# Forecasting Electricity Demand and Prices in PJM and MISO Markets

## Data Visualization

### A Data-Driven Approach for Efficient Utility Management


Group 5

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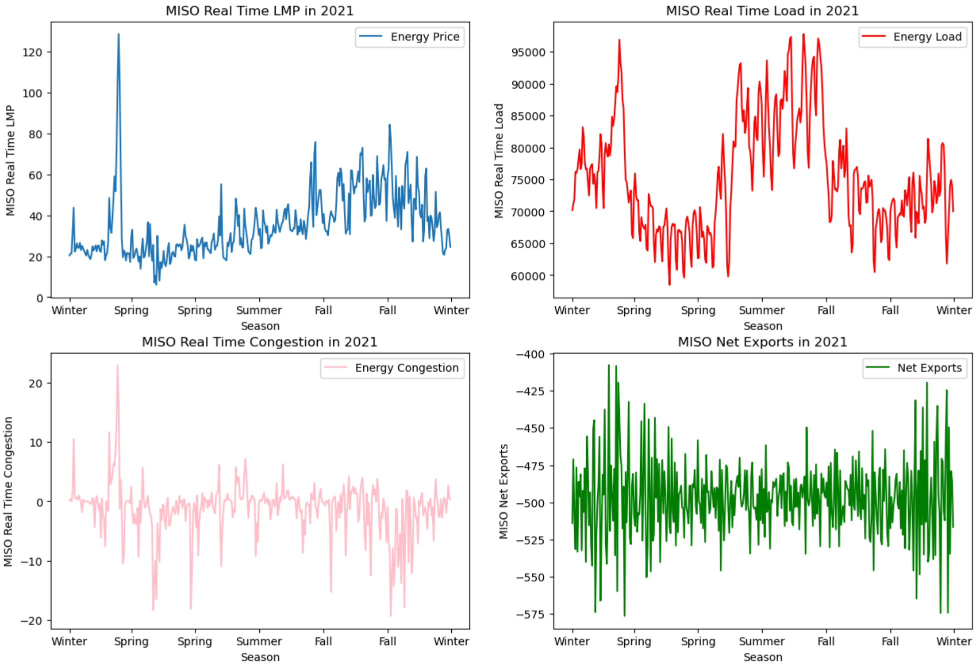
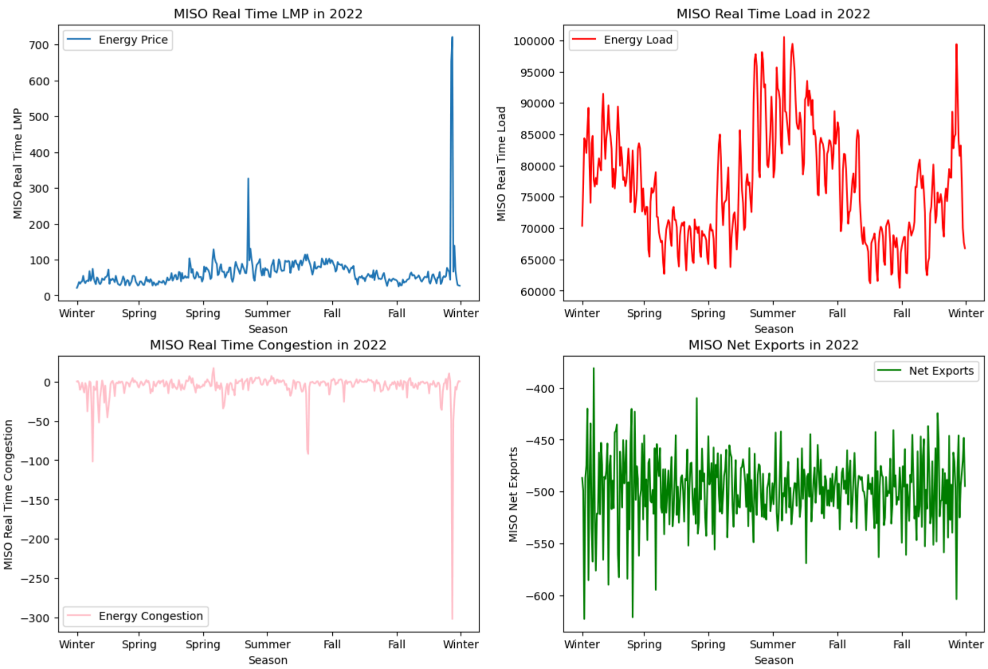
# Line Chart: Various MISO's market components (2021, 2022 and 2023)

