Multi-Objective Auctions for Utility-Scale Solar Battery Systems: Lessons for ASEAN and East Asia

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Abstract

Auctions are an increasingly popular means of competitively promoting and procuring renewable energy to meet energy, social, and climate change objectives. To succeed, the technology designs need to accommodate technological progress, declining costs, and increasing Environmental, Social and Governance (ESG) demand. This analysis examines international experiences with large-scale solar photovoltaic (PV) and battery energy storage systems (BESS) auctions, which may be useful for East and Southeast Asia. It revisits auctions' theoretical and conceptual frameworks while concentrating on the ESG aspect from the perspective of such key stakeholders as investors, government, bidders, and communities, regarding efficient allocations of risks, costs, and benefits. It then relates this framework to real-world practices and international evidence on solar PV with and without BESS. The analysis shows that integrating ESG in auction designs and business models is possible and can benefit business and sustainable development. This analysis' focus on the ESG and solar PV plus BESS in auctions contribute are nearly non-existent in the existing academic literature according to the review by del Río and Kiefer (2023).

Key words: Renewable energy, solar power, battery storage, auction design
JEL Classifications: D0, D4, D8, L0, L1, L9

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1. Introduction

East and Southeast Asia (ASEAN) are dynamic regions undergoing transitions into sustainable growth pathways, especially concerning energy. The International Monetary Fund (IMF), as of October 2022, forecasts Asian economy to expand much more slowly than in the preceding two decades while Asia's economic performance remains relatively sound in an increasingly sluggish global economy (IMF, 2022). Among the 16 Least Developed Countries (LDC) in the United Nations' category of being on the path to graduation, ten are World Trade Organization (WTO) members, including ASEAN members Cambodia, Lao PDR, and Myanmar. The phasing-out of international support measures associated with LDC status may present challenges to graduating LDCs attempting to integrate into the global economy, such as stricter compliance with climate and other environmental, social, and governance (ESG) regulations. Six global brands that source garments and footwear from Cambodia wrote to its government in August 2020, stating that its proposed increase in coal-fired electricity could reduce the country's prospects for attracting future investment (Voice of America, 2020).

According to the International Energy Agency (IEA, 2022), Southeast Asia will see rapid growth in energy demand. In its Stated Policies Scenario (STEPS), based on a business-as-usual assumption, the region's oil-dominated demand rises more than 3 percent annually from 2021 to 2030, faster than in the previous decade. Renewables, natural gas, and coal demand all rise rapidly, with coal continuing to dominate, although its share of power generation declines from 42 percent today to 39 percent by 2030.

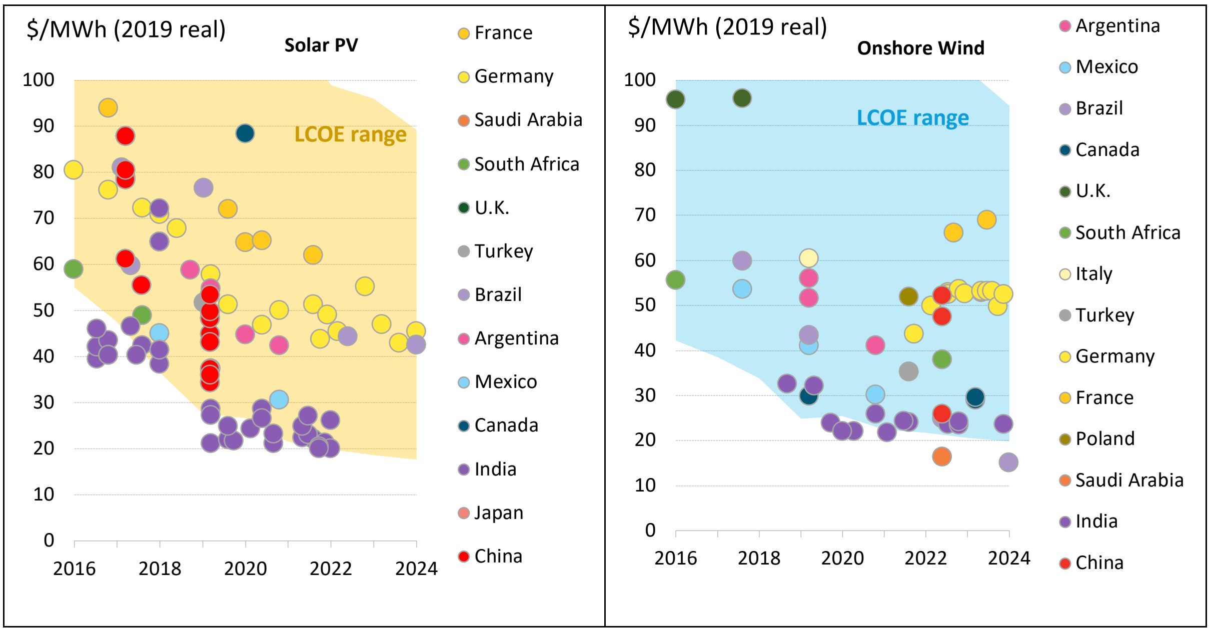
The International Renewable Energy Agency (IRENA) has estimated average annual investment needs for renewable energy and energy efficiency in East and Southeast Asia totaling US$582 billion under its Planned Energy Scenario (PES) and US$830 billion under the Transformative Energy Scenario (TES) during 2016-2050 (IRENA, 2020a; base year for US$ prices unavailable). These needs are despite decreasing renewables costs, as seen in IRENA reporting that total installed costs for utility-scale solar PV plants fell 81 percent between 2010 and 2020, from US$4,731 per kilowatt (kW) to US$ 883/kW (IRENA, 2022; information on nominal or real prices unavailable).

IEA reports utility scale lithium-ion battery prices falling from US$4,285 per kilowatt-hour (kWh) in 2010 to US$1,568/kWh in 2017 (IEA, 2020; information on nominal or real prices unavailable). Notwithstanding, the S&P Global-owned IHS predicts that a battery module price increase of 5 percent in 2022 amid fierce demand for lithium-ion phosphate batteries in electric vehicles (EV) will drive up the overall cost of stationary battery projects by some 3 percent. IHS Markit forecasts that lithium-ion battery prices will not fall before 2024, thanks to rising metal prices, EV demand, and China's near-monopoly on the sector (Hall, 2022). Solar PV system prices have also increased in 2021-2022, due chiefly to supply chain constraints (Stevens, 2022).

In the wake of fossil fuel prices soaring from 2021 to 2022, solar power has helped meet electricity demand and enhance energy security in Asia. In China, India, Japan, South Korea, Vietnam, the Philippines, and Thailand, solar electricity generation reduced potential fossil fuel expenditures by approximately US$34 billion from January to June 2022, equivalent to 9 percent of total fossil fuel costs those countries incurred during that time (Edianto et al., 2022).

Power systems aspiring to high renewables penetration rates with mostly variable renewable resources will probably require a variety of storage technologies, whose owner should procure through a competitive process to meet the power system least-cost objective. As the renewable energy sector progresses, policies must take changing market conditions and new technical and socioeconomic challenges into account to ensure a just and inclusive transition encompassing the energy sector and more. Falling costs of new technologies, expanding growth in variable renewables, i.e., solar and wind, and greater emphasis on climate and other ESG objectives by policymakers and stakeholders have altered the conditions for new market entrants and new power generation projects. One instrument on the rise is auctions to promote competition for the market as policymakers seek to procure renewable electricity at the lowest possible price while fulfilling other social or economic objectives. While enough data for statistical analysis are unavailable, general auction price trends might better reflect technology cost trends than earlier feed-in tariff schemes with government-set prices, per Figure 1.

Figure 1. Levelized bids for auctions across G-20 by project commissioning year, 2016–2024



Source: Bloomberg New Energy Finance (BloombergNEF, 2021).

Note: To make the winning auction tariffs comparable across countries, BloombergNEF levelizes the capacity-weighted average winning tariff, estimating the average inflation-indexed tariff for the lifetime of the project. BloombergNEF removes the effect of subsidies, standardizes inflation, and adds a merchant tail for the lifetime of the project after the auction tariff expires. Levelized bids are shown by their commissioning dates.

Morality in competitive markets is increasingly important for investors, shareholders, and consumers (Tirole, 2017, 2021; Dewatripont and Tirole, 2022). Financiers' demand for return on ESG is on the rise, with global debt issued for ESG purposes forecast to reach US$1.3 trillion in 2022 (Institute of International Finance, 2022) from the approximately US$30 billion in 2013 reported by Bloomberg New Energy Finance (BloombergNEF). The European Union (EU) will require funds to disclose information about how they reduce potential negative impacts of their investments beginning in 2023.

