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# A Comprehensive Analysis of Potential Revenue and Breakeven Viability of Energy Storage in the Day-Ahead Market of MISO

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## ABSTRACT

This study investigates the economic feasibility of Energy Storage Systems (ESS) in volatile market nodes within the Midcontinent Independent System Operator (MISO). As MISO transitions from a coal-dominant energy mix to a more diverse composition of natural gas and renewables, new arbitrage opportunities for ESS emerge, particularly at nodes like ALTW.SPRVAUN1 and NSP.FRENCH3. Utilizing a linear optimization model with perfect price forecasting, the study estimates the potential arbitrage revenues from these nodes from 2008 to 2014 and then from 2020 to 2022. The sensitivity analysis indicates that current market conditions do not favour immediate profitability for ESS due to high relative battery costs. However, projections up to 2030 reveal a potential shift. With battery costs expected to decrease and electricity price volatility likely to increase due to the growing presence of renewables, the future profitability of ESS appears promising. This is particularly evident in the breakeven analysis, which predicts that NSP.FRENCH3 might reach financial viability before 2030, with ALTW.SPRVAUN1 closely following. Conclusively, the study emphasizes the need for ESS operators to adopt flexible strategies, considering long-term market evolutions. The ongoing shift towards renewable energies in the MISO market suggests an advantageous future for ESS, especially in capitalizing on the forecasted market volatility.

## 1 | Introduction

In the rapidly transforming global energy market, the importance of energy storage systems (ESS) has increased considerably [1]. They enhance both the efficiency and reliability of the electrical grid while significantly reducing the variability of renewable energy production [2]. The reliance on extra generation capacities is significantly decreased by integrating ESS into power networks [3]. This strategic integration reduces costs associated with the building and running of new generating plants by a significant margin [4].

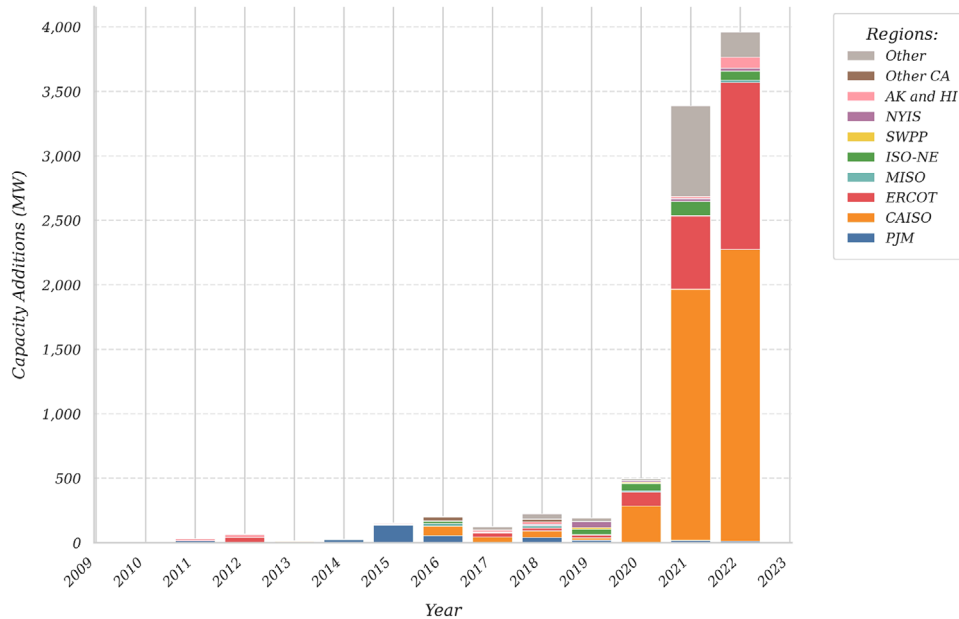
This importance is reflected in the rapid growth of grid-scale battery installations. By the end of 2023, U.S. utilities had approximately 15.8GW of battery capacity in operation a figure expected to more than triple by 2028 [5]. This expansion is driven by the need to balance variable renewable generation and declining technology prices. Notably, operators now report that the primary use for over 10 GW of this battery capacity is energy arbitrage buying low, selling high making arbitrage the most common function of large batteries today [5].

These developments are mirrored across regional energy markets in the United States, where systems like PJM, ISO-NE, and MISO

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### Battery Energy Storage System (BESS) Capacity Additions by Region (2010–2022)



**FIGURE 1** | Large-scale battery energy storage system (BESS) capacity additions by region (2010–2022), illustrating annual increments in megawatts. This figure highlights the contributions of major U.S. regions along with significant additional installations classified as ‘other CA’ and ‘other’. ‘Other CA’ denotes BESS capacity installations within California that are outside the operational areas managed by the California Independent System Operator (CAISO), capturing contributions from smaller or rural utilities within the state. ‘Other’ represents contributions from various smaller regions and markets across the United States that are not listed individually, reflecting a comprehensive national perspective on BESS advancements.

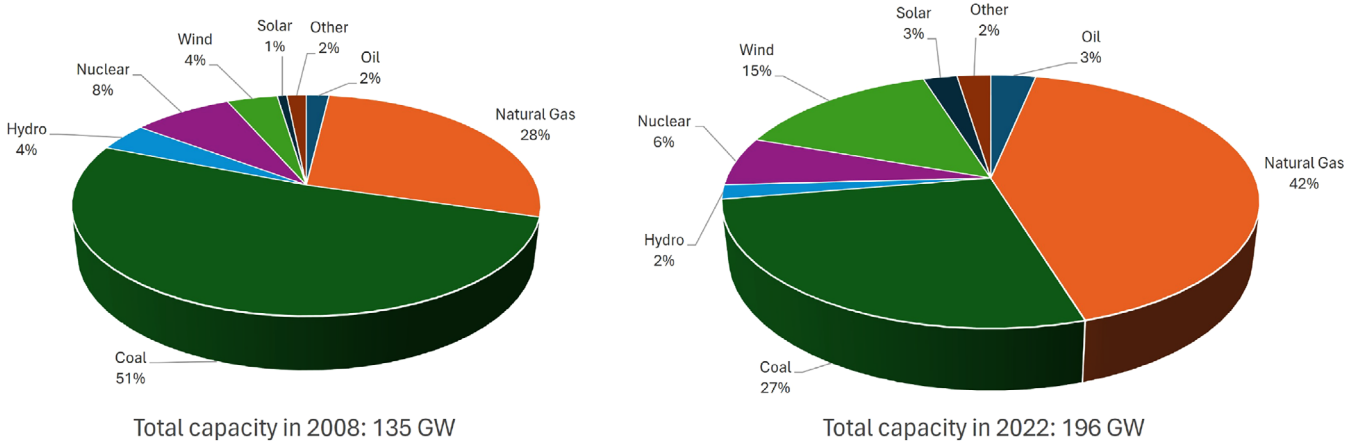
have made substantial strides in expanding ESS capacity [6]. Among the spectrum of ESS technologies, battery energy storage systems (BESS) are notable for their rapid deployment and their use in critical services such as peak shaving, frequency regulation, and emergency backup. Accordingly, BESS play an integral role in stabilizing the grid and enabling the effective integration of renewable energy sources. The importance of BESS in regional energy strategies becomes evident when considering the data from the U.S. Energy Information Administration, which shows a marked increase in large-scale battery storage capacity additions by these regions from 2010 to 2022, as illustrated in Figure 1. This trend highlights a national shift towards greater reliance on battery storage technologies, highlighting their pivotal role within the broader ESS landscape [7].

