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Worth the wait: How South Africa's renewable energy auctions perform compared to Europe's leading countries

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ABSTRACT

Auctions for renewable energy support allocation are on a triumphant global advance. We compare performance of renewable energy auctions in terms of effectiveness (realisation rate and period) and efficiency (price outcomes) from two world regions: South Africa and European countries (Germany, France, the Netherlands). We develop an assessment framework for compliance incentivisation in auction design, covering qualification criteria, penalties, and compliance monitoring. We find that a 100% realisation rate in South Africa is connected to a strong compliance package, while European countries have moderate realisation rates (23%–87%) with relatively lenient compliance packages. We observe that realisation periods are correlated with project size rather than granted realisation period. Although South African projects generally have longer realisation periods (34 months for PV and 40 months for onshore wind) than European projects (16.5–30 months for PV and 19–25 months for onshore wind), they perform comparably considering that they are 10–13 times larger. Comparing average auction prices with equivalent technology-specific LCOE estimates, we find a general convergence towards the global average, with South Africa having the sharpest price decline (75% PV and 54% onshore wind), albeit starting from the highest level. Our findings, especially on importance of compliance incentivisation and weak impact of granted realisation periods, are valid across world regions and can support policymakers everywhere in designing effective and efficient renewable energy auctions.

1. Introduction

Auctions – also referred to as competitive bidding or tendering programmes - have become one of the most widely applied mechanisms for procuring utility scale renewable energy generation capacity. By the end of 2018, 106 countries have used competitive auctions to procure renewable electricity (IRENA, 2019). The rise of auctions has coincided with significant reductions of bid prices for renewable energy technologies in different world regions, and included first mover developing countries such as Brazil, China, Morocco, Peru and South Africa (Lucas et al., 2013), European countries (del Río, 2017; Kylili and Fokaides, 2015), as well as a number of late-comer developing countries, in which auctions were only recently introduced (Lucas et al., 2017).

Competitive procurement of new electricity generation capacity provided by independent power producers (IPPs) gradually emerged in some African countries after the turn of the century (Eberhard et al., 2017). South Africa (SA) and Morocco were the first countries on the continent to implement utility scale renewable energy procurement programmes based on auctions for IPPs. Before the launch of the Renewable Energy Independent Power Producers Procurement Programme (REI4P) in 2011, SA had almost no experience with private power investment or renewable energy. The designers of the auction programme were thus focused on ensuring that the programme was effective – meaning that procured projects would be built on time, and that they provided overall socio-economic benefits. The auction design consequently used a range of stringent qualification and evaluation criteria, including job creation, local content, ownership, management control, preferential procurement, enterprise development and socio-economic development contributions (Hansen et al., 2020; Kruger et al., 2021).

European countries have a long history of implementing large-scale renewable energy projects. Early auction schemes, such as the Non Fossil Fuel Obligation in the UK (1990–98), were used in several countries, but were abandoned mainly due to high transaction costs for

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small projects and problems with public acceptance (Del Río and Linares, 2014). Administratively set feed-in tariffs (FIT) and premiums were the primary support instrument for renewable energy after the turn of the century. In 2014, however, the European Commission, in its guidelines on state aid for environmental protection and energy, stipulated that competitive mechanisms should be used for allocating support to renewable electricity deployment (Szyszczak, 2014). Most European countries subsequently implemented auctions as the main mechanism to procure renewable electricity. This procurement modality has now become dominant worldwide. As a consequence, distinctive auction design and implementation approaches in different countries and world regions have emerged, shaped by a range of contextual factors (del Río, 2017; IRENA, 2019), which has also given rise to a substantial body of research.

Most of the scientific literature on renewable energy auctions relies on qualitative and empirical analysis. A few exceptions use quantitative modelling approaches, mostly consisting of levelised cost analysis or agent based models (Anatolitis and Welisch, 2017; Dobrotkova et al., 2018; Haelg, 2020; Lundberg, 2019). Several of the qualitative studies focus on a particular country and its policy framework (e.g., Eberhard and Kåberger, 2016; Grashof et al., 2020; Leiren and Reimer, 2018; Lundberg, 2019). Other studies have a broader focus involving multiple countries to identify some common design elements and their impact. One strand of this comparative empirical auction analyses literature focuses on auction outcomes in terms of bid price (efficiency) and project realisation rates (effectiveness). Of special interest for our work are two independent studies by Bayer et al. (2018), and by Winkler et al. (2018), who analysed auctions in Brazil, France, South Africa, and Italy. The first paper focused on the capacity installed (effectiveness) and reduction in bid price (efficiency) of auctions, while the second paper (also including the Netherlands) compared the effectiveness and efficiency of auction-based schemes with previous support mechanisms. While no sufficient evidence was found to conclude that auctions are superior to other instruments in terms of effectiveness and efficiency, it was observed that in most countries, auctions have led to a reduced support price (improved efficiency) compared to other support mechanisms. This correlates with findings from the broader auctions literature that generally notes decreasing bid prices over several auction rounds. Most studies emphasise that this cannot be solely attributed to auction design factors, but is also due to external factors such as technology improvement, maturing financial markets and a number of country specific conditions (Bayer et al., 2018; Grashof et al., 2020; Toke, 2015; Winkler et al., 2018).

With respect to effectiveness, a large body of literature suggests using penalties and/or qualification criteria along with streamlining administrative procedures to increase the probability of project realisation (del Río, 2017; Eberhard and Kåberger, 2016; Gephart et al., 2017; Kruger and Eberhard, 2018; Toke, 2015; Winkler et al., 2018). Specifically, Winkler et al. (2018) found that high auctioned volumes, high levels of bid bonds, and strong qualification criteria and penalties can improve realisation rates. Toke (2015) showed, by comparing Denmark and South Africa, that the coordination of grid connection planning, the evaluation of bid financial feasibility, the ability to obtain necessary permits, and the use of penalties all contribute to the successful delivery of projects. Bayer et al. (2018) concluded for Brazil and South Africa that a 100% realisation rate is possible, while delays in project commissioning are inevitable. However, no systematic correlation was found between project realisation, delays and auction design, and project realisation rates were to a large extent related to project specific and country specific conditions.

To summarise, the literature on auction schemes provides suggestions as to how auction design elements influence auction effectiveness and efficiency, while maintaining that underlying socio-economic conditions play an important role, but without systematically contrasting developing countries with industrialised countries. While it is commonly accepted that conditions for the energy transition are different in developing countries than in Europe (Hansen et al., 2018), existing comparative studies including both industrialised and developing countries such as Bayer et al. (2018) and Winkler et al. (2018) do not explicitly include this dimension in their analysis. There is therefore a need for empirical research that focuses on these conditions in the context of underlying factors that distinguish developing countries from industrialised countries.

This paper sets out to close part of this empirical knowledge gap by comparing the South African auction programme to selected European auction programmes, with a special focus on how differences in effectiveness and efficiency of the South African and European auction programmes can be explained by differences in auction design and in terms of different economic, industrial and political contexts. We have gathered data on individual project commissioning, their granted and actual realisation periods and price outcomes, and systematically analysed per auction round the impact of various design elements on average outcomes and outcome distributions at the level of individual projects.

The remainder of this paper is organised as follows. Section two presents the methodology, including analytical framework, case selection, and data collection. Section three presents the results of the quantitative analysis, and section four discusses the main findings, with a focus on the underlying conditions for differences in effectiveness and efficiency. Major conclusions are presented in section five.

2. Methodology and data: comparing auctions for renewable support in Europe and South Africa

2.1. Measuring the performance of auctions across different world regions

The success of auctions is typically evaluated against two main criteria: effectiveness and efficiency (del Río, 2017). Effectiveness encompasses the ability of auction schemes to achieve a desired level of renewable capacity expansion or renewable energy generation. More specifically, effectiveness in the context of renewable auction schemes is measured in two ways: 1) achievement of national targets on renewable capacity expansion (Winkler et al., 2018), and 2) the commissioning (or realisation) of individual renewable energy projects that are awarded support in an auction round (Bayer et al., 2018). In this paper, the scope of effectiveness is limited to the commissioning of projects that are awarded support in a particular auction round. We investigate two dimensions of realisation: realisation rate (the share of winning projects that are commissioned) and realisation period (the time from award to commissioning). Efficiency of an auction scheme relates to the ability of achieving desired renewable capacity expansion at minimum cost. The efficiency assessment of renewable auction scheme is often divided into static and dynamic efficiency. Static efficiency is concerned with short-term minimisation of generation cost, while dynamic efficiency takes into account long-term effects on innovation and cost reduction (del Río, 2017). In this paper, we only focus on static efficiency of a particular auction round and analyse auction price outcomes in comparison to cost estimates.

2.1.1. Realisation rate

To assess effectiveness in terms of realisation rate, we consider several relevant auction design elements identified by the literature, including material qualification, financial qualification in the form of bid bonds, compliance monitoring, and penalties for late commissioning and/or non-commissioning (del Río, 2017; Haufe et al., 2018; Haufe and Ehrhart, 2016). We first analyse them individually, and then combine these elements into a 'compliance package' to ease comparability across cases. We evaluate the ability of compliance packages to explain realisation rate outcomes observed in those countries.

In the framework we developed to identify compliance packages, we consider material qualification, financial qualification, compliance monitoring, and penalties. Different countries have different compliance packages based on their policy objectives, local markets, and other country specific conditions. To compare a wide variety of compliance packages in different countries, we have developed a classification system for each of the four compliance measures and their major requirement indicators, shown in Table 1. Three compliance package components - material qualifications, penalties, and compliance monitoring - have been classified into three groups of varying strictness while the fourth component, namely financial qualification, is classified into two groups, based on whether or not bid bonds were required at bid submission.

The scale of strictness of the compliance package components depends on the number of sub-measures implemented. The material qualifications consist of sub-measures such as the provision of environmental permits, land use permits, business model description, and more. Sub-measures for penalties consist of sanctions upon non-compliance, fixed monetary fines in the form of completion bonds, reduction in support duration, reduction in support payment, and cancellation of the support agreement for extended delays. The classification for compliance monitoring and financial qualification is relatively straight-forward with the former dealing with the frequency of regulatory checks on project development status and the latter with the requirement of submission of bid bonds.

Lastly, the different compliance package components are aggregated by assigning scores to each of the sub-measures, either one or zero, depending on the existence of that particular measure or regulation in the auction round. The total score is calculated by first summing together sub-measures to get the score for each measure and then adding those up using a uniform contribution, i.e. 25% per component, so that a full strictness level in each component corresponds to a score of 25, and in all four measures adds up to a score of 100. We further average the score over all auction rounds in a country, thereby providing a simplified quantitative value to compare the compliance packages between different categories. The framework, along with a more detailed explanation is depicted in appendix B.

2.1.2. *Realisation period*

Realisation period is our second indicator to assess effectiveness, which we define as the amount of time from the date the auction result was announced (the 'award date') to the date a project is commissioned. We distinguish between the 'granted realisation period', which is the amount of time it should have taken a project to be commissioned as stipulated in the bidding rules, and 'actual realisation period', which is the amount of time it actually has taken for the project to be commissioned starting from the award date. The average realisation period of an auction round is found by taking the (unweighted) average over the realisation periods of all individual projects. We evaluate the actual realisation period against the granted realisation period to identify delays or early realisations, and draw conclusions about the influence of the duration of the granted realisation period on project completion time. Furthermore, we explore project size as an explanatory factor for differences in realisation periods.