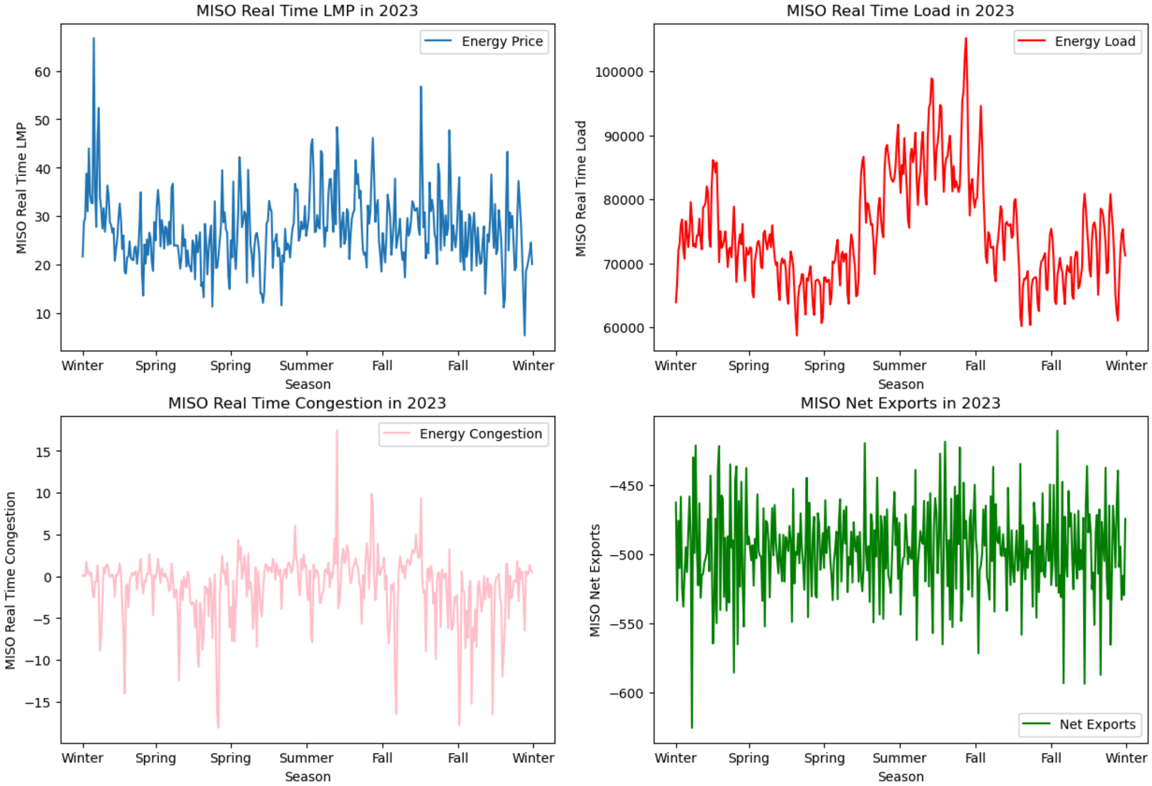
## Plots of 2021




## Plots of 2022



## Plots of 2023




## Insights and Observations for MISO market

### Energy Demand Insights

We can observe seasonal patterns in the electricity demand of MISO market over the plotted period with higher energy loads typically occurring during winter and summer. In addition, Spring and Fall tend to be low demand seasons from the decreasing trends in real time load during these seasons and increase trends during summer and winter months.

### Energy Exports Insights

MISO seems to rely on importing energies from the PJM market since the Net exports are always in the negative regions. However it's important to note that these numbers are not large in the context of energy dynamics.

### Dynamics between Energy Prices and other market components

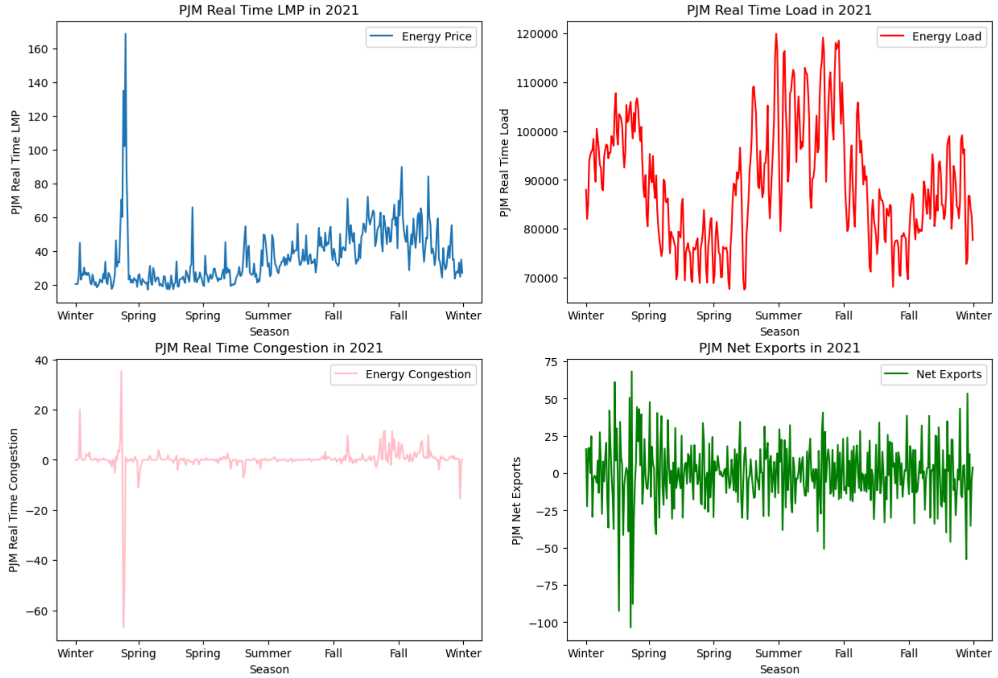
There are no common patterns between real-time price and real-time energy load where energy prices remain volatile regardless of the energy load of the period. For instance, in 2021, the energy price in the MISO experienced an increasing trend throughout after the sudden spike in early spring 2021 and gradually declining from the end of Fall to Winter 2021. On the other hand, the energy load follows the typical seasonal behaviour as explained before.

It's also important that the energy pricing behavior tends to change from year to year. For instance, looking at the overall energy price in 2021, we can see that energy prices are more volatile, ranging from the lows of 10 to extreme spikes at 120 dollars. Prices appear to stabilize a bit towards the end of the year, but with fewer and lower peaks compared to the beginning of the year. On the other hand, the trends of energy price in 2023 seem to exhibit less volatility with the fluctuations contained within a narrower band.

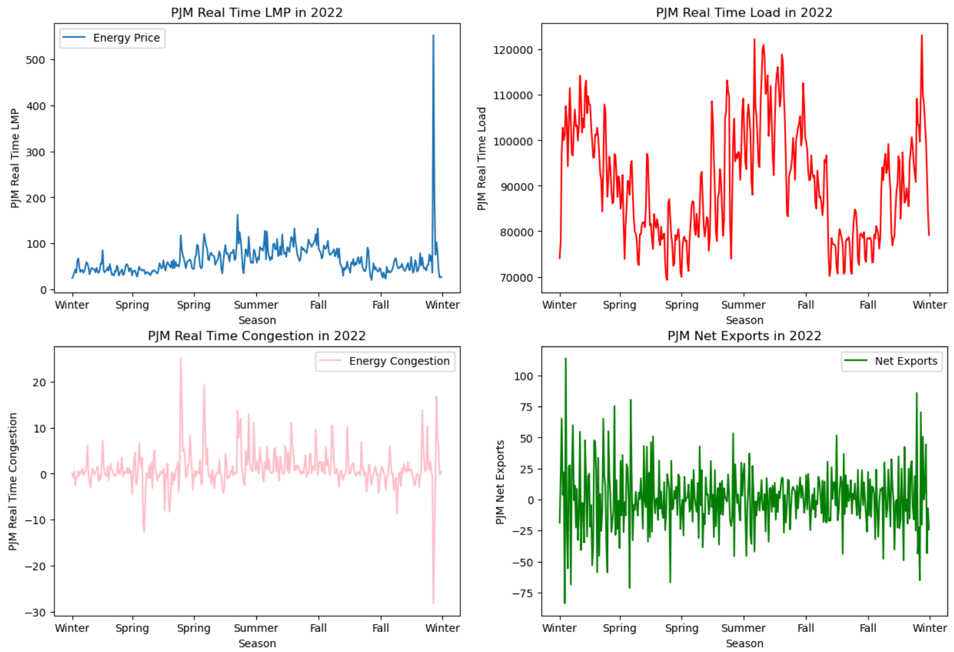
The change in behavior also reflects in 202,2 where price plot and congestion cost plot appear to be a mirror of each other

### Line Charts: Various PJM market components (2021 and 2022)

### Plots of 2021




### Plots of 2022



**Insights and Observations for PJM market**

**Energy Demand Insights**

The Real Time energy load plots show distinct seasonal patterns with demands peaking during summer months and increasing trend in energy loads during winter and summer periods. Similarly, we observe declining trends during Fall and Spring seasons.

