the desired effect of low support levels. The lack of competition in the auctions may explain this outcome. However, other country-dependent variables such as land availability might play a role in this regard as well.

Similar to PV, biomass support levels from auctions in EU countries are in the lower range of those from other support schemes. South African and Brazilian support levels are below European ones, probably due to lower prices for biomass feedstock or less strict sustainability criteria. The fact that auctions do not reach the lowest support levels found in countries with administratively set levels might be due to the exclusion of some fuels from the auctions. The biomass auction results generally confirm the cost-saving potential of auctions when determining support levels.

The comparison of support levels in countries with and without

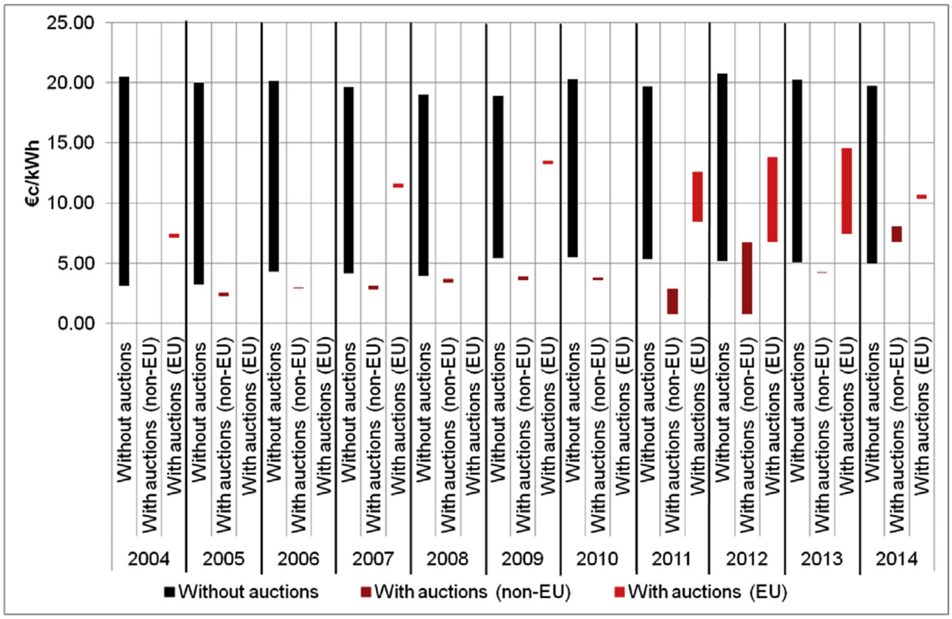

Fig. 7. Development of support levels for biomass in countries with and without auction systems (2014 real values).
Sources: [33,34,37,38,40–42,66,67,72–85].

