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# The Evolution of Electricity Spot Markets, Strategy, Behavior, and Settlement: A Comparative Review

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**Abstract - This review paper synthesizes recent research on the evolution of electricity spot markets, focusing on the transition from national power exchanges to local peer-to-peer (P2P) trading systems(Ahmad 2019; Poplavskaya 2020) . By analyzing market designs in India, Europe, China, and Switzerland, the paper evaluates the effectiveness of various pricing mechanisms, including Locational Marginal Pricing (LMP), zonal pricing, and Marginal Pricing versus Pay-as-Bid (Ableitner 2020; Wang 2022) . Using advanced multi-agent-based simulations (MABS) and reinforcement learning (RL), the review demonstrates that while granular pricing mechanisms like LMP provide superior location signals, they often require hybrid settlement methods—such as System Average Pricing (SAP)—to ensure consumer fairness and acceptance(Ableitner 2020; Wang 2022) . Furthermore, the review explores the behavioral aspects of market participation, identifying a heterogeneous user base in local markets that values a balance between active price-setting agency and automated convenience(Poplavskaya 2020) . The research also highlights innovative frameworks like Iterative Proportional Adjusting (IPA) and Renewable Energy Certificates (RECs) designed to maximize the integration of variable renewable energy sources (RES) while mitigating the impact of strategic bidding and transmission congestion(Ahmad 2019; Ableitner 2020; Wang 2022) . Ultimately, the paper provides a comprehensive framework for understanding how adaptive pricing and robust market modeling can enhance liquidity, stability, and sustainability across diverse electricity market environments(Ahmad 2019; Poplavskaya 2020; Ableitner 2020; Wang 2022; Oprea 2026) .**

## 1 INTRODUCTION

**Motivation:** The global transition toward decentralized and competitive energy systems is primarily driven by the urgent restructuring of electricity markets to enhance liquidity, productivity, and the deployment of non-fossil fuel resources (Ahmad 2019) . National reforms in major economies aim to dismantle traditional monopolies and provide accurate locational economic signals to optimize resource allocation and grid planning (Poplavskaya 2020) . Simultaneously, international regulatory efforts to harmonize balancing markets seek to better align market designs with long-term energy transition goals while facilitating efficient cross-border procurement (Ableitner 2020) . This evolution is further characterized by a paradigm shift where citizens evolve from passive consumers into active prosumers, driven by falling installation costs for distributed energy resources and a desire for sustainable, local energy trading (Wang 2022) . Ultimately, the development of robust local electricity markets and adaptive pricing frameworks is critical to maximize traded volumes and ensure the stable integration of high shares of variable renewable energy (Oprea 2026)

**The Problem:**

The primary **Contributions** of this research are explicitly detailed as follows: This review paper synthesizes the findings of recent studies to address these gaps through several key contributions:

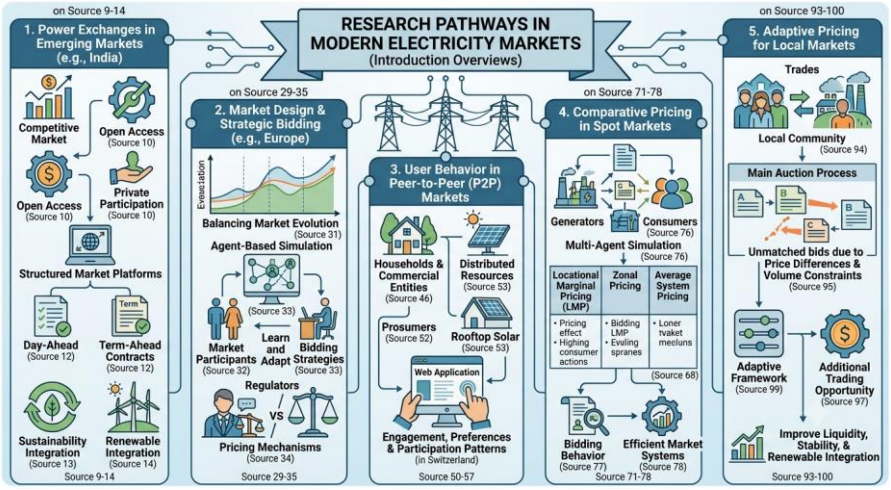
- **Quantitative Market Assessment:** The research provides a detailed assessment of national power exchanges, evaluating the effectiveness of Day-Ahead (DAM) and Term-Ahead (TAM) contracts .(Ahmad 2019)
- **Advanced Strategic Modeling:** Utilizing Agent-Based Modeling (ABM) and Reinforcement Learning (RL), the studies identify market designs—such as standalone balancing energy markets—that dampen strategic price spikes and improve market efficiency .(Poplavskaya 2020)
- **Empirical Behavioral Insights:** This research offers unique insights from real-world P2P energy markets, categorizing users into clusters based on their preferences for active price-setting agency versus the convenience of automation .(Ableitner 2020)



