Analysis of Seasonal Changes in Energy Generation and Pricing in Spain

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Introduction

In Spain, electricity consumption patterns and associated energy prices reflect the rhythm of seasonal changes. During the summer months, from June to September, the country experiences an increase in temperatures, often surpassing 30 degrees Celsius (68 degrees Fahrenheit) during the day and remaining over 20 degrees (86 degrees Fahrenheit) at night (*Temperatures in Spain*, n.d.). This climatic condition escalates the use of cooling systems, leading to a surge in electrical demand. Concurrently, the longer daylight hours result in extended periods of solar generation, which may contribute to the diversification of energy sources.

Conversely, from December to March, the winter months present a stark contrast. The temperature drop increases reliance on heating systems, increasing energy demand. However, shorter days and less intense sunlight can limit solar energy generation, potentially leading to a greater dependence on non-renewable energy sources. These seasonal shifts in energy generation and consumption are critical factors that affect the average energy prices for consumers in Spain. Notably, the interplay between the total actual load, the type of energy sources utilized, and the fluctuating demand outlines the dynamic landscape of energy prices, reflective of the changing seasons. This preliminary analysis sets the stage for a deeper investigation into how seasonal variations influence the average prices for energy consumers in Spain.

Context and Implications

Our scholarly research for this study has shown us how many unique factors during different times of the year influence the price of energy consumption in Spain along with how Spain is producing this energy. All the articles we used for research relate to the energy markets although not all of them are solely focused on the country of Spain. One of our articles focuses on facets of hourly energy consumption in America which relate directly to our research on Spain. They state that “Demand during summer (June, July, and August) and winter (December, January, and February) also tends to be higher than during other seasons” (Longstaff, 2004). This is precisely the same pattern we noticed while doing our research. One of the biggest commonalities they share is how both governments are striving towards a more renewable and environmentally friendly way of producing energy. The main methods for this currently are solar, wind, and hydroelectric power.

During the review of our data, we not only dissected the methods of renewable and non-renewable energy but also the contrast of how much they are being used. In recent decades this conversation has become mainstream due to the concern of climate change. In one of our articles, the author mentions this by saying, “The majority of scholars agree that using renewable resources significantly helps to reduce emissions and safeguard the environment” (Adebayo, 2022).

Spain has already made efforts to move towards a more renewable energy-based system by working with the EU and has worked on multiple projects to improve their energy infrastructure. In the article “Distributed generation: The definitive boost for renewable energy in Spain” the authors give multiple examples of projects Spain has completed or is in the process of completing to help improve their energy infrastructure. Most are collaborative with other countries but some are also internal. These efforts will not only help improve the future environment but also positively influence stakeholders. By finding ways to lower the price of production for companies producing the energy and increasing affordability for energy consumers this could be a win for both parties. A world where energy consumers are paying a cheaper price for the same amount of energy may have seemed too good to be true at first but over the years and with advancements in technology those dreams are becoming a reality.

As of February 2024, prices for renewable energy in Spain are €2 per megawatt-hour compared to its neighboring country France where prices are €67 per megawatt-hour (Farhat, 2024). This sizable difference can be attributed to the surplus in Spain's renewable energy deposits. According to the Spanish Presidency Council of the European Union, Spain has the third highest renewable energy generation capacity in Europe which helps them maintain these low prices.

There are two main stakeholders when it comes to varying prices in energy consumption. The first is the consumers, the families that need the electricity to heat or cool their homes. The second is those supplying the energy, the big corporations that make more money the more people use their electricity. A big ethical concern when it comes to varying prices is how both sides are affected by it. The consumers would prefer lower prices because then a basic need would be easier to afford which leads to a higher quality of living for them. The corporations would prefer higher prices because they would see a large increase in their income. With either a higher or lower energy price one side of the coin would be left annoyed or unsatisfied. Higher prices mean that consumers would have larger expenses that some may not be able to afford and lower prices would mean that the suppliers would generate less money, which satisfies neither side. While a middle ground would be best for both parties it is a hard topic to agree on, often because the consumers can complain about the prices as much as they want but at the end of the day the companies control the prices.