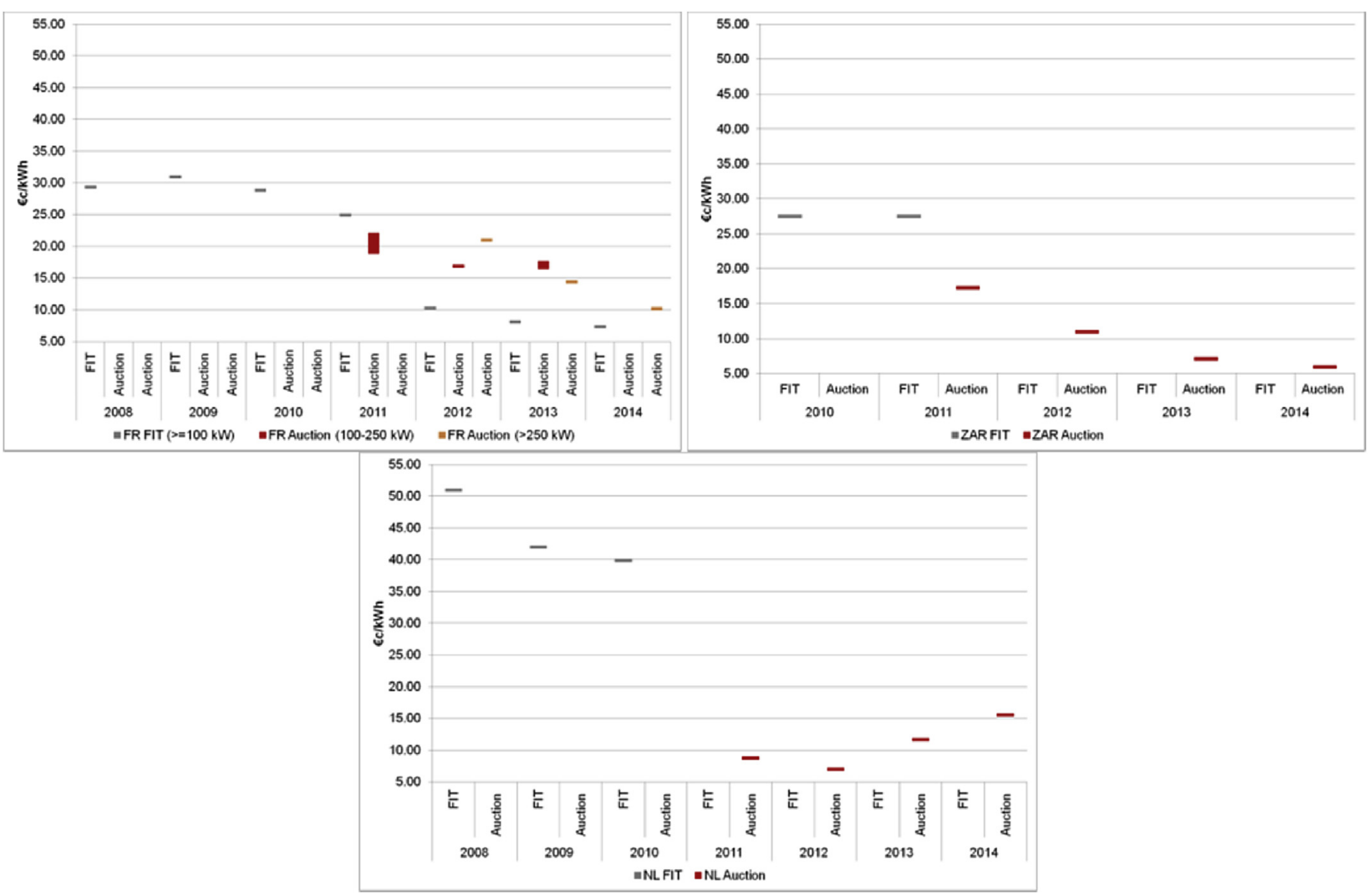

Fig. 8. Development of support level ranges for PV in France, South Africa and the Netherlands. 2014 real values, exchange rates 2014 (1Real = 0.33227 €; 1Rand = 0.06909 €), Auction France > 250 kW: average bid price, results not published, FIP Netherlands represents the overall income per kWh.
Sources: [33,34,37,38,40–42,66,67,72–77,80–83,85].

auctions yields two main results. First, auction schemes do not necessarily lead to lower support levels than administratively set ones. Second, differences between countries regarding land availability, resource endowment, financing conditions and feedstock regulations might be more important than the support scheme design for determining support levels.

A closer look at those countries that switched to auction systems is used to complement the results from the cross-country comparison. Fig. 8 shows the development of PV support levels in France, South Africa and the Netherlands. In slight contrast to the cross-country analysis, developments in these countries confirm the assumption that support levels resulting from auction schemes are usually lower than those from schemes with administratively set support levels. However, this result may also be due to technology cost reductions over time. Some additional results can be deduced from the longitudinal assessment.

First, the decrease of support levels in auction schemes is not automatic. In the Netherlands, budget ceilings increased over time and this led to an increase in support levels, even though costs were reduced at the same time [72]. However, in the first auction rounds in the Netherlands, only very few PV projects were successful so the low support levels imply a lower effectiveness of support.

Second, auctions do not necessarily attract the cheapest projects. In France, auction results are above feed-in tariff levels existing in parallel to the auction systems. At the same time, installed capacities exceed awarded volumes. Thus, some plants are realised that receive only the lower regular feed-in tariff. Assuming they are profitable, they can operate at lower costs than projects awarded in the auction.

Third, competition is vital for low support levels from auctions. In South Africa, the auction volume in the first auction round was very high and all projects participating in the auction were awarded. As a consequence, there was no competitive pressure for low bids. In the second round, auction volumes were substantially decreased and information about auction rules was improved. The increased competition led to a steep decline in support levels between the first and the second auction round [34].

Fourth, using different auctions for different plant sizes might lead to lower competition. In France, the support levels for plants above 250 kW were not below those of smaller plants in all rounds, even though the costs of plants with higher installed capacities are usually much lower. However, this needs to be interpreted in light of the fact that the support levels published for French PV auctions for plants above 250 kW are not auction results but the average bid levels of successful auction participants.

