

# The design of technical requirements in public solar auctions: Evidence from India

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## ABSTRACT

Solar technology diffuses across the globe as countries transition from fossil to renewable energy. Little solar-specific experience and capacity in newly adopting countries can result in technical failures and lower solar plant performance. This contributes to making the investment in solar plants in newcomer countries risky and may undermine political targets of solar energy deployment. One solution suggested by international organizations is for policymakers in adopting countries to include international quality standards as technical requirements in public auctions. Here, we develop a conceptual framework on how international quality standards could help build a solar sector. As a case study, we analyze the explanatory factors of technical requirements in 100 public auctions of utility-scale solar photovoltaic plants carried out in India between 2013 and 2019. Our findings suggest that more international quality standards are required in auctions in which the government rather than a private actor ultimately carries the commercial risk. On the other hand, local content requirements and attracting foreign investors do not correlate with technical requirements. We argue that using minimal quality standards is unlikely to promote local technological catch-up or attract long-term foreign investments but transfers the techno-commercial risk from the government to the private sector.

## 1. Introduction

Solar photovoltaic (PV) technology is currently diffusing across the globe [1], with 106 countries having held renewable energy auctions by the end of 2019 to foster the transition from fossil to renewable energy [2]. However, evidence suggests that solar PV projects may underperform in many low- and middle-income countries, including India. For example, it was reported that 30% of nearly 100 analyzed projects in different countries indicate severe defects [3]. Furthermore, a study of the National Metrology Institute of Germany (PTB) and PI Berlin, a global quality assurance provider, found in all six examined grid-connected solar PV plants in India “sporadic or systemic failures with impact on performance” [4]. Thus, if solar PV projects fail to perform as expected, investors may not recoup their money, undermining future investments and, in turn, political goals for renewable

energy deployment [5–7].

One solution recommended by international organizations such as the International Renewable Energy Agency (IRENA) and PTB is that policymakers in adopting countries include international quality standards<sup>1</sup> as technical requirements in the design of public auctions [4,7,8]. For instance, it was suggested “that strict technical requirements [ ...] should be part of tender requirements [ ...]. [ ...] Lax tender requirements should be avoided as they give comfort to module suppliers and installation companies as no legal framework is forcing them to provide evidence of long-term durable products and failure free installation works” [4, p.6]. Similarly, it was proposed that “the auctioneer can also define other technological requirements, [ ...], such as specifications on the equipment used. Imposing equipment specifications can help ensure that the sector will be developed using state-of-the-art technology and appropriate quality of components” [8, p.32]. Hence, compliance on the part of solar PV plant developers with specific quality

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<sup>1</sup> International quality standards are defined here as formal standards issued by the International Electrotechnical Commission (IEC) and the International Standardisation Organization (ISO) pertaining to solar PV plant component performance and durability, their transport, installation and commissioning. For example, IEC 61215 “solar PV modules peak and life performance ratio” defines the tests and procedures to assess the performance of solar PV modules. We also included national standards (i.e. UL 1541, IEEE 2030.5, EN 1991 and EN 1997) that are broadly recognized internationally.

**List of abbreviations**

BOO	Build-Own-Operate
EPC	Engineering-Procurement-Construction
GW	Gigawatt
IEC	International Electrotechnical Commission
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
LCR	Local content requirement
MNRE	Ministry of New and Renewable Energy
MW	Megawatt
O&M	Operation and maintenance
PPA	Power-purchasing agreement
PV	Photovoltaic
SECI	Solar Energy Corporation of India

standards is expected to reduce quality defects and technical failures. In turn, investor confidence and trust will increase, as uncertainty about generated electricity decreases [7].

However, the existing literature on renewable energy auctions offers few insights related to the optimal integration of technical requirements into auction design. The effectiveness of renewable energy auctions is widely found to depend on their design, which varies across countries [8–17]. Yet, very few authors [17,18] have examined how specific auction design elements condition their effectiveness. Publications have rather focused on comparing auctions with feed-in tariffs [6,11,19,20]. As a result, there is a knowledge gap on designing renewable energy auctions optimally, and on how different design elements (e.g. auction mechanism, qualification criteria and bid evaluation, legal/contractual clauses, local content requirements etc.) shape auction outcomes.

To close this gap and help policymakers choose technical requirements for solar PV auctions in a more strategic way, we develop a conceptual framework on how technical requirements could help build up a domestic solar sector. Based on the framework, we derive three hypotheses on how policymakers can choose to use international quality standards as technical requirements in the design of public auctions for solar PV plants. The three hypotheses are empirically verified in a regression analysis of 100 public auctions for industrial, utility-scale solar PV projects with a total capacity of 51 GW carried out in India between 2013 and 2019. We also examine whether other potential risks such as exclusion of bidders have materialized upon including international quality standards.

Interestingly, “most African countries that held renewable energy auctions (dominated by solar) in 2017–2018 did so for the first time” [2, p.11]. Policymakers in these countries need to choose how to introduce technical requirements and their design choice likely affects the development of a national solar sector. India graduated from virtually zero solar energy to the fifth largest photovoltaic market worldwide within less than a decade. The Indian experience with designing technical requirements to mitigate underperforming solar PV plants can help newly adopting countries avoid similar mistakes.

In the following, section 2 illustrates the contextual background and relevant literature. Section 3 outlines the conceptual framework and develops our three hypotheses on the use of international quality standards by Indian policymakers. Section 4 presents and discusses the results of the empirical analysis. Finally, section 5 concludes with policy implications and a research outlook.

## 2. Background

### 2.1. Public auctions as an instrument for the global energy transition

In the last two decades governments have increasingly used public auctions rather than other policy tools to guide the expansion of solar and wind energy [2,11–13,21]. Several recent publications emphasized the ongoing need for further research on the recent experience with public auctions for renewable energy [6,9,11,14].

Public auctions for solar PV plants work as follows. The responsible government institution allocates the right to build a renewable energy plant to the private company with the best bid. In a reverse auction, as conducted in India, selection is based on price alone and the bidder who offers the lowest price wins. The most general contractual agreement for large-scale utility solar PV projects is Build-Own-Operate (BOO) associated with a power-purchasing agreement (PPA). The PPA stipulates that the government, mostly represented by a public utility, buys the produced electricity for the following 25 years. Another contractual format is Engineering-Procurement-Construction (EPC), which is less frequent but crucial to our analysis. EPC contracts are associated with a specified Operation and Maintenance (O&M) period, after which ownership and liability for the solar PV plant are transferred to the auctioneer.

The prevalent perception is that policymakers have increasingly adopted public auctions to create a domestic market, reduce the procurement price of electricity, avoid excessive subsidy levels and be able to better steer and plan the expansion and integration of renewables into national electricity grids (e.g. Refs. [2,6,14,15]). Several authors have examined whether auctions represent a more effective policy tool than the previously dominant options of bilateral negotiations with project developers, quota and feed-in tariffs [6,11,19,20]. There seems to be a consensus that auctions, if well designed, are a powerful, cost-effective policy tool to create a domestic market and provide a necessary level of investment certainty. Reverse public auctions have led to fierce price competition and historically low electricity tariffs around the globe [22]. For example, the highest winning bids in Indian solar auctions were on average 36 percent lower than the feed-in tariff [23]. Although this is less emphasized, the use of public auctions also led to a transformation of ownership structures in the electricity sector, bringing about a transition from public ownership to increased private ownership [24]. While the EU and US markets are already dominated by private power producers, with a 75% and 80% market share respectively, this share is much lower in developing countries and emerging markets like India and China - around 30 and 40%, respectively [24].

Yet, this consensus on the effectiveness of renewable energy auctions has emerged in the context of a simultaneous decrease in international prices for solar PV modules, the main cost factor of solar PV plants, and the expansion of public auctions in several countries (proof-by-association). Only few authors were cautious enough to underline that there is no rigorous, counterfactual-based, causal identification of the effect of public auctions on electricity price [15]. The concerns or potential drawbacks of public auctions for the development of renewable energy mentioned in the literature are (1) low(er) project realization rates, as a consequence of adventurous or strategic underbidding, (2) a lack or excess of competition, which may lead to market consolidation over time in both cases, and, as a result, (3) insufficient incentives for dynamic learning-by-doing and innovation [10,15,17,25–28]. Lower project realization rates have received most scholarly attention, with most studies focusing on countries in the global north [10,15,16,26, 28–31], while the dynamic effect of auctions on competition/market consolidation [11,32] and local learning-by-doing and innovation have been understudied (excepting [18]). For instance, prices of initially

23–35% below competitive tariffs were found in the first reverse auctions in India and were attributed to underbidding by inexperienced players [5,26]. Several authors have noted that auctions are not a panacea for successful renewable energy deployment given that different countries had varying success rates [6,8,15,25,33]. One conclusion may be that it is crucial to design auctions in line with a country's local institutional and industrial context. Auction design elements, such as technical requirements, may be one powerful mechanism for policymakers to improve the effectiveness of auctions, i.e. reduce or prevent low project realization rates and promote local learning-by-doing (see section 3.2). Several authors noted that countries choose slightly differing auction designs, which makes it difficult to conduct cross-country comparisons, but also suggests that policymakers adjust the auction design to the specific institutional and market context [8–11,19]. Unfortunately, there are only few dedicated studies, mostly based on one or at most a handful of countries for which several auctions at best are observed over time [9,13–16,29]. Hence, there is only a limited understanding of the incentives and rationale driving the auction design choices made by policymakers (exceptions are [17,25]).

