Forecasting Electricity Demand and Prices in PJM and MISO Markets

A Data-Driven Approach for Efficient Utility Management

Group 5

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Objectives
This project aims to forecast electricity demand and prices in the PJM and MISO electricity markets and support efficient utility management for long-term planning. The goals include predicting daily and hourly demand to improve grid performance and reduce the risk of blackouts. In the long term, it focuses on identifying seasonal and annual usage trends, especially during extreme weather to improve infrastructure development and capacity planning.

To observe the effect on change in electricity consumption “Real-time electricity load for MISO and PJM.” and “ Real-time locational marginal pricing for PJMC and MISO” (Target variable). We decided to study the relationship between the mentioned target variables with a potential set of independent variables including the status of loading hours (ON/OFF peak or non-peak consumption hours) as a categorical predictor, the real-time load of central region (Central RT load), the area control error values for both markets(MISO and PJM ACE), the amount of electricity imported/exported from neighbor grids (MISO and PJM Ramp Imports /Exports.

The research question we are trying to answer is whether or not there exists a relationship between electricity prices or demands versus the mentioned factors.

Background
The current U.S. electricity industry is facing several issues and challenges. First, there is a mismatch between supply and demand. Studies indicate that half of the U.S. is at high risk of shortfalls in the next decade (Reuters, 2024). This may result from a surge in demand during extreme weather, such as heatwaves and snowstorms which limits the capacity of the grid supply. Second, resources are limited. More than half of current power plants rely primarily on thermal power generation, while many thermal generators are being phased out due to economic pressures. While renewable energy is a feasible alternative source of energy, its integration into the grid has been delayed by challenges such as infrastructure development. These delays aggravate long-term capacity shortages, leaving gaps that are difficult to fill. Third, rapid changes in demand and congestion costs lead to volatile electricity prices. These fluctuations not only lead to unpredictable electricity bills for consumers but also challenge the utility company's cost stability.

To illustrate these challenges, we focus on two major energy organizations in the U.S., **MISO** (Midcontinent Independent System Operator) and **PJM Interconnection**. MISO's survey results suggested that it could face a widening capacity gap this year, ranging from a capacity shortfall of 2.7 GW to a surplus of 1.1 GW (MISO, 2024). While PJM forecasts a capacity shortage by 2026/2027 due to slow load growth and resource additions (PJM, 2024).

The ultimate objective of our team is important as the prediction of electricity demand will help utility companies manage grid performance and prevent overproduction. The forecast will provide overall better suggestions to lower residential electricity costs in the long term, and eventually optimize energy consumption. Additionally, the forecasted demand may be used by the firm for insights into capacity planning, and to assist governments in introducing sustainable policies. As energy efficiency is improved, it reduces negative environmental impacts and improves ESG performance for the firms. The analysis of the data will help the firms better understand the key variables that are impacting electricity demand and consumption trends, therefore using the results to develop strategies for better matching of demand and generation of energy.

Industry overview

The electricity and utility industries are impacted by a variety of factors, including demographic trends and attitudes, in addition to the environmental impact that contributes to greenhouse gas emissions and climate change. Consumers may behave differently depending on their preference to switch to off-peak hours for electricity use, conserve energy, and other factors. Depending on their perception and level of environmental awareness, these will ultimately impact the electricity demand. Demographic trends such as increased urbanization with a higher density of living units in cities, can potentially lead to higher usage of electricity from transportation, commercial, basic living needs, street lights, and public buildings. According to research, 34% of electricity consumption in the United States in 2022 came from the commercial and public service sectors. The forecasted demand for electricity consumption will be followed by an average growth of 1% from 2025 to 2026, led by growth in the technological sector of electrification (replacing the usage of fossil fuel with electricity-generated energy, which will drive up the demand by an additional one-third of the original increase in electricity consumption (*Executive Summary – Electricity 2024 – Analysis - IEA*, n.d.).

The electricity and utility sector has experienced an advancement in technology in recent years. Sophisticated automation systems are making it possible to distribute electricity to various parts of the United States optimally, as a result of the emergence of energy storage solutions. These electric storage systems (ESS) (*Energy Storage Systems (ESS) and Solar Safety | NFPA*, n.d.), which balance supply and demand, help save energy and electricity during periods of low demand and provide a better model to reduce the waste of unused electricity.

Relevant competitors in the utility and electricity industry are often other Regional Transmission Organizations (RTO) or Independent System Operators (ISO), which manage power grids, generate and distribute electricity in the region that they’re in, and regions might directly overlap with other RTOs (*RTOs and ISOs*, n.d.).

The impact of economic factors on PJM, MISO, and other RTOs can drastically alter electricity’s price, demand, and the pace of integration with renewable energy. Since electricity distribution is a key component of RTO, common factors like interest rate fluctuations can impact the progress of capital investment in transmission projects. These projects are frequently classified as capital-intensive, with an average cost of "$17 billion/year of transmission investments made within the U.S. ISO/RTO regions" (P. Pfeifenberger & Chang, 2019). Increased borrowing costs due to higher interest rates drive up prices for utilities, developers, and manufacturers, eventually driving up the cost of transmission projects. Subsequently may cause expansions or improvements relating to the project to be delayed.