2.1.3. *Price outcomes compared to cost estimates*

For the systematic comparison of auction price outcomes (weighted average strike prices) across countries and auction rounds, we compare average auction prices with the global average Levelised Cost of Electricity (LCOE) for the specific technologies. We gather data on average bid prices of individual projects, and weigh them with their respective project capacity to obtain weighted average auction prices in EURct/kWh per auction round. These are then compared with the global, inflation-adjusted, LCOE average for the respective technology obtained from IRENA's database (IRENA, 2020). This way, we can both identify trends over time and draw cross-country comparisons. Additionally, we explore the influence of subscription rate as a measure of competition level, which we calculate for each auction round by dividing the total volume of submitted bids by the total awarded volume, which in most cases corresponds to auctioned volume. Volume can here refer to either capacity (MW), energy (MWh), or budget (EUR), depending on the auctioned product (see Table 2). A subscription rate of more than one represents oversubscription, meaning that there were more bids than could be awarded, creating a competitive situation, while a subscription rate of less than one corresponds to undersubscription, with little or no competitive pressure between bidders. Finally, we discuss the impact of competition as well as other more external factors, including sovereign credit risk ratings, on the auction price outcomes.

Table 1
Measures and sub-measures considered in our compliance incentivisation framework. More detailed explanation, the scoring system, and compliance package scores for our investigated auction rounds in each category can be found in Appendix B.

Measures	Sub-measures
Material prequalification	• Environmental permit • Building permit • Land ownership or permission • Grid connection agreement • Business plan • Feasibility study/Specification of installation • Binding letter from lenders • Eligibility of site • Construction/development plan • Water use permit
Financial Prequalification	• Existence of bid bonds • Bid bond amount (EUR/kW)
Penalties	• Cancellation of support contract upon non commissioning • Sanction/Exclusion from participation • Fixed penalties -completion bonds • Reduction of support level • Reduction of support duration
Compliance monitoring	• Monitoring of development status of the project (soft monitoring, under special circumstances, or regular obligatory monitoring; obligation to periodically submit status reports)

Table 2
Countries and auction design features relevant for the analysis.

Country	Auction scope, conducted since	Auction Rounds conducted	Auction Rounds with commissioning deadline passed	Remuneration Form	Support Duration [years]	Selection Criteria	Pricing Rule	Volume/ Product	Auctioned Volume
Netherlands	Multi-Tech, 2012	11	6	Sliding FIT	15	Price only	Pay-as-bid	Budget	54 Billions EUR
France	PV, 2011	9	6	Sliding FIT (After 2016 auctions), FIT (before 2016)	20	Price (65–70%), carbon impact (18–30), others	Pay-as-bid	Capacity	5570 MW
	Wind, 2017	4	–	Sliding FIT		Price only			2000 MW
	Multi, Tech - 2018	1	–	Sliding FIT		Price only			200 MW
Germany	PV, 2015	17	9	Sliding FIT	20	Price only	Pay-as-bid	Capacity	3550 MW
	Wind, 2017	13	2						9185 MW
	Multi-Tech, 2018	4	1						800 MW
South Africa	Multi-Tech, 2011	4	3	PPA	20	Price (70%), other (30%)	Pay-as-bid	Capacity	6227 MW*

* 6327 MW has been awarded. This includes 100 MW from the SP-I4P programme.

2.2. Identifying relevant countries for comparison

As we wish to compare the South African renewable energy auction programme with European ones, we first need to establish which European countries should be considered in the comparative analysis. For this, we define several selection criteria. First, only those countries can be considered where auctions are the primary support mechanism for solar PV and onshore wind projects. Here we focused on projects with capacity greater than 1 MW. Second, relevant (project-specific) data must be available for at least two auction rounds for which the deadline for project commissioning had passed by 2020. The three European countries that satisfy the above-mentioned criteria are Germany, France and the Netherlands. We also included Greece and Poland when analysing auction price outcomes as sufficient data is available on overall prices for the two countries.

Many European countries started to implement auctions from 2014, after the new EU guidelines for State Aid came into force (European Commission, 2014; Tews, 2015), with the notable exception of the Netherlands and France. The Netherlands made the switch to the competitive sustainable energy transition subsidy scheme (SDE+) in 2011. The SDE+ auctions take place in multiple phases with a gradual increase in ceiling price in subsequent phases within each auction round. Since 2016, auctions are conducted twice a year. In France, auctions have been a primary instrument since 2011, mainly for solar PV. Initially, the solar auctions were differentiated between medium (100–250 kWp) and large installations (>250 kWp). Since 2016, auctions are conducted separately for rooftop and ground-mounted installations. The applicable remuneration scheme was initially a feed in tariff, ultimately evolving into a sliding premium scheme in later auction rounds (where support is paid as a variable premium between the market price and the guaranteed support, see definition in Kitzing et al., 2012), along with special conditions granted for investment grants, tax incentives, and bonus for crowdfunded projects. Auctions for onshore wind were implemented relatively late, in 2018. So far, four onshore wind auctions have been conducted in France.

Germany, a global pioneer in the use of FITs, made the switch to competitive auction schemes gradually, being subjected to increasing pressure, both domestically through concerns about increasing cost, and at European level through the new State Aid guidelines and related policy (Leiren and Reimer, 2018). After the first pilot auction in April 2015 for solar PV, competitive auctions became the primary renewable support instrument in 2017 with the implementation of onshore wind auctions. Most German auctions are technology-specific and held multiple times a year with a pre-defined schedule. Since 2018, multi-technology auctions were added in which onshore wind and solar PV can participate, and which are conducted twice each year.

South Africa is among the early adopters of auctions to procure renewable electricity. Auctions for large (‘utility scale’) installations are conducted within the REI4P launched in 2011. There have been four multi-technology auction rounds – or bidding windows – as well as a special round for concentrated solar power (CSP). Parallel to REI4P, the Small Projects IPP Procurement Programme (SP–I4P) was launched for smaller installations below 5 MW (Eberhard and Kåberger, 2016). Unlike European countries, where renewable energy support payments are independent of electricity sales, South Africa has no wholesale electricity market, and auction winners (the awarded IPPs) sign 20-year Power Purchase Agreements (PPAs) with the vertically integrated utility ESKOM.

2.3. Data collection process and data treatment

Most data on auction designs for European countries have been gathered from the AURESII database (AURES II, 2020). South African data was provided by the Department of Minerals and Energy’s IPP office, as well as the National Energy Regulator (NERSA). Data on European auction outcomes, including awarded bid price, name of projects and developers, bid numbers and bid volumes, have been found on the websites of the official entities responsible for conducting the auctions (in most cases the national energy regulator). Further, for Germany and Netherlands, data on realisation rates and commissioning dates of the awarded projects have been obtained from publicly available official monitoring data, while for France these data have been obtained from grid connection data registers, available on the website of TSOs In the latter case, grid connection dates are used as a proxy for project commissioning date. Realisation rates have been calculated by aggregating the identified commissioned projects and then comparing it to the officially announced total number of projects awarded after each auction round. Appendix A explains the diverse data sources along with key information extracted. Notably, while the approximation approach for France based on grid connection data enabled us to estimate realisation periods for individual projects, it was impossible for the most recent three French PV auction rounds with passed realisation deadline to estimate the overall realisation rate per auction round, as the grid connection register has many projects marked as confidential, so that those projects that did not achieve grid connection (and were cancelled) could not be correctly identified.

To determine subscription rates, we include all auction rounds that have been conducted until the end of 2020 in our focus countries. In the Netherlands and South Africa, all auction rounds are multi-technology auctions. Here, each auction round has been separated into data related to PV bids and data related to onshore wind. For the Netherlands, subscription rates have been separately determined for onshore wind and PV. For South Africa, the subscription rates of the overall auction round are used, due to lack of data on total bids submitted for each technology (PV and onshore wind). Multi-technology auctions in countries other than the Netherlands and South Africa have been won by PV only, so these auction rounds are here classified as PV auctions.

The analysed auctions have taken place in different countries with different currencies and over a relatively long time period. Hence, to achieve comparability, all prices have been inflation-adjusted by using country specific Consumer Price Indices (CPI) (Department of Statistics South Africa, 2021; International Monetary Fund (IMF), 2020), with 2019 as reference year, and then converted to Euros using yearly average conversion rate (European Central Bank (ECB), 2020; Reuters, 2020).

3. Results

We present the results of our analysis and main observations in two subsections. First, we analyse effectiveness and evaluate auction outcomes with regard to realisation rates and realisation periods. We explore the relation between realisation periods and project size and between granted and actual realisation periods. We then investigate if compliance incentivisation has an influence on realisation rate. The second subsection deals with efficiency and auction outcomes with regard to prices. We explore if subscription rate – as a measure of competition level - has an influence on price outcomes, and if differences in country conditions and risk profiles have caused different price outcomes.

3.1. Realisation rates and realisation periods diverge considerably across countries

First, we analyse effectiveness and evaluate auction outcomes with regard to realisation rates and realisation periods. Table 3 gives an aggregate overview of all applicable auction round outcomes studied in this paper.

Fig. 1 depicts graphically the auction rounds on a timeline along with the commissioning of each individual project that was awarded support. Projects that are not realised are not shown.

Our first observation is that South African projects have longer realisation periods than their European counterparts. South Africa has also achieved remarkably high realisation rates as compared to the more mixed results in most European auctions. This merits further analysis of the underlying drivers behind the differences, which we explore in the following two sub-sections.

3.1.1. Realisation periods depend on project size

Project size could impact the realisation period since larger project can reasonably be expected to take longer to construct. We thus investigate the relationship by disaggregating actual realisation periods into different project size ranges, as shown in Fig. 2.

For PV, the average realisation periods disaggregated according to project size reveals that European projects are typically much smaller than those in South Africa. The Netherlands and France have a similar realisation period for the smaller size category, in which most of their projects belong. South African projects in the same size category have similar realisation periods as those from the Netherlands and France. The short realisation periods of PV projects in Germany may be seen as an outlier, as they may be partially attributed to dispensable permitting requirements, i.e. PV projects did not need to participate in lengthy permitting processes (Wong, 2019). Leaving the German PV projects aside, one can see a trend of increasing realisation periods with larger project sizes – a trend in which South Africa falls in line with Europe.

For onshore wind, there are only few European countries with auction rounds for which the realisation deadline has passed. Again, Germany has considerably shorter realisation periods, which could be due to several reasons: Germany has experienced low subscription rates and increasing prices in consecutive auction rounds. The low realisation rates could be an indicator that mature, late-stage projects started to re-enter subsequent auctions to capture higher support levels, and therefore could realise exceptionally short realisation periods. Furthermore, a large share of the winning projects in some German auction rounds were community-owned, with a prolonged granted realisation period. Most of these projects do not enter our statistics on average realisation periods, as the individual realisation period has not passed yet. However, it is deemed highly unlikely that integrating these projects will change the result much as some of the projects were already resubmitted in subsequent auction rounds (Lundberg, 2019). Across all countries, we can identify a clear general trend indicating a longer realisation period for larger projects, with South Africa featuring the largest projects in the sample.

