

## Forecasting Short-term Wind and Solar Energy Prices Optimizes Revenue in Indian Grid Connected Green Energy Market

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### Abstract

Power suppliers are under pressure to integrate more green renewable energy resources into their grids. Responding to the strong demand for clean energy that is high quality and widely accessible. However, the irregular essence of solar and wind power forces market participants to seek new approaches to energy trading and operational procedures. The research paper proposes several market models for the green renewable energy permitted Indian electricity market, analyzing factors such as green energy generation growth, The Ministry is implementing new and renewable policies, setting state-specific targets, promoting market competition, and ensuring reliable power supply. Each model has advantages and disadvantages, and the execution depends on market participants' requirements. The renewable/energy bilateral contracts model system, based on balance responsible parties, is found to be more efficient and superior than other methods in electricity trading. The proposal proposes a new operational strategy with multiple components for improved results in this market implication.

**Keywords-** Forecasting, Renewable electric energy market model, Bidding operating mechanism, Restructuring electricity market.

### 1. Introduction

The limited accessibility of conventional electric energy resources and their negative environmental impact, such as global warming, drive the need for renewable energy. Smart grid technology is promoting wind and solar power integration, offering deregulation, distributed generation, consumer participation, power quality, operational efficiency, self-healing, and resilience (Ethirajan and Mangaiyarkarasi, 2025). India's renewable energy capacity target is 217.62 GW by 2025, (Kumar et al., 2024a), with solar capacity comprising 97.86 GW and wind capacity comprising 48.59 GW. India's power demand could rise to 800 GW to 900 GW by 2030, necessitating gradual increasing power generation from renewable sources. The ministry of new and renewable energy enforces renewable energy purchase obligations for bulk consumers, while the power grid corporation of India limited established renewable energy management center's (REMCs) with German technical assistance in 2016. Indian states have developed guidelines for renewable energy procurement, including long-term PPA (Power purchase agreement) for solar power projects and feed-in tariffs (Dubey et al., 2023). The Indian electricity market is expected to adopt new models to address challenges posed by renewable energy generation, including renewable energy certificates (REC), PPAs

(Lips et al., 2025). A new entity called balance responsible parties (BRP) (Lucas et al., 2021; Krstevski et al., 2021), is introduced in the second and third models to enhance market participation in the renewable generation energy (Zerta et al., 2008), RE-enabled Indian electricity market. In a future-dominated electricity market dominated by renewable energy, it is crucial to develop market models that minimize electricity prices and enhance operational efficiency (Lopes, 2018). Traditional electricity markets use three restructured models: Pool-Co model, bilateral contracts model, and hybrid models (Jay and Swarup, 2024; Lee et al., 2019). Researchers present market models for renewable energy-enabled electricity markets, including single buyer and pool market models (Snigdhha et al., 2023), for Malaysia's electricity supply industry, emission trading schemes in Europe, financial support schemes in the UK, transmission expansion planning techniques for enhancing renewable energy penetration. The 1948 act nationalized the electricity industry, forming state electric energy boards (SEBs), (Singh and Srivastava, 2005), to manage generation, transmission, and distribution. However, SEBs became inefficient and suffered financially. The Indian power sector underwent restructuring in 2001, dividing generation, transmission, and distribution into separate corporate entities (Devyani et al., 2001; Grzelakowski, 2024). Independent regulatory bodies were established to rationalize electricity tariffs, formulate transport policies, and promote efficient, environmentally friendly policies (Solangi et al., 2011). The electricity act 2003 aims to provide electricity to all areas, rationalize tariffs, ensure transparent subsidies, promote efficient policies, and establish a central electricity authority for planning and controlling with central electricity consultant (Asif and Muneer, 2007). The power grid is becoming smarter with various devices and technologies. In a future-dominated electricity market dominated by renewable energy, it is crucial to develop market models that minimize electricity prices and enhance operational efficiency. Traditional electricity markets use three restructured models: PoolCo model, bilateral contracts model, and hybrid model. Renewable energy sources like solar and wind are volatile, making it difficult to consistently supply energy demands (Whba, 2025). To increase dependability, invest in modern energy storage technology like batteries and pumped hydro storage. High initial costs may discourage investors, hindering the shift to renewable energy. Establish policies that encourage investment, lower financing barriers, and promote cost-effective technology. Lack of clear policies and regulatory uncertainty can hinder the development of the renewable energy sector (Snigdhha et al., 2023), while improving these criteria can contribute to the success of renewable energy initiatives.