According to (Theobald, 2022) major impediments to institutional investments in emerging and frontier markets are that institutions and fund managers are increasingly applying ESG considerations in their investment strategies that exclude or down-weight emerging and frontier markets. However, some investors use an active ESG approach in addition to, or instead of, ESG screening, in which they identify investment opportunities to improve ESG outcomes using the Sustainable Development Goals (SDGs) as their targets (Theobald, 2022). For the following reasons, this study concentrates on auctions for procuring utility-scale solar photovoltaics (PV) and battery energy storage systems (BESS) with long-term power purchase agreements (PPA) on the order of 15-25 years or other sufficient cost recovery periods:

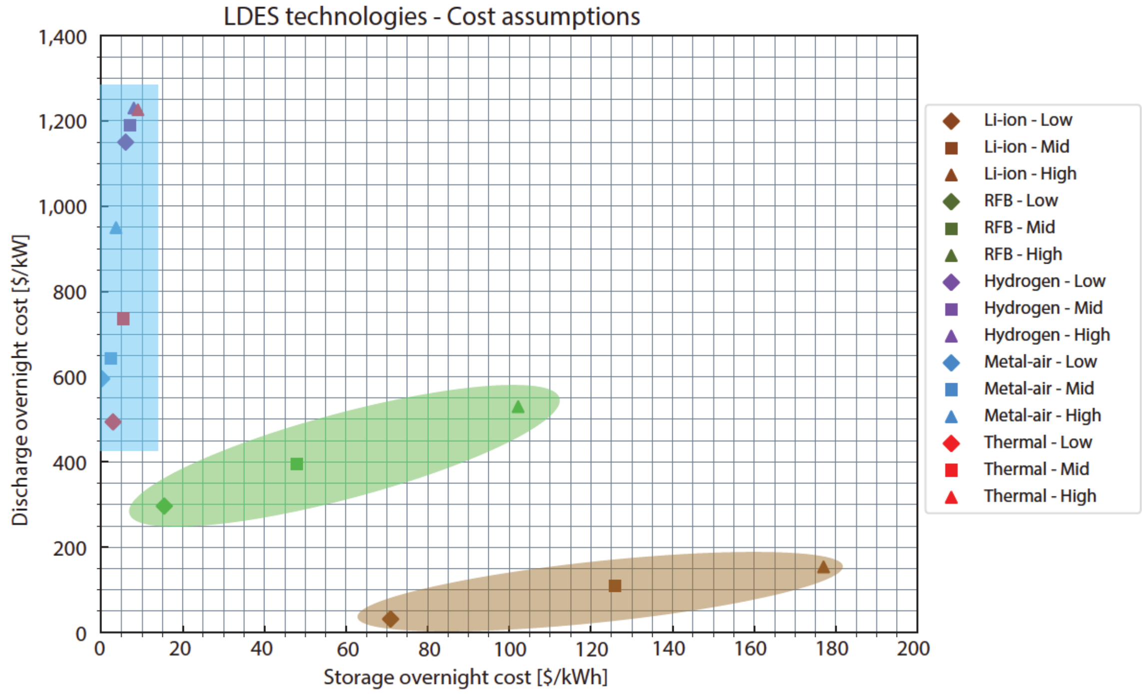
First, some countries in ASEAN and East Asia, such as Japan, Korea, and Singapore, have wholesale electricity markets based on auctions in energy markets, e.g., the day-ahead and real-time markets, and capacity markets, which include forward markets. Other ASEAN countries, such as Vietnam, Cambodia, Indonesia, and Lao PDR, retain a state-owned single buyer model, i.e., centralized agents which purchase power from generators, with electricity purchased from private independent power producers (IPPs) with PPAs often combined with power generated by state-run providers. While the latter countries may lack competitive electricity markets, auctions for procuring contracted amounts of electricity provide opportunities for bidders to compete for specific market segments under the PPAs.

Second, while corporate renewable energy PPA volumes are increasing as companies aspire or need to decarbonize their activities, they face challenges in delivering 24/7 renewable energy power as of 2022 (LDES Council, McKinsey and Company, 2022). Achieving 100 percent decarbonization with variable renewables requires long-duration energy storage (LDES) technologies. As shown in Figure 2, technologies with low energy capacity costs and high power capacity costs (the blue area) are most suitable for longer duration storage applications on the order of days at a time and less frequent charge discharge cycles. Examples include metal-air batteries, hydrogen, thermal storage with low round-trip efficiency (RTE), and pumped hydro storage with medium RTE. Technologies with intermediate capabilities, including redox flow batteries (RFBs) with medium RTE, are in the green area. Technologies in the brown area, including lithium-ion battery high RTE, are better suited to shorter duration applications on the order of hours and more frequent cycling. EV battery development has significantly improved short-duration electricity storage prospects, while long-duration storage technologies have not experienced similar levels of help from other market drivers (MIT 2022).

Small-scale renewable energy and storage systems, such as small islands, tend to approach the 24/7 renewable energy target more closely, as shown in

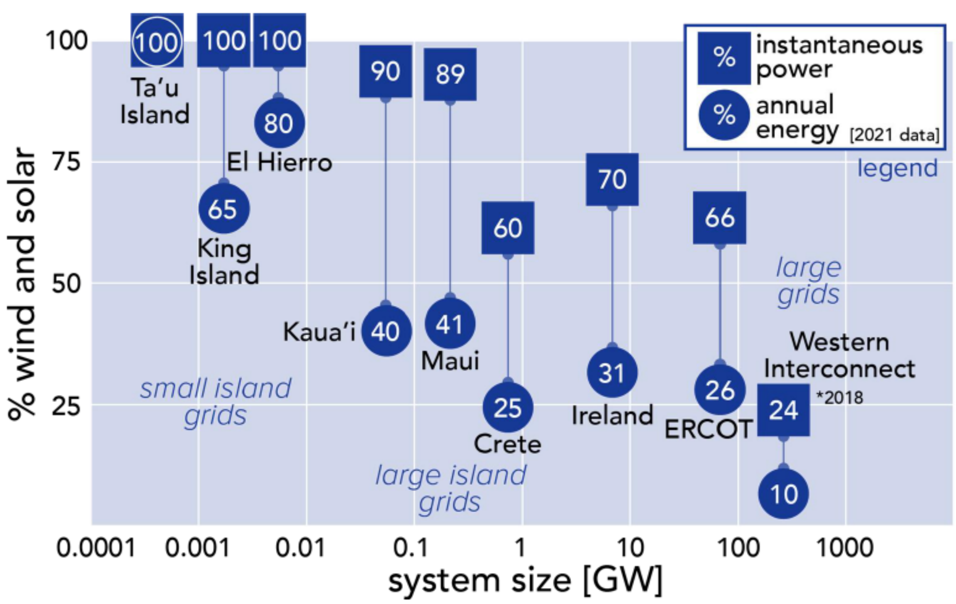
Figure ***3***. Use of lithium-ion batteries for longer durations in larger systems to complement wind power, such as in Ireland, is assessed as too expensive (Newbery, 2020). Competitive auctions improve the transparency of renewable energy PPAs by enabling investments in clean, dispatchable capacity that drives down costs, and more precise climate and ESG compliance.

Figure 2. Three classes of energy storage technologies, grouped by discharge power and storage overnight capital costs in 2050 (US$ 2020 prices)



Source: Massachusetts Institute of Technology (2022)
LDES: Long-Duration Energy Storage
RFB: Redox Flow Battery

Figure 3. Instantaneous power vs. annual energy by grid system size



Source: Kroposki (2022)
ERCOT: Electric Reliability Council of Texas

This study's focus on ESG aligns with and is more comprehensive than the Paris Agreement on climate change. It particularly examines renewable energy installations, which tend to be located in ecologically and socioeconomically sensitive areas. Climate, being an aspect of the "E" for "environment" in ESG, is an abiotic factor of ecosystems. Thus, the global community must consider the impact of its investments on the ecosystem beyond climate mitigation, adaptation, and resilience if we are to achieve sustainability. According to a UN report (UNEP 2022), climate, biodiversity, and land degradation goals will be out of reach unless investments into nature-based solutions reachUS$384 billion/year by 2025, more than double the current US$154 billion/year as of 2022. Annually, private capital represents only an estimated 17 percent (US$26 billion) of total investments into nature-based solutions. Private sector actors will have to combine net-zero with being nature-positive, complying with Task Force on Climate-related Financial Disclosures (TCFD) and Nature-related Financial Disclosures (TNFD).

A review of 607 academic publications renewable electricity auctions identified in March 2022 (del Río and Kiefer 2023) finds that study's focus on multicriteria auctions and auctions on solar PV plus BESS, i.e., dispatchable renewable energy sources (RES) electricity generation, are almost non-existent in their reviewed academic literature. This review's finding is consistent with this study and the facts that in April 2023, the government of United Kingdom issued a call for evidence on introducing non-price factors into the contracts for difference scheme, such as ESGs (Government of United Kingdom 2023) and that the United States Federal Energy Regulatory Commission (FERC) has issued only broad electric storage rulings that are not yet specific to hybrid resources such as solar PV and BESS as of May 2023.

Section 2 begins with a theoretical and conceptual framework of auction markets where demand and supply have their own ESG objectives, before assessing risks and providing case histories of measures to mitigate said risks, including the complementary role of auctions, among other market instruments. Section 3 briefly reviews concerned auction methods and their contractual forms. Section 4 discusses several business models with case histories. Section 5 is a literature review. In Section 6, the conclusion, we note that broader policy support might facilitate integrating ESG into competition and better environmental outcomes.

2. Conceptual Frameworks

2.1. Static, Dynamic, and Incentive Frameworks

2.1.1. Static Framework

Auction design's main objectives include efficiency, fairness, transparency, and simplicity, subject to the firms', i.e., bidders', incentive compatibility, individual rationality, and participation constraints. This analysis uses a simplified framework building on Tirole (2017, 2021) and Dewatripont and Tirole (2022), which assumes a unit-demand, i.e., an official selecting a bidder on behalf of consumers and the public interest, and n sellers, i.e., bidders, $i \in \{1, \ldots, n\}$. To compete, sellers select a price p_i and an ESG choice a_i, both in $\mathbb{R}^+$. Higher a_i values signify higher ESG choice levels, at least in the relevant range $[0, \widehat{a_i}]$ where $\widehat{a_i} \leq +\infty$. a_i has a welfare impact $W_i(a_i)$, with $W"_i < 0$ and $W'_i\,(0) = +\infty$. Thus, there exists $\widehat{a_i}$ such that $W_i(a_i) > 0$ if and only if $a_i < \widehat{a_i}$. Let $a = (a_1 \ldots . a_n)$ denote the vector of ESG choices.