**Energy Exports Insights**

The Net Exports plots depict fluctuations in the net electricity exports from PJM. Throughout the years, there's a general trend of variability with no clear seasonal pattern. The exports do not show significant peaks or troughs aligning systematically with any season.

Suggesting that PJM's net exports are influenced by factors beyond just domestic demand, such as market prices in interconnected grids and operational strategies.

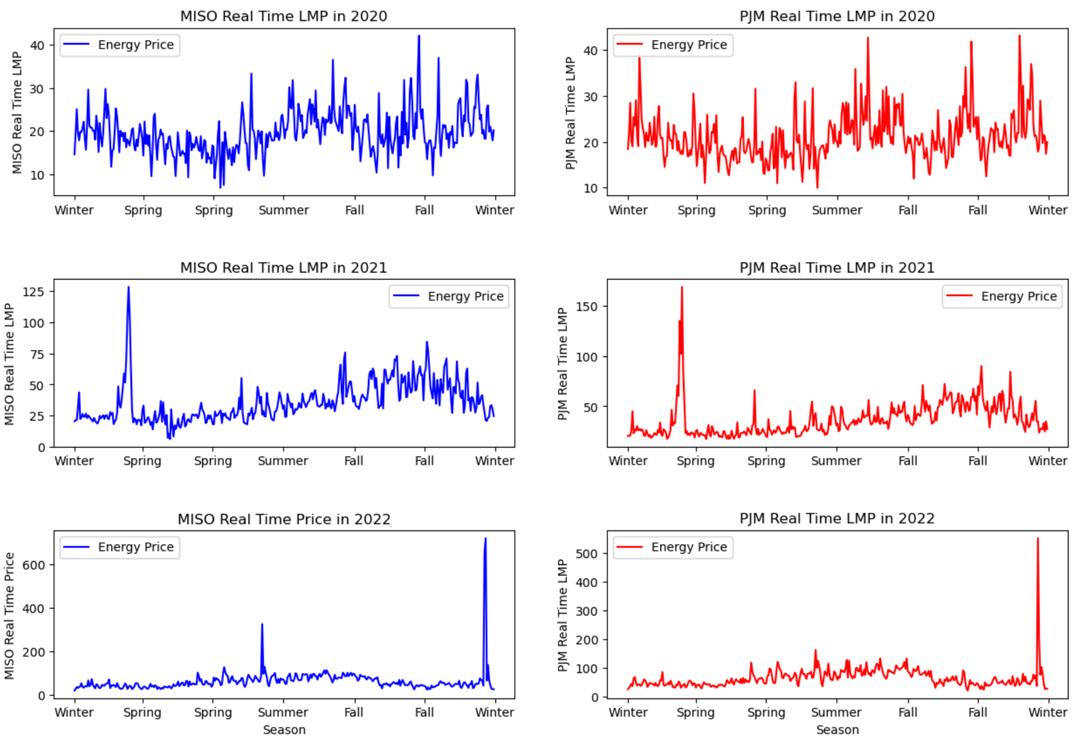
**Energy Price Insights**

Energy prices in PJM show significant volatility with occasional spikes especially in 2021, and smaller yet notable spikes in subsequent years.

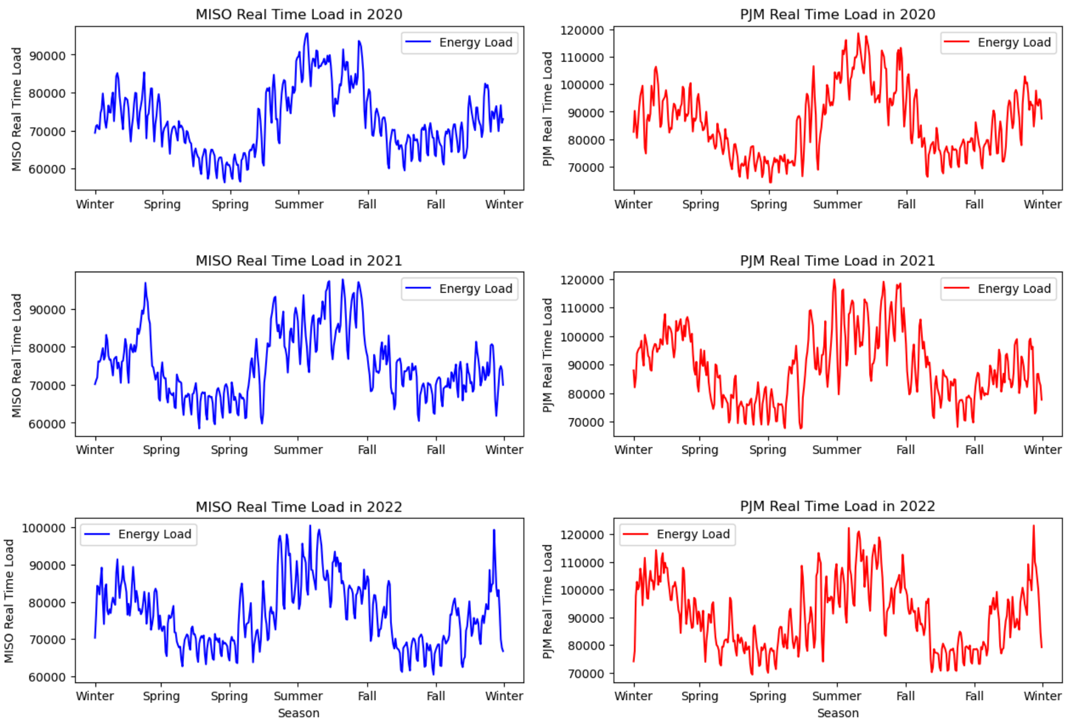
**Dynamics between Energy Prices and other components of the markets**

There are no common patterns between real-time price and real-time energy load where energy prices remain volatile regardless of the energy load of the period. This highlights the complexity in energy pricing as pricing might be influenced by other factors that we don't know, such as fuel costs, availability of generation sources, market regulations, etc.