The literature review examines the strengths and weaknesses of real-time forecasting models, emphasizing the importance of extreme learning algorithms in spot markets.

The research paper outlines the evolution of the Indian electricity market, in Section 2. Presents various market models for renewable energy (RE) enabled markets, analyses in Section 3, and compares these models, in Section 4, outlines the proposed operating mechanism for RE-enabled markets, in Section 5, and concludes with a conclusion in Section 6.

## 2. Assessment of Indian Electric Energy Market

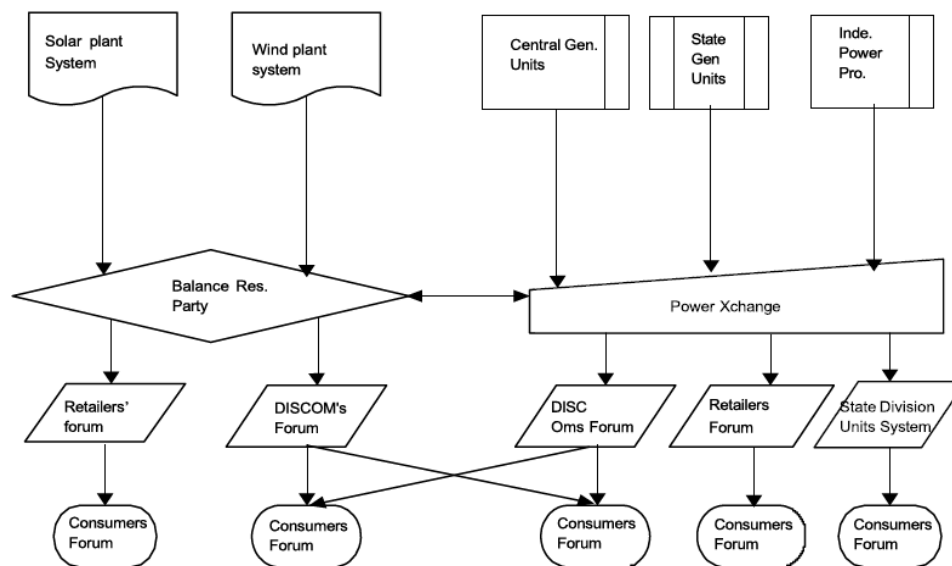
India's energy sector, initially managed by state energy boards, faced financial losses and became inefficient. In 2001, independent regulatory organizations were established to create efficient policies and rationalize electricity rates. The electricity act of 2003 aims to create a central body, rationalize pricing, encourage transparent subsidies, and supply electricity to all communities, promoting competition and privatization (Kumar et al., 2022). Proper market models are needed to minimize electricity prices as renewable energy becomes more prevalent.

### 3. Proposed Market Structures for the Indian Electrical Market with Renewable Energy

The traditional electricity market uses three restructured models: PoolCo, bilateral contracts, and hybrid. PoolCo involves a power exchange (PX) that analyses supply and demand to finalize the optimal price. Bilateral contracts allow traders to negotiate prices without interference from system operators. Hybrid models offer flexibility for customers and utilities (Kumar et al., 2024b). This research explores renewable energy-enabled electricity markets, based on studies on renewable energy policies in India and Malaysia. The model consists of solar, wind, independent power providers IPPs, central generating units CGUs, state generating units SGUs, power exchanges PXs, state distributions SDUs, DISCOM's, and retailers. The power pool finalizes one MCP (Kumar and Bharadwaj, 2020), by matching supply and demand curves, exhibiting monopoly, minimal competition at the supply side, and may be free from congestion except peak demand hours.