As battery deployments increase, their revenue streams are also shifting. In several markets, energy arbitrage has become the dominant revenue source for battery projects, surpassing earnings from ancillary services [5]. This change is driven in part by declining ancillary service prices and greater volatility in energy markets, which together make arbitrage more attractive. For example, in ERCOT, 58% of battery revenue recently came from energy arbitrage after ancillary service prices fell to a five-year low [8]. These dynamics highlight the need for strategic operational adjustments to maximize ESS profitability. They also underscore that profitability remains sensitive to cost and degradation: Studies show that arbitrage-only operation becomes viable only when battery costs drop sufficiently or when price volatility is extremely high [9]. Recognizing these economic constraints sets the stage for careful analysis and strategic planning.

For these reasons, our analysis centres on the Midcontinent Independent System Operator (MISO), which exemplifies the broad role of ESS in a large energy market. MISO is a not-for-profit entity overseeing high-voltage electricity transmission across 15 U.S. states and the Canadian province of Manitoba, facilitating one of the world’s largest energy markets with over \$40 billion in annual transactions. Its operations are critical to delivering reliable, cost-effective electricity to 45 million people [10]. MISO’s advanced market processes and robust energy management make it an ideal setting to explore the arbitrage potential of ESS in a dynamic, forward-thinking grid environment [11].

In the United States, energy markets including MISO utilize the locational marginal price (LMP) pricing scheme, established in 1990 [12]. LMP calculates the cost of adding an extra megawatt of load to the power system at a specific location, based on system energy price, transmission congestion cost, and marginal loss cost [13]. MISO operates two primary market structures based on LMP: the day-ahead market (DAM) and the real-time market (RTM). DAM forecasts the next day’s prices using distributors’ bids and generators’ offers, while RTM adjusts prices in real-time based on actual demand and supply discrepancies from DAM forecasts, both utilizing time-based LMPs [14].

Despite MISO’s importance, few studies have examined battery storage profitability in this region. Most existing analyses focus on markets such as California or Europe [15, 16], with only a handful evaluating arbitrage opportunities within the MISO footprint. One recent study of MISO price data (2008–2022) identified certain high-volatility nodes that could yield above-average arbitrage revenue [17], hinting at untapped opportunities. However,



**FIGURE 2** | MISO installed capacity by fuel mix (2008 and 2022).

comprehensive assessments of battery profitability under MISO's current market rules and pricing dynamics remain scarce.

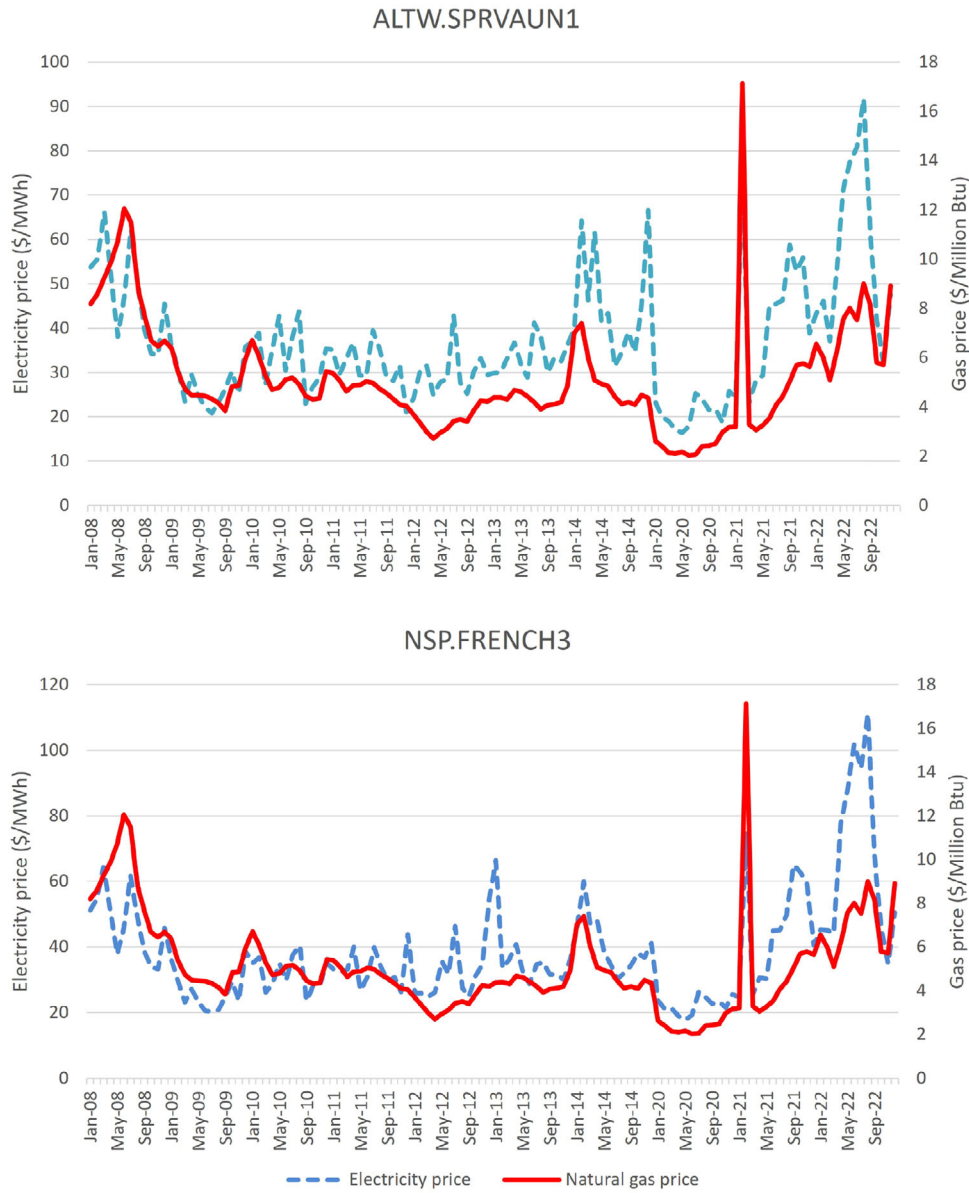
This research gap is especially notable given the evolving landscape of MISO. MISO only recently implemented market rules to fully integrate energy storage resources [18]. Consequently, the region currently lags others in deployed storage capacity (with less than 1 GW online) even as interest rises: over 70 GW of battery projects are now in MISO's interconnection queue waiting to be deployed [19]. MISO's unique generation mix and pricing patterns warrant a dedicated investigation. Previous studies of MISO arbitrage were largely retrospective and did not consider recent rule changes or the long-term effects of the increasing penetration of renewables. In contrast, a specific investigation focused on assessing the potential for arbitrage revenue within the PJM market, utilizing data from 2014, showcased the dynamics within another key energy market [20]. This analysis concentrated on arbitrage opportunities within both the day-ahead and real-time markets, separately, without considering cross-market arbitrage. The findings indicated that the real-time market presented more substantial opportunities for arbitrage, attributed to higher price volatility [21]. Such insights are critical as they highlight the differences in market behaviour across regions and underscore the necessity of precise price forecasting to optimize ESS at targeted nodes within MISO for effective management and profitability [22]. To address this gap, this paper analyses arbitrage potential at high-volatility nodes in MISO under current and projected market conditions, providing insight into the economic feasibility of ESS deployment in this under-explored region.