3.1.2. Actual realisation periods depend to some extent on the granted realisation period

One could expect that project developers have the incentive to capture equipment cost reductions from technology improvements over time. In an auction framework, this could potentially be done by delaying project realisation until the latest possible date without risking penalty payments. This effect would ultimately lead to a convergence of actual realisation period towards granted realisation period, and the longer the granted realisation period, the longer the actual realisation period as well. We hence explore the impact of the granted realisation period against the actual project realisation period, as shown in Fig. 3 for PV projects.

We observe that South Africa grants the longest period to implement PV projects. South Africa even increased the granted realisation period

Table 3
Summary of PV and onshore wind auction rounds (only auctions considered with deadline, passed before end of 2020).

Country	Technology	Number of auction rounds	Realisation rate	Total number of projects (>1 MW) awarded support	Average granted realisation period [months]	Average actual realisation period [months]
Germany	Onshore Wind	2	23.5%	153	44.0	19.3
	PV	10	87.4%	354	21.6	16.5
Netherlands	Onshore Wind	4	74.7%	166	48.0	25.0
	PV	6	85.0%	173	36.0	29.8
France	PV	6	72.7%[a]	225	24.0	23.8
South Africa	Onshore Wind	3	100%	23	45.7	39.9
	PV	3	100%	33	45.7	34.2

[a] For realisation rates in France, data is available for three out of six auction rounds only.

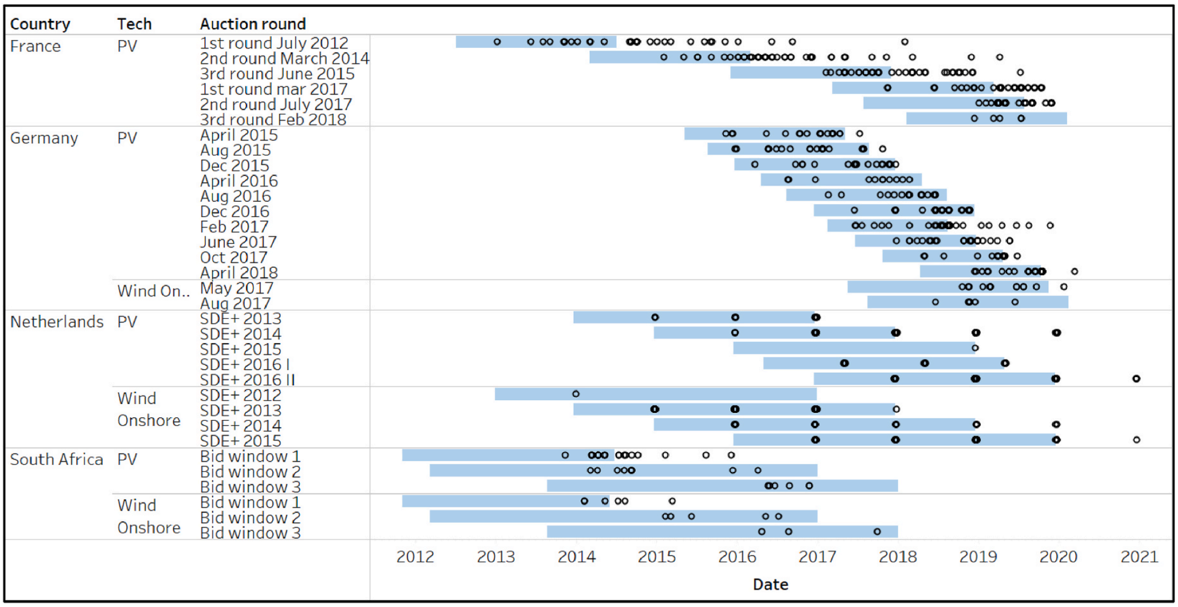

Fig. 1. Overview of different auction rounds considered in this study. Blue bars represent grace period available to develop the project after winning auction. Small hollow circles represent the commissioning of individual projects of respective auctions rounds. Note: For Netherlands, only commissioning year of projects is published instead of an exact date, thus circles have a fixed distance from one another. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

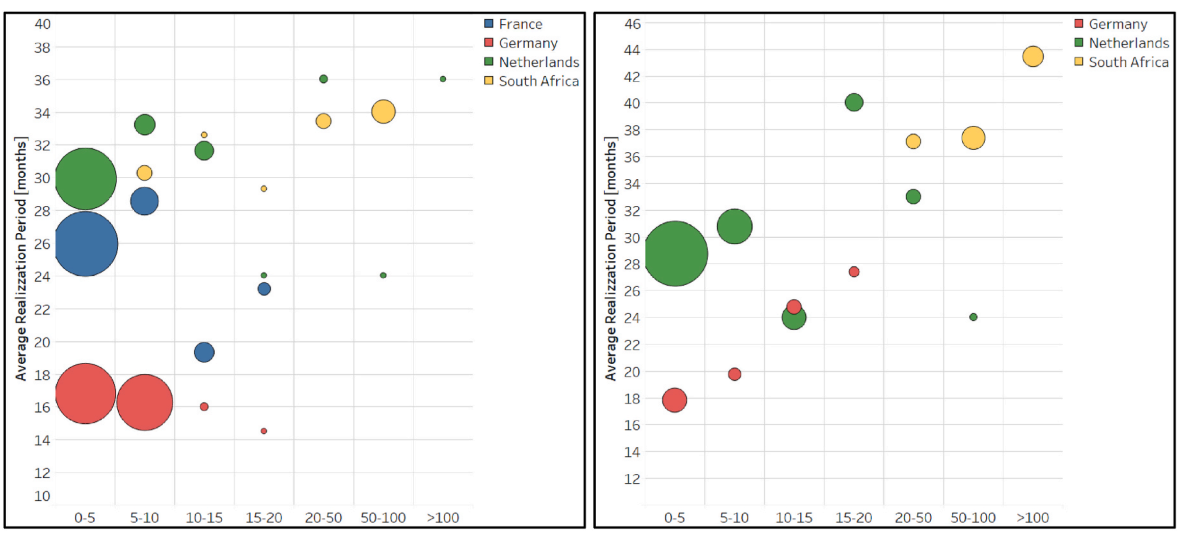

Fig. 2. Average realisation period in months for different size categories for PV projects (left) and onshore wind project (right). The size of bubble represents the number of projects belonging to a particular size category. Size categories are in MW.

for the last two rounds. Interestingly, this did not seem to affect the realisation periods, which are similar across all three rounds. The same observation can be made for Germany, where longer granted realisation periods did not coincide with longer actual realisation periods. A similar observation can be made regarding onshore wind projects, where in South Africa, increasing the granted realisation period had almost no impact on the actual realisation period. Furthermore, actual realisation periods in the Netherlands and Germany are similar, despite a longer granted realisation period in the Netherlands (see Appendix C). Nonetheless, we see a weak general trend towards longer actual realisation periods with longer granted realisation periods when averaging over the whole data sample, as indicated by the trendline in Fig. 3. As the trendline has a slope of less than one, we cannot conclude that developers delay projects toward the realisation deadline, which would imply that *relative* project commissioning should be stable, i.e. that projects are typically commissioned a certain number of days before the granted realisation deadline. In the following, we investigate this relative commissioning in more detail.

3.1.3. *Longer granted realisation periods see earlier relative commissioning*

Fig. 4 and Fig. 5 show actual project realisation periods of each auction round relative to their granted realisation periods. Positive

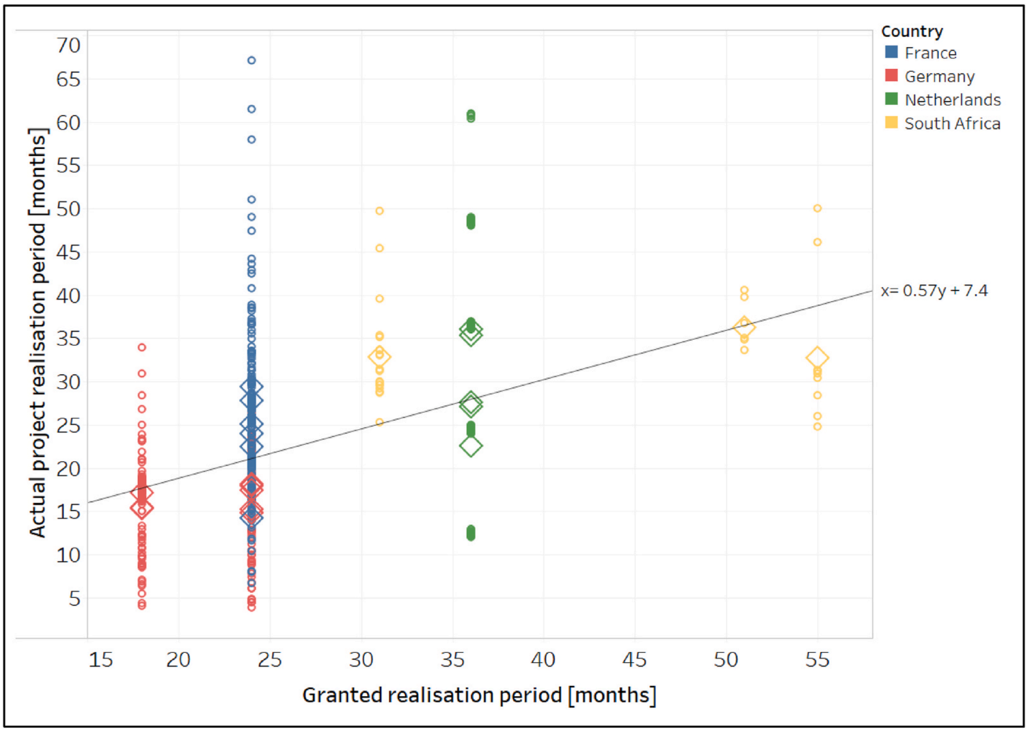

Fig. 3. Actual project realisation periods vs. granted realisation periods in PV auctions. Circles represent individual project commissioning; rhombus shows the average project commissioning per auction round. Colours distinguish different countries. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

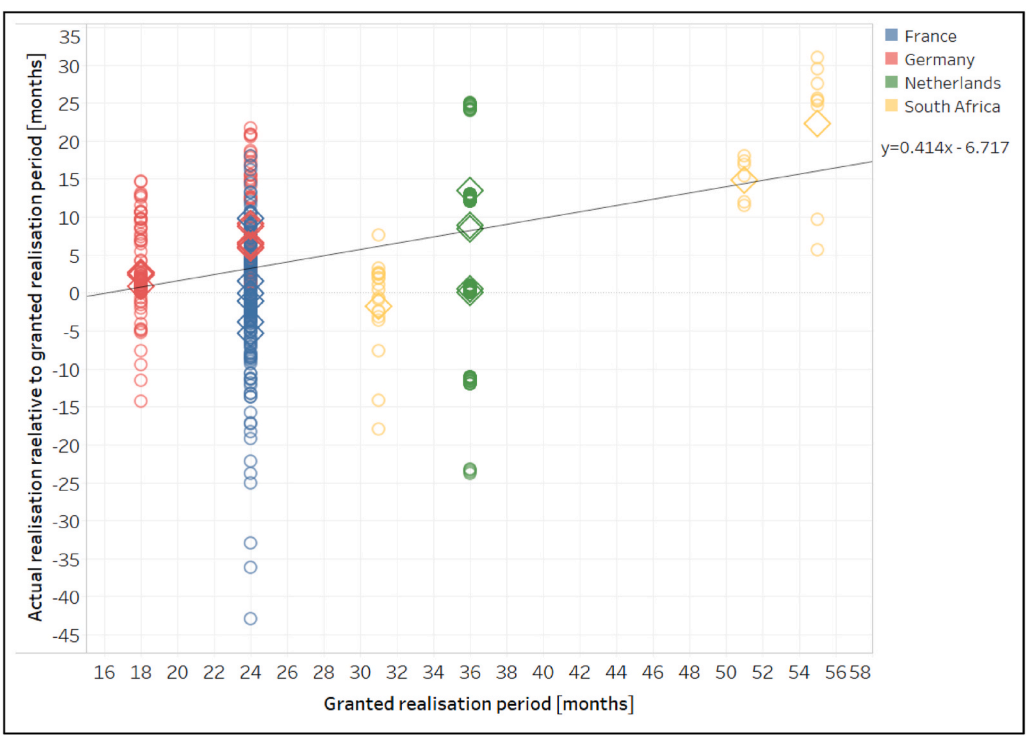

Fig. 4. Actual realisation period relative to granted realisation period for PV auctions. Circles represent individual project commissioning; rhombus shows the average project commissioning per auction round. Colours distinguish different countries. Positive values on y-axis represent earlier project commissioning while negative values represent late project commissioning. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