**Comparing Energy Price in both markets from 2020 to 2022**



### Comparing Energy Load in both markets for 2020 to 2022




### Insights

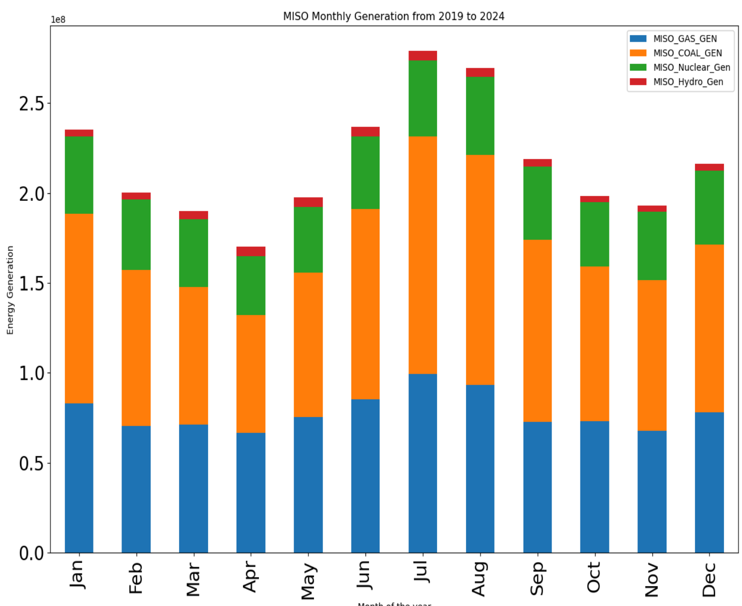
Both markets have very similar patterns in both energy prices and loads over the observed period. This might suggest that both markets respond similarly to broader economic and environmental factors affecting the energy sector such as weather variations and possibly regulatory changes. In addition, the similarity in energy load between both markets implies that consumers share similar energy demands and preferences. This insight is useful to predict energy demand.

### Overall Conclusion

These insights suggest that while certain expected patterns exist, such as increased demand in summer, the PJM energy market exhibits complex dynamics and high volatility influenced by a mix of demand, supply, transmission logistics, and market operations.

The consistent patterns across the two markets highlight the interconnection and possibly shared challenges or strategies within the broader regional or national energy grid.

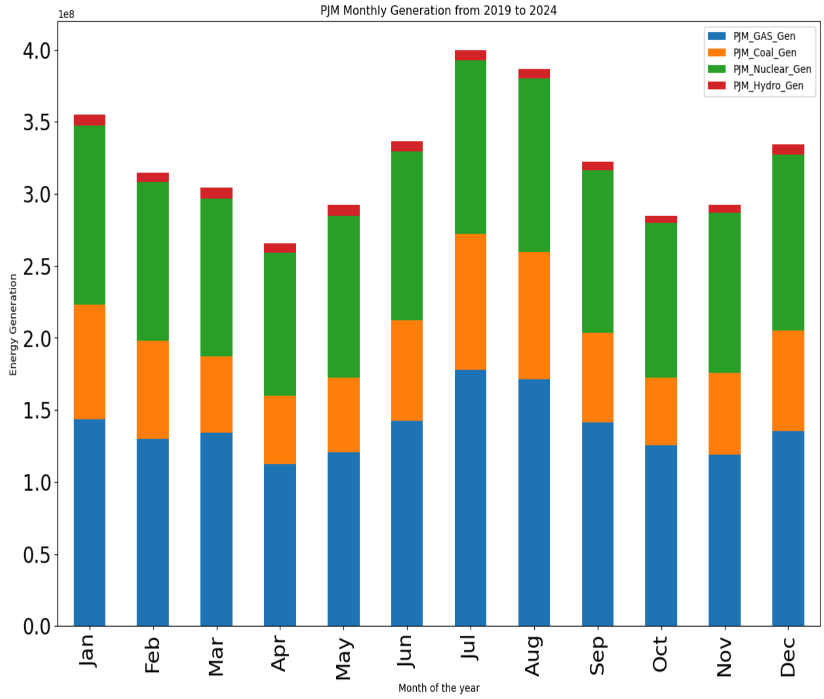
### Monthly Distribution of energy sources over period 2019 to 2024 in MISO




Overall energy generation appears to be consistent across all sources throughout the years. This means that performance in energy generation is fairly stable regardless of external factors such as weather conditions, etc.

In addition, we can observe that MISO very extremely relies on fossil fuel sources with the majority of bar charts covered with fossil fuel sources. This poses challenges going onward due to negative environment impacts if we want to increase energy generation.

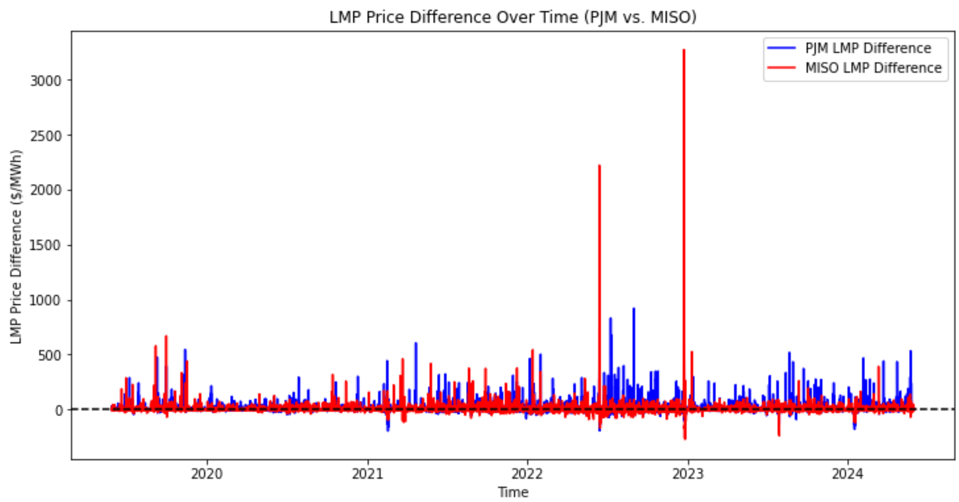
### Monthly Distribution of energy sources over period 2019 to 2024 in PJM




Similar to MISO, the overall generation from all sources appears to maintain a fairly consistent level across the year, suggesting a stable demand and efficient capacity management in the PJM market.

However, we can observe that the PJM grid relies much less on fossil fuel energy generators. Nuclear power plants play a significant role in energy security and support environmental goals by providing a substantial portion of clean and reliable power.