This shortcoming has first been acknowledged in Refs. [8,10], which both provide theoretical frameworks for auction design. Quantitative evidence of the specific effect of auction design elements on the auction outcome was first given in Refs. [17,18]. By comparing the project realization rates for auctions in different countries and years in a regression framework, it was found that pre-qualification measures and penalties are positively correlated with realization rates [17]. Moreover, local content requirements were shown to increase the bidding price in Indian solar PV auctions [18]. Thus, it is a promising avenue for future research to investigate how specific auction design elements condition both the opportunities and the shortcomings associated with renewable energy auctions. This paper contributes to closing this gap by investigating the factors motivating the use of technical requirements in Indian solar auctions.

## 2.2. Solar energy development in India: National Solar Mission

India's domestic solar power generation before 2009 was negligible and consisted only of a few mini-grid projects [19,34]. In 2009, the Government launched the National Solar Mission. Its objective is to install 100 GW solar PV capacity by 2022 and build up local, globally competitive manufacturing. While about 20 export-oriented solar module manufacturers existed already at the outset of the Solar Mission, there was virtually no large-scale solar PV generation in India [34,35]. No cell manufacturing existed yet.

The Ministry of New and Renewable Energy (MNRE) through its executive agency - the Solar Energy Corporation India (SECI) - has managed to nurture and expand solar energy production. Yet, it remains a challenge to establish globally competitive solar component manufacturing at a large scale in India. Initially, MNRE relied on feed-in tariffs and other policy tools (i.e. purchasing obligations for India's federal governments). Reverse public auctions and their eligibility criteria have become the major policy tool to guide the development of solar electricity production and component manufacturing [18,26,35,36]. Among the eligibility criteria used by SECI are local content requirements, restrictions on foreign bidders, and technical requirements.

While the initial approach to technical requirements has been characterized as "laissez-faire", there have been more recent efforts to foster quality assurance and quality upgrading. In 2017, MNRE published the national "Lab Policy for Testing, Standardisation and Certification for Renewable Energy Sector" [37]. The aim is to upgrade the performance quality of solar PV components and turn testing laboratories into centers of global excellence. The policy also requires all components, in particular PV modules, to be tested for reliability and performance in India again. However, execution was postponed on several occasions due to feedback from manufacturers and testing laboratories about insufficient local testing capacity. In 2020, MNRE created a "Renewable

Energy Standardisation Cell", which shall push for further quality upgrading and public policies.

## 3. Conceptual framework and hypotheses

### 3.1. Technical requirements in public auctions of solar PV plants as a policy tool for sustainable, industrial development

Green industrial development at the global frontier focuses on inventing and patenting technologies that are new to the world. In developing and emerging economies, green industrial policy deals mostly with adapting, disseminating and finally catching up with the global technology frontier [38,39]. International quality standards are one mechanism to disseminate state-of-the-art technology and production methods, and foster investment in product testing for trial-and-error innovation in developing and emerging economies [40,41].

Fig. 1 illustrates how governments can require compliance with international quality standards in public auctions for solar PV plants. Firms bidding to develop solar PV plants will need to choose components in compliance with specific technical requirements. Firms have an incentive to invest in upgrading their production methods and product quality accordingly, given that government procurement of electricity creates business opportunities [40,42–45].

The benefits to local industrial development are twofold [41,46–49]. Firstly, international quality standards promote productivity (see section 3.2.). The productivity increase can come from adoption of international best practices and from product tests in accredited laboratories as defined in international quality standards. Product tests are an opportunity for domestic firms to trial-and-error test their products and compare their quality against international benchmarks. For example, less than a handful of Indian companies conducted in-house research and development in 2012 [18,34]. Secondly, quality standards should have a strong positive signaling effect (see section 3.3). Buyers (investors) have incomplete information about the quality of the sellers' production processes, and thus are either unwilling to buy or only willing to pay less [50]. Incomplete information is particularly problematic when a country enters solar PV energy production, given that there is little local data about potential electricity yields and technical component resilience (i.e. in tropical climate conditions) [51]. Scarce information is also likely to be often paired with investors' mistrust against the general investment climate and institutional context of most developing and emerging countries. Hence, adherence to international quality standards is likely to have a strong, positive signaling effect to investors or banks.

Finally, there are also some risks related to the use of (international) quality standards in public auctions to promote green industrial development. Firstly, quality standards exclude non-compliant competitors. This may be a concern for governments in developing and emerging countries, particularly in smaller countries that may only have a few competitors, especially during the initial transition to solar PV [49,52]. Secondly, international quality standards may notably hurt local firms if there are insufficient, costly, or slow testing services available, while idiosyncratic national standards may scare away international competitors [49,53]. Limited local testing capabilities are a common problem in developing and emerging countries, given that testing equipment has high capital costs and requires specialized personnel [7]. Idiosyncratic national quality standards, by contrast, create additional costs for international competitors, which may prevent them from entering a market, particularly if the market is very small. Thirdly, quality standards may raise the bidding price, which in turn raises the cost of electricity for the government. While this is in principle true, engineering studies suggest that the benefits of stringent quality assurance, at least at the project level, outweigh the additional costs of quality [4,54]. Ultimately, a crucial concern anchored in the industrial policy literature is that policymakers may not possess the capabilities to determine which standards should be selected at what stage of industrial

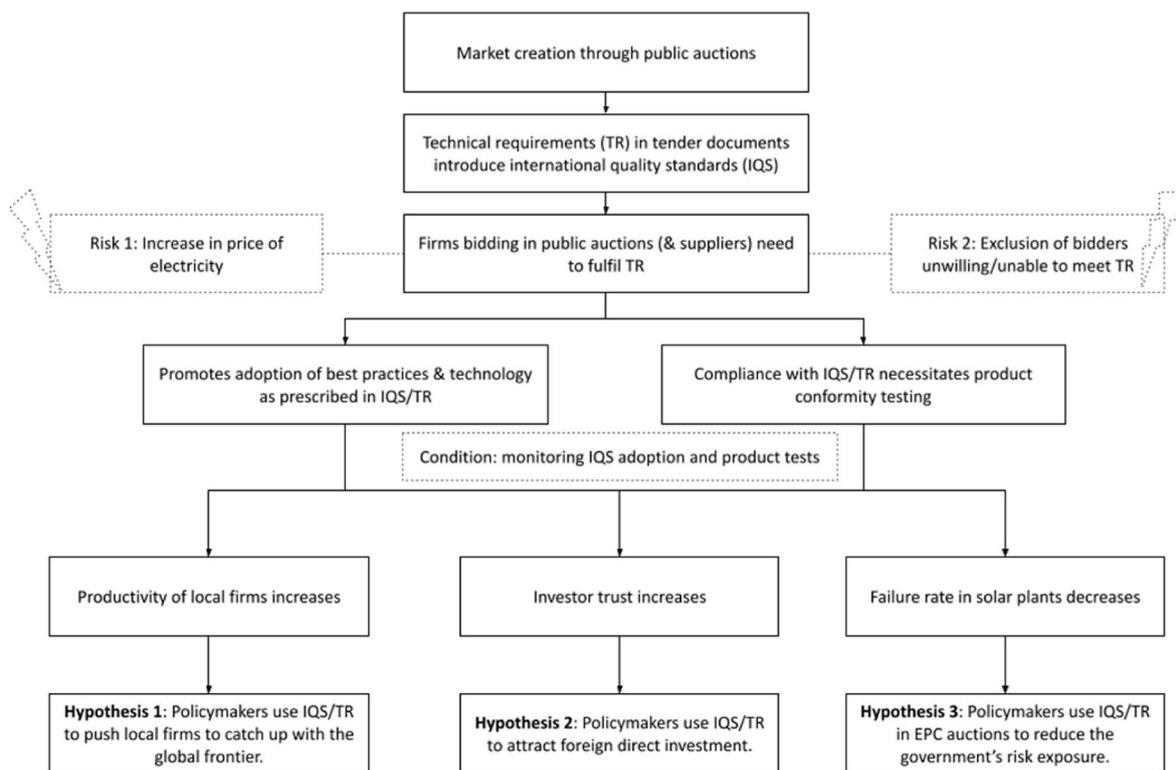


Fig. 1. Flowchart of the conceptual framework presented in section 3.

development [55]. In conclusion, too stringent quality standards could force nascent players to exit the market, while too lenient quality standards may entail that there is no local industrial learning along with reluctance from buyers to invest in solar PV projects.

In the following, we formulate three hypotheses related to the use of international quality standards in public auctions for solar PV plants in India.