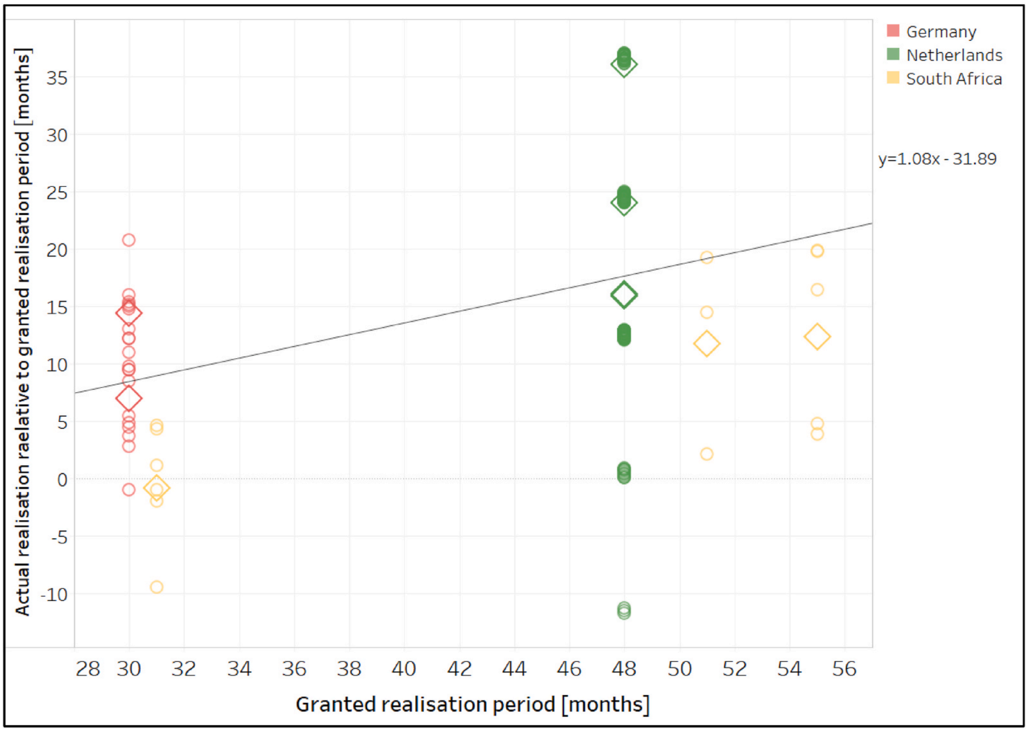

Fig. 5. Actual realisation periods relative to granted realisation periods for onshore wind auctions. Circles represent individual project commissioning; rhombus shows the average project commissioning per auction round. Colours distinguish different countries. Positive values on y-axis represents earlier project commissioning while negative values represent late project commissioning. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Compliance package classification with average realisation rate (in percent) for PV and onshore auctions. 'Overall compliance package score' represents the overall strictness score of the respective compliance package out of 100.

	Material Qualification Strictness			Financial qualification		Compliance monitoring strictness			Penalties Strictness			Overall Compliance Package Score
	Lenient	Moderate	Strict	Lenient	Strict	Lenient	Moderate	Strict	Lenient	Moderate	Strict	
SOLAR PV												
Germany	89.2				89.2	89.2			96		79	40
France			72.7	73			72.7		72.7			31
Netherlands	44.7	75.8		72			71.9		56.7	75.8		33
South Africa			100		100			100			100	85
Average	66.9	75.8	86.2	72.5	94	89.2	72.3	100	75	75.8	89.5	–
ONSHORE WIND												
Germany	23.5				23.5	23.5				23.5		28
Netherlands	90.9	82.8		86.9			86.9		90.9	82.8		31
South Africa			100		100			100			100	85
Average	57.2	82.8	99.7	61.6	86.9	23.5	86.9	99.7	90.9	53.2	99.7	–

values on the vertical axis represent earlier commissioning compared to the contracted deadline, while negative values represent a delayed average commissioning.

We observe that for most of the auction rounds (both PV and wind), projects are typically completed before the deadline has passed. In South Africa, PV projects in the last two rounds, for which the realisation deadline period was increased, are completed long before the deadline, with an average early commissioning of 15 and 23 months, respectively. PV projects in France suffer more delays, which may be due to delays in grid connection licenses (Bayer et al., 2018).

A possible factor in the much earlier commissioning of PV projects in South Africa is that projects are paid 60% of the bid tariff for energy delivered before their scheduled commercial operation date, while the duration of the main off-take contract (PPA) remains unchanged. This acts as a powerful incentive for earlier commissioning, as it effectively prolongs the length of the PPA, thereby increasing overall returns for investors (Eskom Holdings SOC limited, 2014).

Wind onshore projects in South Africa are completed closer to the deadline when compared with the European countries, as shown in Fig. 5. In South Africa, wind projects take on average about 40 months to commission compared to 25 and 19 months in the Netherlands and Germany, respectively. This translates into wind projects being commissioned 24 and 23 months earlier in Germany and the Netherlands, respectively, as compared to 6 months early in South Africa. One explanation for this could be that all countries have comparable granted realisation periods for wind onshore. South Africa, however, does have larger projects for wind onshore, which we have found to coincide with an increased actual realisation period (see Fig. 2).

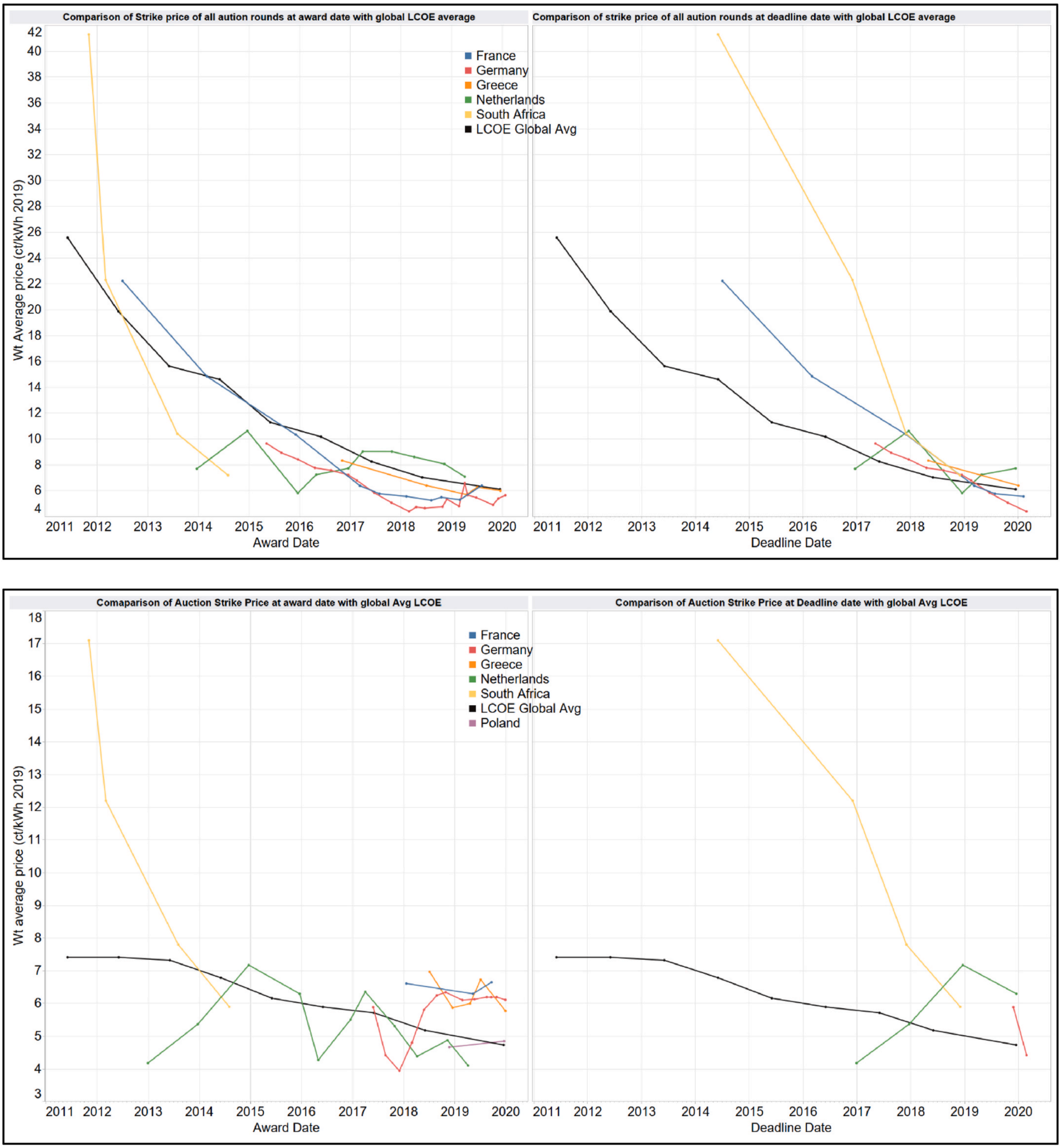

Fig. 6. Price outcomes of auctions in different countries compared with global LCOE average for PV (upper panel), and for onshore wind (lower panel). Comparisons are made between LCOE numbers at the date of award (left panel) and at the date of deadline (end of granted realisation period) (right panel).

Increasing the project realisation deadline in the last two rounds in South Africa has led to no projects being delayed for both PV and onshore wind.

Overall, our analysis indicates that the actual realisation period tends to depend more on the size of project rather than the granted realisation period.

3.1.4. Compliance incentivisation seems to have a strong influence on realisation rate

We now turn to analysing realisation rate, by means of identifying the overall compliance package provided in a particular auction round. Table 4 presents the results of compliance package components classification (as discussed in sub-section 2.3.1) along with corresponding average realisation rate for PV and onshore wind auctions, respectively.