### Line Charts: Difference in Day-Ahead & Real-Time LMP Difference (2019 to 2024)

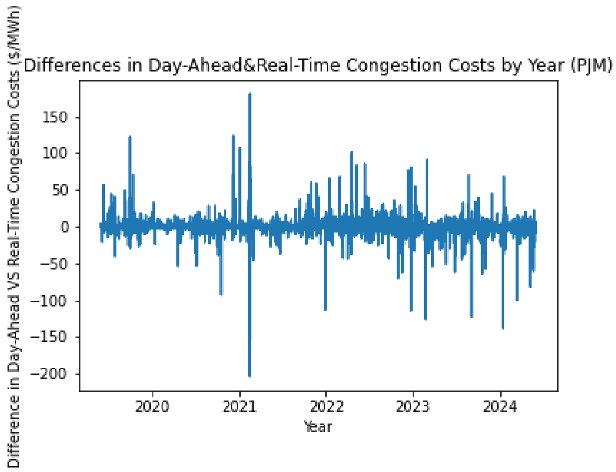


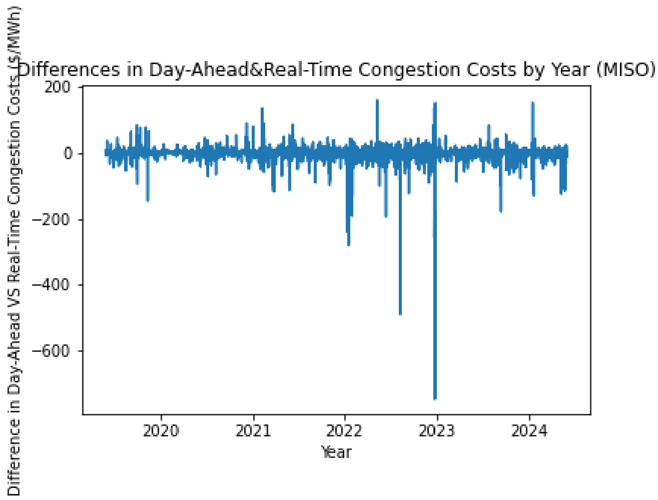

To understand the fluctuations in the LMP differences between the Real-Time price and Day-Ahead price, we plotted the time series of PJM and MISO LMP differences.
From the graph, most of the time, the MISO market exhibits relatively smaller fluctuations than the PJM market and is more concentrated around 0 HW. This indicates that, in general, the MISO market is more accurate in forecasting electricity prices, as reflected by two large spikes in 2022 and 2023. This suggests that MISO is more likely to experience dramatic price changes during extreme events such as supply shocks, weather disruptions, or grid failures. In contrast, the PJM market is more mature and has stronger power reserves, which allows it to regulate power supply within the market.

This insight emphasizes the need to differentially consider grid-related variables (e.g., congestion costs, real-time load, and day-ahead pricing) in the forecasting models for PJM and MISO market. Since price variances reflect forecast errors, understanding their fluctuations over time helps us adjust model parameters and refine risk management strategies.

To illustrate and visualize the difference between day ahead and real-time congestion costs for PJM and MISO, using the column previously created, histograms and line graphs were plotted and generated to see the variance and frequency of overestimation or underestimation by both companies.

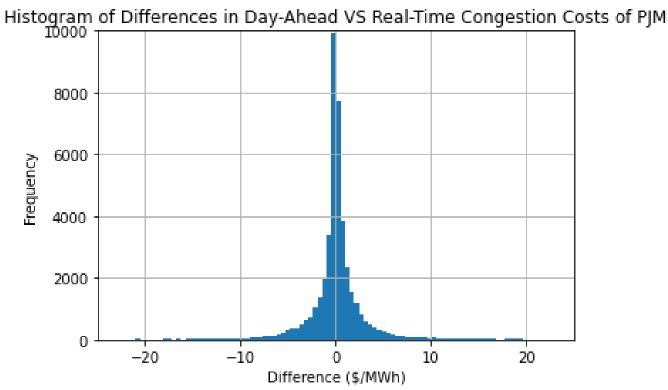
**Line Charts: Difference in Day-Ahead & Real-Time Congestion Costs (2019 to 2024)**

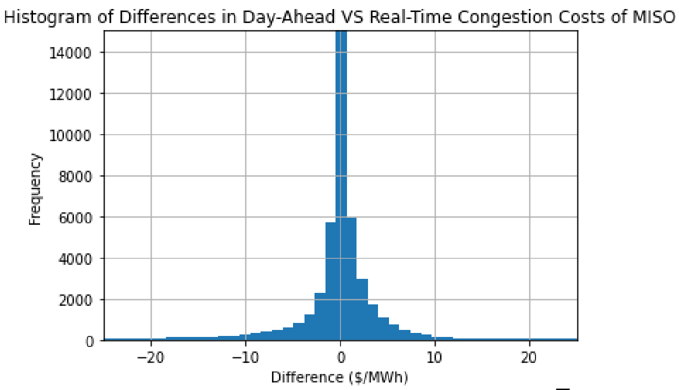



In the line graph of PJM, we are able to see that extreme differences occur rarely throughout each year, while the level of overestimating congestion costs and the level of demand exceeding capacity are balanced out evenly. It is illustrated that most of the differences are in the range within approximately $20/MWH. Meanwhile, for MISO, it is obvious that there are more extreme values under zero, which indicates that for MISO there are more overestimations for congestion costs. Similarly, most of the differences are within small ranges. Both differences in congestion costs have fluctuations, while concentrated around zero. However, MISO shows much larger volatility with much more extreme values, which is a sign that demand was much lower than forecasted and there was a lot more transmission capacity available. In conclusion, MISO may encounter lower demand than PJM in terms of the negative congestion cost differences (when its real-time costs are lower than predicted).

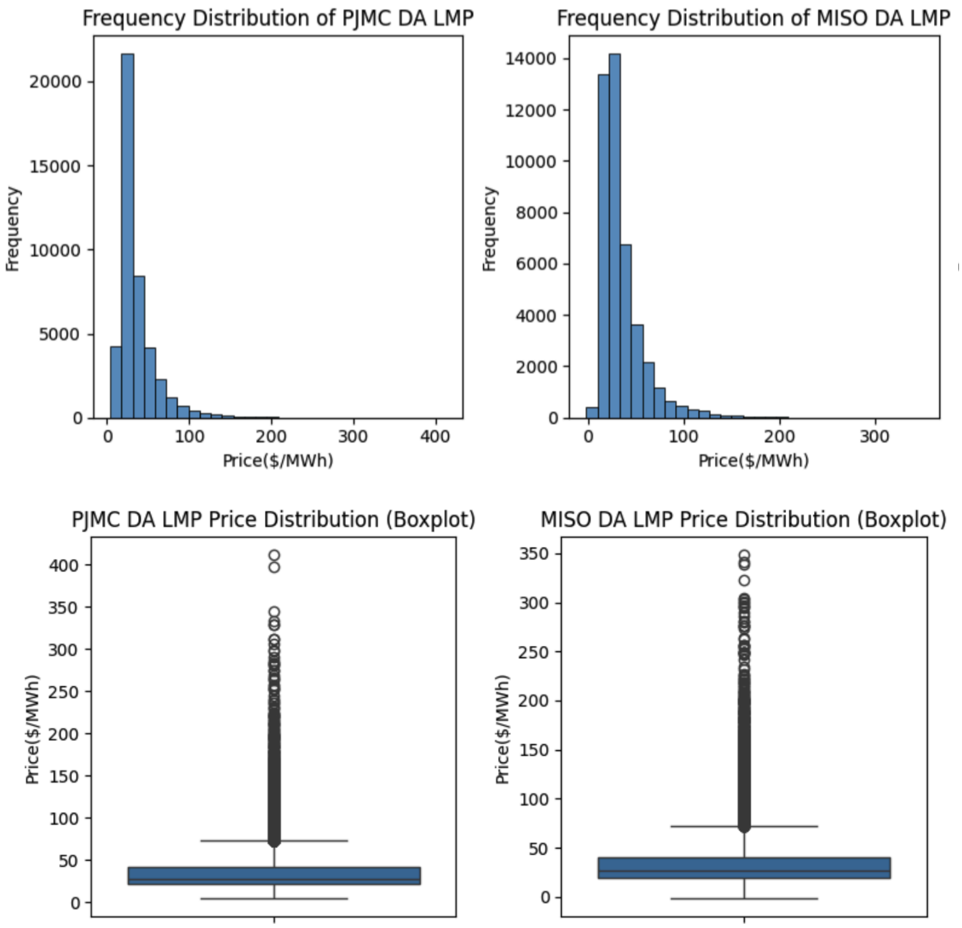
**Histogram: Difference in Day-Ahead & Real-Time Congestion Costs (2019 to 2024)**