#### 3.1 Renewable Electric Energy Pool Model

The proposed model combines renewable and non-renewable energy trading, with two power pools. Conventional generating units submit bids directly to the power exchange (PX), while solar/wind power plants bid through a BRP.



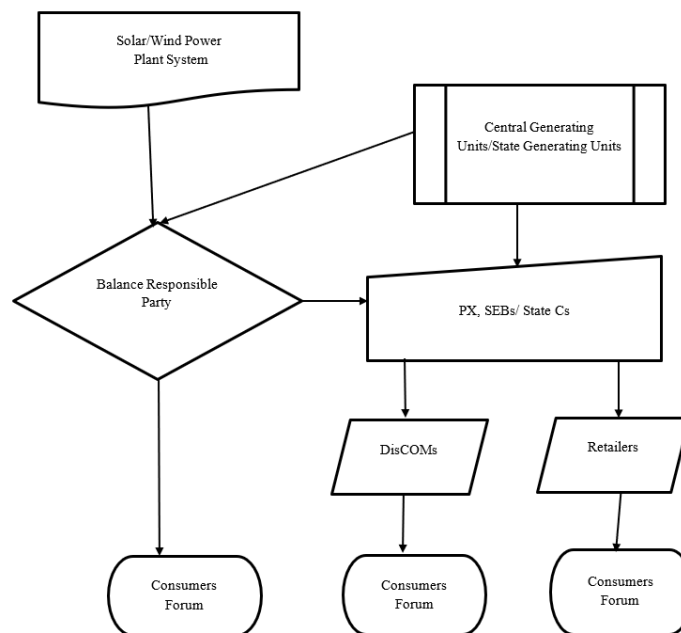
**Figure 1.** Renewable electric energy pool model.

**Figure 1** shows model ensures proper competition, lower tariffs, and benefits consumers. Implementation is easy and fewer complex, but congestion may arise due to wheeling at the distribution levels.

#### 3.2 Renewable Electric Energy Bilateral Structure with BRP

The model introduces a hybrid model that includes entities like CGUs, SGUs, solar/wind power plants, PXs, distribution companies DISCOM's, retailers, and consumers. A novel entity termed BRPs is added to manage renewable energy uncertainty. BRP can negotiate long-term bilateral contracts through distributors and consumers, and can submit bids to sell excess power to PX (Poudineh et al., 2021).

**Figure 2** Shows the model promotes renewable energy usage, urging bulk consumers, but may be more complex to operate due to the additional entity BRP and potentially increase electricity prices.