The paper is structured to provide a comprehensive exploration of the evolving energy landscape in MISO and its implications for ESS investments. Section 2, examines the shift from coal to a more diverse energy mix, including natural gas and wind. Section 3, assesses how natural gas prices affect electricity market dynamics and energy storage opportunities. The detail description of the nodes selection for energy arbitrage is presented in the Section 4. Section 5 details the generic ESS model used for maximizing revenue. Section 6 presents the outcomes of the sensitivity analyses, exploring various scenarios to assess the economic feasibility of ESS at these nodes. Finally, Section 7 provides the conclusion section that summarizing key insights and their significance for ESS operators and stakeholders in MISO's energy market.

## 2 | A Shift in Generation: The Changing Face of MISO's Energy Portfolio

The energy mix of the midcontinent independent system operator (MISO) has changed significantly over the last 14 years, as shown by the pie charts in Figure 2. The installed capacity broken down by fuel type for the years 2008 and 2022 is shown in these charts, which provide a clear visual depiction of the region's changing energy priorities. In 2008, coal accounted for 51% of all energy capacity, making it the dominant source of energy. This significant reliance on coal was typical of the era's energy policies. Fast forward to 2022, and the scenario has shifted considerably. Natural gas has ascended to comprise 42% of the total capacity, reflecting a significant change in the energy infrastructure of the region [23]. This shift away from coal, now reduced to 27% of the capacity, is not solely a result of the global movement towards more renewable energy sources. It's also a consequence of various supply chain disruptions that have compelled coal facilities to adjust their operations, adopting a more conservative approach to coal consumption [24]. These modifications serve as a symbol of the complex interaction that shapes the energy sector between the availability of resources, market forces, and energy policies.

Wind energy, a key component of the renewable energy portfolio, has seen its share in MISO's capacity quadruple from 4% in 2008 to 15% in 2022. This significant increase is a testament to MISO's commitment to diversifying its energy mix and aligning with the global shift towards sustainable and environmentally friendly power sources [25]. The inherent intermittency of wind generation and the faster-ramping dynamics of natural gas (now 42% of the mix) amplify short-term price volatility in day-ahead markets, creating critical opportunities for energy storage systems (ESS) to exploit arbitrage by charging during low-price periods (e.g. midday renewable surplus) and discharging during high-price intervals (e.g. evening gas-driven scarcity) [26]. The overall increase in installed capacity from 135 to 196 GW indicates the region's proactive response to the increasing demand for electricity, driven by both economic growth and population increases. These changes in MISO's energy mix, as captured in the charts, not only reflect the evolving energy landscape but also highlight the region's adaptability in the face of changing economic, environmental, and policy landscapes. They underscore MISO's strategic efforts to balance energy demand with sustainable



**FIGURE 3** | Natural gas price and electricity price for the selected nodes (2008 to 2022).

practices, while navigating the complexities introduced by supply chain dynamics and regulatory frameworks [27]. The transition from a coal-dominated mix to a more diversified portfolio, including significant contributions from natural gas and wind, is indicative of a broader transformation within the energy sector one that embraces innovation, sustainability, and responsiveness to global energy trends.

### 3 | Analysing the Interplay of Gas Prices and Electricity Market Dynamics in MISO

The MISO is experiencing a notable shift towards increased natural gas usage in its energy mix. This transition significantly influences the energy market, as depicted in Figure 3. The figure highlights the connection between natural gas prices and electricity market prices, with specific emphasis on nodes like ALTW.SPRVAUN1 and NSP.FRENCH3, which are characterized

by their high price volatility. As natural gas is anticipated to account for 42% of MISO’s energy mix by 2022, the importance of energy storage systems (ESS) is accentuated. Implementing a strategy that capitalizes on energy price fluctuations becomes crucial. This involves purchasing electricity when prices are low and selling when they are high, a tactic particularly effective in a market shaped by natural gas prices. Furthermore, an integral part of the analysis is determining the financial feasibility of installing ESS at these fluctuating-price nodes. This involves assessing market risks, operational costs, and the evolving regulatory environment. The goal is to validate that installations of ESS at ALTW.SPRVAUN1 and NSP.FRENCH3 are financially prudent and in alignment with the evolving trends in MISO’s energy landscape. The insights provided here are aimed at equipping stakeholders with the knowledge necessary for making informed decisions about ESS in settings with high price volatility. The selection of ALTW.SPRVAUN1 and NSP.FRENCH3 for this analysis was a deliberate decision based on an in-depth node

selection process. This process is crucial for understanding the broader context of the study and involved a detailed analysis of various nodes within MISO to identify those with the most potential for energy arbitrage. The next section will detail this process, explaining the criteria and methods used to identify these specific nodes, highlighting their importance in the context of MISO's changing energy market.