3.2. International quality standards as technical requirements: a performance benchmark to complement local content requirements?

The Indian government aspires to expand domestic solar PV electricity production and create globally competitive domestic manufacturing. Therefore, local content requirements (LCR) were introduced in India’s public auctions for solar PV plants. LCRs obligate independent power producers and project developers to source solar PV modules and/or cells in India [18,35].

LCRs often increase procurement costs, as they are typically introduced when local prices are higher than world market prices [18]. The rationale for LCR is that local producers are temporarily protected from foreign competition, can gain hands-on experience with a certain technology (“learning-by-doing”), and catch up with international players [49,56,57]. Firms learn and improve their efficiency/productivity when beginning to manufacture, in this case solar PV modules and cells, but learning rates decrease over time [56,58]. Once learning-by-doing enables local producers to lower their costs to match world market prices, LCRs are no longer necessary and can be withdrawn. A common criticism towards LCR is that they often fail to provide sufficient incentives for local beneficiaries to improve performance and reduce prices, e.g. because of rent-seeking and government failure, and thus fail to transform nascent industries into competitive ones [59–61].

We are interested, however, in the interplay between LCR and quality standards. Innovation through rule-setting has proven effective, for example in environmental regulation [62] and technological upgrading due to foreign restrictions [40]. In a similar vein, technical

requirements can be combined with LCR to provide performance incentives. Governments can thus require bidders to source components locally and comply with national or international quality standards. Hence, performance standards could be used to drive domestic producers to engage in learning-by-doing rather than import intermediation [59]. For instance, Denmark’s aggressive promotion of standards and quality certification helped the country become and remain a world leader in wind turbines [49]. Similarly, it was argued that the incentives and protection provided by industrial policies (“carrots”) need to be complemented through a “stick” to guarantee that beneficiary firms also engage in learning, quality upgrading and productivity increases [55].

**Hypothesis 1.** Policymakers use technical requirements such as international quality standards to push local firms to catch up with the global solar PV production frontier.

3.3. International quality standards as technical requirements: a signaling tool to de-risk investors?

Globally, the majority of investments in renewable energy since 2016 have been taking place in developing and emerging economies [8, 14,63]. In India, the government orchestrates the expansion of solar PV electricity. Yet, it is the large Indian industrial conglomerates, Indian banks, and non-banking institutions such as international venture capital and hedge funds that develop and finance utility-scale PV plants [22, 64–66].

We apply insights from economic theory on quality uncertainty and adapt it to the context of solar PV auctions [46,47,50,67–69]. As mentioned in section 3.1, compliance with international quality standards has been shown to overcome the buyer’s insufficient information or lack of trust, for example in international trade [47,67,69] and foreign direct investment [48,68]. International quality standards create trust, as they signal use of state-of-the-art production processes. Signaling applies in principle to both domestic and international investors, but information asymmetry and lack of trust are especially relevant for foreign investors [46,47,68,69]. In the following, we outline

how international quality standards introduced as technical requirements in public auctions could help remedy the lack of information and trust in solar PV performance.

Investments in solar PV projects follow the risk-return profile of the respective project [53]. Technical risk is significant in developing countries with low solar-specific industrial capacity, experience and no historical performance data for credible yield estimates [30,51,70–72]. Even in the EU and the US, investors rate technology performance standards as third-best among 12 market-pull policies [73]. A solar PV plant is an attractive asset if it generates the expected energy yield and revenue over a period of up to 25 years. Payback and break-even times increase when components malfunction and underperform. PV modules are the key component of solar PV plants and make up 50% of the costs [7]. In fact, independent assessments of modules have shown they often underperform relative to manufacturer indications at up to 3% already before operation [7] and degrade over time at 0.4% per year in the US and Europe and at about 0.6% up to 5% in PV plants in India [74–76]. Modules can also underperform from day one if they are transported or installed incorrectly, as has been often observed in India [76]. Other components can have similar impacts on plant performance (techno-commercial overviews are available in Refs. [51,54]). Uncertainty is particularly high at the time of market creation and in environments with low information about input parameters, such as irradiation, temperature, component degradation, component peak performance and resistance to environmental conditions, construction and installation capacities [51,54,72,77]. A mixture of low awareness and lack of experience complements scarce publicly available information in countries that kick-start solar PV [51,78].

Based on the above considerations, one can view more stringent technical requirements in public auctions as a quality signal and de-risking instrument to attract foreign investment [66,79]. More stringent international quality standards try to tackle the underlying risk of technical failure and related uncertainty about electricity yields. In addition, international quality standards function as a proxy, which signals high solar PV plant performance in a situation where no prior information exists, information is expensive for international investors, and trust in the institutional framework is low.

**Hypothesis 2.** Policymakers introduce international quality standards as technical requirements in public auctions to attract foreign

investment.

### 3.4. International quality standards as technical requirements: a tool to reduce risk exposure of the public sector?

The bathtub curve in Fig. 2 illustrates that technical failures in solar PV plants occur mainly at the beginning (or even before operation starts, e.g. malfunctioning modules due to microcracks from incorrect transportation) and at the end of their lifetime due to wear and tear [7].

As in a principal-agent model, the Indian government represented by SECI (principal) delegates the task to build and operate a solar power plant to the private company (agent) that offers the lowest bid price in a public auction. The agent enters into an EPC plus O&M or BOO plus PPA contract with the principal. There is a key difference between these two types of contracts. Under EPC plus O&M contracts, the project developer (agent) constructs, operates and maintains the solar PV plants only for a limited number of years and then transfers ownership to SECI (principal). Under BOO contracts, the project developer (agent) is responsible for everything from construction to operation and assumes ultimate ownership. The allocation of technical risk over time thus differs significantly in these two contract arrangements. Fierce price competition in reverse auctions forces project developers to bid close to their expected electricity costs per kilowatt hour. Low, winning bids can turn into a curse if project developers are too optimistic, e.g. about the O&M costs, particularly if they choose low-quality components to be more price-competitive, or if interest rates change etc.

Since SECI ultimately assumes the risk of underperformance of the solar plant over the lifecycle, EPCs have an incentive to ensure the short-term performance and quality of solar plants. By contrast, EPCs have no (economic) incentive to focus on quality beyond their O&M period. In a BOO contract, remuneration is fully performance-based and the owner has a strong incentive to maximize the output over the lifetime of the plant, as it may take several years to amortize costs and generate profits. In line with the principal-agent theory, SECI uses upfront payments, sanctions, and performance targets to monitor and guarantee that the power producers do not simply neglect their contractual obligations.

In section 2.1, underbidding and subsequent lower project realization rates were highlighted as a problem for policymakers in reverse auctions for renewable energy projects, including in India [5,23,26,30,



Fig. 2. Failure curve of a solar PV system, reprinted from Ref. [7], p.12.

31]. Different types of standards and their economic effects in the context of public procurement were discussed in Ref. [80]. Here, the central role of minimum quality standards is to reduce uncertainty and risk for the public procurer. Furthermore, policymakers were recommended to include minimum viability criteria to prevent underbidding in renewable energy auctions [31]. In a similar vein, underbidding could be countered through stringent qualification criteria as a risk management strategy [26].

**Hypothesis 3.** Policymakers require more stringent international quality standards in EPC auctions to reduce the government’s risk exposure as owner and investor (while only minimum quality standards are required in BOO auctions, where private producers assume the ultimate risk as owners and investors).

**4. Empirical analysis: results and discussion**

**4.1. Data**

The primary data we use are tender documents - so-called “Requests for Proposals” - issued by SECI to invite solar companies to submit their bids. These documents contain all the crucial information bidders need to structure their offers, including financial and technical eligibility criteria as well as general and procedural information. Firstly, we downloaded all publicly available tender documents from the SECI website,<sup>2</sup> which provided us with a sample of 59 solar PV auctions. SECI kindly provided another 41 tender documents, which gave us a sample of 100 public auctions conducted since SECI’s creation in 2013 until 2019. In addition, we conducted informal interviews with relevant stakeholders in public institutions, such as SECI, MNRE, the National Institute of Solar Energy, the Indian Renewable Energy Development Agency and other public banks.

**4.2. Method**

We proceeded in three steps. Initially, we screened the tender documents manually to find out how SECI integrates technical specifications and quality standards into the tender documents.

Secondly, we conducted an automated text analysis. For this purpose, we collaborated with PI Berlin, a well-established testing and auditing laboratory, which has audited several solar PV plants in India since 2013. PI Berlin provided a list of 58 international quality standards considered as the global benchmark in terms of stringency. This includes quality standards that are specifically relevant to the Indian context, such as IEC 60068 environmental testing part 2–68 “dust and sand”. Based upon this list, we wrote an algorithm to “mine” our sample of 100 tender documents and count the occurrence of each quality standard in the respective auction.

Note that we took several measures to guarantee that the chosen quality standards truly reflect a global optimal and are relevant to the Indian context. First of all, we refined the list of quality standards during several iterations with PI Berlin. We also took into account the feedback from SECI, e.g. regarding equivalent Indian standards. Furthermore, we reviewed the list with solar PV experts from the National Metrology Institute of Germany to check on the relevance of the chosen quality standards. Moreover, we also compared and complemented the automated results with our manual search.

