

A comprehensive review of pricing models in the electricity retail market: Innovations and trends

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Abstract The electricity retail market has undergone a terrific upheaval in current years, driven by quick technical developments, augmented integration of renewable energy resources, and changing customer prospects. The increasing demand for inclusive power, combined with the shift towards renewable energy and digitalization, has led to significant changes in the electricity retail market. This study examines the account of retail electricity markets, focussed on new pricing systems that intend to enhance competence, incorporate renewable energy sources, and authorize end customers. Different pricing systems, such as Time-of-Use (TOU), Demand Response (DR) and Real-Time Pricing (RTP) are evaluated to handle supply-demand dynamics and support sustainable energy practice. The influence of dispersed energy resources (DERs), renewable energy incorporation, and power system transference is also examined, with a spotlight on lowering carbon emissions and improving grid reliability. Advanced Machine Learning (ML) and Deep Learning (DL)-based pricing systems are evaluated for their capability to estimate power prices. The result emphasize the significance of energy pricing reforms in building a strong, sustainable, and consumer-friendly electricity retail market. This study investigates into the advantages and struggle of executing modern pricing methods, highlighting their possible to influence the prospect of universal energy systems.

Keywords: distributed energy resources, grid modernization, renewable energy, demand response (DR), time-of-use (TOU)

1. Introduction

The increasing demand for electricity, driven by technological advances and a shift towards sustainable energy, has made the electricity retail market a critical component of the broader energy system. Here, electricity is sold directly to end-user such as households, businesses, and industries by electricity retailers. The retail market concentrates on the last phase of the electrical supply chain, in contrast to wholesale markets, which deal with the buying and selling of electricity in bulk. In this market, the final consumer's cost comprises not only the price of energy but also other expenses including taxes, distribution costs, and retail margin. These additional components reflect the operational and regulatory costs associated with delivering electricity to consumers. As the global energy system transitions toward sustainability, decentralization, and digitalization, the retail electricity market faces significant challenges, necessitating the exploration of innovative pricing models. A key innovation in the retail electricity market is the shift towards distribution-level markets, managed by Distribution System Operators (DSOs), to participate in real-time trading. DSO-centric models can significantly reduce electricity rates, through improved DER utilization (Haider et al., 2021).

Another development is the integration of Renewable Energy Sources (RESs), which introduces supply volatility. Although integrating renewable energy lead to higher short-term prices due to supply volatility, the long-term benefits, such as cost reduction and environmental sustainability, far outweigh these costs (Oosthuizen et al., 2022). Innovations in demand response and pricing strategies are critical for balance and value reduction, integrating renewable energy, storage, and electric powered automobiles (Patnam & Pindoriya, 2021). The energy suppliers and customers, a number of pricing models have been designed as the retail electricity market progresses. To optimize grid usage and minimize peak demand, Time-of-Use (TOU) tariffs enable consumers to move their usage during off-peak hours (Yunusov & Torriti, 2021). Consumers are offered more precise pricing signals that represent the cost of energy generation at any given instance through Real-Time Pricing (RTP), which varies throughout the day based on current supply and demand factors (Lu et al., 2021). Since dynamic pricing is reliant on an integer of variables, incorporating grid stability and energy generation projections is more adaptable and sensitive to shifts in the market (Zhao et al., 2021). Additionally, Capacity-Based Pricing aligns price with the capacity to satisfy height load needs

(Lou et al., 2025) even as Subscription-Based Pricing offers clients a fixed monthly charge, presenting predictability in billing. Demand Response (DR) pricing similarly helps to balance grid call for encouraging consumers to reduce utilization throughout peak instances (Keskin et al., 2024). Green Pricing supports using renewable electricity resources by offering customers the choice to pay a premium for purifier energy (Qu et al., 2023). Despite their advantages, the integration of those pricing models needs superior technological infrastructure and lively purchaser participation (Hampton et al., 2022). The complexity of these models, mainly RTP and Dynamic Pricing, requires additional exploration and development. This evaluation will examine the innovation and trends in electricity retail market pricing models, their advantages, limitations, and their position in determining the potential of the retail energy market.