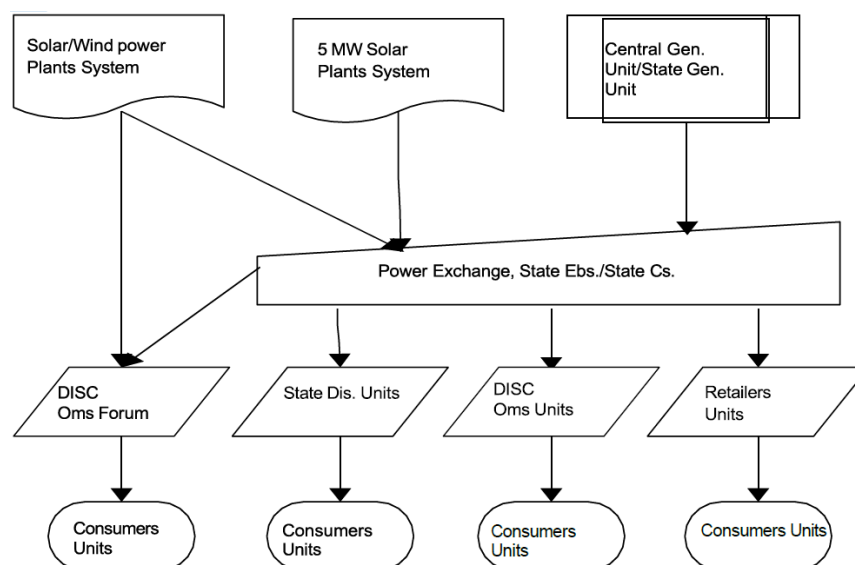


**Figure 2.** Renewable electric energy contracts model with balance RP/BRP.

### 3.3 Renewable -Green Electric Energy Bilateral Structure with DISCOMS and RES

The model outlines a hybrid power trading system where solar/wind power plants have bilateral contracts with DISCOMs, allowing them to sell excess power to the pool and purchase power when needed.

Solar projects under 5 MW can sell power directly to the pool, while DISCOMs establish bilateral contracts with solar/wind power plant owners through long-term power purchase agreements (PPAs).



**Figure 3.** Renewable power pool market model with bilateral contracts of distribution companies and RESs.

**Figure 3** shows model addresses uncertainty in renewable energy by establishing long-term PPAs between solar/wind power companies and DISCOMs, ensuring a smooth transition to renewable energy.

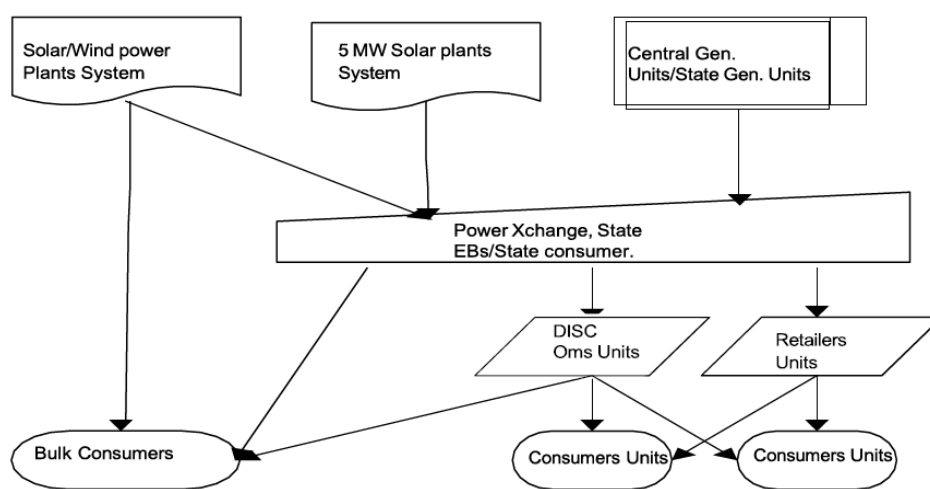
### 3.4 Adaptive Market Structure with Distribution Level Wheeling

The model introduces power wheeling at the distribution level, allowing bulk consumers to buy power from the open market instead of a local utility monopoly. This model allows consumers to choose from many competitive companies, but suppliers incur charges for using the grid. The model fallows consumers to select their distributor, introducing competition at the distribution level, potentially leading to lower tariffs and improved customer service (Hassan et al., 2024).

### 3.5 Modeling Structure of Open Access for Numerous Customers

The open market model allows bulk consumers to purchase power from various companies, overcoming monopoly at distribution level.

**Figure 4** shows allow large customers with linked loads over 1 MW to access affordable power from the open market, ensuring consistent supply and fulfilling renewable procurement commitments and reducing power shortages through intrastate or interstate access.