The vector $\{p_{i,}\, a_i\}$ determines the net price $\widehat{p_i}$ perceived by the buyer. Seller i faces a demand function $D_i(\hat{p})$ where $\hat{p} \equiv \{p_{1,\ldots}\, p_n\}$ denotes the vector of net prices, and also refers to $D_i(\widehat{p_i}, \hat{p}_{-i})$, where $\hat{p}_{-i}$ denotes the vector of net prices charged by seller i's rivals. The buyer's cost or benefit of ESG is a function $\phi_i(a_i)$ with $\phi_i'' \geq 0$ such that

$$\widehat{p_i} \equiv p_i + \phi_i(a_i). \qquad (1)$$

When the buyer is ESG-irresponsible, then $\phi_i'(a_i) > 0$, as demand decreases with the morality of the firm's offer. Conversely, ESG-responsible buyer demand increases with the morality of the firm's offer: $\phi_i'(a_i) < 0$, while ESG-neutral buyer demand remains unchanged regardless of morality: $\phi_i'(a_i) = 0$.

Seller i's unit cost c_i may depend on her ESG choice a_i: $c_i(a_i)$ with $c'_i(a_i) \gtrless 0$. The sellers are substitutes, and hence, demand elasticity is $(\partial D_i/\,\partial \hat{p}_i < 0 < \partial D_i/\,\partial \hat{p}_j)$, and marginal revenue is decreasing in price ($(p_i - c_i)D_i(\hat{p})$ is concave in p_i). $\eta_i(\hat{p};\sigma) \equiv (-\partial D_i/\partial \hat{p}_i)/(D_i/p_i)$ denotes price elasticity of demand for supplier i's services.

Assumption 1 (elasticity of demand): Seller i's elasticity of demand increases with competitive pressure: $\frac{\partial \eta_i}{\partial \hat{p}_j}$.

Objective functions. Sellers care about profit and ESG impact, as ESG is part of requirements to bid in the auction and/or requirements that the seller's, i.e., the firm's, investors impose. Let $\alpha_i \geq 0$ denote seller i's intrinsic ethics, that is, the weight on welfare relative to weight on profit.

Assumption 2 (consequentialism). As net prices determine demand, seller i's social welfare perception depends on net prices and ESG choices: $W_i(\hat{p}, \mathrm{a})$. Perceived welfare impact scales with actual impact, making it proportional to demand: non-increasing function $\Gamma_i(a_i)$ *such that* $\Gamma i(0) = +\infty$ and $\lim_{a_i \to \hat{a}} \Gamma_i(a_i) = 0$, *and* $\frac{\partial W_i}{\partial a_i} = \Gamma_i(a_i)\, D_i(\hat{p})$.

Seller i maximizes the sum of profit and internalized perceived social welfare as ESG impact; letting $\alpha_i \geq 0$ denote the intensity of her social preferences, her utility function is:

$U_i \equiv [p_i - c_i(a_i)]D_i(\hat{p}) + \alpha_i W_i(\hat{p}, a) \equiv \left[p_i - (c_i(a_i) - \alpha_i W_i(\hat{p}, a)\frac{1}{D_i(\hat{p})})\right] D_i(\hat{p}) \equiv [p_i D_i(\hat{p}) + \alpha_i W_i(\hat{p}, a)] - c_i(a_i)D_i(\hat{p})$. (2)

That $\frac{\partial W_i}{\partial a_i}$ is proportional to demand D_i is consistent with consequentialism. ESG choices are uniform over seller i's demand and so their impact is proportional to demand.

The following is a simplified equilibrium behavior illustrating the foregoing in a first-price (pay-as-you-bid) auction with incomplete information. Each of n bidders' private value v (parameter) is drawn from distribution F, denoted as $v_i \equiv p_i(v_i) - c_i(a_i)D_i(\hat{p})$ from equation (2) where $p_i(v_i) \equiv p_i D_i(\hat{p}) + \alpha_i W_i(\hat{p}, a)$. Bidder will bid at bidding price $p_i\ (v_i)$ (decision variable), and the expected utility is:

$$\mathbb{E}\,[u(p_i(v_i), v)] = [p_i(v_i) - v_i]Pr\big(Win\big|p_i(v_i)\big) \quad (3)$$

By the envelope theorem, $\frac{du}{dv} = \frac{\partial u}{\partial p_i(v_i)}\frac{\partial p_i(v_i)}{\partial v} + \frac{\partial u}{\partial v} = \frac{\partial u}{\partial v}$, then, $\frac{du}{dv} = \Pr\,(Win|p_i(v_i)) = \Pr\,(lowest\ bid) = \Pr\,(lowest\ value) = F(v)^{n-1}$. Utility is rewritten as $u(v) = u(0) + \int_0^v F(v)^{n-1}dv = \int_0^v F(v)^{n-1}dv$, which substituted into equation (3) results in: $p_i(v_i) = \frac{u(p_i(v_i),v)}{\Pr\left(Win\middle|p_i(v_i)\right)} + v_i = F(v)^{-(n-1)}\int_0^v F(v)^{n-1}dv + v$. For example, where $v \sim U$ on $[0,1]$, then $F(v) = v$, and $p(v) = \frac{v}{n} + v = \frac{v(1+n)}{n}$. Given that the optimal bid converges to the value as $n \to \infty$, in the limit the buyer can extract the bidder's full surplus. In equilibrium, the bidder bids the expected value of the second lowest value, given that the bidder has the lowest value.

The buyer will select the seller who bids at the lowest price p. While the ESG-responsible buyer may consider social welfare impact $\hat{p} \equiv p + \phi(a)$ in selecting the bidder, they will weigh the bid offer price p higher than $\phi(a)$. As the auctioned quantity (demand) is fixed, seller i tries to minimize the offer price p_i. Rearranging equations (1) and (2) results in:

$$p_i \equiv \widehat{p_i} - \phi_i(a_i) \equiv [U_i - \alpha_i W_i(\hat{p}, a)] * \frac{1}{D_i(\hat{p})} + c_i(a_i) \quad (4)$$

In these equations, the seller i's controllable cost is $c_i(a_i)$. Hence, the seller tries to reduce cost c_i and/or ESG concerns a_i, either by increased efficiency or cutting corners. Examples of the latter include, but are not necessarily limited to, choosing lower-quality and thus cheaper inputs, and reducing ESG performance and/or quality. As cost c_i depends on ESG efforts a_i, however, cutting corners might incur greater costs than the bid offer p_i. Less effort in social and environmental impact assessment, mitigation and management measures, and benefit sharing with local communities could delay contract execution, leading to cost overruns and penalties. Low-quality equipment may cost more in maintenance, repair, and replacement.

2.1.2. Dynamic Framework

In a dynamic intertemporal setting where auctions are held over the years, sellers may choose not to participate in an auction and wait for subsequent auctions, when more information about the auction process may be available. Sellers who do participate, however, will glean more information from participation than those who decline. Assuming an initial auction where all bidders have the same prior information, participating bidders would gain additional information by their participation, resulting in more posterior information. In the next auction, those bidders who participated in the earlier auction thus have updated prior information that those who did not participate perforce lack, leaving the latter at a potential disadvantage.

In the above setting, based on Bergemann and Juuso (2010) and Bergemann and Välimäki (2019), the flow marginal contribution to welfare $m_i(\theta_t)$ of seller i is: $m_i(\theta_t) = M_i(\theta_t) - \delta M_i(\theta_t, h_t^*)$, where M_i is the marginal welfare contribution of seller i, time $t = 0, 1$ ..., common discount factor $\delta \in (0, 1)$, allocation $h_t \in H$, Markovian state $\theta_t = (\theta_{1,t,.....,}\theta_{It}) \in \Theta$, private (Markovian) signal $\theta_{i,t+1}$ of i generated by conditional distribution function $\theta_{i,t+1} \sim P_i(\cdot \ |h_t, \theta_{it})$ and socially efficient allocation rule (after all histories C_t; the histories are bidders reporting state θ_t and allocation):

$$a_t^*: H_t \to [0,1]'. \quad (5)$$

Expanding the flow term with respect to time gives: $m_i(\theta_t) = \left(W(\theta_t) - W_{-1}(\theta_t)\right) - \delta\left(W(\theta_{t+1}|h_t^*) - W_{-1}(\theta_{t+1}|h_t^*)\right)_i$, where the first bracket indicates M_i starting at t and the second bracket indicates M_i starting at $t + 1$ and h_t^* on the right-hand side. Further expending the flow term with respect to identity (rearranging) gives: $m_i(\theta_t) = (W(\theta_t) - \delta\left(W(\theta_{t+1}|h_t^*)\right) - (W_{-1}(\theta_t) - \delta W_{-1}(\theta_{t+1}|h_t^*)\right)$, where the first bracket indicates current value with bidder i and the second bracket indicates current value without bidder i but with h_t^* in the right hand side. Given the marginal contribution to welfare is $M_i = v_i - p_i$, and by rearranging, price bidder i is:

$$p_i = v_i - M_i \quad (6)$$

By adjusting equation (4) into an intertemporal setting, the socially efficient allocation rule (4) satisfies ex post incentive and ex post participation constraint with payment p: $p_{i,t}\left(h^*(\theta_t), \theta_{-i,t}\right) = v_i\left(h^*(\theta_t), \theta_{-i,t}\right) - m_i(\theta_t)$ (7)