The assessment of support level developments within the countries that switched to auctions for onshore wind result in partly different conclusions to the cross-country assessment (compare Fig. 9). In both the Netherlands and Italy, the introduction of auctions led to a reduction of support levels compared to the previous support scheme. This might lend support to the view that reasons other than resource endowment such as land availability or other barriers increase the costs of wind energy in Italy and the Netherlands compared to Germany, Austria and Luxembourg.

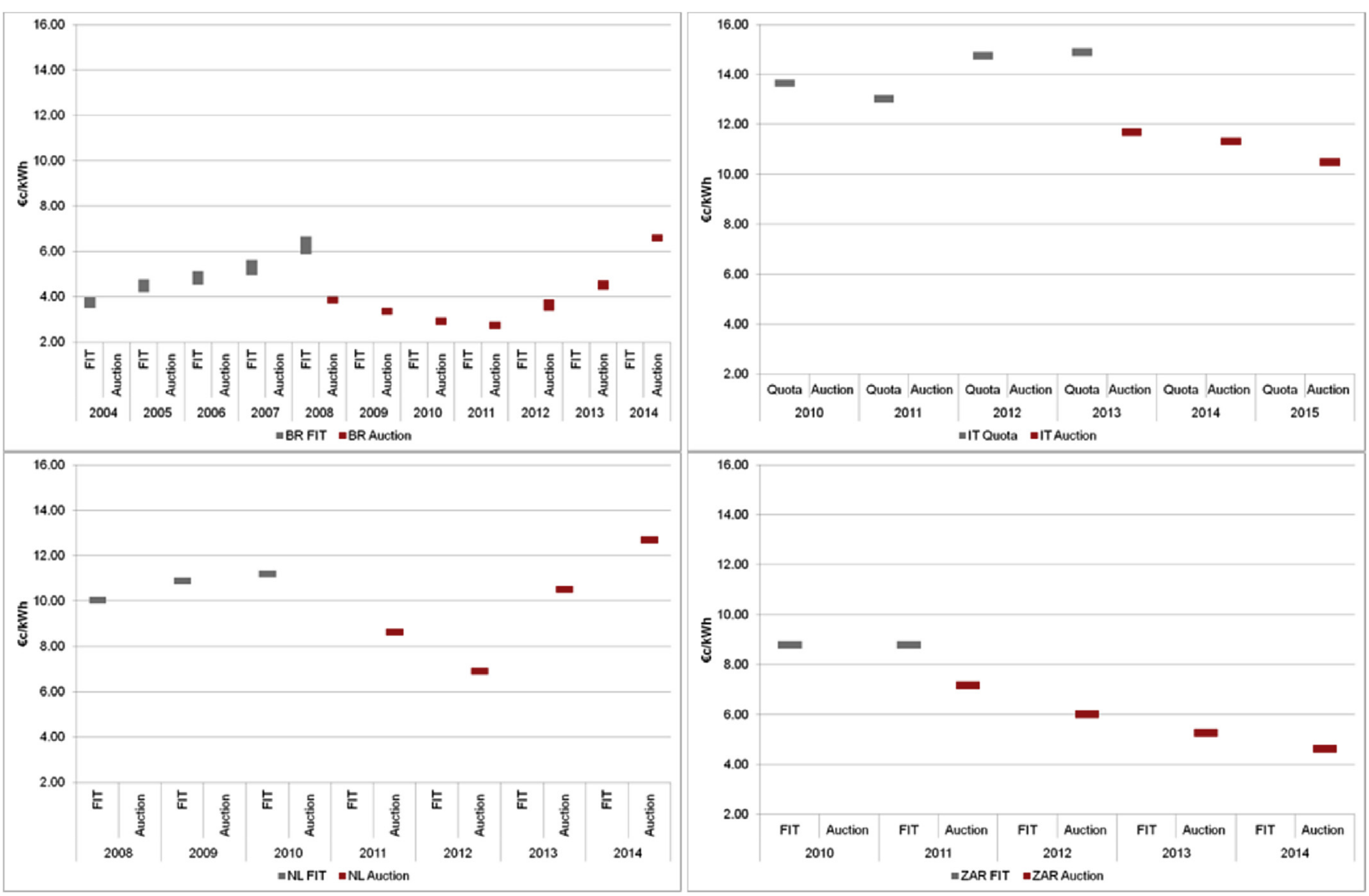

Fig. 9. Development of ranges of yearly support levels for wind in Brazil, Italy, the Netherlands and South Africa. 2014 real values, exchange rates 2014 (1Real = 0.33227 €; 1Rand = 0.06909€).
Sources: [33,34,37,38,40–42,66,67,72–77,80–83,85].