2. Methodology

In this systematic review, "Google Scholar" database was initially used to retrieve 150 papers relevant to the research. After removal of duplicate records, they comprised a sample of 140 records that were screened for title and abstract. A total of 90 papers were subsequently excluded due to irrelevance. The remaining 50 full-text articles were assessed for eligibility, with 15 excluded after careful review because they failed to deal with relevant pricing models, missing issues such as renewable energy integration or ML-based pricing. A thorough search was conducted using a set of predefined search terms. The following Boolean operators were employed to refine the search: AND: to combine terms and narrow the scope; OR: to include synonymous or related terms; and NOT: to exclude irrelevant studies.

Research articles published in various journals were included in the literature search. However, only research papers from top-most journals were chosen for the final literature review analysis. It excluded content from book chapters, lecture notes, and conference proceedings. Almost, 31 full-text articles remained to be evaluated for inclusion. Then, 35 research papers were involved in qualitative analysis, due to the direct relevance of the new pricing models in electricity retail markets, renewable energy integration, and the ML influence in energy pricing systems. Table 1 and Figure 1 demonstrated the inclusion and exclusion criteria for selecting researches on electricity retail markets and renewable energy pricing model.

Table 1 Inclusion- exclusion criteria.

Criteria	Inclusion	Exclusion
Time-period	2020 to 2024 (post-crisis period)	Pre-crisis period
Publication Stage	Only finally published papers	Papers that are pending or still in process
Language	English language	Non-English language
Subject-area	<ul style="list-style-type: none"> • Electricity retail market • Renewable energy integration 	<ul style="list-style-type: none"> • Papers focused on other industries like oil or gas • Not focusing on renewable energy or electricity pricing
Type of Papers	<ul style="list-style-type: none"> • Energy pricing systems (TOU, DR, RTP, etc.) Review articles, research articles	<ul style="list-style-type: none"> • Studies not addressing electricity pricing models Lecture notes, conference presentations, proceedings
Scope of Study	<ul style="list-style-type: none"> • Retail electricity markets, renewable energy, machine learning • Energy pricing models (TOU, DR, RTP) 	<ul style="list-style-type: none"> • Marketing, consumer behavior, human resources • Non-energy-related studies

3. Results and Discussion

3.1. A summary of electricity retail markets

An electricity market was established to facilitate the trading of commodities and services related to electricity. To boost competence, develop dependability, lower energy prices, give customers more flexibility over which dealer they pick, and stimulate innovation and the adoption of low-cost equipment, different strength price lists are required. Furthermore, it is essential to assess the objectives, design, and development of market systems within the electrical region to ensure robust and sustainable energy transactions. Modern energy transactions involve two types of market participants: wholesalers and retailers. Wholesalers acquire electricity from utilities and sell it to retailers, while retailers buy from wholesalers and sell it to consumers. The power sector must design a variety of electricity tariffs, assess market structure and goals, and change their formation to facilitate efficient energy transactions to boost efficiency, dependability, reduce energy prices, and attract modernity and economical solutions (Hampton et al., 2022).

The marketplace for power is designed to address significant issues in the energy interchange market from previous years. The design prioritizes by providing clients with reliable, sustainable, and affordable electricity. Electricity retailing purposes include supporting & process, delivering the finest forces for customers' enduring interests, and ensuring electricity supply and the power system (Aghamohammadloo et al., 2021). The electrical market has evolved to reflect societal progress.

Throughout the twenty-first century, the energy market followed a monopolistic paradigm. Vertical marketing is a concept in a single firm combine’s production, distribution, and transmission. According to critics, this strategy lacks competition, which drives up costs and degrades the quality of services. Consumers allowed choosing their electrical provider or haggling costs, limiting their options. Several countries have adopted furtherreasonable market models, likerelaxed or deregulated ones (Hakam et al., 2020).