2.1.3. Incentive Framework

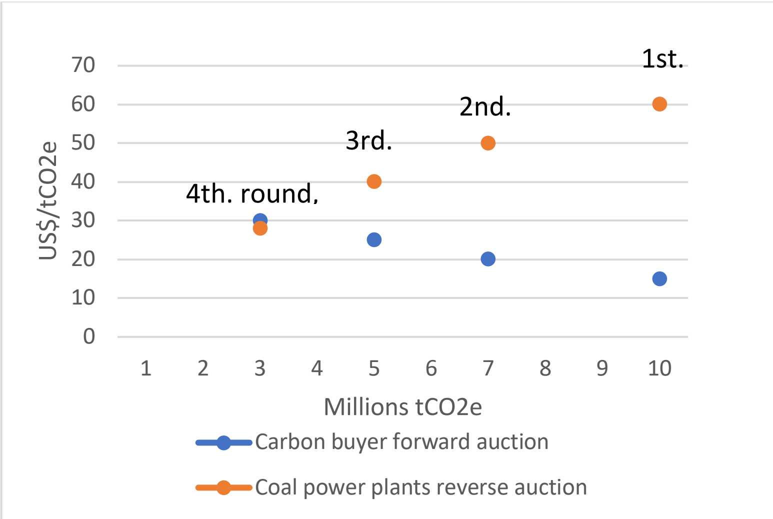
The average age of coal-fired power plants in East and Southeast Asia is on the order of 10-15 years (World Bank, 2022), despite the need for renewable power in these regions. It is thus crucial to plan the retirement of such plants to ensure a smooth and just transition over the medium- and long-term. In some cases, electricity resource planning and adequacy requirement and/or tightening ESG and climate regulations as incentives toward 24/7 green power, especially by corporations, necessitate additional renewable energy, such as solar, to replace the retiring coal, which often provides baseload. A combination of solar PV and BESS is thus one technology option for replacing retired coal-fired power plants such as the foregoing. As a means of early coal power retirement, Germany has been holding one-sided subsidized compensation auctions to purchase the capacity of coal-fired power plants during 2020–2027 with a price cap per capacity (Reuters, 2021; World Bank, 2022).

Coordinated arrangements include staged product-matching auctions. The first stage thereof, building on the radio spectrum reallocation incentive auctions by the United States Federal Communications Commission (FCC) in 2016–2017 (Leyton-Brown et al., 2017; Royal Swedish Academy of Sciences, 2020), is a reverse auction to determine a price at which coal-fired power producers voluntarily relinquish their coal power capacity and indicate the amount of carbon dioxide equivalent (CO_2e) emissions avoided by said retiring coal-fired power capacity. The second stage is a forward auction for avoided CO_2e emissions, which may be repeated until the supply prices of avoided CO2e equal the purchase prices, or the difference is reduced enough for the host government or donors to make up the remaining shortfall.

Figure 4 illustrates the first- and second-stage auctions, repeated over four rounds until demand, i.e., carbon buyers, and supply, i.e., coal-fired power being retired, align. In the third stage of the auction, the corresponding freed-up coal-fired power capacity will be matched by reverse auctions of solar PV and BESS, while such backup generators as gas turbines may be required, as solar PV and BESS alone remain as yet unable to provide 24/7 dispatchable power or replace the baseload, as shown in Figure 2 and

Figure ***3***. Storage retrofit strategies for coal and other thermal power plants may also play a part in the not-too-distant future when the costs and implementations of same become clearer.

Figure 4. First-Stage Reverse and Second-Stage Forward Auctions



Source: Author

2.2. Risks

As in other auctions for renewable energy resources, competitive procurement of paired solar PV and BESS is subject to certain risks, hence returns for investors and economic and social impact; see, e.g., Maurer et al. (2020), Cote et al. (2022), and Roth et al. (2022). Market designs of said auctions must therefore ensure that the benefit of market competition outweighs the cost. They should mitigate and manage risks for the markets to provide incentives and signals for the right investments, in terms of type, amount, timing, and externalities, to deliver affordable quality electricity to consumers. Non-market alternatives, such as non-transparent bilateral contracts negotiated with unsolicited power providers, are likely to result in suboptimal welfare outcomes. Following is a summary of key risks, formats, and measures to mitigate and manage risks, concerning ESG pertaining to the solar PV and BESS auctions.

2.2.1. Bidding

Bidders have the allocation risk of not winning. The resources they expend in applying and preparing, and meeting the physical prequalification criteria of the auction are sunk costs if they lose. Such a risk is significant if the auctioned items are limited, i.e., fixed demand, and if such costs are large relative to the bidder's financial resources and project portfolio. Thus, smaller companies and local community organizations may be at a disadvantage, undermining auctions' diversity, equity, and equality, as well as ESG objectives (Eberhard et al., 2014; Amazo et al., 2021; Cote et al., 2022). As a rule of thumb, sunk costs should not exceed 3–5 percent of capital expenditures (Haufe and Ehrhart, 2018). Expenditures on ESG-related prequalification criteria may reduce overall costs if ESG issues prove too costly and/or time-consuming for project realization. Examples include environmental and social impact assessments (ESIA) or proof of community engagement (Amazo et al., 2021), which may have significant monetary and non-monetary costs, such as political economy, time, and effort. However, less efforts on ESG related prequalification, such as inadequate community involvement may slow or halt renewable energy projects, as in canceled wind farms in Mexico and Kenya (Business and Human Rights Resource Centre, 2018, cited in IRENA 2019). ESG-related prequalification criteria may also make timely commissioning more likely because bidders can account for enhancing, mitigating, and managing expected ESG impact in their bids, thereby reducing ESG uncertainties.

One design option is for the auction planner to pay costs common to all bidders, being more resource efficient than requiring each bidder to individually pay such costs. China provides a case study of this approach, to be discussed hereinafter. For example, if the auction planner identifies a site for solar PV and BESS in advance, the planner should pay for ESIA, community engagement, and land and other permits and authorizations, which each bidder can adjust to reflect their circumstances. A second option is for the auction planner to reduce research costs and information asymmetry among bidders, e.g., large or small, international or local electric utilities, community-based organizations or private companies, etc., by sharing indicative costs and information when soliciting bids. Hawaiian Electric Company, Inc. (Hawaiian Electric) included such indicative costs of Supervisory Control and Data Acquisition (SCADA) communications, security system interconnection, and station services (e.g., overhead lines and transformers) when soliciting bids for renewable dispatchable generation and storage on Oʻahu (Hawaiian Electric, 2019). They could also include indicative ESG-related costs in like manner, as local bidders may have more local ESG information. A third option is to limit prequalification requirements to preliminary social impact evaluations and evidence of community engagement, to be finalized after the bidder wins the award, with penalties for non-finalization or tying granting of licenses to successful finalization (Amazo et al., 2021). Design strategies may include any or all of these.

As suggested above, design should encourage diverse participation by smaller actors and investors who are less able than larger ones to cope with auctions' complexity and competitiveness. Strategies such as (i) reduced prequalification, (ii) different pricing rules, and (iii) quotas, may significantly affect and even distort outcomes. A lack of clear taxonomy of protected groups may result in unintended consequences, as happened in Germany in 2017, where preferential rules led to artificial citizen energy communities for onshore wind that were awarded more than 90 percent of the auction volume (Kitzing et al., 2019; Cote et al., 2022). In Australia, qualifications for the state of Victoria's 2017 renewable energy auction scheme included proof of community engagement and benefit sharing. Community projects and other small-scale actors could not compete against larger and more established players, however, due to (i) nascent community initiatives at the time of the auction, (ii) technology-neutral auction schemes, (iii) high up-front costs for proposal preparation, and (iv) lack of economies of scale. Thus, Victoria had to employ other support schemes, such as grant funding (Renewable Communities Program), to support community energy initiatives (IRENA, 2019). A study of South African renewable energy auction program during 2011-2015 finds (i) some market concentration did not undermine project pricing or market development, (ii) preferential conditions for small, local players has been more effective at counteracting market concentration than lowering of entry barriers and (iii) policy certainty and predictability seem more important to counteract market concentration than any auction design measures (Kruger et al., 2021).

2.2.2. Awarding and Contracting

Bidders, i.e., suppliers or sellers, tend to have differing information about true demand and may have varying cost profiles of the bid item, i.e., solar PV and BESS. They may also have different financial profiles to diversify risk and take more strategic approaches. Winning an auction may also mean that other parties and the demand have better information than the winner about the bid item's value, and as the lowest bid wins, bidders also try to underbid each other, including trying to shade their bids. Doing so, however, may cause them to inflate their bids or bid below what would be financially viable. Such was observed in multi-item auctions under uniform pricing rules in Germany where several bidders submitted bids below €.01/kWh, in Spain when an auction in 2015 resulted in a clearing price of zero, and in the British Contract for Difference (CfD) auctions in 2015 where two solar projects were withdrawn for submitting bids at irrationally low prices (Tongsopit et al., 2017). On the other hand, in first price, or pay-as-you-bid, single-item auctions, the bidders' strategy is to bid just below the second lowest bidder, as described in section 2.1.1.

Irrational underbidding risk is relevant given (i) declining costs of solar PV and BESS, and (ii) uncertainties in financing and materials costs of same. In August 2022, Malaysia extended power purchase agreements from its fourth large-scale solar (LSS4) tender for large-scale PV from 21 to 25 years because of concerns about project bankability, due to rising material prices and fears of rising interest rates. Several project owners asked the Malaysian Energy Commission to review electricity bids, which it rejected. The LSS4 program awarded 823MW of capacity across 30 projects. Out of a total of 2457MW awarded, only 1160MW were operational by the second quarter of 2022 (Table 1; Santos, 2022a).