While a clear downward trend can be observed in South Africa similar to the case for PV, in Brazil, very low and sinking support levels in the first auction rounds were followed by an increase of auction results in later years with levels similar to previous schemes with administratively set prices. A similar development also took place in the Netherlands. However, there were different reasons for the support level increase in each country. In the Netherlands, the higher support levels are explained by a higher budget ceiling in combination with the chosen auction design [72]. In Brazil, the results are probably due to a more realistic evaluation of costs by market participants as early auction results were often interpreted as not being profitable for investors.

The results of auctions regarding support levels are also ambiguous in the case of biomass (compare Fig. 10). In the Netherlands and Italy, support levels decreased compared to previous schemes. In South Africa and Brazil, support levels are partially markedly above the level of FITs. This could be a sign for low auction efficiency, but also the effect of increased prices for biomass fuels or non-profitable FIT levels. In France, the auctions for biomass plants led to tariffs in the same range as the new FITs for plants below 12 MW, i.e. economies of scale were not exploited by auction participants. However, the results for biomass need to be interpreted carefully due to the very low number of projects awarded in many cases. Also, the LCOE of biomass vary substantially between technologies and with

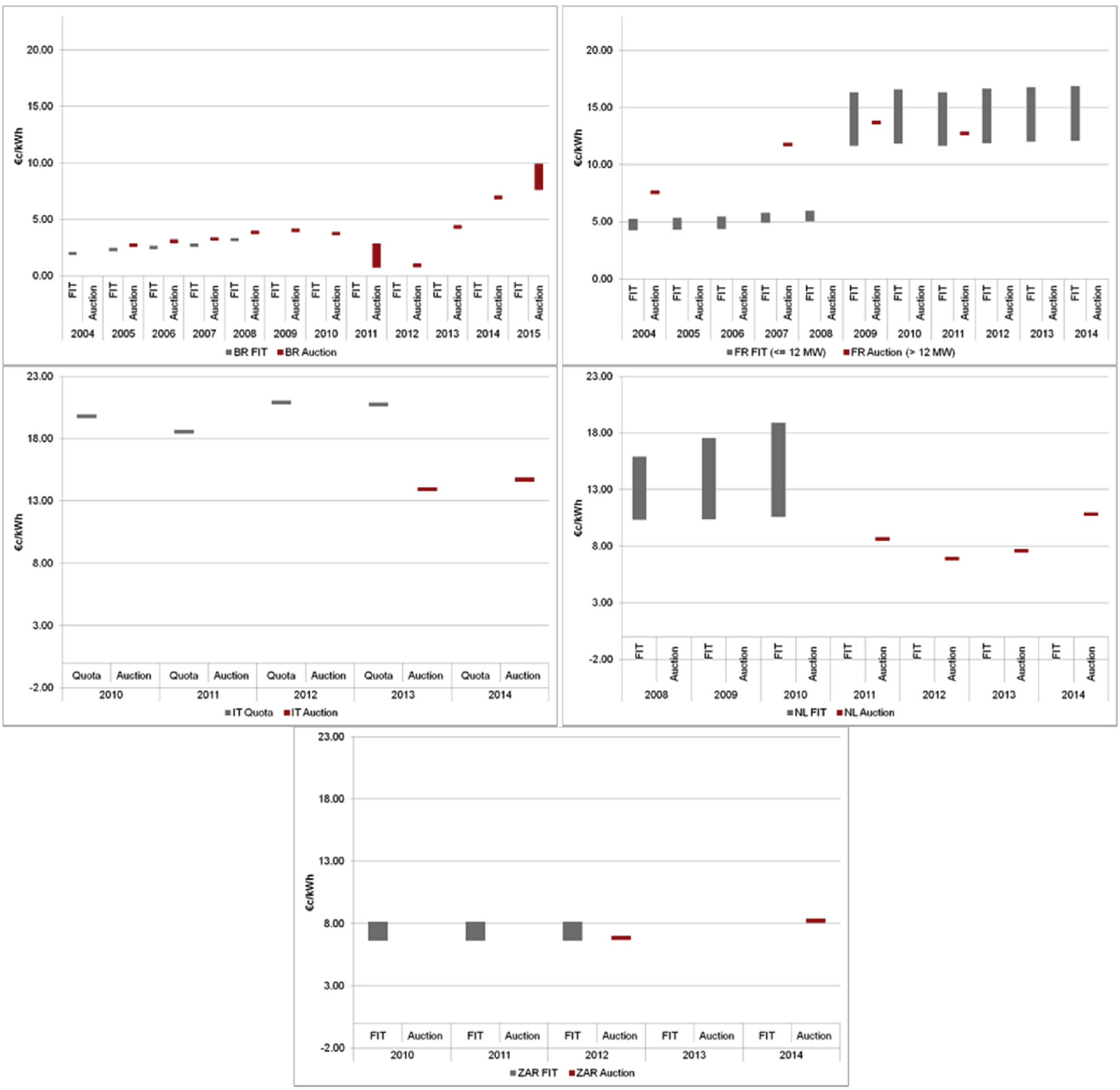

Fig. 10. Development of ranges of yearly support levels for biomass in Brazil, France, Italy, the Netherlands and South Africa. 2014 real values, exchange rates 2014 (1Real = 0.33227 €; 1Rand = 0.06909 €).
Sources: [33,34,37,38,40–42,66,67,72–77,80–83,85].

changing biomass prices [86].

To sum up, we find no clear evidence that auctions lead to reduced support levels even though the introduction of auctions was accompanied by decreasing remuneration in some cases. The analysed cases suggest that auctions can contribute to increased support efficiency, but so far there is insufficient evidence to conclude that this is generally the case.

5. Conclusions and policy implications

There is a growing use of auctions as an element of support schemes for electricity generation from renewable sources. In theory, auctions can increase both the efficiency and effectiveness of support schemes when compared to quota schemes and systems with administratively set tariffs. The current policy debate about auctions is very polarised; some actors suggest auctions are the generic solution to the challenges of renewable energy support schemes (e.g. Ref. [2]); others argue that existing successful policies could be severely undermined by switching to auctions (e.g. Ref. [9]). Our paper provides no evidence to support either of these extremes. Based on the existing evidence, no general conclusion can be drawn that auctions increase the effectiveness and efficiency of support, although this is the case in some of the analysed countries.

This study compared support scheme effectiveness and support level developments between countries using auctions and countries not using auctions as well as over time in countries that had switched to an auction scheme. Due to limited data availability, no full statistical analysis of the effect of auctions was possible, but the combination of cross-country and within-country analyses controls partially for both external developments over time and cross-country differences such as resource endowment or land availability.