## 4 | Node Selection for Energy Arbitrage

In this research, selecting specific nodes within the MISO energy market for their potential in energy arbitrage was a critical step. This selection was based on an in-depth analysis of the nodes, with a particular focus on those exhibiting significant price fluctuations, a crucial factor for identifying nodes with profitable arbitrage opportunities.

### 4.1 | Data Collection and Preliminary Analysis

The process began with the collection of locational marginal prices (LMPs) data from the MISO website, covering the periods 2008-2014 and 2020-2022. The initial focus was on preparing this data for analysis, which involved:

- Cleaning the data to remove irrelevant information.
- Calculating average hourly prices for each node.

### 4.2 | Identifying High Volatility Nodes

Identifying high-volatility nodes is essential for analysing energy arbitrage potential within the MISO market. Volatility here refers to the level of variation in electricity prices at each node over time. This is assessed by calculating the standard deviation of average hourly prices for each node. Standard deviation is a statistical measure that shows how much prices at a node vary from the average over a specific period. A higher standard deviation indicates more significant price fluctuations at that node. These price changes are crucial for energy arbitrage, as they provide opportunities to buy electricity at lower prices and sell at higher prices.

In this process, the average hourly price for each node in the MISO market was determined first, providing a reference point for measuring price deviations. Nodes with a high standard deviation were categorized as high-volatility nodes. These nodes are particularly important for the study because greater price volatility offers more opportunities for profitable energy arbitrage. The study concentrates on these high-volatility nodes to explore where energy storage systems can be most effectively used for arbitrage, taking advantage of the frequent and significant price changes at these nodes for economic benefit.

### 4.3 | Quartile-Based Categorization

Nodes were systematically categorized into quartiles based on their volatility using their standard deviation values. The top 25%

of nodes, classified in the third quartile (Q3), were identified as the most volatile. This categorization is visually represented in a quartile-based scatter plot as shown in Figure 4, which is illustrated in the accompanying figure. The scatter plot depicts the annual hourly average price versus standard deviation for nodes categorized as high, medium, and low volatility. It clearly shows that high-volatility nodes experience greater price fluctuations compared to their medium and low-volatility counterparts. This plot also highlights the node with the highest standard deviation each year, providing a visual aid in understanding the varying risk and revenue generation profiles for battery operators in the MISO market.

### 4.4 | Final Selection of Nodes

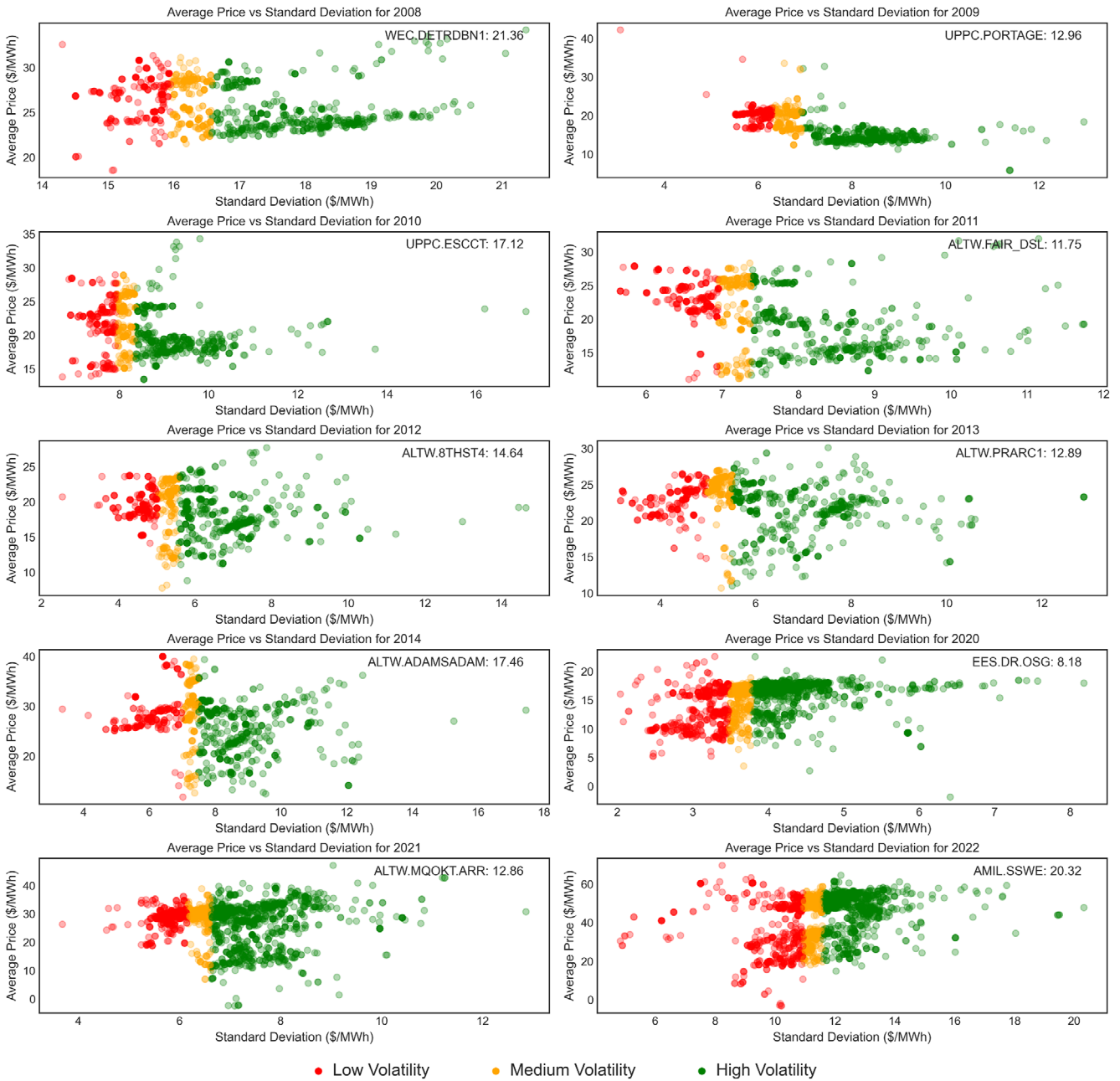
After categorizing the nodes based on their volatility, the next crucial step was the final selection of specific nodes for in-depth analysis. Although several nodes stood out each year due to their high volatility and the greatest standard deviations for example, the nodes like WEC.DETRDBN1, UPPC.PORTAGE, UPPC.ESCCT, ALTW.FAIR.DSL, ALTW.8THST4, ALTW.PRARC1, EESDR.OSG, ALTW.ADAMSADAM, ALTW.MQOKT. ARR and AMIL.SSWE as shown in Figure 4, the study mainly focused on the top 150 nodes with the highest standard deviations each year. This approach was applied to two distinct periods: from 2008 to 2014, which included 971 nodes, and from 2020 to 2022, encompassing 2331 nodes. Through this selective process, ALTW.SPRVAUN1 and NSP.FRENCH3 were consistently identified as highly volatile nodes. Their repeated presence among the top nodes across these periods highlighted their suitability for energy arbitrage analysis.