Table 1. Auctioned Project Realization Rates

	India	Malaysia	Brazil	United Kingdom	The Netherlands	France	Ireland	California, US	China
Auction years	1997-2022	2016-2022	2009-2010	1990-2001	2011	2011	1995-2003	2011-2015	2003-2004
Technology	Wind	Solar PV	Biomass, wind, small hydro	Technology neutral	Technology neutral	Solar PV	Wind, hydro, biomass, and CHP	Technology neutral	Wind
Realization rate	25% by 2022	47% by 2022	~30% by 2014	~30%	68% by 2015	<50%	~30% by 2005	>75%	100% by 2007

Source: Wigand et al. (2016), Kreiss et al. (2017), REN21 (2022), and Santos (2022a).
CHP: Combined Heat and Power

Table 1 shows that barely a quarter of the capacity awarded by auction in India since 2017 had been commissioned as of early 2022, and several companies that had been awarded PPAs surrendered capacity, due chiefly to low tariffs and rising costs. Indian turbine manufacturers are turning to exports, while developers are moving from auctions and long-term PPAs to options that fetch better prices through direct sales to commercial and industrial customers and sales via the Indian Energy Exchange. Other longer-term challenges in India include the high cost of capital, grid connection, permitting, and land acquisition. Large wind and solar power projects require large amounts of land, often leading to development on local communal lands. Land rights issues are thus becoming more contentious around the world (REN21, 2022).

Delays and underbuilding may arise from factors beyond the developer's control. Significant causes of construction underperformance include obtaining environmental and social permits and grid access. It is therefore essential to allocate such responsibilities fairly between bidder and auctioneer (Diniz et al. 2023). Alternatively, qualification requirements may include permits, although doing so may constrain the pool of participants. Many jurisdictions should streamline and make permitting processes more transparent. In Mexico, social impact permits have become a bottleneck in deploying awarded projects, especially due to unclear and lengthy institutional processes. While Mexico made such permits as prequalification, instead of a post-award requirement, in the fourth auction round, Mexico ultimately cancelled the auction (IRENA 2019).

Reducing uncertainty is one design strategy for mitigating underbidding risk if bidders are rational. Each bidder would revise its bid if they had information about other bidders. Such information might be inferred by competitors' bids in open, though not sealed bid auctions. Thus, the reverse clock auction yields lower bids, theoretically. An auction planner can set time limits on project completion to reduce underbidding. Maurer et al. (2020) notes reverse clock auctions are likely to become the industry standard as business models for standalone and co-located or hybrid BESS facilities mature. Disclosures could, however, invite bidders to implicitly collude, especially with large multi-project bidders in an environment with low competition, while setting a reserve price could mitigate same (Haufe and Ehrhart 2018).

A Vickrey auction or a Vickrey-Clarke-Groves (VCG) mechanism will induce bidders to bid their true values (no shading) as their dominant strategy, because the winning bidder would be awarded the opportunity cost, regardless of the bidder's own value. For a single item, the mechanism is referred to as a second-price sealed-bid auction, or simply a Vickrey auction where bidders simultaneously submit sealed bids. While the highest bidder wins the item, unlike standard sealed-bid tenders, the winner pays the amount of the second-highest bid. In reverse auctions, the buyer instead pays the second-lowest bid. This second-price sealed bid is de facto equivalent to the English clock auction. While economists have been extensively researching VCG, including in section 2.1.2, it is rarely applied in practice. Ausubel and Milgrom (2002) discuss several possible weaknesses of VCG, including possibilities of very low revenues (in reverse auction, very high revenues) or vulnerability to collusion.

Under-contracting risk is an auction outcome where the amount of capacity or generation contracted is less than expected, which may be high if an auction has a low participation rate and/or does not impose penalties on winning bidders who do not sign PPAs. The design strategy for mitigating under-contracting is to require bid bonds or impose other penalties to make it costly for selected bidders to walk away without signing contracts. A selected bidder may still choose not to sign a PPA because the financial penalties are usually larger for breach of contract than turning down a contract (Maurer et al., 2020).

If a firm bids to supply more than the contracting capacity required at auction, it faces a risk of over-contracting and having to buy on the spot market to honor the contract. A study of the Chilean experience from 2006 to 2011 finds that a higher cost of over-contracting for entrants, especially smaller ones, than for incumbents may pose a barrier to entry (Bustos-Salvagno 2015). The study finds that incumbents are on average presenting lower bids than entrants, due in part to a significant difference in the cost of over-contracting, which is directly related to their level of risk-aversion. Incumbents with diversified portfolio of generating technologies have an advantage over entrants, especially the smaller ones. Consequently, entrants are asking for a risk premium that influences competition, as their bids do not represent a serious threat for incumbents (Bustos-Salvagno 2015). One strategy for mitigating risk and increasing competition is to design auctions to cater to technology profiles, e.g., variable renewable energy. In its electricity auction of November 2014, Chile allowed renewable bidders to bid for eight-hour blocks. This rule allowed solar and wind generators to bid more aggressively since they could bid when their over-contracting cost was at a minimum. While the historical average was around four generators, there were seventeen bidders in this instance (Bustos-Salvagno 2015).

2.2.3. Construction and Operation

Nonrealization risk is the failure of auction winners to implement their contracted projects. Selected bidders may opt out before signing contracts. As seen in Table 1, projects often have low realization rates for such reasons as underbidding, low prequalifications, cost increases, missing deadlines, permits, ESG impacts, unavailability or more remote location of grid connections than expected, and premature commencement (Kreiss et al., Tongsopit et al., 2017; 2017; Kitzing et al., 2019; Szabó et al., 2020). In China, the government secured the land and procured environmental permits, and most of the bidders were state-owned companies that could cross-subsidize their wind projects and bid low prices (Wigand et al., 2016). In Germany, deadlines can be extended once when a lawsuit has been filed against a project, and lawsuits against onshore wind construction are not uncommon there (Tongsopit et al., 2017). Conflicting policy objectives in designs, e.g., lowest price versus local content, might also result in a low realization rate of the winning projects, as in Indonesia (Tongsopit et al., 2017).

A design strategy for improving realization rates might include high financial prequalifications and adjusted physical prequalifications relative to sunk costs, penalties covered by financial prequalifications (e.g., bid bonds), and increased competition (Kreiss et al., 2017; Kitzing et al., 2019; Haufe and Ehrhart, 2018; Matthäus, 2020). While stricter prequalifications and penalties might increase bids and reduce participation, increased competition may offset same. A study based on 250 observations from 220 auctions taken place in 16 European countries from 2012 to 2020, suggests that policymakers should either strive for short realization periods with financial prequalifications or for long realization periods with no financial prequalifications (Anatolitis et al., 2022). In Germany, increased competition and decreased public support may improve project realization rates (Haufe and Ehrhart, 2018). By contrast, a 2021 survey found that developers tend to be less willing to participate in highly competitive auctions (Cote et al., 2022). Kremer (2022) notes a low ratio of private to social return with low barriers to entry.

Auctions are also used to allocate grid connections. Portugal held two large-scale tenders in 2019 and 2020 to resolve a glut of grid permit requests for solar projects. Some 52 percent of awarded grid-connection capacity went to PV or PV and BESS projects. The projects gain full access to the wholesale and ancillary services market and the option to sign a PPA with a utility or corporate off-taker. All projects under this merchant option will pay the system operator €5–40/MWh for 15 years for lifetime grid access (BloombergNEF, 2021).

A theoretically and empirically proved design with low complexity for the bidders might facilitate appropriate bidding strategies to optimize outcomes, including ESG. Auctions should minimize incentives for strategic supply reduction, possibly with markets diversified into forward and wholesale segments. A long-term auction schedule ensures a degree of certainty, helping investors avoid risk. Ad hoc auctions undertaken without future auctions scheduled might force bidders to underbid to limit their losses of projects already at the advanced development stage.

A study shows that continuity in auction rounds, rather than ad-hoc auctions, increases long-term certainty for participation, as in California, and further finds that auction frequency depends on context and technology (Kitzing et al., 2019). In general, lower auction frequencies are appropriate for technologies with fewer bidders and larger projects, e.g., offshore wind, and more frequent rounds for technologies with more potential participants, e.g., solar PV (Kitzing et al., 2019). In China, solar PV auctions were held annually between 2019 and 2021, while renewable energy auctions have been held biennially in the UK since 2015, and quarterly in Italy between 2019 and 2022 (BloombergNEF, 2021).

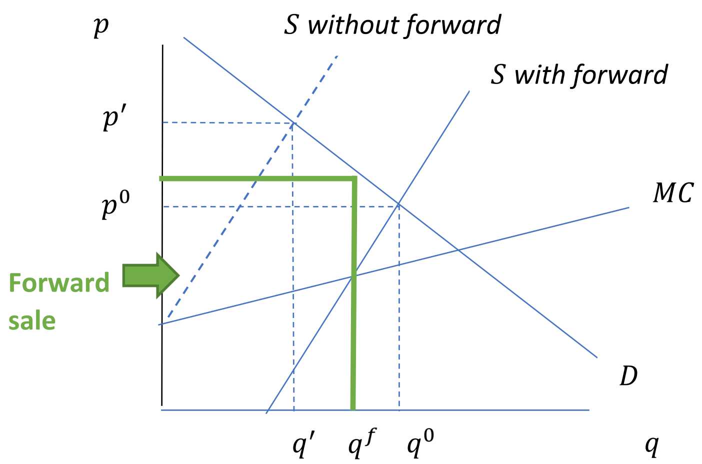
2.3. Role of Auctions among other Policy Instruments

As each policy instrument has its own strengths, selecting and designing a complementary mix of instruments may better mitigate and manage risks in scaling up solar PV and BESS in the electricity market. Kwon analyzes (2020) the effects of South Korea’s policy mix of auctions, feed-in tariffs (FiT) for small solar PV producers, and renewable portfolio standards (RPS), summarized as follows. The country’s long term contract auction scheme with sliding premiums is capable of (i) alleviating price risk for renewable electricity suppliers under RPS by fixing remuneration over long periods, (ii) counteracting lowered competitive pressures brought about by FiTs with the intense market competition of auctions, and (iii) reducing asymmetric information by influencing renewable energy certificates’ (REC) spot prices and providing a reference price for FIT rates. A weekly REC spot market may mitigate sales risks arising from the long-term contract auction scheme holding only two rounds of bidding opportunities annually. FiTs can lower RPS price risks and mitigate transaction costs and sales risks of long-term contract auctions. Intense RPS market competition may also counteract the reduced competitive pressures that FiTs may engender. The following example demonstrates these complementary circumstances. The adoption of long-term contract auctions in 2017 resulted in falling REC spot prices due to rapid increases in small and medium solar PVs. Re-introducing FiTs for small solar PV suppliers in 2018 drove REC spot prices lower than long-term contract auction prices, implying that current REC spot prices may be lower than break-even prices for small solar PV. Hence, it may be necessary to raise the RPS target to reverse the falling trend in REC prices.