The analysis of the effects of introducing auctions as an element of the support scheme for electricity from renewable sources yielded the following results:

Adequately designed auctions with auction volumes in line with renewable energy extension targets that include sufficient guarantees and penalties can reach a high degree of effectiveness in competitive markets. Countries with auctions showed lower deviations from targets for onshore wind and partially PV but not for biomass in the cross-country analysis. In the countries with auctions, the alignment of auction volumes and awarded capacities to targets as well as realization rates vary widely by case study country and technology. We showed that effectiveness can be high in specific cases, but we did not find a general trend that introducing auctions increases effectiveness.

A similar conclusion holds for the efficiency of support. In some countries and for some technologies, auction-based support levels were clearly below those in previous support schemes and show a clear downward trend. However, auctions do not generally lead to lower support levels than schemes with administratively set support levels, possibly due to the influence of other cost drivers such as land availability. Furthermore, the use of auctions does not necessarily imply a constant decrease of support levels since outcomes are always determined by the degree of competition on the market and the associated behaviour of market participants.

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. However, it does seem feasible to design auctions in a way that increases both the effectiveness and efficiency of support compared to other support schemes if the market is competitive. If auctions are to be effective, their design and volume must be adjusted to the extension targets and must include sufficient mechanisms to assure realization of the awarded projects. A positive development of support levels requires sufficient competition so that target volumes must be adjusted to the market conditions in the respective country.

Auctions can be a good support option if carefully designed, especially in countries where previous schemes resulted in high costs of support or low deployment. Auctions can also be suitable in countries with mature markets where policy makers are now focusing on volume control and competitive price setting. In addition, the competitive determination of support levels can help to avoid delays in adapting to changing framework conditions such as strongly declining costs. However, based on the available data, it is not possible to prove that auctions as an element of renewable support schemes are more advantageous than other support schemes. This should be taken into consideration by EU policy makers when reviewing the guidelines for renewable support policies. Policy makers in countries which already use effective and efficient support schemes need to be very careful when designing auctions in order to obtain the targeted improvements. When introducing auctions, changes in effectiveness and efficiency but also other project characteristics need to be closely monitored in order to adapt the auction design when and where required.

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