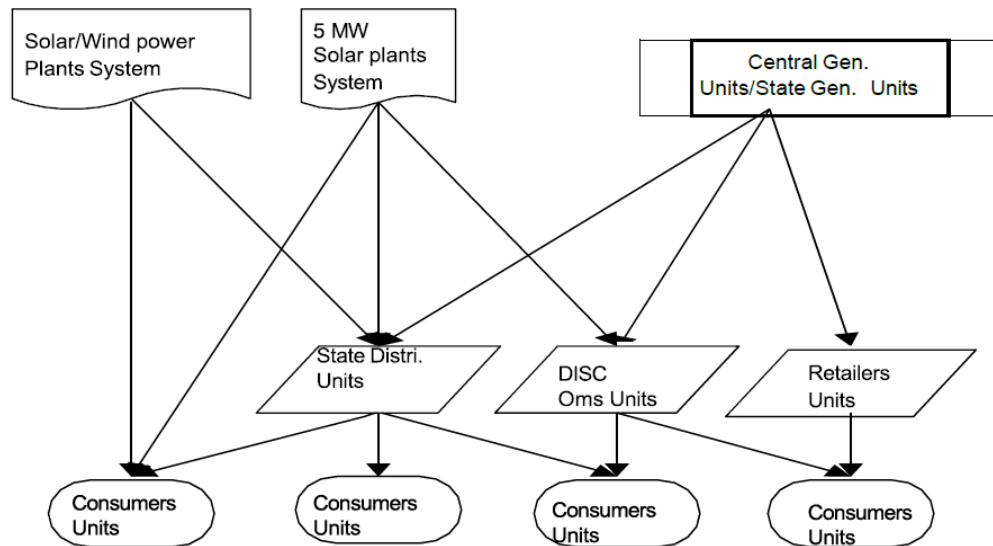


**Figure 4.** Renewable electric energy open access model for bulk consumers.

### 3.6 Markets Strategy Designed to be Adaptable for Distributors and Customers

This model allows DISCOMs/SDUs to purchase power from various sources, including CGUs/SGUs, solar/wind power plants, and other sources. Consumers have the flexibility to choose a distributor with a distribution license for multiple consumers or areas. Bulk consumers can purchase power from any DISCOM/SDU or directly from these plants. To compete with CGUs/SGUs, state governments and MNRE should offer incentives and subsidies.

**Figure 5** show's model aims to provide a market-based solution with economic efficiency for congestion management. Buyers typically prefer the cheapest generators, but congestion can lead to overloading of cheaper generators. Price settlement is area-wise, with lower prices for excess generation and higher prices for excess load.



**Figure 5.** Renewable electric energy flexible power market model for consumers and distribution units.

#### 4. Comparative Discussion of Various Methods

Table 1 presents the key findings from the comparison of all the above-mentioned models in action with respect to implementation, rivalries, congestion, tariff, and dependability. **Table 1**, Comparative discussion of various methods.