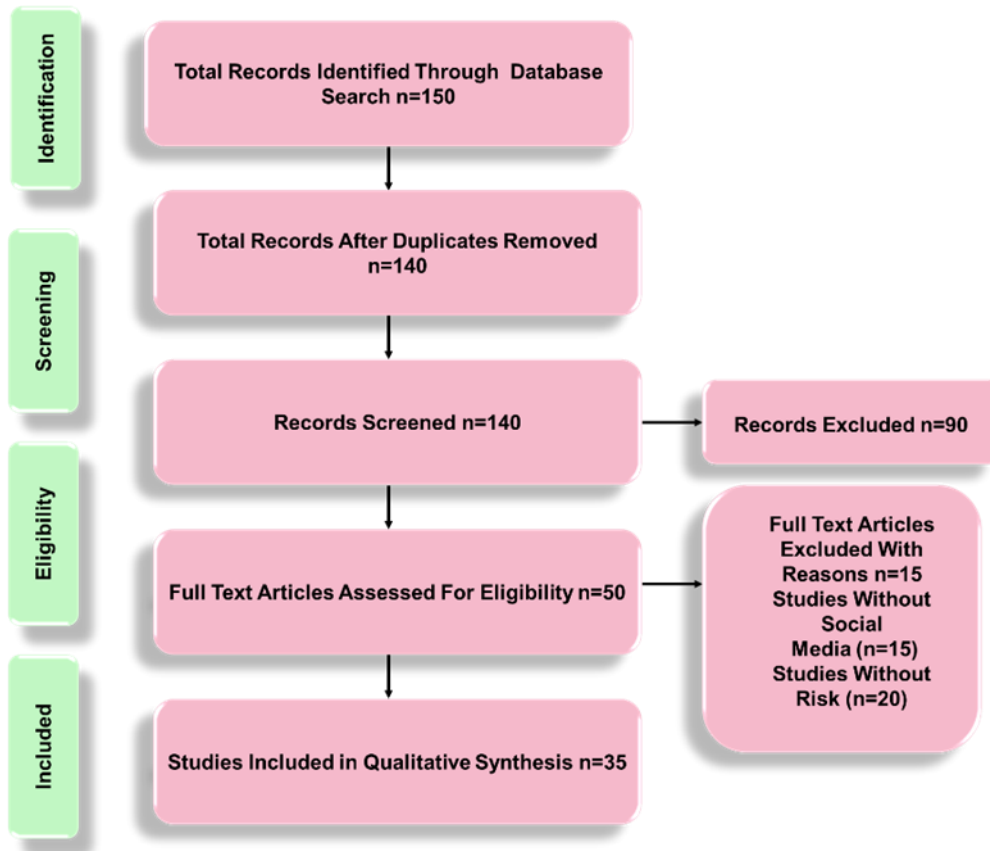


Figure 1 Survey analysis.

Customers have options and haggle pricing, resulting in better overall service. Independent power producers and established power production corporations have created competition in the power generation sector. Acquisition activities obtain power from both energy production companies and independent electricity suppliers. Distribution Businesses are required to abide by the policies of the framework and are not allowed to select their power providers. The one-layer approach promotes private participation in the electricity market (Favras et al., 2022). The energy market is designed to be decentralized and competitive, driven by government policy. Reform policies are rapidly reshaping the corporate structure, posing obstacles and promoting changes to the market design. The market structure is changing from monopolistic to competitive, with customers having various options for power sources and service providers (Hakam, 2023). Figure 2 demonstrates the retail market structure.

