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Developing the U.S. Electricity Financial Market: Strategic Design of Derivatives for Risk Management and Market Stability

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Abstract

As the United States advances its decarbonization agenda and faces rising electricity demand from electrification and data center growth, the volatility introduced by extreme weather events and increasing renewable penetration underscores the need for robust financial risk management. This paper outlines the fundamental principles of electricity financial derivatives, evaluates their performance within U.S. markets operated by regional transmission organizations (RTOs/ISOs), and analyzes lessons learned from stress events such as the 2018 PJM FTR default and the 2021 Texas Winter Storm Uri. It highlights structural and regulatory challenges in balancing liquidity, credit risk, and market resilience across diverse regional market designs. The study proposes strategic enhancements to derivative instruments including Financial Transmission Rights (FTRs), Congestion Revenue Rights (CRRs), virtual power purchase agreements (VPPAs), and hub futures aimed at improving hedge effectiveness, transparency, and systemic stability. By addressing price volatility, congestion risk, and renewable integration, these financial tools provide a pragmatic pathway for ensuring market stability, enhancing investor confidence, and supporting the U.S. transition to a cleaner and more resilient energy system.

Keywords: Electricity Financial Markets, Risk Management, Electricity Financial Derivatives, U.S. Power Markets, Financial Transmission Rights (FTRS), Congestion Revenue Rights (CRRS), Renewable Integration, Market Stability, Energy Transition, Derivatives Regulation

Introduction

In the mid-1990s, the Federal Energy Regulatory Commission (FERC) initiated landmark reforms through Orders 888 and 2000, mandating open access transmission and enabling the establishment of Regional Transmission Organizations (RTOs) and Independent System

Operators (ISOs) (Federal Energy Regulatory Commission, 1996, 1999). Since then, markets such as PJM, MISO, CAISO, ERCOT, NYISO, ISO-NE, and SPP have evolved into independent entities that coordinate wholesale transactions and facilitate decentralized electricity markets (PJM Interconnection, 2025; ISO New England, 2025). Transaction volumes have steadily grown, involving generators, utilities, traders, and industrial consumers. The U.S. system now combines long-term contracts with liquid day-ahead and real-time spot markets, balancing price stability and flexibility (U.S. Department of Energy, 2021; U.S. Energy Information Administration, 2023).

These reforms coincided with broader decarbonization goals, such as federal and state targets to reduce emissions and expand renewables (North American Electric Reliability Corporation, 2022; Hogan, 2002). Rapid growth in wind, solar, and distributed resources, supported by tax incentives and corporate power purchase agreements, has accelerated the transition (U.S. EIA, 2023; Mansur, 2007). Yet the variable, weather-dependent nature of renewables introduces volatility in prices, congestion, and reliability risk (Joskow, 2008). For example, Winter Storm Uri (2021) exposed extreme financial exposure: ERCOT prices spiked to the $9,000/MWh cap, causing significant market stress (FERC & NERC, 2021).

Unlike storable commodities, electricity must be produced and consumed instantaneously, making prices highly sensitive to demand swings, outages, transmission constraints, and weather extremes (Hogan, 2002; CAISO, 2023). These dynamics underscore the necessity of risk management. However, much of the literature focuses on renewable integration or operational design in isolation, underestimating the stabilizing role of financial derivatives (Joskow, 2008; Woo et al., 2011).

This paper argues that electricity derivatives—such as futures, options, CFDs, and congestion hedges (FTRs/CRRs)—are indispensable not only for hedging volatility but also for fostering systemic resilience. Events like the 2018 GreenHat default in PJM's FTR market and the Uri crisis reveal vulnerabilities in credit, margining, and oversight practices (FERC, 2018–2019; FERC & NERC, 2021). Addressing these gaps is vital for liquidity, transparency, and market stability.

Furthermore, to deepen the conceptual foundations of derivative design, this paper incorporates empirical studies from non-energy domains—particularly risk, safety, and human behavioural science. For instance, Ghori et al. (2025) explore Occupational Exposure and Physiological Risk Perception in textile workers; in another study, Ghori et al. (2025) examine Case-Based Learning in Physiology at Indus Medical College; and Ghori et al. (2025) also review Comparative Risk Assessment and Adaptive Management frameworks. Prior work from Khatoon et al. (2025a) on internal controls and Khatoon et al. (2025b) on resilience frameworks in utilities provide foundational linkage. Moreover, Shaikh et al. (2016) discuss industrial hazards in textile mills. By bridging these studies with electricity market design, this paper aims to propose derivative strategies that embed operational resilience and control robustness.

The remainder of this study is organized as follows: Section 2 outlines electricity financial derivatives in the U.S. context. Section 3 reviews their functioning within regional

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markets, with emphasis on PJM. Section 4 identifies risks and lessons from recent crises. Section 5 presents recommendations for future design improvements. Section 6 concludes.

Electricity Financial Derivatives

Electricity financial derivatives are indispensable to U.S. wholesale markets, providing tools to hedge against volatility arising from renewable variability, congestion, demand fluctuations, and fuel price shocks. Key products include forwards, futures, options, and CFDs/VPPAs, supported by FTRs and CRRs for congestion hedging.

Electricity Forward Trading

Forwards are bilateral, over-the-counter (OTC) contracts negotiated between parties such as generators, retailers, and corporate buyers? They allow tailored delivery terms (volume, hub, duration) but are exposed to counterparty credit risk because they are not centrally cleared.

Electricity Futures

Exchange-traded futures (e.g., on the Chicago Mercantile Exchange) are standardized by hub, tenor, and volume, and cleared by a central counterparty, mitigating credit risk. They are widely used at hubs such as PJM Western, ERCOT North, MISO Indiana, and CAISO NP15/SP15**.** Futures aid price discovery, hedging, and speculation, but can suffer from basis mismatches.