The selection of ALTW.SPRVAUN1 and NSP.FRENCH3 for their high volatility within the MISO market leads to the subsequent phase of this study: exploring the ESS optimization methodology. This section will delve into how the ESS model is theoretically applied to these nodes. It aims to assess, under current and forecasted market conditions, whether ESS can effectively leverage potential arbitrage opportunities, despite the current challenges such as high battery costs and market dynamics. The methodology aims to provide insights into the operational feasibility and potential economic outcomes of ESS deployments in these dynamic market environments.

## 5 | Methodology

In this study, an ESS operating in a market as a price-taker is modelled to assess arbitrage opportunities. The model is founded on a generic linear optimization approach, incorporating a perfect forecast of hourly-based electricity price data spanning an entire year. The primary objective is to maximize the potential for arbitrage revenue, following the approach detailed in [28]. The energy arbitrage model, as described in [28], leverages a perfect foresight analysis to determine an optimal storage policy.

Central to the model's premise is the assumption that individual storage operations, given their scale, do not exert influence on the market's equilibrium price outcomes, thus qualifying as price-takers. The model operates with full knowledge of fluctuations in electricity prices throughout the simulation period, allowing it



**FIGURE 4** | Quartiles-based analysis of price volatility in MISO energy market nodes: This figure presents a scatter plot mapping the annual hourly average price against standard deviations for nodes categorized into high, medium, and low volatility within the MISO energy market. The plot effectively illustrates the distribution pattern of these nodes, revealing that nodes classified under high volatility exhibit more pronounced price fluctuations relative to those in the medium and low volatility categories. Additionally, it identifies the node with the highest standard deviation for each year under study. Such graphical representation is crucial for elucidating the diverse risk and revenue generation potentials that energy storage operators encounter in different segments of the MISO market.

to optimize the charging and discharging schedule to maximize revenue. The strategy follows a price-driven approach in which the battery charges when electricity prices are low and discharges when prices are high. The only operational constraint is the state of charge, which dynamically evolves based on past charging and discharging events.

The model assumes an ideal operator with perfect foresight of both electricity prices and battery state of charge to assess the economic feasibility of BESS. This assumption enables a breakeven analysis under optimal market conditions, providing

insight into the revenue potential of the BESS operation. The mathematical formulation of the model is represented by the following Equation (1):

$$\max_{c,d,s} \sum_{t=1}^T p_t (d_t - c_t) \quad (1)$$

$$s_t = s_{t-1} + \eta c_t - d_t,$$

$$d_t, c_t \in [0, \kappa]$$

$$s_t \in [0, h\kappa]$$

In this model,  $d_t$  and  $c_t$  signify the discharge and charge power of the storage device in hour  $t$ , respectively, while  $s_t$  denotes the state of charge. The term  $\eta$  represents the round trip efficiency, encapsulating energy losses during storage and retrieval.  $T$  refers to the total number of hours in the dispatch horizon. The variable  $p_t$  corresponds to the energy price in hours  $t$ . The model also incorporates the power capacity ( $\kappa$ ) of the storage device and the number of hours it can discharge at its rated power ( $h$ ). This framework enables a comprehensive analysis of the storage device's operational strategy, focusing on optimizing the charge and discharge cycles to align with price variations and maximize revenue potential.

## 6 | Results

The analysis examines arbitrage revenues at the ALTW.SPRVAUN1 and NSP.FRENCH3 nodes within the MISO network, analysing the period from 2008 to 2014, and resuming from 2020 to 2022. The ESS optimization model uses a refined electricity price forecast to get the maximum possible revenue. The model, which is set up for an ESS with a 4MW power capacity, 4 h of storage, and a 95% round-trip efficiency, offers a theoretical maximum revenue that may be generated in the best-case scenario of market operations. The findings, which are depicted in the Figure 5, show a strong correlation between the market prices for electricity and the potential profits from strategic energy arbitrage. This link validates the effectiveness of the optimization method that was implemented in response to the varying costs of energy, confirming the ability of the ESS to profit from market volatility. Over the years, there has been a constant trend of arbitrage possibilities, with major deviations during times of market disruption, including the substantial decline in 2020 that was ascribed to the COVID-19 pandemic's economic effects. The historical effectiveness of energy arbitrage and the inherent potential within MISO's high-volatility nodes are revealed by examining revenue trends along with market electricity prices. It provides an outline for comprehending the relationship between the dynamics of energy pricing and the strategic use of energy storage technologies. Although ESS like batteries are inherently short-duration assets (e.g. 4-h storage), they capitalize on seasonal natural gas price trends through cumulative daily arbitrage cycles. For example, natural gas price spikes during the winter months amplify the volatility of the daily electricity price, creating larger spreads between midday renewable-driven lows (e.g. solar overgeneration) and evening gas-driven scarcity peaks. ESS exploits these daily spreads, and the aggregated revenue over months reflects seasonal trends. Figure 5 illustrates this phenomenon, demonstrating elevated revenues at nodes like ALTW.SPRVAUN1 during winter quarters (Q1 and Q4), where gas price volatility is most acute due to heating demand and supply constraints.