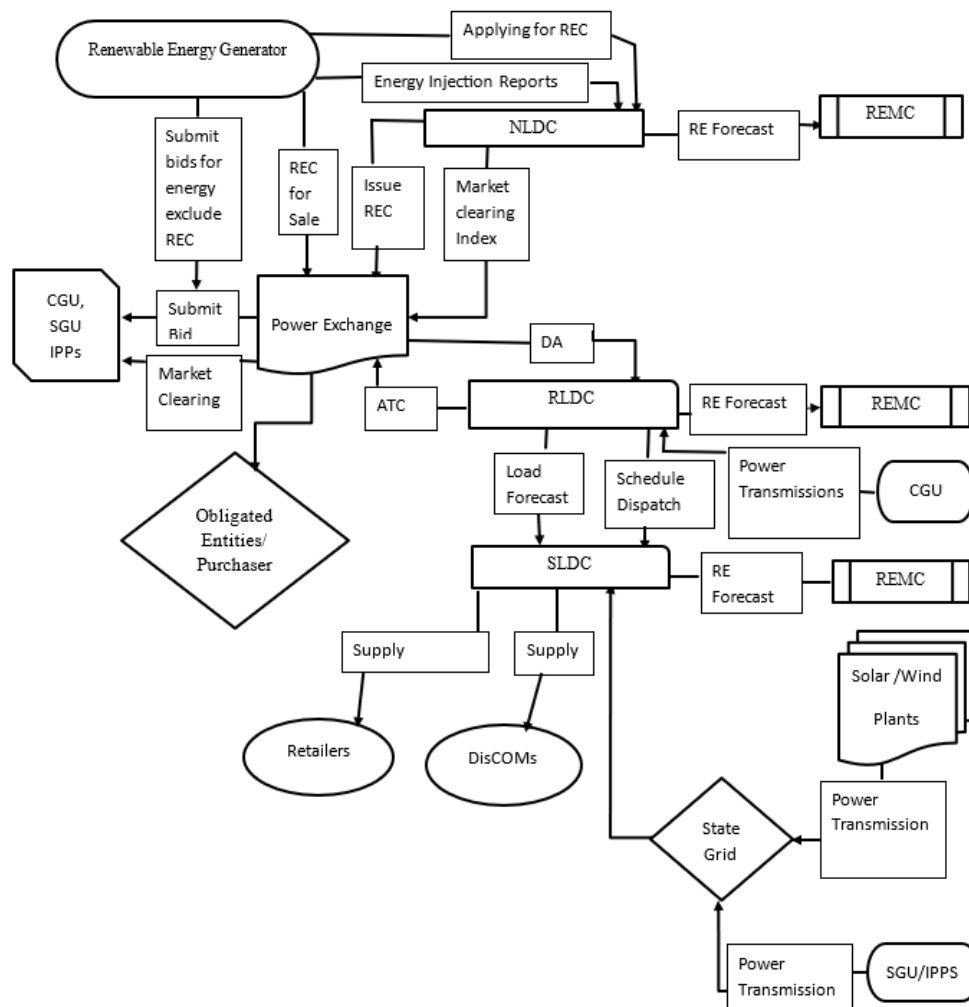
**Table 1.** Comparative discussion of various methods.

| Model/ System                                                | Implementation of the model/System | Market competition phases | Congestion phases | Power tariff system   | Reliability of power supply phases |
|--------------------------------------------------------------|------------------------------------|---------------------------|-------------------|-----------------------|------------------------------------|
| Energy pool model system                                     | Simple and easily working          | Less/ Low efficient       | Nil               | More higher efficient | Inferior                           |
| Renewable energy pool model system                           | A little difficulty involving      | Medium involving          | Less involving    | Mediumm involving     | Good involving                     |
| Renewable/Energy bilateral contracts model system balance RP | Control to easy                    | More efficient            | More efficient    | More efficient        | Superior                           |

**Table 1**, shows the comparative discussion of various methods on comparing these methods, energy pool models, renewable energy pool models and renewable/Energy bilateral contracts model system along with balance RP is more efficient and superior comparative other methods involving in electricity trading.

#### 5. Operative Mechanism System

The operating mechanism for the future Indian electricity market involves forecasting loads and renewable energy generation. The system involves SLDC, RLDC, and PX coordinating with REMC for renewable energy details. All generating units participate in bidding, and PX finalizes MCP for a day ahead power schedule.



**Figure 6.** Functional mechanism of Indian green electric energy market.

**Figure 6** shows the system also includes entities like RE generators and renewable energy certificates (RECs), which are issued by central agencies like NLDC. Green REs generators submit bids to PX for remaining power generation.

## 6. Conclusions

The research paper proposes various market models for the RE-enabled Indian electricity market, analyzing factors such as growth of renewable energy generation, MNRE policies, state-specific targets, market competition, and dependable power supply. The models are compared in terms of implementation, rivalry, traffic, pricing, and dependability. The implementation depends on market players' needs, and a proposed operational method with numerous novel components is suggested to run this market. Renewable Energy bilateral contracts model system with balance responsible party is more appropriate than other available market methods model, and highlights the importance of renewable energy integration in the Indian electricity market.



### Conflict of Interest

All authors declare that they have no conflicts of interest. The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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### AI Disclosure

The author(s) declare that no assistance is taken from generative AI to write this article.

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