Having more than one policy instrument providing diverse market opportunities is particularly relevant for solar PV and BESS, given the ability of BESS to complement or substitute for other power system elements, including generation, transmission, distribution, and demand response. With climate change having uncertain impact on electricity demand and supply, sophisticated markets and analysis may help better plan, operate, and regulate future power systems, and ensure that these systems are reliable and efficient. In Australia, the Hornsdale wind power and BESS plant participated in an auction for frequency regulation and uses part of its storage for price arbitrage in the wholesale market, which may allow revenue and risk diversification based on a complementarity between price arbitrage (MWh) and frequency regulation (MW).

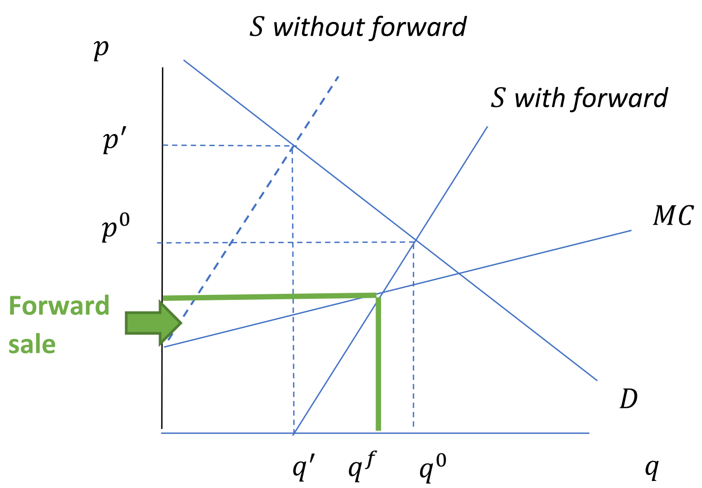
Forward auction markets can mitigate potential prices significantly above marginal costs in wholesale spot markets, e.g., day-ahead, real-time, etc. As shown in Figure 5, forward price higher than wholesale spot market (Cramton and Stoft 2008; Ausubel and Cramton 2010; Cramton 2020), and in Figure 6, forward price lower than same, a dominant wholesale market player might have less incentive to bid much higher than their marginal cost in the spot market as their forward sales secured through long-term contract auctions place them in a more balanced position (Cramton and Stoft 2008; Ausubel and Cramton 2010; Cramton 2020). A large electricity supplier with many projects in its portfolio or a supplier building a larger capacity than the auction requires, may behave like that. In the latter case, bidders may bid some of their capacity to anchor some of their revenues and sell the remainder on the spot market or to corporate off-takers.

Figure 5 Forward Auction Contracts May Mitigate Market Power in Spot Market, Case 1.



Source: Cramton (2020)

Figure 6. Forward Auction Contract May Mitigate Market Power in Spot Market, Case 2.



Source: Author building on Cramton (2020)

The winner of the July 2022 Chilean auctions, a 253 megawatt-peak (MWp) solar and 1 gigawatt-hour (GWh) BESS project, will sell a portion of the electricity generated to distribution companies under 15-year PPAs and the rest to private off-takers (NS Energy 2022). In such instances, the auction price could be lower than a solar PV/BESS wholly dedicated to the auction could achieve, by diversifying risks and achieving economies of scale. Brazil held multiple auctions for hydropower plants, where the developers sell most of the energy in the regulated market through the auction scheme and part of the remaining energy via corporate forward contracts. Solar PV/BESS suppliers' behavior across these different markets need to be closely monitored and audited. Regulators need to mitigate anti-competitive behavior and unreasonable cross-subsidies, as well as evading ESG obligations outside contract under auctions.

3. Modalities of Auctions and Contractual Agreements

3.1. Technology- Specific or Technology-Neutral Auctions

Auction designers must decide whether technology-neutral or technology-specific auctions better suit their objectives, per Table 1. The advantage of technology-neutral auctions over technology-specific auctions is lower costs especially large-scale projects, through encouraging diverse participants and competition (Anatolitis et al., 2022). In December 2017, a technology-neutral auction was held in Colorado in the US. Although storage capacity was not explicitly solicited, 105 of the 430 proposals included storage components with the median solar PV and BESS bid price being 20 percent lower than the cheapest prices under PPA in the US at the time (Lackner et al 2019). The disadvantage of technology-neutral auctions versus technology-specific auctions is that they restrict diversification in such conditions as technology types, locations, and companies. For example, a study of European multi-technology auctions 80 percent of all multi-technology auction rounds from 2011 to 2020 were skewed, strongly or exclusively favoring one technology, while the dominant technologies of individual rounds vary (Melliger, 2023) Different technologies have different planning, cost, construction, and operations characteristics. Thus, prequalification criteria and realization periods may affect them differently, potentially complicating ensuring a level playing field in such auction design aspects as ceiling prices, material and financial prequalification, penalties, and deadlines. While holding several auctions by technology category, rather than holding a single technology-neutral auction, might simplify auction design, it might also reduce competition for technologies that have limited application or are relatively new. Highly competitive technology-specific auctions such as those for ground-mounted solar PV in Germany are possible, with the influence of such sector characteristics as preexisting support (Wigand et al., 2016). Technological neutrality has been especially popular in Latin America (IRENA 2019).

3.2. Auction Contract Types

The major auction contract types are PPAs in most developing countries and contracts for differences. e.g., in the UK and Italy. Examples of PPAs are (i) blended tariffs including solar PV plus BESS, e.g., Malawi; Arizona, US; and Israel, (ii) solar energy tariffs and BESS capacity payments, e.g., Nevada, US; Portugal; and Uzbekistan, (iii) time variant tariffs, e.g., Chile, Nevada and Arizona, and India, and (iv) monthly lump-sum payments based on theoretical maximum PV output minus penalties for BESS unavailability or underperformance, e.g., Hawaii, US. While type (i) is the simplest, it does not offer different benefits, hence the values of the multiple services that BESS provides. Type (iv) is for small systems requiring long-term firm energy.

4. Solar PV and BESS Business Model

This section briefly describes the business model of solar PV and BESS business model, which includes either co-located plants that pair two or more generators and/or that pair generation with storage at a single point of interconnection, and full hybrids that feature co-location and co-control. Systematic empirical data and analysis on the business model and solar PV and BESS and PPAs are scarce, not to mention integrated ESG, especially in academic literature. The following is a summary of four business models in the United States (Seel et al., 2022) , where the hybrid and co-located plants, dominated by solar PV and BESS, are growing rapidly at scale in many configurations and are distributed broadly across the United States where each state or region has distinct characteristics in terms of energy resources, regulations, markets, climate, etc.

4.1. Merchant Plant

The merchant plant business model is applicable for those countries with wholesale electricity markets, such as South Korea, the Philippines, Singapore, etc. The plant operator or IPPs maximize profit by responding to competitive price signals in organized electricity markets. The merchant solar PV+BESS plants earn revenue through (i) energy markets through energy arbitrage by charging the battery when wholesale electricity prices are low and selling when they are high, (ii) forward capacity markets and (iii) ancillary service markets. Even if wholesale electricity market prices do not always reflect system needs precisely, they provide a more dynamic dispatch signal to plants than regulated tariffs or incentive program rules and requirements.

4.2. Peak Load Reducer

The peak-load reducer business model generates value by reducing the load of a load-serving entity during peak times. The solar PV+BESS peak-load reducer primarily uses the battery to reduce load-serving entity costs. For example, utilities in Independent System Operator of New England (ISO-NE) pay for transmission service via a regulated peak-load pricing schedule and pay for capacity based on the forward capacity market price. The avoided costs from lower transmission-related and capacity related demand charges can be significant. The peak-load reducer business model forecasts monthly and annual peak hours, assesses the demand charges and dispatches the solar PV+BESS plant to reduce its reliance on the transmission network during those hours. Also, energy from the solar PV+BESS plant can lower the energy charges for the load-serving entity at the wholesale energy price. When not being utilized to lower peak load, the solar PV+BESS plant provides ancillary services sold directly to ISO-NE rather than indirectly reducing load-serving entity costs. The billing determinants based on coincident peaks become the primary dispatch signal. To the extent that system conditions coincide with the operator's expectations of the annual and twelve-monthly peak load events, the dispatch signal is dynamically responsive to grid needs, though not as directly as the merchant plant.

4.3. Incentive Program Participant

At an early stage of deployment of solar PV+BESS plants, an option of business models is to earn revenue by participating in government's incentive programs, such as feed in tariff, energy attribute certificates (EACs) such as renewable energy credits (RECs), tax credits and grants. The incentive program participant operates solar PV+BESS plants to comply with incentive program rules and regulations, such as a demand-response program, discharge at specific time periods, charging requirement from its paired solar PV, etc. As these incentive rules can deviate from direct wholesale market signals, solar PV+BESS plants that maximize revenue from such programs will operate differently from merchant plants and will yield a lower market value, while still likely being privately profitable. The United States offers a private owner of a solar PV+BESS plant an investment tax credit (ITC) for the BESS investment if it charges 75-100 percent of the time from the co-located solar PV unit. Despite the ITC support to the high capital costs of BESS, qualifying batteries charging at least 75 percent from the PV unit may limit the value these plants can provide to the grid. A solar PV+BESS plant operator may forgo charging from the grid, even if electricity costs are near-zero or negative, because doing so would reduce the share of the ITC the project can claim. Similarly, the operator may choose not to provide regulation-down service outside of hours when the solar PV is generating because doing so could reduce its ITC eligibility. Solar PV+BESS plants usually use this business model to complement the other primary business models and are typically IPPs.