The main ethical viewpoint to look at for this would be deontological. From the perspective of the companies that supply the electricity and change the prices, we are looking to see if they are justified in doing so or if they are taking advantage and charging far more than they should. Since deontology focuses more on adherence to principles and duties, we are using research to find if companies have the right to change their prices on electrical services based on the seasons. If we can come to the conclusion that the companies are changing their prices fairly and in a reasonable way then from a deontological perspective they are justified. However, if we come to the conclusion that they are unfairly changing prices, making them more expensive than they should be and taking advantage of consumers, then from our perspective they are not justified in doing so.

Measurement

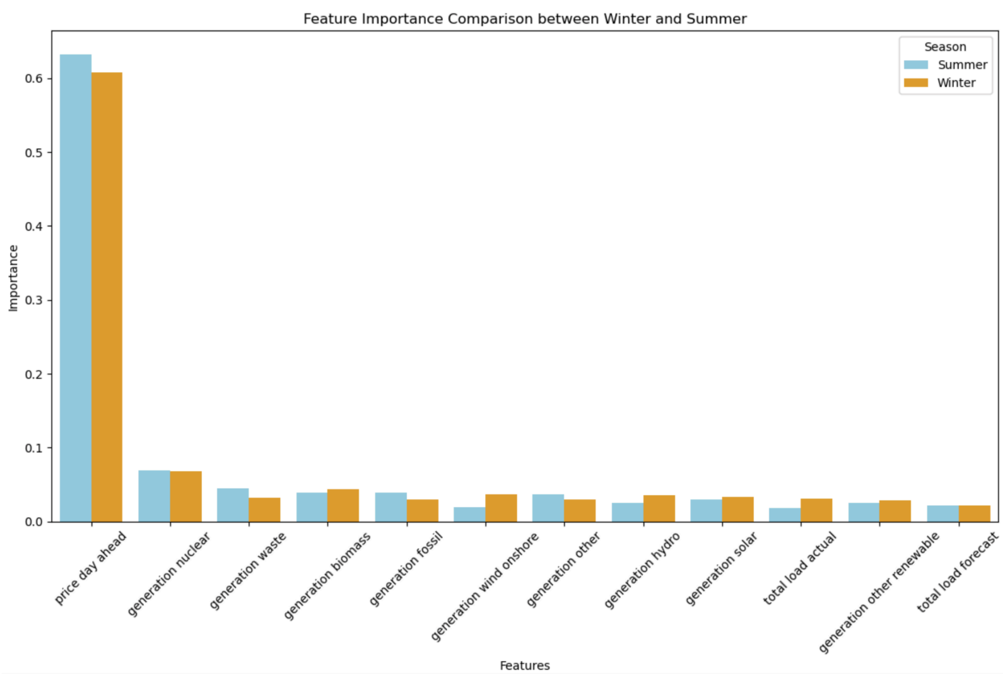
The primary objective of this research is to identify whether there is a difference in pricing between the summer months and the winter months in Spain. If there is a difference, we can further investigate the cause. We want to understand if the difference is due to price gouging–a result of companies taking advantage of higher electrical demand–or if it's due to the source of the energy, which may differ in each season due to climate differences and the type of energy consumers are utilizing. We used random forest regression models to determine how different sources of energy contributed to the actual price of energy.

It is important to first understand how to interpret the dataset. It contains the amount of energy generated from several different energy sources, gathered hour by hour over four years. Each row shows how much energy was generated in that particular hour, as well as the forecasted and actual electrical demand and price. When creating the models, which is detailed in the next section, it was found that 7 columns were key for accurately predicting the actual price. Six of these columns are operationalized by how many MW of energy was generated, and the final one is an estimate in MW of the total energy demand. These columns included energy generation from fossils, nuclear sources, miscellaneous renewable sources, waste, and biomass, as well as the forecasted electrical demand. The conceptualization of these columns is pretty self-explanatory The final column "price day ahead", which is conceptualized as the forecasted energy price for the hour, is measured in EUR/MWh.