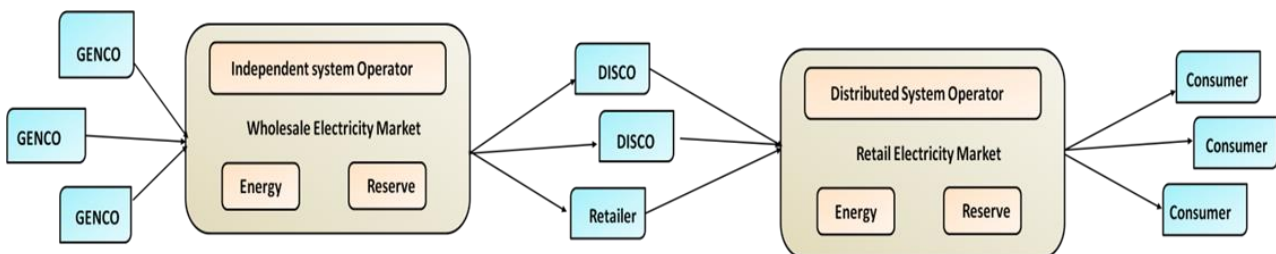


Figure 2 Architecture of retail marketing. Note: GENCO- Generation company, DISCO-Distribution company.

Independent system operators (ISO) ensure adequate power generation and transmission capacities, as well as backup sources for balancing generation and load private (Neuhoff et al., 2023). It detached from economic interests. ISOs are dependable for ensuring grid resilience and maintaining energy reserves during peak demand periods (Simeone et al., 2023). Market operations require both day-ahead and real-time marketplaces. The economic market companies purchase and trade

electricity at agreed-upon prospect prices (Brown et al., 2020). Electricity supply costs and energy-related service fees are included in the power pricing paid for consumption, in addition to the cost of energy use (Ansarin et al., 2020). Figure 3 depicts the features that control energy prices.

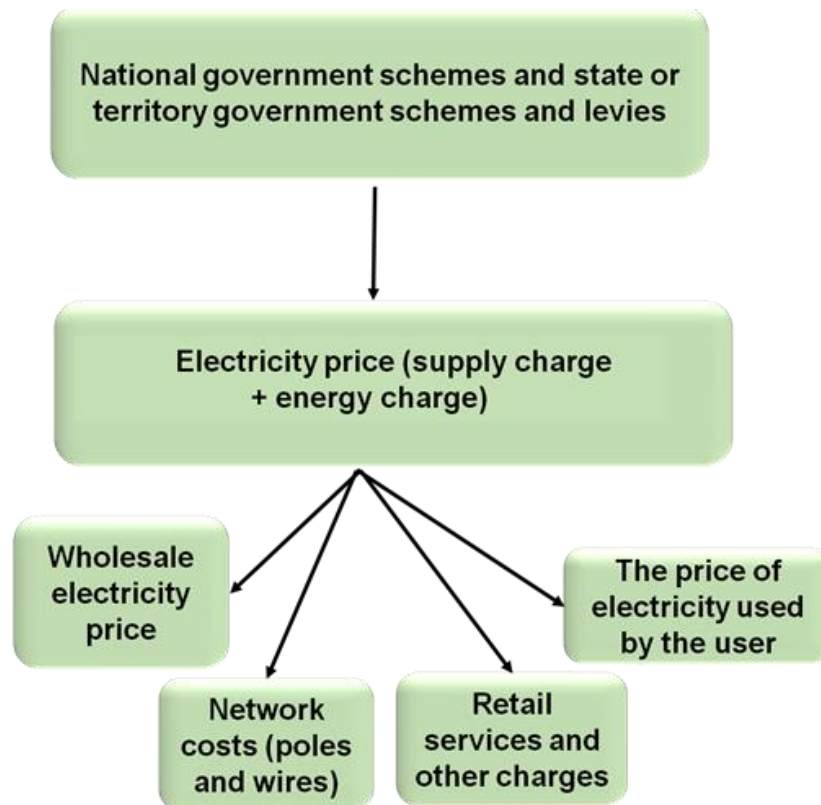


Figure 3 Impact of electricity prices.

Retail services provide customers with several energy programs and selections based on their specific requires and inclinations (Boscán, 2020). Services offer guidance on electricity competency, renewable energy sources, and innovative methods to help customers reduce their energy usage and expenses (le Roux et al., 2024). Retail services are vital for ensuring energy market efficiency and offering high-quality support to clients. Their skills and knowledge empower clients to make informed decisions and minimize their energy practice and expenses, while also causative to a sustainable powerpotential (Tomei et al., 2020).