4.4. Large Energy Consumer

Under a large energy consumer business model, private end-user characteristics are a major determinant of the dispatch of a solar PV+BESS and not bulk power system needs. This business model includes, but is not limited to, large manufacturing, industrial or commercial facilities, water treatment plants and mining operations. The large energy consumer typically places a premium on the ability to ride out multi-day outages and shorter outages lasting several hours. To meet these criteria, the battery unit may be kept at full state-of-charge during most hours and cycled only infrequently in the event of an outage. This operating strategy does not straightforwardly benefit the electric grid, although it can provide significant benefits to the end-user and possibly the local community in the event of a natural disaster or other form of major outage.

Large energy consumers are typically enrolled in industrial electricity tariffs, and a solar PV+BESS can reduce end-customer bills. In the United States, some large energy consumer faces a noncoincident peak demand charge and the solar PV+BESS discharges to reduce its monthly maximum demand, irrespective of whether it lines up with system demand. Lowering customer demand can reduce local congestion along the utility's distribution system, but the dispatch of the solar PV+BESS may provide less market value than if it directly responded to wholesale electricity market price signals. Industrial electricity tariffs may also include a coincident peak demand charge, which then provides a dispatch signal comparable to that of the peak-load-reducer business model.

This business model may be useful for export oriented large commercial and industrial firms in ASEAN and East Asian counties. Those firms need to meet increasing climate, 24/7 clean energy and other ESG regulations, and often grid electricity generation mix includes fossil fuels in many countries in the region.

Table 2. Summary of Solar PV/BESS Business Model Example

Circumstance or Objective	Suitable Business Model	Ownership
Meet the real time electricity system needs, capacity adequacy and ancillary services needs	Merchant	IPPs
Reduce transmission and capacity costs and meet ancillary services needs	Peak Load Reducer	Load serving entities
Transform from an early development stage to full commercialization and improve demand response with feed in tariff, EACs such as RECs, tax credits, grants, etc.	Incentive participant	IPPs
Reduce electricity payments, increase resilience, and meet climate, 24/7 clean energy and other ESG requirement.	Large energy user	Large manufacturing, industrial and commercial firms.

5. Toward Sustainable Development and 24/7 Clean Energy Transition

Table 3 summarizes key ESG risk mitigation and management costs vs. avoided ESG costs and achieved benefits. As shown in section 2, if ESG risk mitigation and management costs exceed avoided ESG costs and achieved benefits, bidders would be willing to transfer their private benefits, i.e., their net revenue, to ESG risk mitigation and management costs. Such transfer payment between private costs/benefits and externalities costs/benefits (welfare) is the concept that this analysis introduced to incorporate ESG in competitive auctions. The effect can be seen in using cheaper ESG bonds and equity than non-ESG alternatives and grants (Kenway, 2021; Lamdouar et al., 2022; Leonard Energy, 2022). El Salvador's 2014 tender for solar and wind power required developers to invest three percent of their revenue in community social projects (IRENA, 2019). The following are key findings of selected reviews of literature in addition to references already discussed in the previous sections.

Table 3. Key ESG risk mitigation and management costs vs. avoided ESG costs and achieved benefits

ESG Risk Mitigation and Management Costs	Avoided ESG Costs and Achieved Benefits
Environmental and social impact assessments and stakeholder engagement Benefit sharing Local employment, content, industry, and participation 24/7 clean power arrangements	Higher financing costs due to project delays Increased capital and operations and management costs Penalties Bid bonds (securities) and sunk costs due to project cancelation Greenwashing or non-compliance

	Local development benefits

5.1 Toward Sustainable Development

ESG goals should be embedded in project definitions for renewable auctions, or in other words, project qualification preconditions. Qualified bidders would then move to the next phase, where awards are based solely on price. Other current practices are to establish (i) one formula selection method including price and non-price factors with their weights in criteria, as in South Africa, Uganda, and Taipei, and (ii) merit adjustments to bid price, as in Malaysia (IRENA, 2019; Amazo et al., 2021). Mixing monetary, i.e., price, and non-monetary, i.e., non-price, values run the risk of subjective judgement or loss of nuance. While some projects may have low social and environmental scores, and hence high risk, the low prices they offer as compensation result in their having the highest overall scores. Therefore, such projects are likely to win, which however could result in nonrealization of the projects due to the negative social and environmental issues that the low scores signify. Making price the only award criterion is more transparent, ensuring that only qualified bids are awarded contracts. If multi-criteria auctions are implemented, those criteria should be specific, quantitative, and similarly transparent to bidders.

ESG measures in auction designs should not expect too much from one project to generate local economic and social development, and thus need policy support. Examples of such support include local development, such as local factories, industry, research and development (R&D) facilities, supply, ownership, and employment. For example, the Chinese government provided significant policy support to develop the local solar industry, including several supply-side tools, such as grants, subsidies and low-cost loans, for more than a decade before it combined them with demand-side policy tools linked to performance requirements in cell manufacturing, such as cell efficiency in the Chinese top runner program (Münch and Scheifele 2023).

Local content is a blessing if capacity exists or is easy to build, or a curse if capacity hardly exists or preconditions for same are absent, such as regulatory frameworks and market potential. An initial step is understanding material and human resource requirements of various renewable technologies, assessing these requirements in the context of existing domestic resources and capabilities, and identifying ways to maximize domestic value creation by leveraging and enhancing local industries. Some countries, including Brazil, Russia, Malaysia, Argentina, Saudi Arabia, and Turkey, have imposed strict local-content requirements, which may cause auctions to fail consequently. South Africa discovered that creating a domestic manufacturing sector requires more than local content requirements, namely, a convincing government commitment to renewables and visibility about future demand. The government's years-long delay in signing PPAs with renewable auction winners was thus damaging. The lack of predictability and a small local market did little to encourage developing local industry, and most players that built factories have since shut down (BloombergNEF, 2021). One reason for delays in early projects in Brazil was that its nascent domestic wind industry was not yet capable of supplying the equipment for developers to fulfil their local content quotas (IRENA, 2019).

An India case study provides the first causal estimate of local content on firm-level innovation and production of solar PV auctions (Münch and Scheifele 2023). The Indian government simultaneously held solar auctions with and without local content from 2013. The study digitizes the results from the 41 auctions worth US$8.65 billion in solar module demand and collects annual revenue and solar patents of the 113 participating firms between 2004–2020. For causal identification, the study compares winners of local content with similar open auction winners in a staggered difference-in-difference estimation. Overall, the study finds winning local content auctions does not significantly increase firms' solar patents or sales. The key reasons why the policy did not create sustainable effects that local content are that (i) the small size and irregular frequency of auction, which neither allowed continuous and scale up of production to enable learning by doing nor generate sufficient revenue for re-investment in R&D and (ii) the reduction in competition in auctions due to lack of performance requirement that resulted in no incentive for the bidders to innovate.

Other emerging potential storage technology options might provide more feasible local supply opportunities. The currently dominant lithium-ion batteries that support solar PV, with their large-scale effects, are hard to produce locally. Such potential technology choices for LDES as flow batteries, compressed air storage, or thermoelectric storage might prove easier to localize because they involve a large portion of mid-technology local assembly.

The challenge of designing auctions to create long-term higher-skilled employment opportunities necessitates broad long-term systematic enabling policies. Long-term auction schedules and volumes signal longer-term market and job opportunities through project pipelines. In Uganda, staggered rather than simultaneous project development created learning curves that extended employment terms, reducing costs in time and resources on later projects. Quantitative employment targets in auctions should be accompanied by such benchmarks as quality, sustainability, and diversity. While South Africa's auctions exceeded job creation targets, most of the labor provided by its citizens was unskilled and short-term, leaving training, education, and development needs to fall by the wayside. Short-term, low-paid, unskilled jobs are not a lasting solution to poverty nor a path to sustainable development. In Senegal and Uganda, skilled construction workers for renewable energy projects were mostly expatriates, while the local community held mostly unskilled positions (IRENA, 2019). The Noor-Ouarzazate concentrated solar power (CSP) complex in Morocco offered a wide range of employment opportunities to women, who represented only four percent of its workforce (IRENA, 2019). Labor skill level development paths need broader policies in such areas as education and skills development to build local capacities as the sector evolves, which requires long-term planning. Attracting and retaining skilled workers is challenging in rural areas which are the sites of large renewable energy projects that could contribute to local economic development.

Local communities with high rates of poverty and inequality usually expect more from electricity supply projects than they can deliver. Engaging communities and maximizing benefits on the local level are crucial for project sustainability and can enable just and inclusive transitions. At the Morocco Noor-Ouarzazate CSP complex, local communities opted for as infrastructure and social services to benefit everyone, including women and children, rather than cash compensation for land use, which would benefit only male landowners (IRENA, 2019). The South African Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) required a community trust or a company that represents local communities, and as project shareholders, communities earn dividends to be invested in community development initiatives. In Namibia, NamPower, the national utility, included disadvantaged Namibians in auctions by such measures as 30 percent shareholding, management positions, skills and entrepreneurship development, community investments, and local hiring (IRENA, 2019). Local community engagement can be a lengthy process, and as indicated, often involves land issues and political economy. Despite support from donors and international financial institutions, many initially promising projects, such as Guajira in Colombia and Turkana in Kenya, continue to face challenges (Mbugua 2021; Azzopardi 2022). In other instances, engagement may take the form of community power initiatives in Germany and Japan, onsite participatory planning with indigenous communities in Mexico, Latin America, and the Caribbean (IRENA, 2019). Assessments of local stakeholder engagement are among the requirements for environmental and social impact assessments and governance, especially for projects financed by international institutions of the abovementioned kind.