Thirdly, we manually searched the tender documents for further

characteristics of each auction to develop bivariate graphs and conduct a multivariate regression analysis.

**4.3. Descriptive statistics**

The 100 investigated tenders intended to auction a total of 51,455 MW (~51.5 GW).<sup>3</sup> Table 1 provides an overview of the main characteristics of the analyzed auctions. The dependent variable - the required number of quality standards - varies between zero and 22 quality standards. One has to note that one quality standard can encompass several hundred pages that lay out various tests to control product conformity with design, security and performance characteristics. Hence, a standard deviation of about 5 quality standards can entail substantial increase in costs or exclusion of suppliers that cannot conduct the required tests. The three major explanatory variables - global versus domestic auction, auction with or without LCR, and EPC versus BOO - provide substantial variation to explore. About two thirds of the auctions were limited to domestic players (including foreign firms with subsidiaries in India), while one third of the auctions were open to global competition (foreign firms need to set up an Indian company in case they win the auction). Finally, about 60% of the auctions were BOO with an associated PPA while 40% were EPC plus O&M arrangements for at least two and up to 35 years. Fig. 7 in the appendix illustrates that the average (median) BOO project size (296 MW (50 MW)) is about 10 times higher than the average (median) EPC project size (23 MW (6 MW)).

Fig. 3 gives an overview of our sample and the evolution of required quality standards over time. On the left-hand side, we observe at least four auctions and at most 36 auctions per year between 2013 and 2019. There is a steady increase in the number of auctions in the first years, reflecting the political goal to accelerate the expansion and deployment of solar PV energy. On the right-hand side, the average number of required quality standards is seen to increase between 2013 and 2015. It then remains constant at 14 quality standards on average until including 2019.<sup>4</sup>

**Table 1**  
Summary statistics for the 100 auction documents.

Variable	Obs	Mean	SD	Min	Median	Max
Quality standards	100	13.80	4.76	0	12	22
Cancellation	100	0.27	0.45	0	0	1
Number of bidders	51	7.10	6.74	1	4	27
LCR	100	0.41	0.49	0	0	1
Global (vs. domestic)	100	0.33	0.47	0	0	1
EPC (vs. BOO)	100	0.38	0.49	0	0	1
Subsidy	100	0.51	0.50	0	1	1
Plant type	100	2.42	0.93	1	2	5
Cell technology	100	0.63	0.49	0	1	1
Contract length (years)	100	18.97	8.79	2	25	35
Max. project size (MW)	100	192.45	421.36	0	50	2500

Note: Plant type can be rooftop, floating, ground-mounted, any of the three, and solar or wind; see Fig. 8 in the appendix. Cell technology refers to requirements for crystalline cells versus technology agnostic. For the number of bidders, the observation count is lower, as there are no bidders for the 27 canceled auctions and the bidder information was incomplete for the remaining 22 auctions.

<sup>2</sup> [https://www.seci.co.in/archives/data\\_archives](https://www.seci.co.in/archives/data_archives) (last accessed on October 6th, 2020).

<sup>3</sup> Given that SECI canceled and delayed some of the tenders and considering that some tenders were underbid, the actual amount of auctioned electricity as well as the actual number of realized projects is lower.

<sup>4</sup> All figures in this paper have been created using the Stata 15 command “plotplain” for which credit goes to Ref. [79].

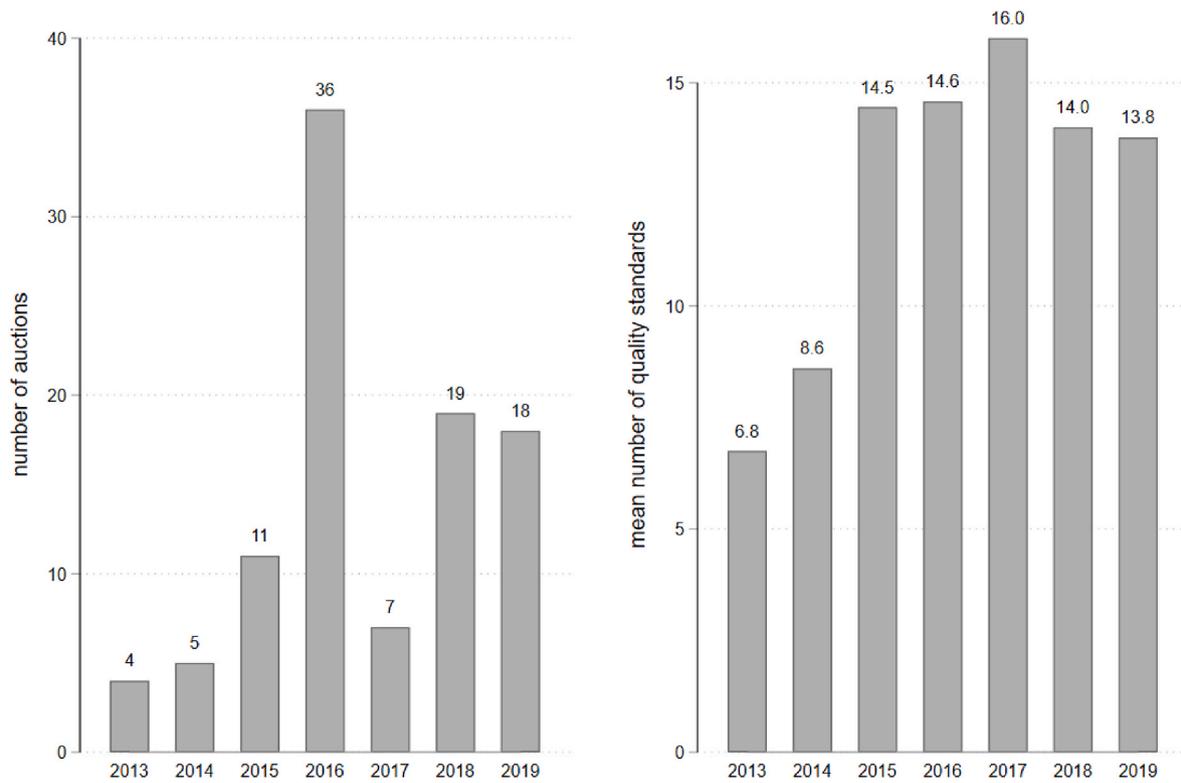


Fig. 3. Observed auctions (left panel) and standards required (right panel) from 2013 to 2019.

4.4. Model

Given that the number of quality standards per auction is strictly positive and constitutes a count, we use a Poisson count regression model. We opt for a Poisson rather than a negative binomial regression model as the dependent variable is not strongly overdispersed (the unconditional variance is not more than two times the mean of the dependent variable).<sup>5</sup> We detect no presence of multicollinearity given a variance inflation factor below 10.

In our primary specification, we estimate the number of international quality standards *IQS* required in a public auction *a* in the following form:

$$IQS_a = P(\alpha + \beta_1 LCR_a + \beta_2 Global_a + \beta_3 EPC_a + \gamma Controls_a + \epsilon_a) \quad (1)$$

where *P* stands for the Poisson transformation,  $\alpha$  is a constant, *LCR* is a dummy for local content requirements, *Global* indicates whether an auction was open to foreign firms and investors, and *EPC* states whether the contractual arrangement for the auctioned solar PV plant was EPC plus O&M or BOO with PPA. We also consider several control variables, including plant location, contract length, solar cell technology to be used, maximum auctioned project size, whether a subsidy was offered, whether the plant will be located in a solar park, and a control for the auction year to cover time trends.

In a second step, we also estimate two further regressions that relate to the concern that too stringent technical requirements may repel bidders, leading in the worst case to the cancellation of an auction due to an insufficient number of bidders.

The second model is a logistic model of the following specification:

<sup>5</sup> Accordingly, the dispersion parameter “Alpha” in Table 8 column (3) is not significant when estimating a negative binomial regression model in Stata 15, which speaks for the Poisson model. The results also hold if estimated with an Ordinary Least Square model.

$$canceled_a = G(\alpha + \beta_1 IQS_a + \beta_2 LCR_a + \beta_3 Global_a + \beta_4 EPC_a + \gamma Controls_a) \quad (2)$$

where *canceled* is a dummy variable (1 = auction canceled; 0 = auction conducted), *G* is the cumulative distribution function of the standard logistic distribution, *IQS* is the number of international quality standards, and all other variables are the same as in equation (1).

The third model is a negative binomial model<sup>6</sup> of the following form:

$$bidders_a = exp(\alpha + \beta_1 IQS_a + \beta_2 LCR_a + \beta_3 Global_a + \beta_4 EPC_a + \gamma Controls_a) \quad (3)$$

where *bidders* is the number of bidders (a strictly positive count), *exp* stands for exponential as the conditional mean of the outcome variable is modeled with an exponential function,<sup>7</sup> and all other variables are the same as in equation (2).