Currently, energy pricing policies include flat tariffs, block rate tariffs, seasonal tariffs, time-of-use tariffs, and variable peak load. Table 2 demonstrates the types of pricing policies (Chatterji & Bazilian, 2020).

The changing power sector has led to energy pricing reforms in the distribution system. Reforming energy pricing will improve efficiency and lower wholesale electricity costs, creating a more balanced system. It promotes regional markets by utilizing more renewable sources (Dragasevic et al., 2021). DERs minimize carbon emissions, expand access to electricity, and improve stability (Chodakowska et al., 2021; Gencer et al., 2020).

- Energy storage devices, or Distributed Energy Resources (DERs), are a sign of improved power management, reduced prices, and decentralisation of the power market (Cai et al., 2021). DER owners require a regulated, competitive market, but utilities benefit from real-time pricing (Abhyankar et al., 2020).

- Retail electricity rates have been reduced as an effect of the increased use of renewable power resources, digitization, and enhanced power supply quality (Karami & Madlener, 2021). Distribution firms provide dependable and economical electricity, with smart appliances helping to optimize energy consumption.

- Energy pricing regulations, when combined with renewable energy sources, improve system reliability and efficiency. The decentralization of power systems and the transition to smart grids have reduced pressure on traditional power systems, enhancing supply reliability (Ohler et al., 2020).

- While marketplace decentralisation, smart homes, and renewable energy use are creating a more balanced demand-supply situation, efficient energy supply has proven challenging with traditional ways (Steffen & Patt, 2022).

- Demand response solutions entail lowering electricity use during peak demand periods to ensure system dependability.

Table 2 Types of pricing policies.

Pricing policy	Description	Key characteristics
Flat pricing	Prices remain static still if demand adjusts	The tariff is the identical for all customers, regardless of consumption. - Have a negative influence on utility income and uniform billing. - Prices rise as the total load increases.
Block Rate Tariff	Differentiates users based on their electrical consumption, with several categories.	The inclining rate plan raises prices in tandem with consumption. - The declining rate plan lowers prices as consumption increases.
Seasonal Tariff	Prices are depending on the changing demand across different seasons.	Prices vary seasonally according to demand. - Prices are greater during peak demand (winter) and decrease during low demand (summer). - Tariffs beyond the 300-kilometer transmission zone are higher.
Time-of-Use Tariff	Prices alter supporting on the instance of day, with greater costs	- Peak hours incur increased fees. Changes occur seasonally.
Super Peak Time-of-Use Tariff	The peak window is shorter, and prices during peak periods are significantly higher.	Peak seasons are typically shorter and more expensive, especially during the summer months.
Critical Peak Pricing	Pricing dynamically based on retail market rates or emergency conditions.	Prices grow during peak demand periods.
Variable Peak Load	It providers must keep customers informed of any changes.	- Prices change from day to day. - Traders should engage with consumers by increasing high costs.
Real-Time Pricing Policy	Prices fluctuate at usual periods, ranging from an hour to a few minutes, allowing customers to regulate their energy consumption by avoiding peak consumption periods.	Prices fluctuate in real time. - Consumers can lower their energy consumption during peak hours. - Communication routes must be clear.

3.2. Electricity retail marketing structure and pricing modules

Electricity price forecasting is the process of anticipating future electricity costs by examining features like supply-demand dynamics, weather, and market rules. Traditional methods include time series models such as AutoRegressive Integrated Moving Average (ARIMA) for linear trends, regression analysis for factor-based forecasts, statistical learning models such as Support Vector Machine (SVM) for complicated dependencies, and fundamental models for market economics (Zalzar et al., 2020). Hybrid approaches combine these methods with optimization techniques to improve precision. Accurate forecasting is critical for market efficiency, risk management, renewable energy integration, policy development, operational planning, and cost reduction. It promotes the stability and efficiency of electricity markets by allowing for better decision-making and adaptation to changing market needs.