### 6.1 | ESS Profitability Study: Sensitivity Analysis

After the framework is validated, we can proceed to verifying if the installation of ESS units in the referred nodes is economically viable. Furthermore, we conducted a comprehensive sensitivity analysis to study the effect of electricity price average, standard deviation and forecast of battery costs (considering only the cost

per storage capacity). This analysis focused on comparing the projected revenues against the costs of the battery systems to determine the ESS operator profitability. The assessment was structured around two distinct ESS configurations:

- **Battery 1:** This system boasts a 95% roundtrip efficiency, with a power output of 4 MW and a storage capacity of 4 h.
- **Battery 2:** Similar in efficiency at 95%, this variant differs with the same power output of 4 MW but a shorter storage duration of only 1 h.

As expected from [28], the battery with 1 h of storage would have a better revenue per capacity than any other possible configuration. This behaviour can be observed along the entire analysis. The figures show how distant the ESS system is from breakeven. (if the bar reaches zero or positive numbers, the ESS is economically feasible).

#### 6.1.1 | Sensitivity Analysis 1: Analysis of Average Electricity Price Impact

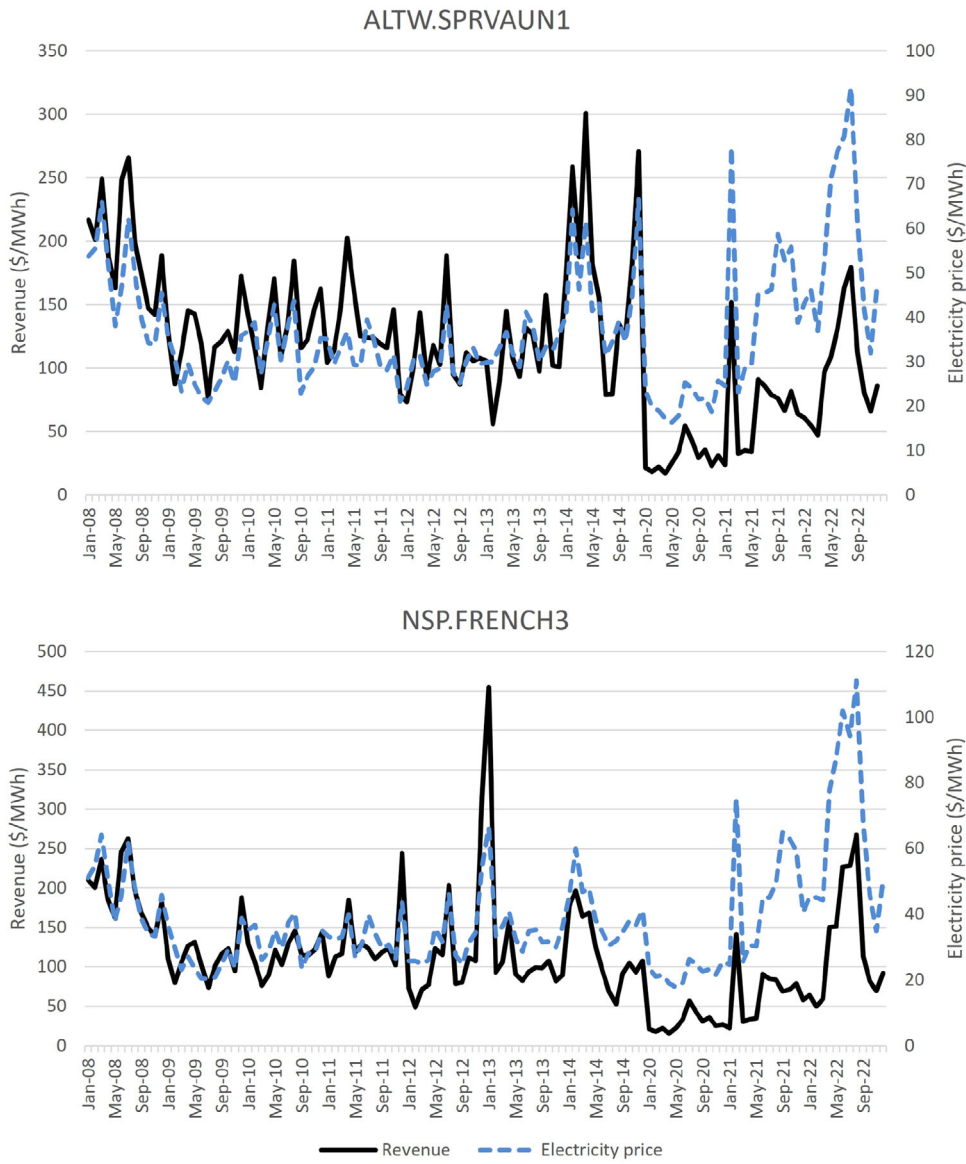
In the first set of analyses, as illustrated in Figure 6, only the average electricity price observed in 2022 was manipulated, while the standard deviation remained constant. Intriguingly, it was observed that as the average electricity price increased, the revenues for both nodes decreased, failing to reach the breakeven point even with significant price variations (up to -100%)

#### 6.1.2 | Sensitivity Analysis 2: Analysis of Standard Deviation Impact on Revenue

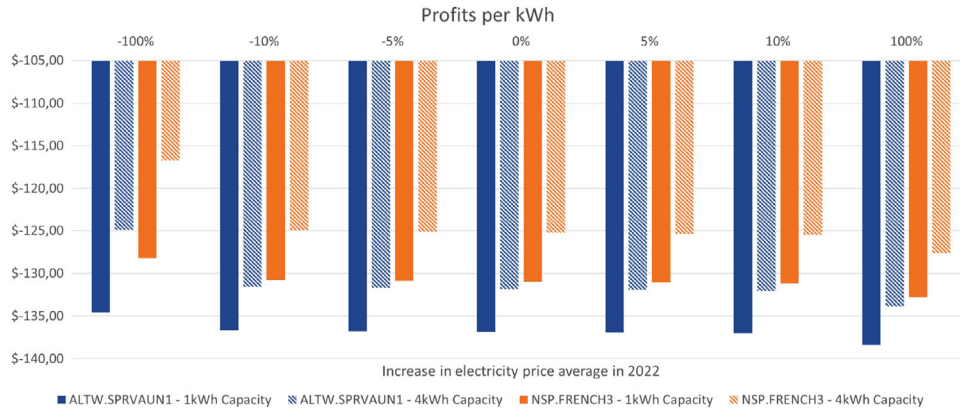
In the second set of analyses, illustrated in Figure 7, the focus was on altering only the standard deviation of the electricity price for 2022, while keeping the average price constant. This analysis revealed that as the standard deviation of electricity prices increased, indicating higher price volatility, there was a corresponding rise in potential revenue. However, it's crucial to note that even with these increases in volatility (up to +100% in standard deviation), the generated revenues were still insufficient to offset the total costs of deploying and operating the ESSs at each node.