In the histograms of differences between day-ahead and real-time congestion costs for PJM and MISO, both distributions are centered towards $0/MWh, which means the forecasted congestion cost did not deviate from real-time congestion costs by a lot. The distribution appears to be normal, with a spike in the middle, near zero, which means the differences that occur the most frequently are very small. In comparison, the histogram of MISO appears to be less squeezed and less tight than PJM, which means MISO has more extreme values, aligning with what was interrupted from the line graphs. Overall, PJM has a more stable forecast of demand, and MISO should work on reducing demand forecast errors as it will improve overall capacity utilization by making better predictions of transmissions. The volatility also suggests that there are large fluctuations in electricity demand and sometimes are very hard to predict, especially if special situations occur. Therefore, electricity companies should improve seasonal demand predictions, and especially MISO should aim to minimize prediction errors, therefore enhancing grid efficiency.

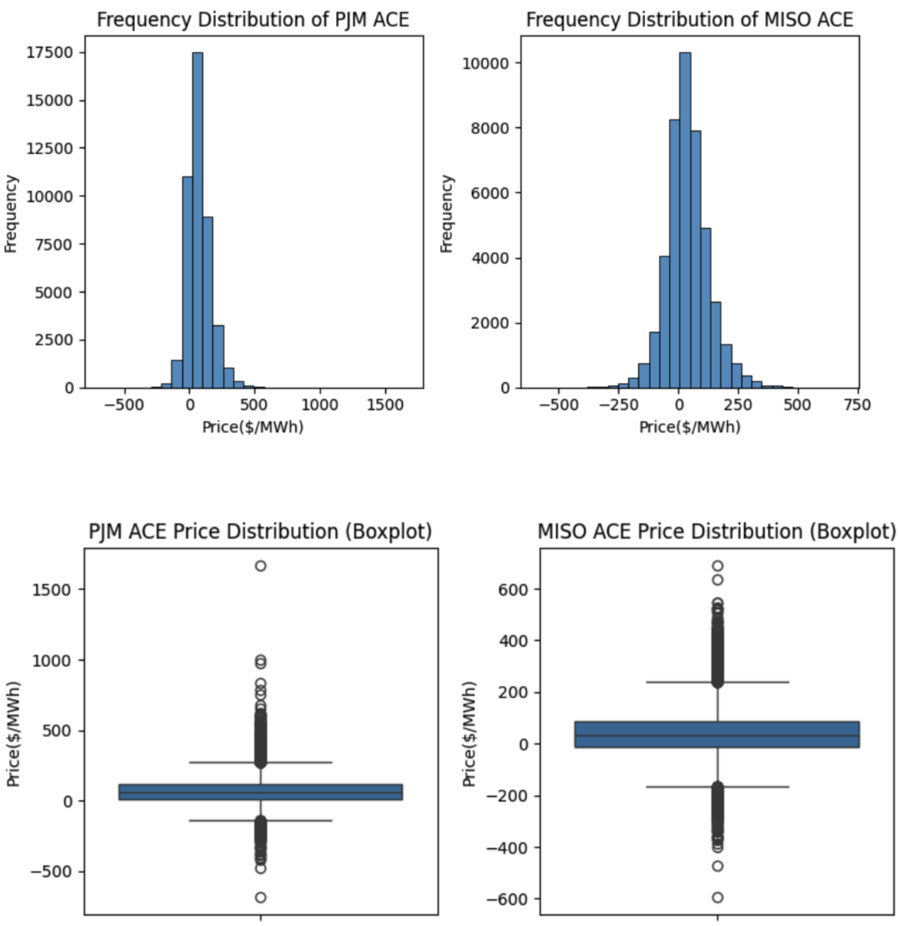
**Subplots - Histogram & Box plot: Frequency of low or high electricity day-ahead prices of PJM and MISO**




Focusing more on day-ahead price in both markets, the distribution of PJMC DA LMP(Day-Ahead Locational Marginal Price for PJM) is right-tailed, where the majority of the price occurrence is located between $0/MWh to $100/MWh, meaning that marginal price for the day ahead usually is around a relatively low price range, although occasionally some price spikes (above $100/MWh) occur throughout the relevant time range, however, it is not a regular occurrence. MISO DA LMP (Day-Ahead Locational Marginal Price for MISO) also follows a similar trend, where the majority of the price range is under $100/MWh, as shown in the histogram and box plot. Compared to MISO, PJM has a higher frequency of low prices, where lower prices occurred close to 5000 (Histogram), whereas MISO only had less than 1000 times the occurrence.

Overall the marginal price for both markets tend to follow a similar trend, as price is distributed relatively low with occasional spikes. Some key takeaways for the similar price trend are likely to occur because of external factors such as the weather conditions, such as if heat waves in the PJM area, household requires more electricity consumption(demand), thus driving PJM region price up, MISO would export additional electricity to PJM to earn a profit, but this would also cause a decrease of electricity stored in MISO, thus driving the prices up (Indicating prices follow similar patterns).