4.5. Results

Table 2 summarizes the results obtained from regressing several explanatory factors on the dependent variable “number of international quality standards” across all 100 public auctions investigated.

The first coefficient of Table 2 in column (3) indicates no statistically significant correlation between the use of LCR and the number of international quality standards required in public auctions of solar PV plants in India between 2013 and 2019. We read this as evidence that

<sup>6</sup> Here, we use the negative binomial model because the dispersion parameter is significant and hence this model is more appropriate than a Poisson model. For completeness, the interested reader can find the estimated coefficients for Poisson, negative binomial, and Ordinary Least Square regression in Table 5.

<sup>7</sup> See Ref. [81] p. 74 onwards for the formal specification of the model, p. 241 for an empirical application, and the Stata 15 base reference manual p. 1707 for further documentation of the negative binomial regression implemented here.

**Table 2**  
Regression results highlighting the factors driving the use of quality standards in public auctions of solar PV plants in India.

Variables	(1) quality standards	(2) quality standards	(3) quality standards
LCR		-0.132*** (0.0450)	0.0192 (0.0410)
Global		-0.00549 (0.0451)	0.179* (0.101)
EPC		0.477*** (0.0377)	0.547*** (0.169)
Contract length			-0.000499 (0.00710)
Cell technology			-0.00712 (0.108)
Subsidy			0.0584 (0.0667)
Solar park			-0.0836* (0.0490)
Time trend			0.0564*** (0.0218)
Max. plant size			-3.98e-05 (5.09e-05)
Location controls			YES
Plant type controls			YES
Constant	13.80 [4.759]	2.475*** (0.0185)	2.254*** (0.225)
Observations	100	100	100

Note: Column (1) provides the average number of international quality standards included as technical requirements in solar PV auctions in India between 2013 and 2019 (“~14”) with the standard deviation in square brackets. Columns (2) and (3) provide average marginal effects, which can be multiplied by 100 to be interpreted as percentage changes in the number of required international quality standards. Standard errors are given in round parentheses.

Indian policymakers have not used technical requirements as a performance benchmark to guarantee that local products perform according to international norms (Hypothesis 1). The second coefficient in column (3) suggests that the scope of the auction - whether it was open not only

to domestic but also international competitors - did not relate to the number of required quality standards either. This suggests that Indian policymakers did not use technical requirements as a tool to reduce foreign investors’ (perceived) uncertainty about solar energy yields by guaranteeing the performance of PV plants per international quality standards (Hypothesis 2). The third coefficient in column (3) illustrates that the dummy variable defining the type of contractual arrangement - EPC vs. BOO - is statistically significant at the 1% level. EPC auctions increase the number of international quality standards by an estimated 54.7% relative to BOO auctions. We read this as evidence for the hypothesis that SECI has used technical requirements as a means to reduce its own technological and commercial risk exposure (Hypothesis 3).

Fig. 4 highlights the higher number of international quality standards required by Indian policymakers in EPC relative to BOO auctions. We argue that the difference arises because ultimate ownership and thus risk lies with SECI in EPC auctions, while it lies with the private electricity provider in BOO auctions. This line of reasoning is backed up by an additional analysis of the role of contract length and the composition of additional quality standards employed by SECI in EPC tenders.

4.5.1. Quality standards, contract length and risk allocation

While there is generally a standard contract length of 25 years for a PPA associated with a BOO tender, the contract length varies between 2 and 25 years for O&M periods associated with EPC tenders (very rarely up to 35 years). The longer the O&M period, the longer an EPC company has to bear the risk of technical failure and incur associated costs of reparation, replacement, and lost electricity sales. Fig. 5 shows that SECI requires on average as many technical requirements in EPC tenders with O&M periods above 10 years as in BOO tenders. Yet, SECI requires on average 55% more international quality standards (6 more, a total of 18 on average) in EPC tenders with an O&M period of 10 years or less. In other words, the technical requirements are more stringent if SECI (or another government institution) assumes ownership and full responsibility for the solar PV plant after less than 10 years of operation. This confirms our finding that Indian policymakers employ international

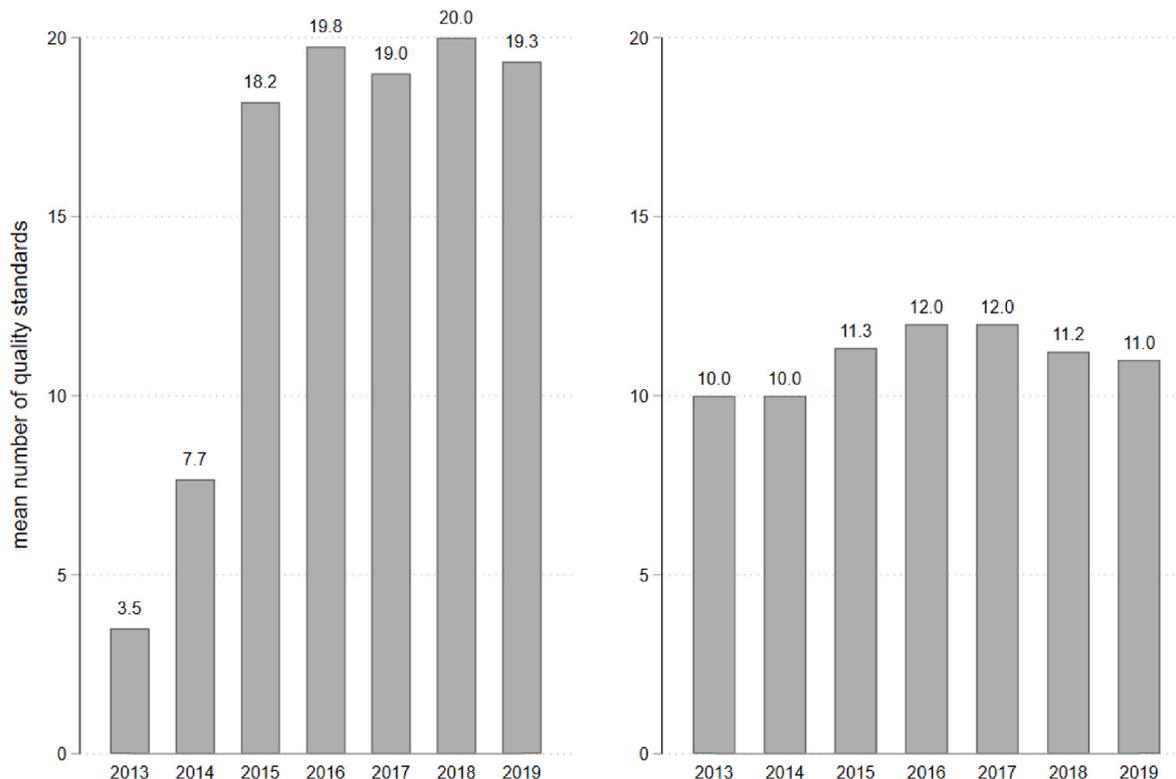


Fig. 4. Mean number of quality standards required in EPC (left) and BOO (right) solar PV auctions from 2013 until 2019 in India.

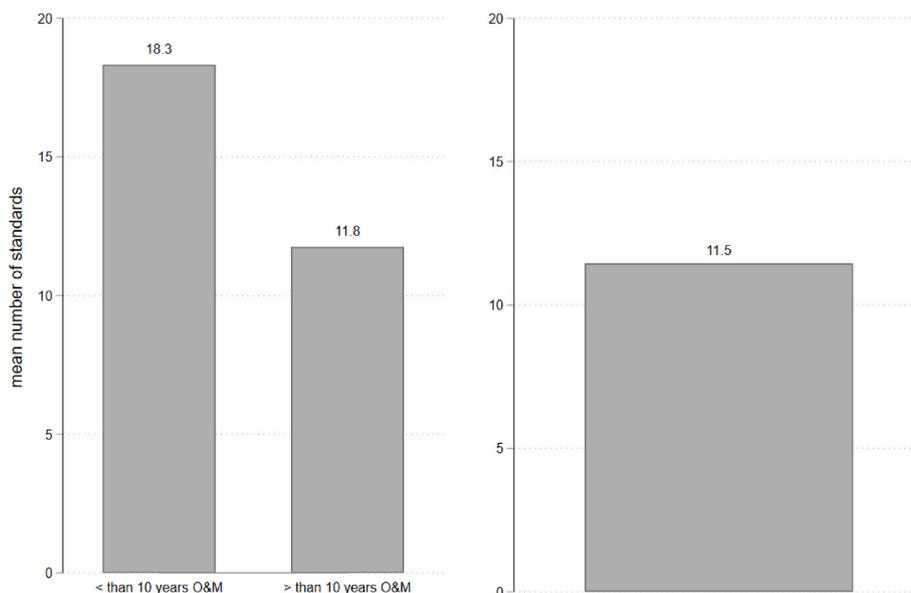


Fig. 5. Number of required standards as a function of the contract length for EPC tenders (left panel). The BOO tenders (right panel) are also shown for comparison.

Table 3

Some of the international quality standards present in EPC but not in BOO auctions.