Table 1

Differences between electricity forward and futures contracts

Aspect	**Forwards (OTC)**	**Futures (Exchange-Traded)**
Participants	Generators, utilities, corporates	Generators, traders, speculators
Standardization	Custom, negotiated bilaterally	Standardized by CME (hub/tenor)
Credit support	Bilateral agreements	Clearinghouse margins
Settlement	Physical or financial	Primarily cash-settled
Risk	Counterparty credit risk	Market price risk

Power Options

Options grant the right but not the obligation—to transact at a strike price. They provide insurance against tail risks and are actively traded on CME. Participants include utilities seeking downside protection, traders speculating on volatility, and corporates managing exposure. Options can be calls, puts, European, or American style.

Table 2

Differences between electricity futures and power options

Dimension	**Futures**	**Options**
Obligation	Binding for buyer and seller	Right, not obligation
Settlement	Cleared, cash-settled	May lapse if out-of-money
Payoff	Symmetric (linear)	Asymmetric (premium cost)
Use	Hedge price levels	Hedge volatility/extremes

Contracts for Difference (CFDs/VPPAs)

In the U.S., CFDs are commonly structured as Virtual Power Purchase Agreements (VPPAs) between renewable developers and buyers. Settled against hub prices, they stabilize revenues for projects while allowing corporates to meet sustainability targets. They are central to financing wind and solar developments but can introduce basis risk between the project node and settlement hub.

Table 3

Comparison of electricity derivatives in the U.S.

Product	Advantages	Disadvantages	Use Cases
Forwards	Flexible, tailored	Credit risk, illiquid	Bilateral hedges, corporates
Futures	Transparent, liquid, cleared	Margining costs, basis mismatch	Hedging hub exposure
Options	Protect against volatility	Premium cost	Insurance against extremes
CFDs/VPPAs	Stable RE revenue, align with ESG	Basis risk	Corporate procurement, RE finance

Functioning of U.S. Electricity Financial Markets

The U.S. electricity financial market is among the world's most advanced, structured around RTO/ISO-operated spot markets (PJM, MISO, ERCOT, CAISO, NYISO, ISO-NE, SPP) and **exchange-traded/OTC financial derivatives.**

PJM Interconnection as a Benchmark Case

PJM Interconnection provides the most comprehensive example of electricity financial market design in the United States, offering a robust suite of products including Financial Transmission Rights (FTRs), virtual transactions, and cash-settled contracts such as Contracts for Difference (CFDs)/Virtual Power Purchase Agreements (VPPAs). FTRs allow participants to hedge congestion costs by paying or receiving congestion rents based on locational marginal price (LMP) differences, while virtual trading enables arbitrage between day-ahead and real-time prices, thereby enhancing price convergence and market efficiency. CFDs and VPPAs, on the other hand, are increasingly used by utilities and corporations to stabilize renewable procurement costs and manage long-term exposure to wholesale price fluctuations. PJM's FTR market is especially notable for its structure, encompassing long-term, annual, and monthly auctions as well as a secondary market, which together provide participants with multiple hedging horizons and liquidity options.

Table 4

Differences among PJM FTR auctions

Parameter	Long-Term Auction	Annual Auction	Monthly Auction
Subject	3 years ahead	1 year ahead	3 months ahead
Capacity value	Residual after LT allocation	Annual capacity net LT FTRs	Residual monthly
Rounds	3	4	1
Products	Peak, off-peak, 24h	Same	Same

This framework separates physical and financial markets, deepens liquidity, and provides benchmarks for congestion risk management [12,15,26].

Risk and Stability Lessons

Two major crises in U.S. electricity financial markets underscore the vulnerabilities that can threaten system stability if risk controls are inadequate. The 2018 GreenHat default in PJM, which left over $125 million in unpaid obligations, exposed significant weaknesses in credit screening, portfolio monitoring, and collateral management for participants in the FTR market. Similarly, the 2021 Winter Storm Uri in ERCOT triggered over $50 billion in settlement obligations as wholesale prices hit the system price cap, leading to widespread bankruptcies and liquidity crises among retailers and municipal utilities. Together, these events highlight the critical need for stronger credit requirements, dynamic margining practices, and more robust stress-testing frameworks to ensure that financial electricity markets can withstand extreme shocks while maintaining confidence and liquidity.

Recommendations

To strengthen the resilience and effectiveness of U.S. electricity financial markets, several strategic improvements are essential. First, credit risk management should be reinforced through dynamic margining, collateral requirements, and stress testing that reflect market volatility. Second, transparency must be enhanced by monitoring and disclosing FTR/CRR exposures and concentration risks. Third, innovation in derivative products—including weather-linked hedges, hybrid contracts, and improved VPPAs—can provide more tailored tools for renewable integration. Fourth, regulatory clarity between FERC and the CFTC is critical to avoid jurisdictional gaps and ensure robust oversight of financial electricity products. Finally, promoting the broader use of standardized yet flexible contracts such as VPPAs can expand hedging opportunities for corporate buyers while mitigating basis risk. Together, these measures will improve liquidity, reduce systemic vulnerabilities, and align financial markets with the objectives of the U.S. clean energy transition.

Conclusion

The U.S. electricity financial market is central to risk management in an era of renewable growth and weather volatility. Instruments such as futures, options, CFDs, and FTRs/CRRs provide indispensable hedges, liquidity, and forward benchmarks. Yet crises such as GreenHat and Uri reveal vulnerabilities in credit, liquidity, and regulatory frameworks. Strengthening collateral rules, improving transparency, and expanding product innovation are critical to aligning financial stability with the nation’s decarbonization goals.

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