#### 6.1.3 | Sensitivity Analysis 3: Projection Analysis Considering Future Battery Costs

The third and final analysis, detailed in the Figure 8, incorporated a forecast of declining battery costs extending to 2050. In this scenario, revenue projections for both nodes were held constant at their 2022 levels. The results indicated a noticeable narrowing in the gap between revenue and battery costs, marking a significant shift from earlier analyses. However, despite this trend towards reduced costs, the decrease was still not enough to achieve profitability for the ESS. Various factors were considered—including changes in average electricity prices, fluctuations in standard deviation, and future cost predictions—yet none of these scenarios led to the ESS investments becoming financially viable.



**FIGURE 5** | Total monthly revenue per capacity versus average electricity price for the selected nodes (2008–2014 and 2020–2022). Peaks in Q1 (January–March) and Q4 (October–December) align with winter months, where heightened natural gas price volatility amplifies daily arbitrage opportunities for ESS.



**FIGURE 6** | Sensitivity analysis on average of electricity price for 4-h and 1-h storages.

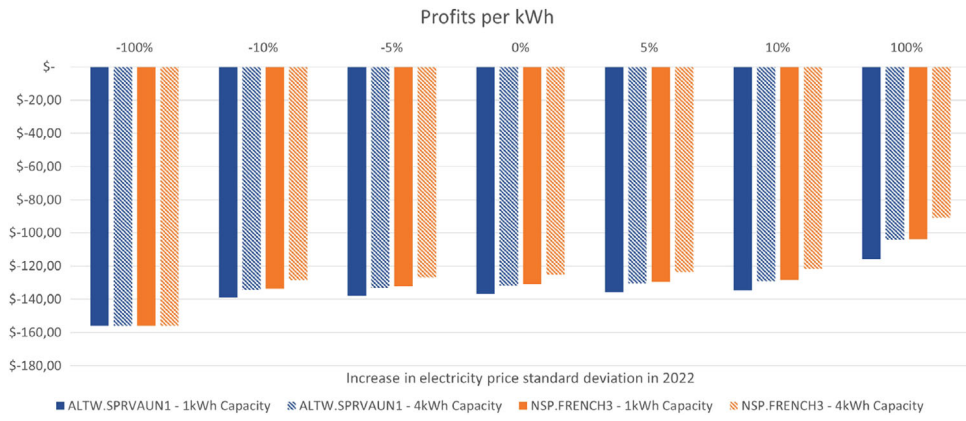


FIGURE 7 | Sensitivity analysis on standard deviation of electricity price for 4-h and 1-h storages.