Quality standard	Component addressed	Frequency
IEC 60076	power transformers	25 out of 38
IEC 62271	high-voltage switchgear	24 out of 38
IEC 61724	PV system performance monitoring	24 out of 38
IEC 62446	commissioning tests and inspection	16 out of 38
IEC 60364	low-voltage electrical installations	14 out of 38
IEC 62305	earthing and lightning protection system	12 out of 38
IEC 62852	MC4 connector for cable inputs	12 out of 38

quality standards as a tool to reduce the government’s own techno-commercial risk. At the same time, they pursue a minimum quality standards laissez-faire strategy if private companies assume the risk for more than 10 years.

4.5.2. Which additional standards are required in EPC tenders, and why?

Table 3 presents some of the additional quality standards required in EPC compared to BOO auctions. While some relate to additional activities that SECI has to assume in EPC auctions (e.g. IEC 62446 commissioning tests and inspection of the solar PV plant), the remaining ones relate to other components of the solar PV plant. Examples include IEC standard 62271 for high-voltage switchgear, IEC 60076 for power transformers, and IEC 62852 for cable connectors, all related to the choice of components. On the other hand, IEC 60364, 61724 and 62446 relate to the quality of labor efforts, including electrical installations and measurement and monitoring of plant performance at the commissioning stage. The purpose of these additional international quality standards is to reduce the handling options for EPC companies seeking to decrease their costs and increase their profits, e.g. by selecting low-quality components or minimizing labor efforts.

In section 3.1, we outlined the concerns related to including more international quality standards as technical requirements in public auctions of solar PV plants. In the following, we investigate whether some of these concerns are manifest in the Indian solar PV auctions.

4.5.3. Did international quality standards lead to the cancellation of public auctions due to an insufficient number of bidders?

A major concern raised in our discussions with Indian policymakers is that technical requirements may exclude bidders and, in the worst case, lead to cancellation of public auctions if no (domestic) bidder can comply. In fact, in our sample of 100 public auctions, about 27 have been canceled, according to SECI. The main reason for the cancellation was an insufficient number of bidders. In the following, we investigate whether cancellation correlates with the number of required international quality standards.

Table 4 shows the results for regressing the cancellation dummy “canceled” (1 = auction canceled; 0 = auction conducted”) on several auction-level explanatory variables. At first sight, column (3) suggests that international quality standards are positively associated with cancelling public auctions of solar PV plants. However, this positive correlation suffers from an omitted variable bias, as illustrated in column (4). Here we drop all the eight auctions that were somewhat “experimental” or “unconventional”, namely three auctions of “floating” power plants, four open renewable auctions (wind or solar) and one open solar auction (ground mounted, rooftop or floating). Once these auctions are removed, the positive association of international quality standards with the cancellation variable becomes insignificant. This suggests that SECI has used more international quality standards in these eight PV auctions, likely as an insurance mechanism given the increased uncertainty related to the experimental nature of these auctions.

Instead, two other factors are primary reasons for auction cancellations. We had to drop plant type and plant location from the regression, as they perfectly predict an auction cancellation. In terms of plant type, SECI canceled 5 out of the 8 experimental auctions mentioned above. In

**Table 4**

Regression results showing the factors driving the cancellation of solar auctions in India.

Variables	(1) cancellation rate	(2) canceled	(3) canceled	(4) canceled
Canceled	0.270 [0.446]			
Quality standards		0.00957 (0.00831)	0.0344* (0.0178)	0.0308 (0.0219)
LCR			-0.136 (0.101)	-0.0756 (0.102)
Global			0.0865 (0.118)	-0.0286 (0.128)
EPC			-0.213 (0.221)	-0.322** (0.136)
Contract length			0.00705 (0.00912)	0.0101 (0.00917)
Cell technology			-0.0484 (0.206)	-0.194 (0.174)
Subsidy			-0.00709 (0.107)	-0.0526 (0.107)
Solar park			0.0298 (0.117)	0.0396 (0.117)
Time trend			-0.0184 (0.0359)	-0.0138 (0.0380)
Max. plant size			-0.000441** (0.000218)	-0.000362* (0.000203)
Observations	100	100	100	92

\*\*\*p < 0.01, \*\*p < 0.05, \*p < 0.1

Note: Column (1) provides the mean cancellation rate (“27%”) with the standard deviation in square brackets. Columns (2)–(4) provide average marginal effects, which can be read as percentage changes in the cancellation rate. Standard errors are given in round parentheses.

terms of location, SECI conducted only very few auctions in some of the federal states like Haryana (one, not canceled), Assam (one, canceled) and Madhya Pradesh (two, both canceled). The 24 auctions with no specific location requirement were the most successful, with only one auction canceled.

Table 5 illustrates the results for regressing the number of bidders on all auction-level explanatory variables. Firstly, international quality standards are shown not to affect the number of bidders for each auction. We also checked whether this finding depends on the type of contractual arrangement, given our result that EPC auctions drive the increase in technical requirements. However, we do not find that international quality standards in EPC auctions reduce the number of bidders.

Moreover, the results provide interesting information about other factors that have affected the number of bidders. LCRs reduce and subsidies seem to increase the number of bidders. This suggests that another possible way of introducing technical requirements would be to make access to subsidies conditional on compliance with international quality standards. At the same time, it is not clear whether linking technical requirements to LCR would reduce or increase the number of bidders. For example, international quality standards may attenuate the negative effect of LCR on the number of bidders if this were due to the reluctance of international competitors to bid. On the other hand,

**Table 5**

Regression results showing the factors driving the number of bidders in India’s solar auctions.

Variables	(1) OLS bidders	(2) OLS bidders	(3) Poisson bidders	(4) Nbreg bidders
Quality standards		-0.564 (0.644)	-0.0426 (0.125)	-0.0479 (0.117)
LCR		-6.403*** (1.533)	-0.886*** (0.207)	-0.954*** (0.198)
Global		8.886*** (2.236)	0.762*** (0.252)	0.806*** (0.278)
EPC		4.402 (11.99)	0.0264 (2.291)	0.179 (2.283)
Contract length		-0.269 (0.446)	-0.0311 (0.0871)	-0.0231 (0.0899)
Cell technology		-0.815 (1.674)	0.0842 (0.442)	0.0418 (0.415)
Subsidy		6.155** (2.328)	0.659** (0.309)	0.559* (0.328)
Solar park		5.791** (2.689)	0.632** (0.246)	0.571** (0.262)
Time trend		-2.098*** (0.546)	-0.192** (0.0760)	-0.233*** (0.0772)
Max. plant size		0.000826 (0.00164)	0.000211 (0.000249)	0.000233 (0.000246)
Lnalpha				-1.758*** (0.274)
Constant	7.098 [6.739]	24.93*** (8.184)	3.366* (2.011)	3.529* (2.083)
Observations	51	51	51	51
R-squared		0.568		

\*\*\*p < 0.01, \*\*p < 0.05, \*p < 0.1

Note: Column (1) provides the average number of bidders (“7”) with the standard deviation in square brackets. Column (2) provides average effects for an Ordinary Least Square model, which can be read as unit changes in the number of bidders. Columns (3) and (4) are based on a Poisson and negative binomial model, respectively. Coefficients in columns (3) and (4) can be multiplied by 100 and interpreted as percentage changes in the number of bidders. Standard errors are given in round parentheses. “Lnalpha” suggests that the Nbreg model is the most appropriate to use, as the dependent variable is a count and overdispersed.

international quality standards could further reinforce the negative effect of LCR on the number of bidders if bidders in LCR auctions are mainly young domestic companies for whom compliance with technical requirements is more costly and complicated.

4.6. Implications

The gradual increase in the stringency of technical requirements in EPC auctions illustrates SECI’s accrued technical expertise and underlines that the minimal requirements in BOO auctions represent a strategic political choice. This strategy to transfer risks to project developers benefits the public budget. However, the strategy may have a few unintended, negative consequences. Firstly, given that fierce price competition from cheap, imported components erodes profits, it is unlikely that project developers will invest in research and development and quality upgrading. High-end companies likely either exit the market

or lower the quality/costs of their components. As a result, the actual project costs may be higher and the generated electricity lower than expected. Secondly, it seems plausible that more stringent technical requirements could have helped to attract investors with a longer time horizon. Technological risk is one factor that explains why some banks and international investors remain reluctant to finance solar power projects in India [24]. In the early days, it was easier to get equity finance from international venture capital with higher risk appetite than debt from national and international banks. Given the short time horizon of these players and the variable loan rates in India, non-performing power plants could lead to a sudden withdrawal or reduction in equity/debt finance. Suppose many project developers have engaged in speculative or Ponzi financing [24,82]. In that case, this could lead to bankruptcies due to project developers' inability to pay the interest with the returns from low electricity generation. Project developers with more stringent technical requirements will also resell their solar PV plants on the secondary market, which has started in recent years, more easily and for higher prices. In contrast, others may sell at a loss [70,83].