A Canadian renewable electricity auction program case study demonstrate success in Indigenous equity participation and privately financed development (Hastings-Simon et al., 2022). The Alberta's Renewable Electricity Program in Canada implemented a series of reverse auctions for contracts-for-differences (CfD) between 2015 and 2019. It contracted for new renewable generation at prices in the range of CA$30 to CA$43/MWh (US$23 to US$33/MWh), well below expectations and among the lowest costs globally at the time, resulted in the government revenue of CA$75.5 million (US$60 million). The program steered new entrants into Alberta's power market, including through mandated Indigenous equity participation in one round of auctions. The price discovery and the incentive to develop new projects under the program spurred privately-financed development.

Auction designs could cope with land constraints, which are common in renewable energy projects, as described above. In Malaysia's Large-Scale Solar PV auction, plans to use land for economic activities besides solar generation, e.g., agriculture, might work significantly to the bidder's advantage. Germany's solar PV auctions cap the number of sites for ground-mounted projects on arable land, providing incentives to deploy in industrial zones rather than use land having agricultural or other alternative uses (IRENA, 2019).

Auction planners could integrate geospatial least-cost electrification roll-out plans in auction designs, which can help exploit synergies between the energy sector and the broader economy to optimize energy transition benefits. Such plans, which have been applied in such countries as Kenya, Rwanda, Myanmar, and Papua New Guinea, represent the principle of one goal with many partners, which helps the government in policymaking and working with donors and partners, as well as serving as an investment prospectus. They coordinate off-grid and on-grid electricity alike, integrating demographic and geographic information system mapping techniques that combine technical, economic, demographic, and demand and supply data. Such plans constitute an inexpensive, dynamic planning platform capable of undertaking rapid updates to adapt to changes in key parameters, as with said geographic information systems (Independent Evaluation Group, 2016). Designs thus based on geospatial electrification planning may mitigate projects being concentrated in resource-rich regions, resulting in more even regional distributions capable of spreading the socio-economic benefits of renewable energy projects, while also facilitating grid integration. The plans also help maintain the balance between achieving socio-economic objectives and procuring electricity at low prices, by aligning deployment policies with enabling and integrating polices. They increase project realization rates as they also coordinate auction schemes with permitting, e.g., the Netherlands, spatial planning, e.g., Ireland and the Netherlands, and grid availability, e.g., Brazil and Portugal (Wigand et al., 2016).

Auctions designs that integrate ESG and just and inclusive energy transitions may require policy support and grants which recipients win competitively with monitoring, reporting, and verification (MRV) requirements. They may include (i) industrial policies that enhance domestic capabilities, such as business incubation, research and development, supplier development, and support for small and medium enterprises in key sectors, (ii) education and training policies to increase technical, business and environmental management, and socioeconomic development capacities, (iii) labor market and social protection policies, including such employment services as job matching, on- and off-job training and labor mobility, and (iv) financial policies to ensure just transitions, including carbon pricing, green bonds, and revenue recycling schemes (IRENA, 2019).

The US played an important role in introducing competitive bidding for energy procured by regulated utilities to serve their customers. A key piece of legislation was the Public Utility Regulatory Policies Act (PURPA) of 1978, which, while originally intended to increase conservation and foster co-generation, indirectly also provided a roadmap for regulators to mandate that utilities seek the most effective way to meet their customer needs, whether building new power plants or acquiring energy competitively from emerging IPPs. Different states adopted different methodologies, with the initially prevailing approach being establishing competitive tenders or requests for proposals, and basing award on both price and non-price factors, the most important of the latter being flexibility and dispatchability, while also taking ESG objectives into account (Plummer and Troppmann, 1990). Over the years, many states have moved to pure auctions, where the price is the only factor in awarding contracts. In 2002, New Jersey pioneered an auction process for procuring most of its electric needs through an Internet-based auction whose winners were responsible for fulfilling all requirements, i.e., capacity, energy, ancillary services, etc., and the state's renewable portfolio standards (Fox 2005; BGS Undated).

5.2. Clean Energy Transition

As previously discussed, as of 2022, solar PV and BESS can approximate 24/7 clean energy supplies only in small and/or isolated systems. At the same time, many enterprises confront increasing pressures to use clean energy and report same, especially those associated with multinational concerns. Such large corporations are accordingly shifting from offsetting energy emissions, mostly by buying Renewable Energy Certificates (REC), to time-location tracked energy procurement. Several initiatives aim to accelerate the transition to 24/7 clean energy. One of these is EnergyTag, with more than 100 global participants including such tech giants and energy companies as Statkraft and Vattenfall. Google and Microsoft have also created partnerships that make their data centers more sustainable through hourly energy monitoring and matching with carbon-free sources from their clean-energy portfolios. The UN also launched the 24/7 Carbon-Free Energy Compact in 2021.

The transition to 24/7 clean energy might also drive higher ESG scores, which could facilitate access to cheaper capital in financial markets eager for green investment portfolios. An initial step for enterprises in ASEAN and East Asia to achieve 24/7 clean energy of allowing enterprises to trade RECs or equivalent and monitor and report types and amounts of energy used would help remain in global value chains and become more competitive. Rooftop solar regulations also need updating. In

Cambodia, enterprises have challenges in installing solar PV on rooftops and cannot trade the resulting power among consumers. The regulator needs to rationalize electricity tariffs, for example, to set a fair level of capacity charge based on the highest amount of energy each consumer estimated to consume from the grid, i.e., excluding consumption from consumer's own generation such as rooftop solar PV, to operate, maintain, and invest in systems to ensure that electricity remains available at all times to all consumers and help reduce unnecessarily high peak demand. Carefully designed tariffs are becoming even more important as the system needs to integrate variable renewable energy, consumers, buildings, and EV within the system to achieve 24/7 green power as closely as possible.

5.2.1. Case Study: Thai Partial-firm Renewables Auction

In 2017, Thailand conducted its third renewable energy-exclusive auction, as part of a new Small Power Producers (SPP) Hybrid Program. It had a ceiling of 300MW capacity from 10 to 50MW plants, and a starting (ceiling) price of Thai Baht (B) 3.66 (US$0.11) per kilowatt hour (kWh). Bidders proposed their maximum percentage discount from the ceiling price (IRENA, 2019; O'Mealy et al., 2020).

Thailand became the first country in Asia to require developers to supply partial-firm power generation, i.e., delivering electricity at full capacity during peak hours, rather than merely installing new capacity. It also held the first auction in Asia to allow bids based on either a single technology, or a hybrid combining two or more technologies, to allow consistent feed-in to the grid. PPAs required that providers deliver between 100±2 percent of specified capacity during peak periods, defined as 9AM-10PM on weekdays, and limit output at other times to 65±2 percent of capacity (IRENA, 2019; O'Mealy et al., 2020). The Thailand Energy Regulatory Commission (ERC) reported that 42 of 85 bids submitted had passed the pre-qualification stage and announced 17 projects with accepted bids. Of these, 14 were for biomass and the other three were hybrids with solar PV and BESS. The accepted bids ranged from 15.6 to 99.99 percent of the ceiling price, with net prices of B1.85–3.38/kWh (US$0.06–0.11/kWh) (IRENA, 2019; O'Mealy et al., 2020).

In March 2018, the Minister of Energy announced that the Government of Thailand (GoT) would not buy additional power from new renewable energy projects for the next five years due to a high reserve power margin. The GoT later stated, however, that it might consider procuring new renewable energy projects that could sell electricity below the Electricity Generating Authority of Thailand's (EGAT) wholesale price. It also noted that it would tie new renewable energy procurement to its new Power Development Plan. These announcements left domestic and international renewable energy developers and investors alike uncertain about the Thai renewable energy development policy and regulatory environment, with some shifting their plans and investments elsewhere in the region (O'Mealy et al., 2020). The 2017 auction participants noted low winning prices for project realizations (O'Mealy et al., 2020). As of October 2022, the GoT reports many uncompleted projects in past programs (Santos, 2022b).

6. Conclusion

This study offers the following conclusions. First, theoretically and empirically proved auction market design with low levels of complexity for bidders may facilitate bidding strategies intended to optimize outcomes, including ESG. A design strategy intended to improve realization rates might include high financial prequalification and adjusted physical prequalification relative to sunk costs, penalties covered by financial prequalification, and increased competition. Designs incorporating multiple select policy instruments rather than one policy instrument would enable said instruments to complement each other, e.g., PPAs awarded through long-term contract auctions, wholesale markets, etc.

Second, ESG goals in renewable auctions should be part of project definition and as such should be preconditions for project qualification, allowing awards based solely on price. Auction planners might integrate auction designs within geospatial least-cost electrification roll-out plans, which could facilitate exploiting synergies between the energy sector and the broader economy to optimize the benefits of green transitions. Designs that integrate ESG and just and inclusive energy transitions may require policy support and grants that recipients win competitively and adhere to MRV requirements.

Third, the transition to 24/7 clean energy may drive higher ESG scores, which might facilitate access to cheaper capital in financial markets eager to greenify investment portfolios. An initial step for enterprises in ASEAN and East Asia to build 24/7 clean energy would be allowing enterprises to trade RECs or equivalent, and building capacity for monitoring and reporting types and amounts of energy used, would help such firms remain in global value chains and make themselves more competitive.

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