In this study, different ML and Deep Learning (DL) techniques of pricing models are analyzed. Some of the analyzed pricing models are U-Net Convolutional Neural Network with Gated Recurrent Units (UCNN-GRU) (Li et al., 2022), Extreme Gradient Boosting XGBoost (Albahli et al., 2020) and AlexNet- Differential Multi-Objective Algorithm (AlexNet-DMOA) [35 AlexNet-DMOA (Almazroi & Ayub, 2023) using Mean Absolute Percentage Error (MAPE), Mean Squared Error (MSE), and Mean Absolute Error (MAE). The MAE and Root Mean Square Error (RMSE) utilized to examine the difference in error in a wide range of estimations. It has adversely situated scores: It is preferable to have lower self-estimated values. Table 3 and Figure 4 represent the outcomes of pricing models.

- RMSE

It is one of the key criteria that evaluates the well-established prediction models in energy pricing systems. This study uses RMSE to refer to estimated and actual electricity prices in different pricing models-metrics like TOU, demand DR, and RTP. A smaller RMSE value means better prediction accuracy, which is important for the optimization of a pricing system, the management of supply-demand dynamics, and allowing integration of renewable energies into a better grid reliability and sustainability in the retail electricity market.

• MAPE

It is used pervasively to evaluate any forecasting model's accuracy, MAPE quantifies, in this study, a mean percentage difference between the predicted and actual electricity prices under various pricing systems such as TOU, DR, and RTP. The absolute percentage error calculation allows MAPE to assess how well the predicted price values matched the actual market values. In other words, MAPE offered an insight into the accuracy of prices with lesser MAPE indicating better performance of the model; hence, MABE will be useful in improving price accuracy to cater for supply and demand fluctuations and pursue sustainability through integrating renewable resources into the electricity retail market.

• MSE

It is a metric that evaluates how accurately any predictive models work with respect to pricing systems in energy. In this study, to measure the MSE, the predicted electricity prices using different pricing methods were compared to the actual realizations: TOU, DR, and RTP. By squaring the errors and averaging them, MSE penalizes larger ones much more than smaller ones, giving considerable weight to major deviations. The lower the MSE, the better the model, which may be a crucial factor in price optimization, demand management, and adaptation with renewable energy resources for sustainability and grid reliability within the context of the electricity retail market.

• MAE

It refers to a paradigm that seeks to measure the accuracy of predictive modeling by averaging the absolute differences between the predicted and actual electricity prices. In this study, MAE is invoked in assessing the efficiency of various pricing models: TOU, DR, and RTP. By concentrating on absolute errors, MAE provides a very simple measure of the distance between the predictions and the actual numbers, and henceforth very useful in checking the performance of pricing systems in managing supply-demand dynamics, integrating renewable energy systems, and creating more sustainable and reliable electricity retail markets.

Table 3 Evaluation of pricing models.

Method	RMSE	MAPE	MSE	MAE
UCNN-GRU (Li et al., 2022)	2.622	5.24	6.87	1.48
XGBoost (Albahli et al., (2020)	9.25	40.90	15.66	3.74
AlexNet-DMOA (Almazroi and Ayub 2023)	5.23	3.85	6.23	5.46

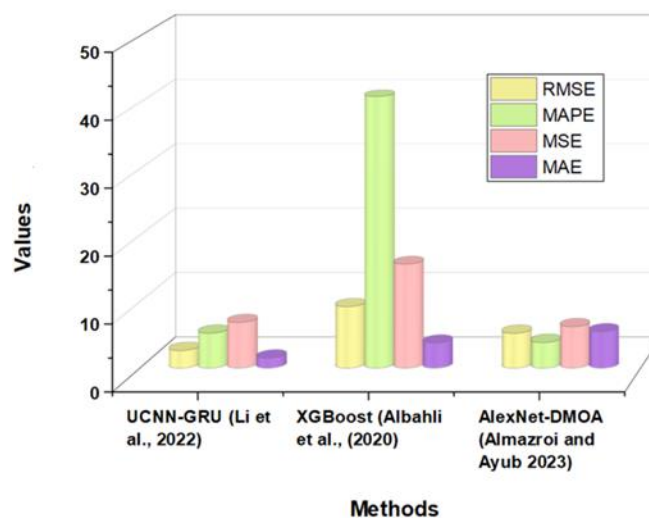


Figure 4 Outcomes of pricing models. *Source:* Li et al. (2022), Albahli et al. (2020), Almazroi and Ayub (2023).