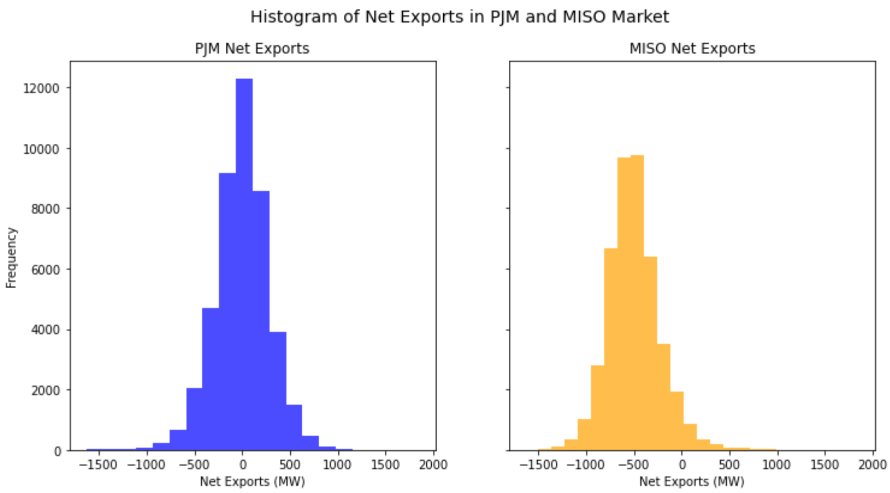
**Subplots: Histogram & Box plot: ACE Distributions in PJM and MISO - Grid Control Efficiency**




The histogram of PJM ACE shows where most values lie around the center (Mean of $0/MWh), indicating that the error control is relatively stable across the relevant range, however, there is both positive(undersupply) and negative(Oversupply of electricity) values, indicating that occasionally there is grid fluctuation in the area. As well as MISO follows a similar trend, where the occurrence is gathered around the center near the mean of zero, however, MISO ACE has a bigger spread in the middle range, while PJM has a larger spread due to extreme values (*Referred to in the box plot*), where some extreme value reaching above 1500MW. The smaller range of ACE distribution indicates that MISO might be monitoring its power more effectively, where positive error (Box plot: outliers are frequent only up until 600MW) incurred less than PJM ACE.

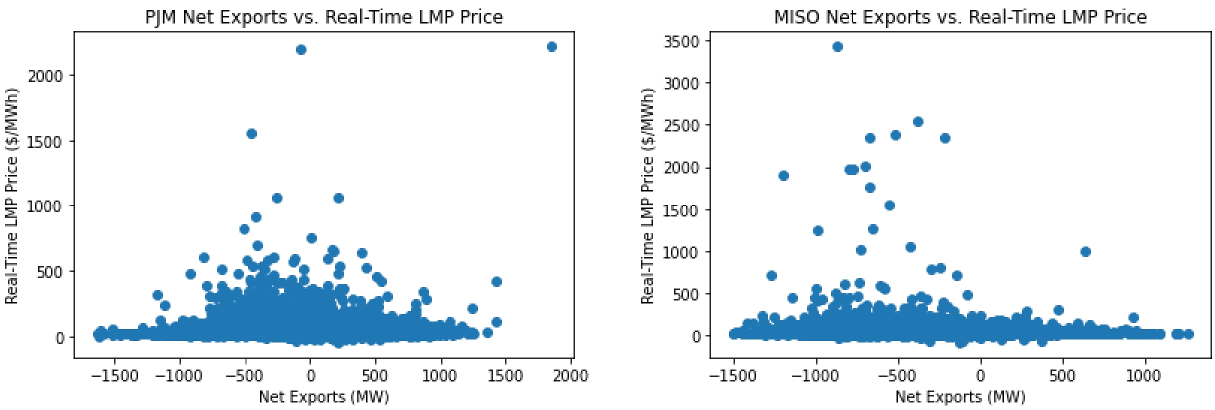
Some of the possible reasons for MISO's ACE less variance might be its more efficient control of power generation in the MISO region, resulting in less extreme over- or undersupply of power. However, overall, grid operators for both markets remain relatively stable and constantly monitored, as they will adjust to the mismatch between supply and demand (*How The Electricity Grid Works*, 2015).

**Histogram: Net exports in PJM and MISO markets (2019 to 2024)**




To examine the distribution of electricity exports and imports, we plotted histograms of net exports for both PJM and MISO.
PJM's net exports distribution appears nearly symmetric and centered at 0 MW, the majority of values are between -500 MW and 500 MW, suggesting that PJM frequently operates at a balanced net export position. MISO's net exports distribution is slightly left-skewed and centered around -500 MW, meaning MISO is more often a net importer than a net exporter. Although neither market consistently imports or exports power on a large scale, MISO relies more on external power supply than PJM, indicating potential supply constraints in the MISO market.
This analysis establishes a basic understanding of the net export model and builds a foundation for further exploration of its potential relationship with electricity prices. By understanding how net exports typically behave in each market, we can better explain their impact on real-time LMPs in the next step of the analysis.

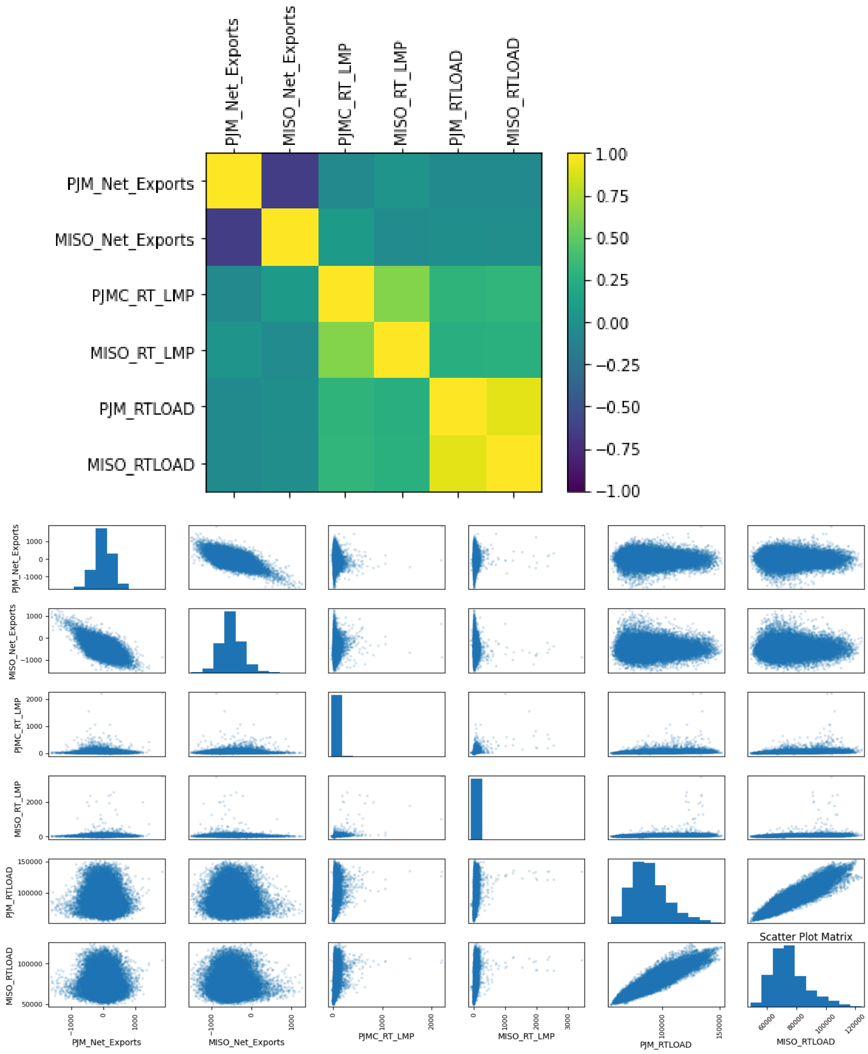
**Scatter Plot: relationships between Real-Time LMP and net exports in PJM & MISO**



In order to determine how net exports impact electricity price, we created two scatter plots showing relationships between Real-Time LMP and net exports in PJM and MISO markets. Based on the scatter plots, real-time LMPs are centered between $0-$500/MWh. While there are some extreme price spikes, these are not consistently associated with high or low net export values, making it difficult to summarize clear trends.