The PV auctions in Germany show a high realisation rate with relatively little regulatory control on material qualification and compliance monitoring, but with strict financial qualifications and penalties. Since 2017, two important changes were made in the PV auction design: the reduction of granted project realisation period from 24 to 18 months, and making penalties more punitive. These changes coincide with an observed negative trend in realisation rate. Three out of four rounds subjected to such change show high realisation rate (84%–99%) while only one show a realisation rate of 35% ultimately bring the overall realisation rate to 79% (see Appendix D). For France, data on realisation rates are only available for auction rounds that were conducted before 2016. While substantial changes were made for PV auctions after 2016, their impact cannot be studied due to limited data availability. Overall, France has, in contrast to Germany, chosen relatively strict material qualification criteria and compliance monitoring, but lenient financial qualification and penalties. The realisation rates for PV achieved in France are relatively low. Difficulty in obtaining grid connection has been identified as a prominent hurdle towards an even higher realisation rate in France (Bayer et al., 2018). Like in Germany and France, the Netherlands have, after experiencing low realisation rates for PV projects, had a change in compliance package with focus on making material qualifications and penalties stricter to improve the realisation rate (Jakob et al., 2019). South Africa, on the other hand, is the only country with a 100% realisation rate for PV auctions, likely in part due to the strictness of the compliance package.

For onshore wind auctions, Germany has an even more lenient compliance package, where only penalties can be classified as strict. At the same time, realisation rates are low. This is likely related to special privileges for community owned wind farms, increasing strike prices in consecutive auction rounds, and strategic, bidding behaviour (Lundberg, 2019), as also mentioned above. For the Netherlands, it seems at first that a stricter compliance package can be associated with lower realisation rates. However, the average 90.9% realisation rate during lenient compliance regime stems from two auction rounds with 100% and 81.8% realisation rates, respectively. It is interesting to note that the first auction rounds with 100% realisation rate only contains one project, so the statistical relevance of the first auctions is limited. South Africa, yet again, has a strict compliance package with a 100% realisation rate.

The Netherlands and France are the only two countries in our analysis with no requirement for bid bonds. The Netherlands have no requirement for completion bonds either. In South Africa, bid bonds are priced at almost half the value of those in Germany. In Germany, even the community cooperatives for onshore wind (which benefit from many exemptions) are required to submit half of the bid bonds as compared to non-cooperatives. Completion bonds are in South Africa again priced at almost half the price as compared to European counterparts.

South Africa stands out in terms of material qualification, as it goes beyond the standard project development requirements, and also includes a signed letter from debt and equity investors confirming that they have completed due diligence on the project and that they are committed to provide funding on the stipulated terms. This is likely a key reason for the high realisation rates in the country's auctions.

The overall score confirms the clear difference of compliance package regimes in South Africa and European countries. Although European countries in some selected auctions have been able to achieve relatively high realisation rates with comparatively lenient regulatory measures, often the auctions have only been moderately effective.

Acknowledging the rather limited amount of data that we operate with, we observe that there is a general tendency towards higher realisation rates with an overall stricter compliance package. This trend seems more prominent for PV auctions, where we also have more data available.

Table 5
Overview of auction price outcomes and level of competition (subscription rate), averaged per country, technology and year (for detailed overview per auction round, see Appendix D).

Country	Tech	Auction Year	Average subscription rate	Average Strike Price ct/kWh
Germany	PV	2015	3.8	9.0
		2016	3.1	7.5
		2017	3.1	5.9
		2018	2.3	4.8
		2019	3.0	5.5
	Wind	2017	2.7	4.8
		2018	1.0	5.8
		2019	0.6	6.2
Netherlands	Wind	2012	180.0	7.6
		2013	1.1	4.3
		2014	2.1	4.8
		2015	1.3	6.4
		2016	5.1	5.2
		2017	1.2	6.0
		2018	1.3	4.6
		2019	1.0	–
	PV	2012	7.0	5.3
		2013	1.8	1.8
		2014	1.5	7.5
		2015	1.3	5.9
		2016	3.2	7.4
		2017	1.2	8.9
		2018	1.3	8.3
		2019	1.9	–
France	PV	2011	4.2	22.2
		2013	4.3	14.8
		2014	3.0	10.3
		2017	3.7	6.1
		2018	1.8	5.4
		2019	1.2	5.9
	Wind	2017	1.8	6.6
		2018	0.5	–
		2019	1.7	6.5
South Africa	PV	2014	0.6	41.3
		2016	2.5	22.3
		2017	4.1	10.4
		2018	2.0	7.2
	Wind	2014	0.6	17.1
		2016	2.5	12.2
		2017	4.1	7.8
		2018	2.0	5.9

3.2. Auction price results per country compared to the respective average LCOE

We now evaluate the efficiency of auction rounds in terms of auction price outcome in comparison with the global average LCOE. Fig. 6 shows

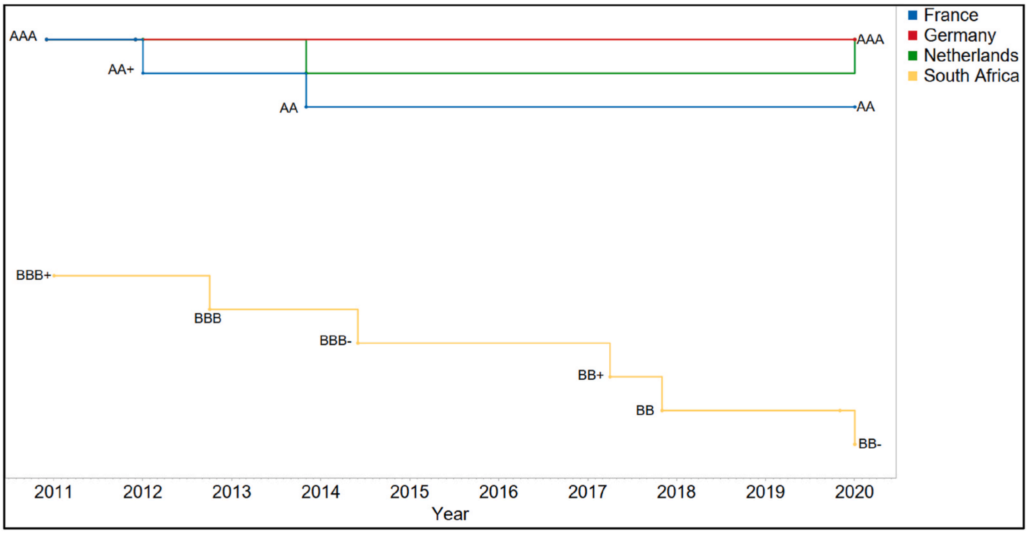

Fig. 7. Country Credit ratings by Standard&Poor's, own illustration based on Standard & Poor (2020).

auction price outcomes across auction rounds where commissioning deadlines have passed and for those with auction rounds conducted until end of 2020 (adding Greece and Poland into the comparison) converted to EURct/kWh 2019, and makes the comparison to global average LCOE.

We observe that especially in recent years, auction price outcomes are converging with the global average LCOE. South Africa shows a sharp price decrease in its consecutive auction rounds, which is quite unlike the investigated European countries, where auction price outcomes can be better described as meandering. It should be noted, though, that the South African auctions were conducted earlier than most auctions in EU countries and that prices in the first two rounds were high, presumably due to low competition levels (Kruger et al., 2021).

In South Africa's fourth auction round, PV auction prices seem to have dropped below the global average LCOE. However, this is not the case when using the deadline date as basis for comparison rather than the award date. The former may be the more reasonable choice for comparison, considering the fact that LCOE are typically determined ex-post (from commission date) and that auction bidders may have had access to equipment quotations that only later materialise in LCOE averages.[1]

The early Dutch auctions showed low price outcomes for both PV and wind onshore. They were actually significantly lower than the global LCOE at the time. This is more prominent for PV auctions. In later auction rounds, prices increased above the global LCOE average, which is quite unlike the development in other countries, and otherwise only seen for onshore wind in Germany in the most recent auctions.

In general, the auction price outcomes for PV seem to be more aligned with the global LCOE average and its general trend over time. This may be related to a more global market for equipment and fewer locational factors that influence overall cost, but is likely also influenced by the level of competition present in the auctions. We hence investigate impact of competition levels in the next section, by analysing subscription rates.

3.2.1. *Subscription rate seems to have an influence on price efficiency*

Table 5 presents average subscription rates alongside the price outcomes for all relevant auction rounds.

To evaluate the statistical relationship between subscription rate and price outcome, we first control for a general trend of decreasing cost over time by calculating the difference between price outcome and LCOE at the time. Here, two scenarios are possible: 1) LCOE at the award date; 2) LCOE at the deadline date. For both scenarios, we create a correlation matrix across all our data points on the subscription rate and auction outcome/LCOE differential. We observe some correlation between subscription rate and auction price outcome for both scenarios. The first scenario has correlation values of −0.43 and −0.33 for PV and onshore wind respectively, while the correlation values for the second scenario are −0.41 and −0.54. The correlation matrix can be found in appendix E. It has to be noted that the second scenario has limited data points available due to the fact that only those auction rounds can be analysed for which the deadline has passed. Nonetheless, the values found here suggest some correlation between subscription rate and auction price/LCOE differential.

It should be noted that competition levels are not merely determined by the number of bidders (e.g. quantitatively determined based on subscription rate), but also the relative strength or quality of bidders (Ballesteros-Pérez et al., 2016; Mora Alvarez et al., 2017). Bigger, more experienced bidders can for example drive down project prices through using economies of scale; accessing corporate finance; negotiating better terms with equipment suppliers, financiers and service providers; integrating more parts of the value chain to diversify revenue streams; and bidding portfolios of projects. We see this dynamic play out in South Africa's fourth round of bidding, where larger multinational companies (incl. European utilities) entered the market and submitted aggressively priced bids to secure large shares of the auctioned volumes (Kruger et al., 2021), potentially offsetting an impact by the lower number of bids noted in Table 5.

Auction price outcomes are likely also influenced by factors other than competition level. Factors of particular interest for our cross-country comparative study are different country conditions and risk profiles associated with investments, which we know can significantly influence both LCOE and auction prices, especially for capital-intensive renewable energy projects (Egli et al., 2018). We explore this thought further in the following.

3.2.2. *Similar price outcomes despite different country conditions and risk profiles*

The countries analysed in this study fall broadly into two categories, with European countries in the first category with stable economic conditions and South Africa in the other with more challenging

[1] It should be mentioned here that the stipulated date of financial close could be the more appropriate date to use for such comparison, but due to unavailability of data, this was not poosible here.

economic conditions. Challenging economic conditions can impact the risk associated with investments in renewable energy projects, thus increasing the risk-adjusted cost of capital, resulting in more expensive projects (Dobrotkova et al., 2018). A look at country credit ratings, as depicted in Fig. 7, illustrates the continuously deteriorating country risk situation in South Africa, while the European countries have a long-term stable outlook with the highest ratings.

Interestingly, South Africa's consecutive credit rating downgrades coincided with a sharp decline in auction price outcomes (see Fig. 6). While one would expect lower country credit ratings to translate into more expensive debt, and thus more upward pressure on project prices, the opposite seems to have happened. This can partly be due to the fact that the majority (90+%) of project debt was being provided by local South African banks, who – in large part because project tariffs were denominated in local currency (South African Rand) – were not pricing debt based on the country's credit ratings. In addition, the auctions included a 40% local ownership requirement, effectively diluting the impact of foreign equity on project prices. These results also seem to indicate that competition levels played a more decisive role in determining South Africa's auction price outcomes.