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- **Pricing Framework Comparisons:** By comparing LMP, zonal, and System Average Pricing (SAP), the research establishes settlement methods that minimize deviations from actual nodal costs while ensuring the sustainability of generating units.(Oprea 2026)
- **Adaptive Pricing Frameworks:** The review highlights innovative post-auction mechanisms, such as Iterative Proportional Adjusting (IPA), designed to maximize traded volume and the integration of renewables by dynamically adjusting to real-time market conditions.(Wang 2022)




## 2 LITERATURE STUDY

### 2.1 Thematic Grouping of Existing Research

- **National Market Reforms and Infrastructure:** Research evaluates the transition of large-scale systems, such as India's power exchange and China's pilot spot markets, to enhance liquidity and dismantle monopolies through mechanisms like Day-Ahead Markets (DAM) and Locational Marginal Pricing (LMP) (Ahmad 2019; Poplavskaya 2020) .
- **Strategic Modeling and Market Design:** Studies utilize Agent-Based Modeling (ABM) and Reinforcement Learning (RL) to simulate participant behavior, identifying opportunities for strategic bidding in balancing markets and evaluating the efficiency of Marginal Pricing versus Pay-as-Bid (Ableitner 2020) .
- **Decentralized Local Markets (LEMs):** Emerging research focuses on the shift to user-centric peer-to-peer (P2P) trading, exploring the technical feasibility of blockchain settlement and the development of adaptive pricing to maximize local renewable integration (Wang 2022; Oprea 2026) .

### 2.2 Critical Analysis and Comparative Evaluation

- **Efficiency vs. Fairness:** While LMP is optimal for providing spatial signals, it is often too volatile for consumer acceptance; research shows that System Average Pricing (SAP) or zonal pricing provides a "fairer" settlement by smoothing extreme nodal price deviations (Poplavskaya 2020) .
- **Mechanism Performance:** In balancing markets, marginal pricing consistently yields lower weighted average prices than Pay-as-Bid (Ableitner 2020) . For local markets, the Iterative Proportional Adjusting (IPA) method achieves 47% buyer cost savings, outperforming standard uniform pricing in reducing price volatility (Oprea 2026) .
- **Simulated vs. Empirical Behavior:** RL simulations reveal that strategic bidders can spike prices 4–5 times above benchmarks (Ableitner 2020) . Conversely, real-world P2P field studies indicate human behavior is heterogeneous, with many users prioritizing convenience and environmental salience over pure profit maximization (Wang 2022) .

### 2.3 Identification of the Research Gap

- **The "User Gap":** A significant lack of empirical data exists regarding actual user engagement and long-term acceptance in real-world P2P settings, as most research remains rooted in technical feasibility or hypothetical simulations (Wang 2022) .



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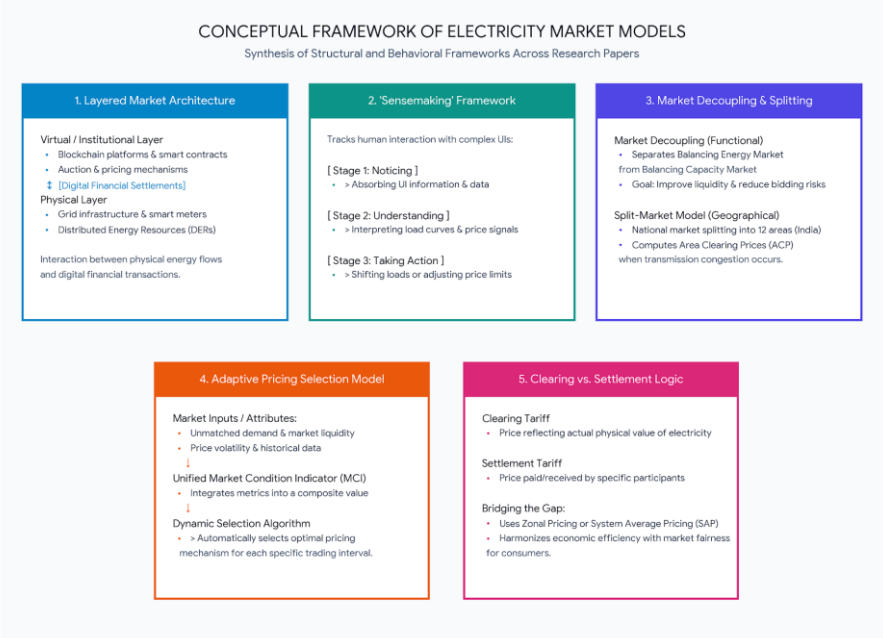
- **Post-Auction Inefficiencies:** Current mechanisms frequently leave participants unmatched due to price discrepancies; there is a need for structured adaptive pricing selection frameworks to manage these post-auction quantities (Oprea 2026) .
- **Unresolved Market Power:** Existing designs fail to completely eliminate strategic gaming in concentrated markets, and further research is needed to determine the optimal mix of market access conditions and pricing rules (Ableitner 2020) .
- **Unified Market Indicators:** There is an absence of a unified Market Condition Indicator (MCI) that integrates liquidity, volatility, and historical trends to dynamically drive pricing strategy selection (Oprea 2026) .