## 5. Conclusion and outlook

After analyzing 100 public auctions for solar PV plants in India, we find that policymakers seem to use technical requirements as a tool to reduce the government's own techno-commercial risk exposure rather than a signaling device to promote foreign investment or to encourage domestic industrial upgrading. Within three years since its creation, SECI started to require more stringent technical requirements in EPC auctions where the government assumes the final risk as the ultimate owner of the project. However, there has been no increase in the quality level required in BOO auctions, representing about 60% of the auctions and the lion's share of auctioned electricity. We believe this is a missed opportunity: had international quality standards been connected to LCR or subsidies, Indian and foreign bidders would have had a stronger incentive to catch up with the global frontier, and more international and long-term investment may have been gained.

Based on these results, we recommend policymakers in India and other countries adopt a strategic and proactive approach to the use of technical requirements. A gradual increase in the number and stringency of international quality standards, ideally combined with forward guidance (early announcement, transition period), incentives to adopt international quality standards (e.g. making access to subsidies conditional on compliance with international quality standards), and support measures to set up domestic laboratories or vouchers for product testing, should promote productivity increases through learning from international standards. This gradual increase could prevent negative consequences from a too ambitious use of international quality standards, such as excluding nascent local companies. To facilitate learning-by-doing, the communication of technical requirements should be improved, as this is particularly important for new players. For example, guidelines and videos could be added to the required international quality standards, potentially in collaboration with and financed by international institutions (i.e. IEC, IRENA, World Bank). Governments should also actively promote the market entry of private laboratories by guaranteeing that specific tests will be required in public auctions in the future and offering low-interest credits for investments in new laboratories or equipment for new tests. Finally, governments should seek to enable real-time, central monitoring of the amount and efficiency of electricity generation from PV plants to reduce information asymmetry

between project developers, investors, and state utilities.

In the future, it would be interesting to investigate whether there are any potential unintended consequences of the Indian government's minimum quality standard approach. For example, we suggest exploring whether certain firms exited the market or adapted their business strategies to favor price competition over quality. It would be equally relevant to analyze whether minimum quality standards have led to low performance of solar PV plants, e.g. due to the use of low-quality components, inadequate transportation or installation of components. Finally, it would be important to examine whether international quality standards could attract more investment including investors with a longer time horizon as well as incentivize firms that benefit from LCR.

## Credit author statement

Conceptualization: F.M. and A.M.; Methodology: F.M. and A.M.; Formal analysis: F.M.; Writing—original draft: F.M. and A.M.; Writing—review and editing: F.M. and A.M.; Visualization: F.M., Both authors have read and agreed to the current version of the manuscript.

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## 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

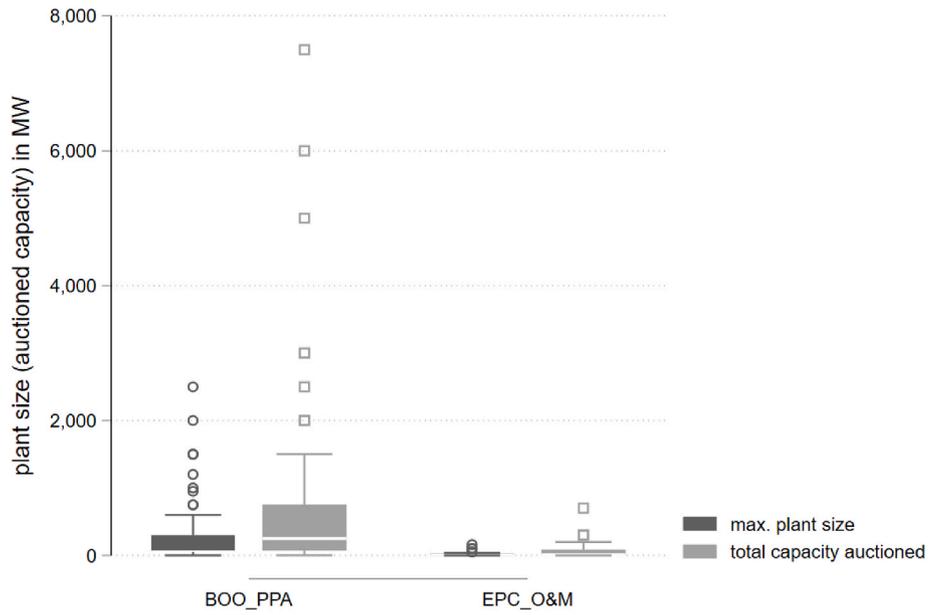


Fig. 6. Maximum admissible project size and total auctioned capacity for BOO and EPC auctions

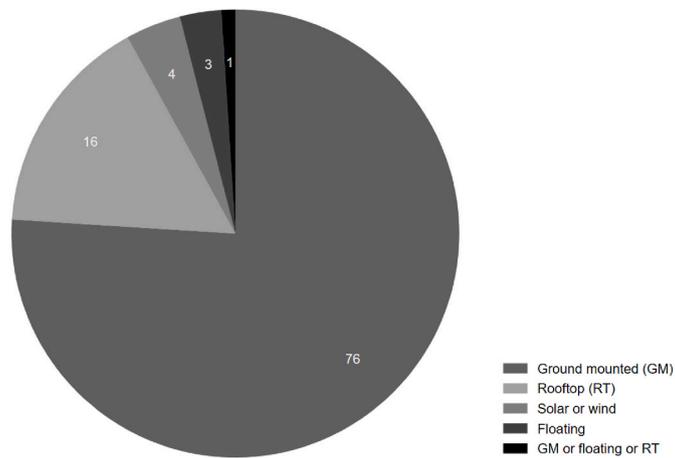


Fig. 7. Number of auctions observed by type of solar PV plant

**Table 6**  
List of the International Quality Standards used in the analysis of the solar auction documents issued by SECI

Component	IEC norm	Description
Modules	IEC 62093	Proof of qualification of specific electrical components for the PV power
	IEC 62804	PID free test
	IEC 61701	Salt mist corrosion testing of photovoltaic (PV) modules
	IEC 60068	Environmental testing; Part 2-68: Tests -Test L: Dust and sand
	IEC 62716	Photovoltaic (PV) modules - Ammonia corrosion testing
	UL 1703	Flat-Plate Photovoltaic Modules and Panels
	IEC 61730	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction; mainly for international markets
	IEC 61215	Crystalline Silicon Terrestrial PV Modules; mainly for international markets
	IEC 60364	Low-voltage electrical installations
	IEC 61646	Thin-Film Terrestrial PV Modules; mainly for international markets
	ASTM E2481-06	Standard Test Method for Hot Spot Protection Testing of Photovoltaic Modules
	IEC 60904	Photovoltaic devices
	IEC 61853	Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and power rating
	EN 50380	Datasheet and nameplate information for photovoltaic modules
	IEC 60189	Electrical materials and components in DC applications to withstand 1000 V DC (or 1500 VDC if applicable) with PVC insulation
Inverters	EN 50178	Electronic equipment for use in power installations
	IEC 61683	Photovoltaic systems - Power conditioners – Procedure for measuring efficiency
	IEC 62109	Safety of power converters for use in photovoltaic power systems – Part 1: General requirements
	IEC 62116	Utility-interconnected photovoltaic inverters – Test procedure of islanding prevention measures
	EN 50524	Data sheet and name plate for photovoltaic inverters
	EN 50530	Overall efficiency of grid connected photovoltaic inverters
	UL 1741	Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources
	IEEE 1547	Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
	IEEE 2030.5 2018	Smart Energy Profile 2.0 for DER integration
	IEC 60721	Classification of environmental conditions: Part 1: environmental parameters and their severities
	EN ISO 1461	A hot-dip galvanized class II coating
	EN 50251	Connectors for PV systems
	IEC 60227	Low-voltage installations
	IEC 60228	Low-voltage installations
	Combiner Boxes	IEC 61000
IEC 62852		MC4 connector at each cable input
Transformers	EN 50521	Connectors for photovoltaic systems; Safety requirements and tests
	IEC 60076	Power transformers (type test and routine test)
Auxiliary System	IEC 62040	UPS
Switchgear	IEC 60502	High-voltage installations
	IEC 60840	High-voltage installations
	IEC 62271	High-voltage switchgears (type test records containing dielectric tests, short-time withstand current and peak withstand, internal fault)
	IEC 61936	High-voltage switchgear and maintenance and operating areas
	IEC 62548	PV power plant
Earthing and Lightning Protection System	IEC 62305-3	The design of the earthing and lightning protection system
	EN 50539	The type and location of the SPDs
	ISO/IEC 31010	Risk assessment
	IEC 60721	Transformer accessories
	OHSAS 18001	Health and Safety documentation
Cold Commissioning at PAC	IEC 62446	Commissioning
	IEC 61724	Commissioning
	IEC 60904 series	Commissioning
	IEC 62305-3	Commissioning
Pre-Energizing Tests	IEC 61557	Measuring instruments and monitoring equipment and methods
	IEC 61010	Measuring instruments and monitoring equipment and methods
Visual Inspection	IEC 60079-17	Explosive atmospheres - Part 17: Electrical installations inspection and maintenance
	IEC 61829	Photovoltaic (PV) array: On-site measurement of current-voltage characteristics
IV Curve Testing	IEC 60891	Photovoltaic devices: Procedures for temperature and irradiance corrections to measured I-V characteristics
	EN 1991	Actions on structures
	EN 1997	Geotechnical design - Part 2: Ground Investigation and testing
	IEC 62727	Photovoltaic Systems: Specifications for trackers
	IEC 61345	UV test for photovoltaic (PV) modules
	IEC 62759	Transportation testing of photovoltaic (PV) modules - Part 1: Transportation and shipping of PV module stacks
	IEC 62817	Photovoltaic Systems - Design qualification of trackers