4. Discussion

The differences between South Africa and Europe are substantial and multi-layered, and go far beyond the factors investigated above. The overall conditions of the renewable energy market are almost diametrically different between South Africa and the European counterparts. Renewable energy markets in Europe have matured over long periods under the protection of feed-in tariffs before auctions were introduced. South Africa had no prior support scheme for renewable energy in place before auctions were introduced, leaving the emerging sector with a wealth of uncertainties and risks. Also, secondary policy objectives diverge between South African and European policy makers. In Europe, renewable energy is mostly procured to bring down carbon emissions of an already stable and reliably operating energy system. The South African government has an explicit desire to both procure low-cost energy and promote local socio-economic development (Eberhard and Kåberger, 2016), which are strong arguments for implementing auctions (rather than feed-in tariffs), as they feature immediate competitive price formation, typically lower support cost, and more options to incorporate multiple selection criteria (Becker and Fischer, 2013).

South Africa is further dealing with inadequate power generation capacity, making a high realisation rate in renewable auctions paramount. These conditions influenced the design and implementation of the country's renewable energy auctions. Indeed, stricter compliance packages in South Africa as compared to European countries appear to have contributed to high auction effectiveness. Then again, South Africa's strict compliance package is also partly responsible for the low competition levels in the first auction rounds, thereby contributing to relatively high price outcomes (Eberhard and Naude, 2016).

The unit size (capacity) of projects adds another interesting dimension to the discussion of compliance package and its impact on effectiveness. We found a notable difference between South Africa and European countries, with South African projects being much larger. The smaller European projects might present a hurdle for stricter compliance packages, potentially inducing excessive transaction costs. Often, the smallest projects involve citizens rather than professional energy companies, which may make strict compliance requirements less manageable or acceptable.

Interesting questions for further investigation in this regard may be: why do European countries accept the relatively low realisation rates?; could there be any merit in moving compliance packages closer to the South African model?; and which barriers (regulatory, economic, cultural, or other) would prevent countries from doing that? It is also worth investigating whether the continued use of such a strict compliance package is still warranted in South Africa, given the high realisation rates and relative maturation of the sector.

We acknowledge that our framework to compare various components of the compliance package is simplified. We did not differentiate between different types of material qualifications, which are rather diverse across the countries with different requirements and administrative procedures for permits and licenses. Our framework does not differentiate between the size of bid bonds and completion bonds. South Africa, for example, only requires around half of the financial commitment as compared to European countries. Similarly, penalties are simplified in our framework as we do not disaggregate different measures (such as one-off payments, support reductions or auction exclusions) or different magnitudes (varying from few months to several years). Furthermore, penalties are not always enforced, which we did not consider for this study.

Our findings related to realisation periods are noteworthy. One could have expected that bidders, in their pursuit of minimising bids and maximising profits, would tend to strive for an actual realisation period that is close to the granted realisation period, e.g. to benefit from the downward cost trend of renewable energy technologies. With annual technology cost reductions between 12% and 23% (Rubin et al., 2015), the planned postponing of equipment purchases to the absolute last possible moment would seem to provide a considerable competitive advantage for bidders. In reality, we observed that early commissioning of projects, even of more than a year ahead of time, is not uncommon. There seems to be only a weak relation between granted and actual realisation periods – within some countries, we even observed similar actual realisation periods despite prolonged granted periods. Further studies could investigate the reasons behind this observation, which may be related to permitting and contracting restrictions, or business practices and portfolio optimisation by the renewables industry.

5. Conclusion and policy implications

Competitive auctions for the procurement of renewable energy are on a triumphant advance across the world. In fact, they are becoming equally popular in countries with diverse economic and electricity market conditions. The evolution of auctions as the main mechanism for allocating support for renewable electricity has followed a different path in South Africa than it has in Europe. This made for a compelling and illuminating comparative analysis, which showed that auction schemes can perform comparatively well in different world regions, despite substantial differences in economic and financial conditions. We have conducted a detailed and disaggregated analysis of auction performance in South Africa, Germany, France and the Netherlands (the only three European countries with sufficient data available for comparison) with regard to effectiveness, represented by realisation rates (the share of winning projects that are commissioned) and realisation periods (the time from award to commissioning), as well as efficiency, represented by auction price outcomes as compared to technology cost. We find that auction performance in South Africa is higher than in European countries in regard to realisation rate, comparable in regard to realisation period when considering larger project unit sizes, and also comparable in regard to price outcomes (at least in later auction rounds).

We observed that actual project realisation periods depend mostly on project size, and are only weakly correlated with the granted realisation period. South Africa has an average realisation period of 34 months for PV and 40 months for onshore wind as compared to European countries where the realisation period varies between 16.5 and 30 months for PV and 19 and 25 months for onshore wind. But South Africa also has the largest projects, and all differences are in line with the overall trend that larger projects require longer realisation periods.

Our results suggest that compliance incentivisation has a strong influence on realisation rates. We have developed a framework to assess strictness of an auction scheme's compliance package, consisting of material prequalification, financial qualifications, penalties upon late commissioning and/or non-commissioning, and compliance monitoring.

European countries have achieved only low to moderate realisation rates (23%–87%) with relatively lenient compliance packages, while a stronger compliance package in South Africa has led to 100% realisation rates, despite of an emerging renewable energy sector and deteriorating country credit ratings. We see the high achieved realisation rates in South Africa as a deliberate measure to ensure capacity additions, to mitigate risks, to nurture the emerging renewable energy sector and help tackle power system inadequacy.

South African auctions have the sharpest reductions in auction price outcomes, with 75% for PV and 54% for onshore wind over three rounds, while in European countries similar sharp price reductions are only observed in French PV auctions with 74% price reduction but over six auction rounds. We found some correlation between subscription rate (as a measure for competition in the auction) and price outcome – the higher the competition, the lower the auction price outcome across our data sample. We also found auction price convergence towards global technology cost estimates (LCOE) across all investigated countries, even though South Africa – in contrast to many European countries – is often considered to be a higher risk investment destination, lacking an established renewable energy industry, mature value chains and even a functioning electricity market.

We derive the following policy implications from our analysis: 1) if high realisation rates are paramount, countries would be well advised to adopt strict auction compliance packages – at least during initial auction rounds while the market is being established; 2) generously granted realisation periods do not seem to delay project realisation, nor to be an effective tool for reducing procurement cost for renewable energy. This is especially the case as long realisations periods, when coupled with lenient compliance packages, may induce unwanted strategic behaviour and render the auction itself less effective. Incentivisation towards smaller projects may accelerate commissioning, as they are generally built faster than larger ones; 3) With careful, tailor-made auction design that considers specific country risks, it is possible to achieve prices that converge around the global LCOE, even under challenging country circumstances. This insight supports earlier findings that auction design should be tailor-made to local conditions, encompassing the market realities that they will operate in, and be adjusted to the specific desired outcomes (see also Mora Alvarez et al., 2017). Overall, we conclude that auctions have been successfully – albeit differently - implemented in the two investigated world regions.

Lastly, the data availability on auction participation, awarded projects, price outcomes and subsequent project progress is rather limited in many instances. While most of this data is readily available for South Africa, this is not the case for the European countries. In particular, project commissioning data is not publicly available in France, and cancelled projects are completely removed from the monitoring database in the Netherlands, making the analysis of e.g. realisation rates challenging. Furthermore, there are only few European onshore wind auction rounds with realisation deadline passed. This makes comprehensive analysis for onshore wind auctions difficult. While the latter challenge will solve itself over time, the former can only be mitigated by policy action, e.g. a European initiative on auction data transparency, which surely will be welcomed by many stakeholders in the sector.

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.

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Appendix F. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2022.112999.

Appendix A. Detail of data sources used

Country	Data Source	Information Extracted
Germany	Bundesnetzagentur - Tenders[1]	Awarded bid price, name of project & developer, Competition in terms of bid numbers & bid volumes, realisation rate (only for Solar auctions)
	MaStR market register[2]	Installed capacity of awarded projects (MW), commissioning date
France	French Energy Regulatory Commission (CRE) [3]	Awarded bid price, name of project & developer, capacity of project (MW), awarded volumes
	Ministry of Ecology & Inclusive Transition - Solar portal[4]	Realisation rate of solar auctions conducted before 2016
	French Public Data Platform - National Register of electricity production & storage facilities[5]	Grid connection date of awarded projects (proxy for project commissioning)
Netherlands	The Netherlands Enterprise Agency (RVO) - SDE + Projects under management[6]	Awarded price, name of project & developer, installed capacity (MW), status on commissioning, commissioning year
South Africa	IPP office National Energy Regulator of South Africa	Awarded strike price, name of project and developer, project capacity, delivery year, awarded volumes, competition, project commissioning dates

[1]https://www.bundesnetzagentur.de/EN/General/Bundesnetzagentur/About/Functions/functions_node.html.
[2]https://www.marktstammdatenregister.de/MaStR.
[3]https://www.cre.fr/recherche?search_form%5BcontentType%5D=/1/2/16997/120/17000/.
[4]https://www.ecologique-solidaire.gouv.fr/solaire#e10.
[5]https://www.data.gouv.fr/en/datasets/registre-national-des-installations-de-production-delectricite-et-de-stockage-au-31-decembre-2019/.
[6]https://www.rvo.nl/subsidie-en-financieringswijzer/sde/feiten-en-cijfers/feiten-en-cijfers-sde-algemeen.

Appendix B. Compliance package classification

B.6. Classification of material prequalification

Country	Auction round	Technology	Material Prequalification										Realisation rate %	Material qualification classification	*Score of material pre-qualification
			Environmental permit	Building permit	Land ownership or permission	Grid Connection	Business plan	Feasibility study/ Specification of installation	Binding letter from lenders	Eligibility of site	Construction/ development plan	Water use permit			
Netherlands	SDE+ 2012	PV	x		x							x	32.7	lenient	30
	SDE+ 2012	Wind onshore	x		x							x	100	lenient	30
	SDE+ 2013	PV	x		x							x	56.7	lenient	30
	SDE+ 2013	Wind onshore	x		x							x	81.81	lenient	30
	SDE+ 2014	PV	x	x	x		x	x				x	74.67	medium	60
	SDE+ 2014	Wind onshore	x	x	x		x	x				x	98.2	medium	60
	SDE+ 2015	PV	x	x	x		x	x				x	77.1	medium	60
	SDE+ 2015	Wind onshore	x	x	x		x	x				x	67.4	medium	60
	SDE+ 2016 I	PV	x	x	x		x	x				x	80.95	medium	60
	SDE+ 2016 II	PV	x	x	x		x	x				x	70.3	medium	60
Germany	Feb 2017 PV Auction	PV			x					x	x		98.85	lenient	30
	Jun 2017 PV Auction	PV			x					x	x		96.74	lenient	30
	Oct 2017 PV Auction	PV			x					x	x		35	lenient	30
	Apr 2018 Joint Auction	PV			x					x	x		84.4	lenient	30
	Apr 2015 PV Auction	PV								x	x		99.4	lenient	20
	Aug 2015 PV Auction	PV								x	x		89.9	lenient	20
	Dec 2015 PV Auction	PV								x	x		92	lenient	20
	April 2016 PV Auction	PV								x	x		99.9	lenient	20
	Aug 2016 PV Auction	PV								x	x		96.3	lenient	20
	Dec 2016 PV Auction	PV								x	x		99.1	lenient	20
	May 2017 Wind Auction	Wind onshore	x							x			33	lenient	20
	Aug 2017 Wind Auction	Wind onshore	x							x			14	lenient	20
France	First Round Mar 2017	PV	x	x			x	x		x			–	strict	50