## 3 PROPOSED APPROACH

The analyzed research employs a diverse range of methodologies to evaluate electricity market performance, participant behavior, and pricing efficiency:

- **Multi-Agent-Based Simulation (MABS) and Modeling:** This is the most prevalent approach for analyzing complex market interactions. Researchers use Agent-Based Modeling (ABM) to simulate individual market participants (agents) who make independent bidding decisions to maximize profit . These models often incorporate Reinforcement Learning (RL), to adapt their strategies over repeated auctions based on historical success and market feedback (Ahmad 2019; Poplavskaya 2020) .
- **Mixed-Methods Empirical Field Studies:** To move beyond simulation, research includes real-world deployments involving residential households . This methodology combines quantitative data collection (via smart meters and web application system logs) with qualitative insights gathered through participant surveys and semi-structured interviews .(Wang 2022)
- **Quantitative Market Assessment:** This approach involves the statistical analysis of historical transaction data from established national power exchanges . It evaluates metrics such as total transacted volume, Market Clearing Price (MCP), and the volume of electricity left uncleared due to transmission congestion .(Oprea 2026)
- **Algorithmic Framework Design:** For emerging local markets, a theoretical and computational approach is used to design and test new pricing mechanisms, such as Iterative Proportional Adjusting (IPA) . These frameworks are validated through simulations that compare the performance of multiple pricing models (e.g., VCG, Shapley Value, and Nash Bargaining) under identical market conditions .(Ableitner 2020)

## 4 CONCEPTUAL MODEL






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## 5 KEY FINDINGS

- National market reforms in major economies emphasize dismantling monopolies and enhancing liquidity through the establishment of centralized power exchanges and pilot spot market programs (Ahmad 2019; Poplavskaya 2020)
- While Locational Marginal Pricing (LMP) is theoretically optimal for reflecting resource scarcity, its inherent volatility often necessitates hybrid settlement methods like System Average Pricing (SAP) to ensure consumer acceptance and fairness (Poplavskaya 2020)
- Real-world peer-to-peer (P2P) market implementations reveal a heterogeneous user base whose engagement is driven by a balance between active price-setting agency and automated convenience (Ableitner 2020)
- Innovative post-auction mechanisms, such as Iterative Proportional Adjusting (IPA), significantly increase traded volumes and cost savings in local electricity environments by dynamically refining price bids (Oprea 2026)

## 6 DISCUSSION:

- The collective research highlights a significant evolution from traditional, centralized regulatory models toward decentralized, data-driven electricity markets capable of integrating high shares of variable renewables. .
- Although national-scale reforms in economies like India and China demonstrate that competitive bidding reduces market clearing prices, physical infrastructure constraints such as transmission congestion remain a persistent barrier to achieving full market liquidity. .
- Furthermore, advanced modeling of balancing markets indicates that while marginal pricing is economically superior to pay-as-bid, strategic bidding in concentrated markets can still drive prices up to five times higher than competitive benchmarks. .
- On a local level, the transition to P2P trading is no longer just a technical challenge but a behavioral one; successful market design must address the "user gap" by offering interfaces that support both active price-setting and automated agents. .
- To manage these complexities, the adoption of a unified Market Condition Indicator (MCI) to drive adaptive pricing selection—ranging from bargaining solutions to modified VCG mechanisms—is essential for optimizing trading outcomes and reducing overpayment risks.

## 7 CONCLUSION

- Modernizing electricity spot markets requires the harmonization of granular economic signals, advanced strategic modeling, and user-centric participation frameworks (Ahmad 2019) .
- Standalone balancing energy markets and marginal pricing rules have proven effective at dampening the impact of strategic bidding and enhancing overall market efficiency (Poplavskaya 2020) .
- Empirical findings from P2P pilot programs confirm that providing users with transparent data and pricing agency can successfully shift participant roles from passive consumers to active prosumers who engage in sustainable practices like load-shifting (Ableitner 2020) .
- Additionally, the use of zonal settlement methods and unit-cost compensation provides a viable transitional tool for balancing the need for location signals with the requirement for fair economic surplus distribution among stakeholders (Wang 2022) .
- Ultimately, the integration of adaptive frameworks like Iterative Proportional Adjusting (IPA) provides a robust pathway for maximizing the local integration of variable renewable sources while maintaining price stability across varying market conditions (Oprea 2026) .

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