The performance comparison of multiple approaches using the metrics RMSE, MAPE, MSE, and MAE demonstrates that UCNN-GRU surpasses the other methods with the lowest values across all measures, particularly in RMSE (2.622) and MAE (1.48), indicating higher accuracy and efficiency. XGBoost, while effective, has much higher values for MAPE (40.90) and lower values of MAE (3.74), indicating inferior performance. AlexNet-DMOA delivers a balanced performance with lower values than XGBoost, but it falls behind UCNN-GRU in RMSE and MSE. This suggests that UCNN-GRU is the best strategy for the current problem.

Qu et al. (2023), lacked in the analysis of economic aspect of Green Pricing with the added cost for renewable energies, as it has not touched on consumer behavioral or market adoption issues. Furthermore, the study does not adequately address some of the barriers to the broad implementation of Green Pricing: technological, regulatory, and difference in renewable energy resources across geographical areas, which would affect the scalability and effectiveness of the system. Keskin et al.



(2024) was limited to DR pricing and its impacts on peak load reduction. It does not consider any long-term behavioral pattern or impact on grid stability over time. It does not take into account constraints in consumer participation such as ignorance or unwillingness to shift patterns of consumption. The DR pricing approaches failed to consider differences between regions in terms of infrastructure and energy demand; hence, it may not be universally applicable. The present pricing structures in power retail markets have some shortcomings, incorporating rigidity, difficulty, disparity, and data isolation trouble, all of which delay their alteration to novel systems.

These systems resist adjusting varying energy demand outlines and purchaser behavior, reasoning uncertainty and reluctance among customers to accept energy-efficient performance. Additionally, the difficulty of these methods, as well as the prospect of unbalanced cost-sharing, aggravates these subjects, mainly among low-income households. Functioning problems, like high execution expenses and the opportunity of market direction, create matters more complex. Future investigate should focus on creating flexible, consumer-centric pricing methods that relation for intermittent renewable energy incorporation, encourage contribution in peer-to-peer energy operation, and tackle impartiality concerns. There is also requiring for models that develop market energy, sincerity, and affordability while advancing energy competence. Integrating complicated technologies like ML and blockchain enhanced the accuracy and safety of pricing organizations, ensuing in more robust, reasonable, and capable energy organizations.

4. Conclusion

In current years, the increase of RESs has radically impacted the electrical market, ensuing in shifts in energy manufacture and utilization. Electricity pricing is one of the most significant features of this change, as it has a straight influence on different market traders. With an increasing integer of imagines, the concentration has controlled to developing a decentralized and dispersed network. This has resulted in the evolution of power methods from a federal, upright included market to an additional diverse configuration that includes trade and extensive markets. The retail electricity market is quick alteration, due to the integration of renewable power resources, devolution, and modernization. Modern pricing systems, like TOU, RTP, and DR, are shifting the path of energy is inspired and administered, providing customized resolutions to reduce prices and enhance competence.

The results of this examination emphasized the significant function of management policies, laws, and knowledge developments in manipulating the electricity market and its pricing strategy. Policymakers exploit these insights to increase effectual policies that support struggle and modernism, while industries and customers use this information to create knowledgeable decisions about reserves, production, and utilization. Finally, sensitive the shifting power market organization and costing systems is significant for promoting enduring expansion and competence in the energy manufacturing. However, these models have difficulties in terms of infrastructure inclination and customer commitment. Despite these improvements, the complexities of active pricing system and concurrent market demands necessitate further study to ensure faultless incorporation and extensive performance. Addressing these limits through strong knowledge architecture and customer education is critical to creating a sustainable and reasonable energy market that achieved both financial efficiency and ecological responsibility.

Ethical Considerations

Not applicable.

Conflict of Interest

The authors declare no conflicts of interest.

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