Since no obvious positive or negative correlation between Net Exports and LMP can be concluded from those two scatter plots, further correlation analysis is needed before determining whether to include net exports as an independent variable in the predicting model.

**Scatter matrix & Heatmap: correlations between net exports & RT load and price**



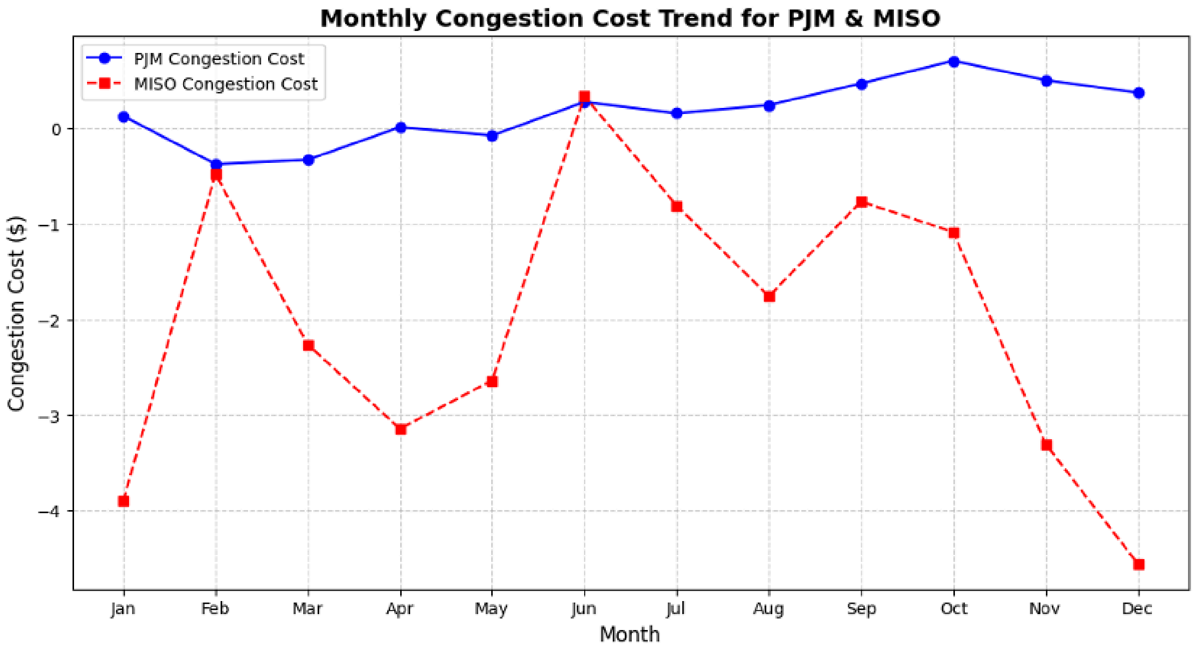

To quantify the actual relationships between Net Exports and LMP, we decided to come up with a scatter correlation matrix and heatmap.

From the metrics and heatmap, net exports in both PJM and MISO show a very weak correlation with their respective Real-Time LMP. It suggests that electricity exports and imports are not primary drivers of electricity price fluctuations. In contrast, there’s a strong positive relationship (~0.65) between Real-Time Load (RTLOAD) and Real-Time LMP, which aligns with market expectations that higher demand leads to higher electricity prices.

It helps refine the independent variable selections for the forecasting model. As load is the dominant driver of price changes, it should be included as a key independent variable. Since net exports show weak correlation with both Load and LMP, net exports may not be a necessary feature in the model. To refine our understanding of Net Exports' impact on LMP and Load, we checked correlations with additional grouping by season, weekday/weekend, and hour category. The consistently low correlation confirms that net exports do not significantly impact LMP or Load. As a result, net exports may be excluded from the model except in extreme cases that require further exploration. This ensures that our machine learning model selects features more accurately.

**Line Chart - Changes in Congestion Cost Trends by Month for PJM and MISO**

The congestion of the power grid directly affects electricity prices and market operation costs, so analyzing the monthly trend of congestion costs can help optimize the scheduling strategy of the power grid. In addition, if there is a high congestion cost in a month, it means that the transmission of the power grid during this period will be limited or the market demand during this period will be too high. On the contrary, if the congestion cost is relatively low, it indicates that the electricity transmission in the market this month is relatively smooth, and the supply and demand are relatively balanced.




From the line chart, it can be seen that the congestion cost of PJM is relatively stable overall, which means that the market has strong grid scheduling capabilities and fewer congestion situations. The congestion cost of PJM is close to zero most of the time, which means that the transmission lines in the market are relatively stable, and congestion costs can be controlled. On the other hand, the congestion cost of MISO fluctuates significantly. This may be due to the market adopting additional market regulation measures at certain times, such as optimizing power transmission. And the partial constraint congestion cost of MISO is even negative, especially in January, March, June, November, and December. The decrease in market costs may be due to lower electricity demand or more optimized transmission lines. But this may also mean that the market transmission lines are not fully utilized, which may result in additional fees being paid to promote electricity flow in the silent area.

**Line graph of difference of Real-time load and forecasted load in PJM vs MISO market**

To compare real-time electric loads and forecasted loads over time in the PJM and MISO electricity markets. We calculated the difference between the actual load and the forecasted load and made a line graph to analyze these differences more intuitively. In the PJM market, the variance is typically between -4000 and +3000 MW, with relatively stable fluctuations. In most cases, it is below 0, meaning that the real-time load is lower than the forecasted load. However, there are some significant changes in 2020 and 2024 that push the difference above the usual average. In contrast, the MISO market has a relatively larger difference, fluctuating between -10,000 and +10,000 MW, which represents that MISO has greater forecast error or greater real-time load fluctuations. While both markets show continued changes, the differences are more pronounced in the MISO market, suggesting that the MISO market is more challenged to accurately forecast demand and that improved forecasting models are needed to improve grid reliability and efficiency.