(*continued on next page*)

(*continued*)

Country	Auction round	Technology	Material Prequalification										Realisation rate %	Material qualification classification	*Score of material pre-qualification
			Environmental permit	Building permit	Land ownership or permission	Grid Connection	Business plan	Feasibility study/ Specification of installation	Binding letter from lenders	Eligibility of site	Construction/ development plan	Water use permit			
	Second Round Jul 2017	PV	x	x			x	x		x			–	strict	50
	Third Round Feb 2018	PV	x	x			x	x		x			–	strict	50
	First Round Jul 2012	PV	x	x		x		x					81	strict	40
	Second Round Mar 20014	PV	x	x		x		x					72	strict	40
	Third Round Jun 2015	PV	x	x		x		x					65	strict	40
South Africa	Bid Window 1	PV	x		x	x		x	x	x	x	x	100	strict	80
	Bid Window 2	PV	x		x	x		x	x	x	x	x	100	strict	80
	Bid Window 3	PV	x		x	x		x	x	x	x	x	99	strict	80
	Bid Window 1	Wind onshore	x		x	x		x	x	x	x	x	100	strict	80
	Bid Window 2	Wind onshore	x		x	x		x	x	x	x	x	100	strict	80
	Bid Window 3	Wind onshore	x		x	x		x	x	x	x	x	99	strict	80

Explanation of different sub-categories of Material prequalification.
Business plan: Business plan is broadly used, and includes future expected cash flows, and other supply chain related contracts mainly about supplier of solar panels and/or wind turbines, and other components.
Feasibility study/Specification of installation: This includes assessment of wind or solar resource at the location of project and expected full load hours for wind and thus, specification of renewable plant based on the resource assessment.
Eligibility of site: Sometimes, a separate certificate or license is required for site eligibility, proving that a particular site is not reserved for other purposes or that commercial activities are not restricted.
Construction/development plan: This includes contracts and sub-contracts with project development/construction firms.
***Score of material pre-qualification** = (Sum of sub-regulations that are implemented)/(sum of total sub-regulations) * 100.

B.2. Classification of financial prequalification

Country	Auction round	Technology	Financial prequalification		Realisation rate %	*Score of financial pre-qualification
			Existence of bid bonds	Bid bonds EUR/KW		
Netherlands	SDE+ 2012	PV	No	0	32.7	0
	SDE+ 2012	Wind onshore	No	0	100	0
	SDE+ 2013	PV	No	0	56.7	0
	SDE+ 2013	Wind onshore	No	0	81.81	0
	SDE+ 2014	PV	No	0	74.67	0
	SDE+ 2014	Wind onshore	No	0	98.2	0
	SDE+ 2015	PV	No	0	77.1	0
	SDE+ 2015	Wind onshore	No	0	67.4	0
	SDE+ 2016 I	PV	No	0	80.95	0
	SDE+ 2016 II	PV	No	0	70.3	0
Germany	Feb 2017 PV Auction	PV	Yes	5	98.85	100
	Jun 2017 PV Auction	PV	Yes	5	96.74	100
	Oct 2017 PV Auction	PV	Yes	5	35	100
	Apr 2018 Joint Auction	PV	Yes	5	84.4	100
	Apr 2015 PV Auction	PV	Yes	4	99.4	100
	Aug 2015 PV Auction	PV	Yes	4	89.9	100
	Dec 2015 PV Auction	PV	Yes	4	92	100
	Apr 2016 PV Auction	PV	Yes	4	99.9	100
	Aug 2016 PV Auction	PV	Yes	4	96.3	100
	Dec 2016 PV Auction	PV	Yes	4	99.1	100
	May 2017 Wind Auction	Wind onshore	Yes	30	33	100
	Aug 2017 Wind Auction	Wind onshore	Yes	30	14	100
France	First Round Mar 2017	PV	No	0	–	0
	Second Round Jul 2017	PV	No	0	–	0
	Third Round Feb 2018	PV	No	0	–	0
	First Round Jul 2012	PV	No	0	81	0
	Second Round Mar 20014	PV	No	0	72	0
	Third Round Jun 2015	PV	No	0	65	0
South Africa	Bid Window 1	PV	Yes	9.048	100	100
	Bid Window 2	PV	Yes	9.048	100	100
	Bid Window 3	PV	Yes	9.048	99	100
	Bid Window 1	Wind onshore	Yes	9.048	100	100
	Bid Window 2	Wind onshore	Yes	9.048	100	100
	Bid Window 3	Wind onshore	Yes	9.048	99	100

***Score of financial pre-qualification** = if (Existence of bid bonds = Yes) then 100, else 0. B.3. Classification of penalties.

Country	Auction round	Technology	Penalties					Penalties strictness	Realisation rate %	*Score For Penalties
			cancellation of support contract upon non commissioning	Sanction/ Exclusion from participation	Fixed penalties -completion bonds	Reduction of support level	Reduction of support duration			
Netherlands	SDE+ 2012	PV	x					Lenient	32.7	20
	SDE+ 2012	Wind onshore	x					Lenient	100	20
	SDE+ 2013	PV	x					Lenient	56.7	20
	SDE+ 2013	Wind onshore	x					Lenient	81.81	20
	SDE+ 2014	PV	x	x				Medium	74.67	40
	SDE+ 2014	Wind onshore	x	x				Medium	98.2	40
	SDE+ 2015	PV	x	x				Medium	77.1	40
	SDE+ 2015	Wind onshore	x	x				Medium	67.4	40
	SDE+ 2016 I	PV	x	x				Medium	80.95	40
	SDE+ 2016 II	PV	x	x				Medium	70.3	40
Germany	Feb 2017 PV Auction	PV	x		x	x		Medium	98.85	60
	Jun 2017 PV Auction	PV	x		x	x		Medium	96.74	60
		PV	x		x	x		Medium	35	60

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(*continued*)

Country	Auction round	Technology	Penalties					Penalties strictness	Realisation rate %	*Score For Penalties
			cancellation of support contract upon non commissioning	Sanction/ Exclusion from participation	Fixed penalties -completion bonds	Reduction of support level	Reduction of support duration			
	Oct 2017 PV Auction									
	Apr 2018 Joint Auction	PV	x		x	x		Medium	84.4	60
	Apr 2015 PV Auction	PV			x			Strict	99.4	20
	Aug 2015 PV Auction	PV			x			Strict	89.9	20
	Dec 2015 PV Auction	PV			x			Strict	92	20
	Apr 2016 PV Auction	PV			x			Strict	99.9	20
	Aug 2016 PV Auction	PV			x			Strict	96.3	20
	Dec 2016 PV Auction	PV			x			Strict	99.1	20
	May 2017 Wind Auction	Wind onshore	x		x			Medium	33	40
	Aug 2017 Wind Auction	Wind onshore	x		x			Medium	14	40
France	First Round Mar 2017	PV			x	x		Medium	–	40
	Second Round Jul 2017	PV			x	x		Medium	–	40
	Third Round Feb 2018	PV			x	x		Medium	–	40
	First Round Jul 2012	PV			x			Lenient	81	20
	Second Round March 20014	PV			x			Lenient	72	20
	Third Round Jun 2015	PV			x			Lenient	65	20
South Africa	Bid Window 1	PV	x		x		x	Strict	100	60
	Bid Window 2	PV	x		x		x	Strict	100	60
	Bid Window 3	PV	x		x		x	Strict	99	60
	Bid Window 1	Wind onshore	x		x		x	Strict	100	60
	Bid Window 2	Wind onshore	x		x		x	Strict	100	60
	Bid Window 3	Wind onshore	x		x		x	Strict	99	60

***Score of Penalties** = (Sum of sub-penalties that are implemented)/(sum of total sub-penalties) * 100.

B.4. Classification of compliance monitoring

Country	Auction round	Technology	Compliance monitoring classification*	Realisation rate %	Score for compliance monitoring
Netherlands	SDE+ 2012	PV	Medium	32.7	50
	SDE+ 2012	Wind onshore	Medium	100	50
	SDE+ 2013	PV	Medium	56.7	50
	SDE+ 2013	Wind onshore	Medium	81.81	50
	SDE+ 2014	PV	Medium	74.67	50
	SDE+ 2014	Wind onshore	Medium	98.2	50
	SDE+ 2015	PV	Medium	77.1	50
	SDE+ 2015	Wind onshore	Medium	67.4	50
	SDE+ 2016 I	PV	Medium	80.95	50
	SDE+ 2016 II	PV	Medium	70.3	50
Germany	Feb 2017 PV Auction	PV	lenient	98.85	0
	Jun 2017 PV Auction	PV	lenient	96.74	0
	Oct 2017 PV Auction	PV	lenient	35	0
	Apr 2018 Joint Auction	PV	lenient	84.4	0
	Apr 2015 PV Auction	PV	lenient	99.4	0
	Aug 2015 PV Auction	PV	lenient	89.9	0
	Dec 2015 PV Auction	PV	lenient	92	0
	Apr 2016 PV Auction	PV	lenient	99.9	0
	Aug 2016 PV Auction	PV	lenient	96.3	0
	Dec 2016 PV Auction	PV	lenient	99.1	0
	May 2017 Wind Auction	Wind onshore	lenient	33	0
	Aug 2017 Wind Auction	Wind onshore	lenient	14	0
France	First Round Mar 2017	PV	Medium	–	50
	Second Round July 2017	PV	Medium	–	50
	Third Round Feb 2018	PV	Medium	–	50
	First Round Jul 2012	PV	Medium	81	50
	Second Round March 20014	PV	Medium	72	50
	Third Round June 2015	PV	Medium	65	50
South Africa	Bid Window 1	PV	Strict	100	100
	Bid Window 2	PV	Strict	100	100
	Bid Window 3	PV	Strict	99	100
	Bid Window 1	Wind onshore	Strict	100	100
	Bid Window 2	Wind onshore	Strict	100	100
	Bid Window 3	Wind onshore	Strict	99	100

*Explanation of compliance monitoring classification:
Lenient: No monitoring of development status of the project.
Medium: Soft monitoring (monitoring once or under special circumstances).
Strict: Regular obligatory monitoring of project development status. Project developer are obliged to periodically submit reports on development status.
Score for Compliance Monitoring.
Lenient = 0.
Medium = 50.
Strict = 100.