Data source and description

The dataset we used originated from U.S. electricity market data uploaded to Kaggle by Jared Andreatta, consisting of 43872 rows x 46 columns. This dataset contains data on the MISO and PJM electricity markets at 15-minute intervals for the five-year period from 2019 through 2024, including real-time and day-head Local Marginal Pricing(LMP), real-time and day-ahead congestion cost and electricity load for MISO and PJM market and so on.

Here is the breakdown on categorized list and descriptions of all variables:

Time and Interval Information:

- Weekday: Day of the week (e.g., 4 = Thursday).
- ON/OFF: Indicates peak ("ON") or off-peak ("OFF") hours.
- HE: Hour Ending, marking the end of the time interval.
- DATE and Date/Time: Date and timestamp.

Locational Marginal Pricing (LMP) and Congestion:

- PJMC RT LMP & MISO RT LMP: Real-time locational marginal pricing for PJMC and MISO.
  - the price of electricity (in wholesale market) at a specific time and location on an electric power grid
- PJMC DA LMP & MISO DA LMP: Day-ahead locational marginal pricing for PJMC and MISO.
  - the price of energy in a day-ahead energy market. It's based on the energy bids and offers from market participants
- PJMC RT CONG & MISO RT CONG: Real-time congestion costs.
  - costs associated with supplying power to areas of the electric grid that are experiencing high demand
  - Congestion occurs when there isn't enough transmission capacity to meet the demand for energy.
- PJMC DA CONG & MISO DA CONG: Day-ahead congestion costs.
  - costs associated with congestion in the day-ahead energy market.

Load (Electricity Demand):

- MISO RTLOAD & PJM RTLOAD: Real-time electricity load for MISO and PJM.
- MISO LOAD FC & PJM LOAD FC: Forecasted load for MISO and PJM.

- Central RT LOAD: Real-time load for a central region.
- Central LOAD FC: Forecasted load for the central region.

Generation Data:

- Gas, coal, nuclear, and hydro generation data for MISO and PJM (e.g., MISO GAS GEN, MISO DA GAS, PJM GAS GEN).
- Generation data refers to information about the amount of electricity produced by different types of power plants or generators, categorized by their fuel type (e.g., coal, natural gas, nuclear, hydro, wind, solar).

Net Load and Imports/Exports:

- MISO Net Load & PJM Net Load: Net electricity load for MISO and PJM.
    - Net Load is the difference between the total electricity demand in a system and the electricity generation provided by variable renewable energy sources (such as wind and solar).
    - represents the amount of demand that must be met by non-renewable (or "dispatchable") power sources like natural gas, coal, nuclear, or hydroelectric plants.
- PJM/MISO Net Load: Difference in Net Load between PJM and MISO
- PJM Ramp Imports & PJM Ramp Exports: Ramp imports/exports for PJM.
    - Ramp Imports: Represent how quickly and by how much electricity can be imported into a system (e.g., MISO) from neighboring systems (e.g., PJM).
    - Ramp Exports: Represent how quickly and by how much electricity can be exported from a system to a neighboring system.
- MISO Ramp Imports & MISO Ramp Exports: Ramp imports/exports for MISO.
    - Ramp Imports: Represent how quickly and by how much electricity can be imported into a system (e.g., MISO) from neighboring systems (e.g., PJM).
    - Ramp Exports: Represent how quickly and by how much electricity can be exported from a system to a neighboring system.

ACE and Market Comparisons:

- MISO ACE & PJM ACE: Area control error values for MISO and PJM.
    - real-time measure used in electricity grid operations to ensure the balance between electricity supply and demand within a specific region or Balancing Authority Area (BAA)
    - reflects the difference between the scheduled power flows and actual power flows into or out of the area, as well as frequency deviations from the nominal grid frequency
- MISO/PJMC DALMP & MISO/PJMC RTLMP: Difference in day-ahead and real-time LMP between markets.
    - a method used in electricity markets to determine the price of electricity at specific locations (nodes) in the power grid

    - represents the cost of delivering an additional megawatt-hour (MWh) of electricity to a specific location, accounting for the cost of generation, transmission, and grid constraints
- PJM/MISO RT LOAD: Comparison of real-time loads.
    - the difference of electricity load on the grid between PJM and MISO markets at any given time

Model Planning

To forecast and predict electricity price and demand in MISO and PJM regions, we proposed implementing **multiple linear regression** and **time series models** and comparing the model's performance to choose the better one. Under the multiple linear regression models, the real-time electricity price for each market, and the response variables will be fitted against different combinations of predictor variables such as on/off hours indicator (categorical), congestion cost, real-time electricity, etc. The output of this will help us explore what factor might affect the electricity price in both markets as well as tell us how well can the model forecast energy based on the R-Square which ultimately tells how much variability of the electricity price that it can explain.

However, due to the constraint in assumptions of predictors variables such as Linearity, etc. There might be chances where it is not possible to fit a regression model on this dataset once we actually implement it. Hence, we will also consider time series models such as ARIMA and SARIMA in addition to linear regression. In fact, we think these models will perform better than the regression one due to the nature of the dataset. This dataset is a collection of data over a 5-year period split into 60-minute intervals which is the ideal environment to apply time-series analytics methods. The ARIMA model will be used to predict future electricity demand or prices, delivering accurate forecasts for market planning. SARIMA, an extension of ARIMA, will capture seasonal variations in electricity demand and price where seasonal trends will be analyzed.

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