**Table 7**  
Full version of the regression analysis summarized in Table 2

Variables	(1)	(2)	(3)
	international quality standards	international quality standards	international quality standards
Local content requirement		−0.132*** (0.0450)	0.0192 (0.0410)
Global		−0.00549 (0.0451)	0.179* (0.101)
EPC		0.477*** (0.0377)	0.547*** (0.169)
Contract length			−0.000499 (0.00710)
Cell technology			−0.00712 (0.108)
Subsidy			0.0584 (0.0667)
Solar park			−0.0836* (0.0490)
Time trend			0.0564*** (0.0218)
Max. plant size			−3.98e-05 (5.09e-05)
Assam			−0.244*** (0.0781)
Chhattisgarh			−0.0924 (0.0622)
Delhi			−0.0491 (0.0921)
Gujarat			−0.0565 (0.0534)
Haryana			−1.040*** (0.134)
Himachal Pradesh			0.0485 (0.151)
India-wide			−0.505*** (0.122)
Jammu & Kashmir			−0.291*** (0.0940)
Karnataka			−0.0782 (0.0604)
Kerala			−0.0383 (0.117)
Lakshadweep			−0.334** (0.138)
Madhya Pradesh			−0.195* (0.0994)
Maharashtra			−0.101* (0.0598)
Odisha			−0.0386 (0.0628)
Puducherry			−0.0950 (0.0632)
Rajasthan			−0.130* (0.0729)
Tamil Nadu			−0.222*** (0.0851)
Telangana			−0.174* (0.0971)
Union Territory			−0.448** (0.197)
Uttar Pradesh			−0.140** (0.0703)
West Bengal			−0.0967 (0.0722)
Ground mounted (GM)			0.0634 (0.0580)
GM or floating or RT			0.164 (0.120)
Rooftop (RT)			−0.0511 (0.0989)
Solar or wind			−0.584* (0.319)
Constant	13.80 [4.759]	2.475*** (0.0185)	2.254*** (0.225)
Observations	100	100	100

Note: Columns (1) to (3) are the same as in Table 2 and were described in detail there. Here, Andhra Pradesh is the reference category for the location controls and floating for the plant type controls.

**Table 8**  
Sensitivity of the estimates presented in Table 2 to the regression model used.

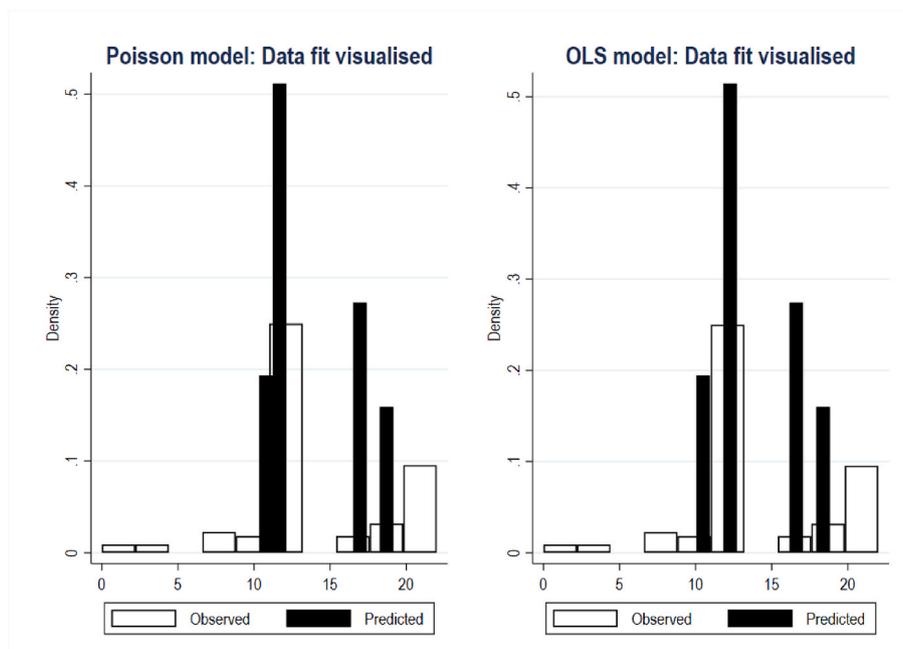
Variables	(1)	(2)	(3)	(4)
	Mean	Poisson	Nbreg	OLS
International quality standards	13.80 [4.759]			
LCR		0.0192 (0.0410)	0.0192 (0.0410)	0.390 (0.614)
Global		0.179* (0.101)	0.179* (0.101)	1.855 (1.292)
EPC		0.547*** (0.169)	0.547*** (0.169)	6.999** (2.768)
Location controls		YES	YES	YES
Plant type controls		YES	YES	YES
Time trend		YES	YES	YES
Alpha			7.11E-10	
Constant		2.254*** (0.225)	2.254*** (0.225)	9.528** (3.778)
Observations	100	100	100	100
R-squared				0.784

Note: \*\*\*p < 0.01, \*\*p < 0.05, \*p < 0.1. All standard errors are robust. Column (1) provides the mean number of international quality standards required in the 100 public auctions. Column (2) provides estimates based on the Poisson model. Column (3) provides estimates for a negative binomial model, which correspond to a Poisson model given that the dispersion parameter alpha is insignificant and thus a Poisson model is estimated. Column (4) presents estimates for an ordinary least squares (OLS) model. Location and plant-type control variables are the same as in Table 7 of the appendix.

**Table 9**  
Sensitivity of the estimates presented in Table 2 to omitting one variable

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	IQS										
Global	0.180* (0.101)		0.164 (0.106)	0.179* (0.101)	0.177* (0.105)	0.144* (0.0796)	0.185* (0.0999)	0.202** (0.0888)	0.171* (0.0975)	-0.0188 (0.0677)	0.0422 (0.0630)
EPC	0.558*** (0.170)	0.536*** (0.159)		0.555*** (0.125)	0.552*** (0.153)	0.549*** (0.166)	0.570*** (0.171)	0.643*** (0.182)	0.555*** (0.172)	0.461** (0.201)	0.411*** (0.124)
LCR		0.0238 (0.0414)	0.0686 (0.0422)	0.0189 (0.0433)	0.0183 (0.0371)	0.0238 (0.0406)	0.0261 (0.0411)	-0.0174 (0.0395)	0.0212 (0.0394)	-0.0165 (0.0419)	0.0406 (0.0390)
Constant	2.250*** (0.227)	2.280*** (0.208)	2.821*** (0.182)	2.243*** (0.142)	2.249*** (0.219)	2.272*** (0.217)	2.252*** (0.226)	2.367*** (0.237)	2.268*** (0.219)	2.328*** (0.292)	2.252*** (0.196)
Observations	100	100	100	100	100	100	100	100	100	100	100

Note: \*\*\*p < 0.01, \*\*p < 0.05, \*p < 0.1. Robust standard errors are given in parentheses. All coefficients are estimated with a Poisson model in Stata 15. For each column, one variable is dropped at a time beginning with the three major explanatory variables.



**Fig. 8.** Observed versus fitted data for the Poisson and ordinary least squares (OLS) models

**Table 10**  
Descriptive statistics for observed versus Poisson and OLS predicted outcome variable

Variable	Observ.	Mean	Std. Dev.	Min.	Max.
No. of required quality standards	100	13.8	4.759	0	22
Poisson prediction	100	13.8	3.139	10.353	19.15
OLS prediction	100	13.8	3.132	10.065	18.813

#### 1. PV MODULE QUALIFICATION

The PV modules used in the grid connected solar power Projects must qualify to the latest edition of any of the following IEC PV module qualification test or equivalent Indian standards.

Standard	Description
IEC 61215-1 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements
IEC 61215-1-1 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules
IEC 61215-1-2 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules
IEC 61215-1-3 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules
IEC 61215-1-4 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,Ga)(S,Se) based photovoltaic (PV) modules
IEC 62108 Ed. 2.0	Concentrator photovoltaic (CPV) modules and assemblies - Design qualification and type approval
IEC 61730-1 Ed. 2.0	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction
IEC 61730-2 Ed.2	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing
IEC 61701 Ed.2	Salt mist corrosion testing of photovoltaic (PV) modules (Applicable for coastal and marine environment)

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Fig. 9. First page from the technical requirements section of a solar auction document issued by SECI in 2019

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