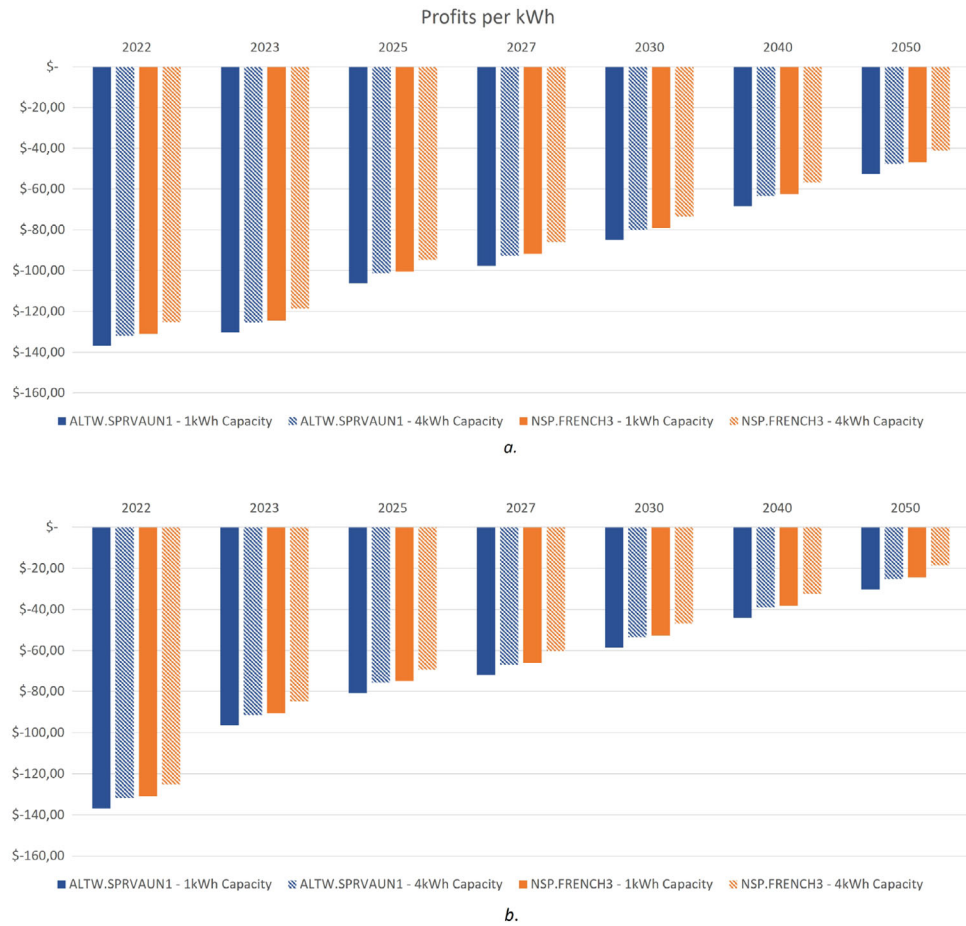


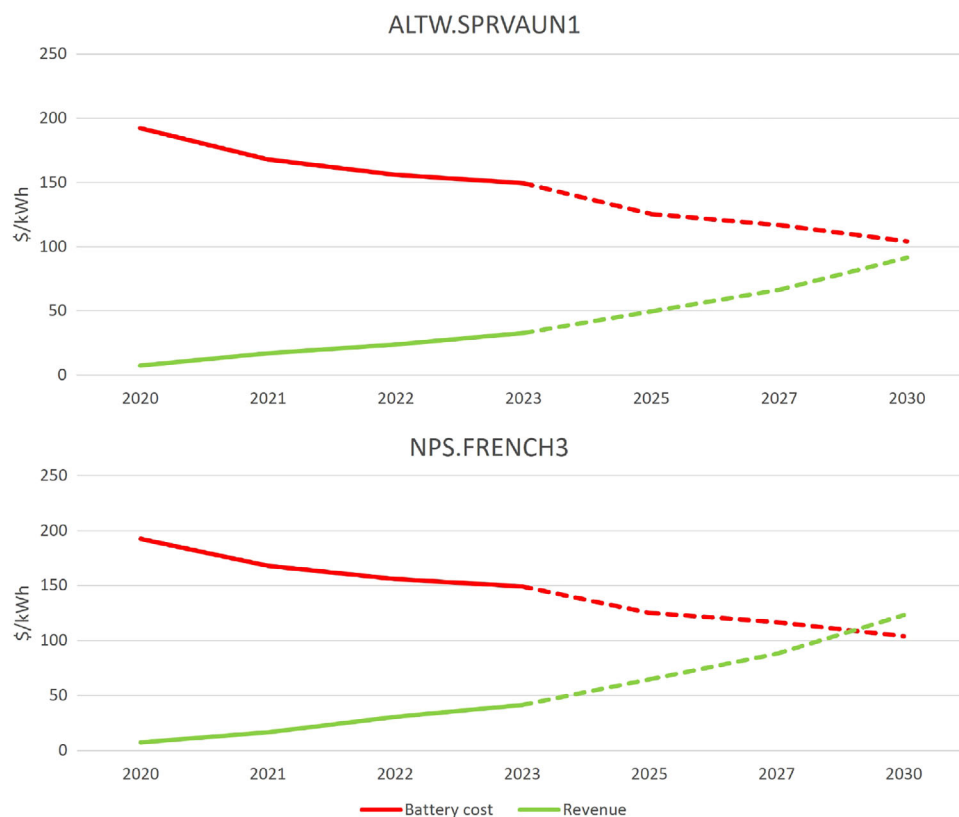
FIGURE 8 | Sensitivity analysis on battery cost forecast from 2023 to 2050 for (a) mid-estimation and (b) low-estimation, considering 1-h and 4-h storage for both nodes.

## 7 | Conclusion

This paper explored the dynamic changes in the MISO energy landscape, focusing on the evolving role and profitability potential of ESS. The study traced MISO's shift from a coal-dominated energy mix to an increasingly diverse blend of natural gas and renewable energy sources. A key part of this investigation was the analysis of how fluctuations in natural gas prices correlate with electricity market dynamics, particularly in the context of

the high-volatility nodes ALTW.SPRVAUN1 and NSP.FRENCH3. Insights gained from this part of the study shed light on potential opportunities for energy arbitrage.

The results section presents a sensitivity analysis revealing that ESS investments, under current market conditions, do not yield immediate profits. This part of the study scrutinizes the impact of electricity price fluctuations and the expected decline in storage technology costs, offering



**FIGURE 9** | Breakeven projection for ALTW.SPRVAUN1 and NPS.FRENCH3.

detailed insights into the market's sensitivity to changing energy prices.

Although this study focuses on energy arbitrage due to data limitations in ancillary service pricing, ancillary services (e.g. frequency regulation, spinning reserves) represent a complementary revenue stream for ESS in MISO. These services, which often command higher profitability by addressing short-term grid imbalances [29], could further enhance ESS viability in future work with the adequate regulation to permit that kind of operation. Future research should integrate these services into the optimization framework to evaluate multi-service ESS deployments.

While our model optimizes daily arbitrage, standalone batteries remain inherently limited in addressing long-term seasonal storage needs. Achieving seasonal arbitrage would necessitate hybrid systems—such as pairing batteries with hydrogen storage or flexible gas peaking plants or policy frameworks incentivizing cross-seasonal energy trading (e.g. inter-monthly price hedging). These solutions lie beyond the scope of this study but represent critical avenues for future research to address the temporal mismatch between storage duration and seasonal price dynamics.

Despite the current challenges, the study projects a brighter future for ESS within the MISO market, as depicted in Figure 9. The energy storage price forecasts are based on market analyses and long-term technology trends [30], considering factors such as economies of scale, advancements in battery chemistry, and supply chain dynamics. Projections indicate significant cost reductions driven by increased production efficiency and

declining material costs. With a shift toward a renewable-focused energy mix on the horizon, an increase in electricity price volatility is expected, which could improve the profitability of ESS. The breakeven analysis within the research predicts that the node NPS.FRENCH3 may become financially viable before 2030, with ALTW.SPRVAUN1 not far behind in achieving a positive return on investment.

In conclusion, while current market conditions may not be immediately conducive to the deployment of ESS, the study highlights an expected shift in the energy sector. The declining costs of battery technologies and evolving market trends point toward a future where ESS could become a financially viable option. Thus, the study showed the importance of strategic planning and adaptability for ESS operators, emphasizing the need to remain attuned to long-term market evolutions and the emerging opportunities in energy arbitrage and ancillary services within the MISO market.

#### Author Contributions

**Muhammad Zubair:** conceptualization, data curation, formal analysis, investigation, methodology, resources, software, supervision, validation, visualization, writing – original draft, writing – review and editing.

**Mauricio Salles:** conceptualization, data curation, funding acquisition, investigation, methodology, resources, software, supervision, validation, visualization, writing – original draft, writing – review and editing.

**Mateus Luis de Sousa:** conceptualization, data curation, formal analysis, investigation, methodology, resources, software, supervision, validation, visualization, writing – original draft, writing – review and editing.

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## Conflicts of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

The data supporting the findings of this study are available within the article. Additional data that support the findings of this study are available from the corresponding author upon reasonable request. The energy price data analysed during the current study are available from the Midcontinent Independent System Operator (MISO) public database. Any further data generated during the study, such as optimization model outputs, are available from the authors upon request and are not publicly available due to containing information that could compromise the privacy of research participants.

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