B.5. Overall compliance package score

Country	Auction round	Technology	Score for material pre-qualification	Score for financial pre-qualification	Score for penalties	Score for compliance monitoring	Total score for compliance package*
Netherlands	SDE+ 2012	PV	30	0	20	50	25
	SDE+ 2012	Wind onshore	30	0	20	50	25
	SDE+ 2013	PV	30	0	20	50	25
	SDE+ 2013	Wind onshore	30	0	20	50	25
	SDE+ 2014	PV	60	0	40	50	37.5
	SDE+ 2014	Wind onshore	60	0	40	50	37.5
	SDE+ 2015	PV	60	0	40	50	37.5
	SDE+ 2015	Wind onshore	60	0	40	50	37.5
	SDE+ 2016 I	PV	60	0	40	50	37.5
	SDE+ 2016 II	PV	60	0	40	50	37.5
Germany	Feb 2017 PV Auction	PV	30	100	60	0	47.5
	Jun 2017 PV Auction	PV	30	100	60	0	47.5
	Oct 2017 PV Auction	PV	30	100	60	0	47.5
	Apr 2018 Joint Auction	PV	30	100	60	0	47.5
	Apr 2015 PV Auction	PV	20	100	20	0	35
	Aug 2015 PV Auction	PV	20	100	20	0	35
	Dec 2015 PV Auction	PV	20	100	20	0	35
	April 2016 PV Auction	PV	20	100	20	0	35
	Aug 2016 PV Auction	PV	20	100	20	0	35
	Dec 2016 PV Auction	PV	20	100	20	0	35
	May 2017 Wind Auction	Wind onshore	20	100	40	0	40
	Aug 2017 Wind Auction	Wind onshore	20	100	40	0	40
France	First Round Mar 2017	PV	50	0	40	50	35
	Second Round Jul 2017	PV	50	0	40	50	35
	Third Round Feb 2018	PV	50	0	40	50	35
	First Round Jul 2012	PV	40	0	20	50	27.5
	Second Round Mar 20014	PV	40	0	20	50	27.5
	Third Round Jun 2015	PV	40	0	20	50	27.5
South Africa	Bid Window 1	PV	80	100	60	100	85
	Bid Window 2	PV	80	100	60	100	85
	Bid Window 3	PV	80	100	60	100	85
	Bid Window 1	Wind onshore	80	100	60	100	85
	Bid Window 2	Wind onshore	80	100	60	100	85
	Bid Window 3	Wind onshore	80	100	60	100	85

***Total score for compliance package** = (0.25 * Score for material prequalification) +.
(0.25 * Score for financial prequalification) +.
(0.25 * Score for penalties) +.
(0.25 * Score for compliance package).

Appendix C. Actual project realisation periods over granted realisation periods for onshore wind auctions

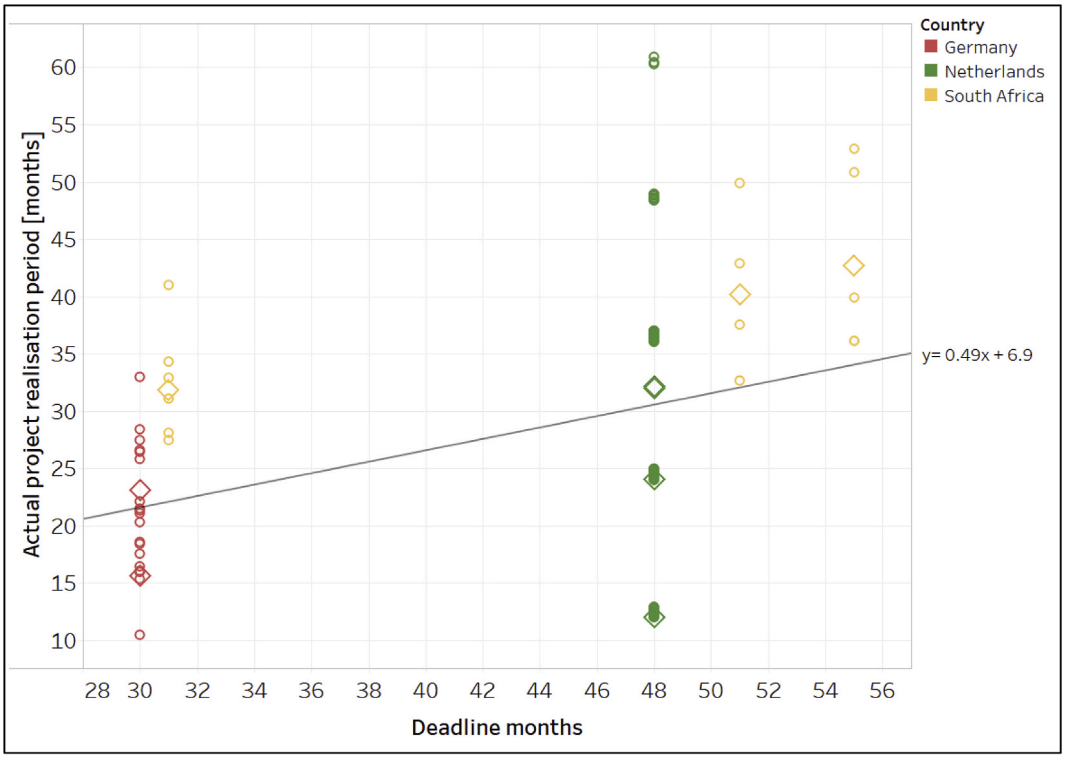

Fig. C1. Actual project realisation periods over granted realisation periods in onshore wind auctions. Circles represent individual project commissioning; rhombus shows the average project commissioning completion per auction round. Colour code is used to distinguish different countries.

Appendix D. Detailed overview of the subscription rate and strike price for each auction round

Country	Auction round	Technology	Subscription rate	Strike price ct/kWh	LCOE global average (IRENA)
Germany	Apr 2015 PV Auction	PV	4.8	9.7	11.3
	Aug 2015 PV Auction	PV	3.7	8.9	11.3
	Dec 2015 PV Auction	PV	2.8	8.4	11.3
	Apr 2016 PV Auction	PV	4.3	7.8	10.2
	Aug 2016 PV Auction	PV	2.5	7.6	10.2
	Dec 2016 PV Auction	PV	2.6	7.2	10.2
	Feb 2017 PV Auction	PV	2.4	6.8	8.3
	Jun 2017 PV Auction	PV	3.2	5.8	8.3
	Oct 2017 PV Auction	PV	3.8	5.1	8.3
	Feb 2018 PV Auction	PV	2.7	4.4	7.0
	Jun 2018 PV Auction	PV	2.0	4.7	7.0
	Oct 2018 PV Auction	PV	3.0	4.8	7.0
	Feb 2019 PV Auction	PV	2.7	4.8	6.1
	Mar 2019 PV Auction	PV	1.7	6.6	6.1
	Jun 2019 PV Auction	PV	3.7	5.5	6.1
	Oct 2019 PV Auction	PV	4.3	4.9	6.1
	Dec 2019 PV Auction	PV	2.7	5.6	6.1
	May 2017 Wind Auction	Onshore wind	2.7	5.9	5.7
	Aug 2017 Wind Auction	Onshore wind	2.9	4.4	5.7
	Nov 2017 Wind Auction	Onshore wind	2.6	3.9	5.7
	Feb 2018 Wind Auction	Onshore wind	1.4	4.8	5.2
	May 2018 Wind Auction	Onshore wind	0.9	5.8	5.2
	Aug 2018 Wind Auction	Onshore wind	1.1	6.3	5.2
	Oct 2018 Wind Auction	Onshore wind	0.6	6.3	5.2
	Feb 2019 Wind Auction	Onshore wind	0.7	6.1	4.7
	May 2019 Wind Auction	Onshore wind	0.5	6.1	4.7
	Aug 2019 Wind Auction	Onshore wind	0.4	6.2	4.7
	Sep 2019 Wind Auction	Onshore wind	0.4	6.2	4.7
	Oct 2019 Wind Auction	Onshore wind	0.3	6.2	4.7
	Dec 2019 Wind Auction	Onshore wind	1.4	6.1	4.7
	Apr 2018 Joint Auction	PV	2.0	4.7	7.0
	Nov 2018 Joint Auction	PV	1.6	5.3	7.0
	Apr 2019 Joint Auction	PV	3.6	5.7	6.1
	Nov 2019 Joint Auction	PV	2.6	5.4	6.1

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(*continued*)

Country	Auction round	Technology	Subscription rate	Strike price ct/kWh	LCOE global average (IRENA)
Netherlands	SDE+ 2012	Onshore wind	180.0	4.2	7.4
	SDE+ 2012	PV	7.0	1.4	19.9
	SDE+ 2013	Onshore wind	1.1	5.4	7.3
	SDE+ 2013	PV	1.8	7.7	15.6
	SDE+ 2014	PV	1.5	10.6	14.6
	SDE+ 2014	Onshore wind	2.1	7.2	6.8
	SDE+ 2015	PV	1.3	5.8	11.3
	SDE+ 2015	Onshore wind	1.3	6.3	6.2
	SDE+ 2016 I	PV	7.0	7.2	10.2
	SDE+ 2016 I	Onshore wind	7.0	4.3	5.9
	SDE+ 2016 II	Onshore wind	3.2	5.5	5.9
	SDE+ 2016 II	PV	3.2	7.7	10.2
	SDE+ 2017 I	PV	1.1	9.0	8.3
	SDE+ 2017 I	Onshore wind	1.1	6.4	5.7
	SDE+ 2017 II	Onshore wind	1.3	5.3	5.7
	SDE+ 2017 II	PV	1.3	9.0	8.3
	SDE+ 2018 I	Onshore wind	1.4	4.4	5.2
	SDE+ 2018 I	PV	1.4	8.6	7.0
	SDE+ 2018 II	Onshore wind	1.1	4.9	5.2
	SDE+ 2018 II	PV	1.3	8.1	7.0
	SDE+ 2019 I	PV	1.2	7.1	6.1
	SDE+ 2019 I	Onshore wind	1.0	4.1	4.7
France	1st Period PV Ground Mounted	PV	5.3	6.4	8.3
	2nd Period PV Ground Mounted	PV	2.0	5.8	8.3
	3rd Period PV Ground Mounted	PV	2.2	5.6	7.0
	4th Period PV Ground Mounted	PV	1.4	5.3	7.0
	5th Period PV Ground Mounted	PV	1.1	5.3	6.1
	6th Period PV Ground Mounted	PV	1.3	6.4	6.1
	1st Period Dec 2017	Onshore wind	1.8	6.6	5.2
	2nd Period June 2018	Onshore wind	0.5	6.8	5.2
	3rd Period Apr 2019	Onshore wind	1.9	6.3	4.7
	4th Period Aug 2019	Onshore wind	1.5	6.7	4.7
	Sep 2011 PV > 250 kWh	PV	4.2	22.2	19.9
	Mar 2013 PV > 250 kWh	PV	4.3	14.8	14.6
	Nov 2014 PV > 250 kWh	PV	3.0	10.3	11.3
	Joint Auction 2018	PV	1.8	5.5	7.0
South Africa	Bid Window 1	PV	0.6	41.3	25.6
	Bid Window 1	Onshore wind	0.6	17.1	7.4
	Bid Window 2	PV	2.5	22.3	19.9
	Bid Window 2	Onshore wind	2.5	12.2	7.4
	Bid Window 3	PV	4.1	10.4	15.6
	Bid Window 3	Onshore wind	4.1	7.8	7.3
	Bid Window 4	PV	2.0	7.2	14.6
	Bid Window 4	Onshore wind	2.0	5.9	6.8

Appendix E. Correlation matrix for subscription rate and difference between strike price and LCOE

	Difference (Strike price – global LCOE at award date)	Difference (Strike price – global LCOE at granted realisation date)
	PV Auctions	
Subscription rate	−0.43	−0.41
	Onshore Wind Auctions	
Subscription rate	−0.33	−0.54

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