Data

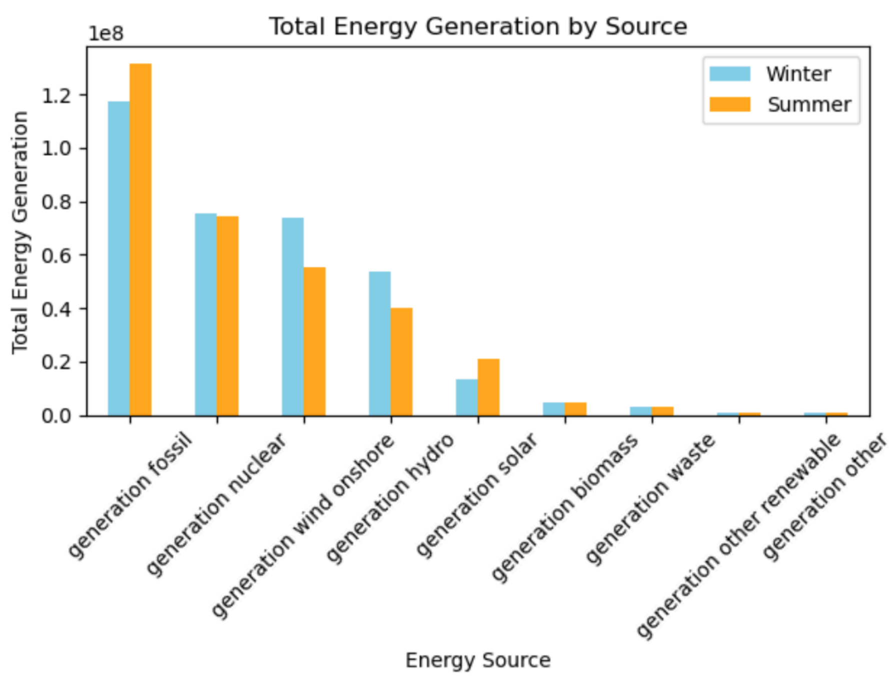
The original energy dataset consisted of 35,064 rows and 29 columns detailing hour-by-hour energy generation, forecasts, and pricing from January 2015 through December 2018. First, we dropped all columns that had a mean equal to 0 because they made no contribution to the dataset. Then, we found the rows that had missing values and since the amount was relatively small, it was appropriate to remove these rows as the change to the overall data would be negligible. Next, we removed other columns that were irrelevant to our data analysis, such as "forecast solar day ahead" and "forecast wind onshore day ahead". We also had to ensure that the "time" column consisted of datetime objects. To wrap up the data manipulation, we created two new columns, "generation fossil" and "generation solar", to hold the sum of the values found in all solar and hydro energy-related columns (i.e. "generation fossil brown coal/lignite", "generation fossil gas", "generation hydro pumped storage consumption", "generation hydro run-of-river and poundage", etc.), and dropped the old columns from the dataframe. After the consolidation, the final energy dataset contained 35,018 rows and 14 columns. Next, since our research is focused specifically on summer and winter, we created two new dataframes, summer_energy and winter_energy. They both retain the same 14 columns but only contain rows for the hottest months (June through September) and the coldest (December through March) over the four years that the data was collected (*Temperatures in Spain*, n.d.).

To begin the process of creating models for the summer and winter datasets, we looked at the feature importance for each. Here, we can see that they have “price day ahead”, “generation nuclear”, and “generation biomass” in common as top features. It makes sense that the forecasted price has high correlation with the actual price. As for biomass and nuclear energy, they are both expensive renewable sources that contribute greatly to the overall price of energy, even if they don’t make up the bulk of the actual total energy generation. After testing models with the top 5 features, we determined that these variables alone were not enough to accurately predict the price.

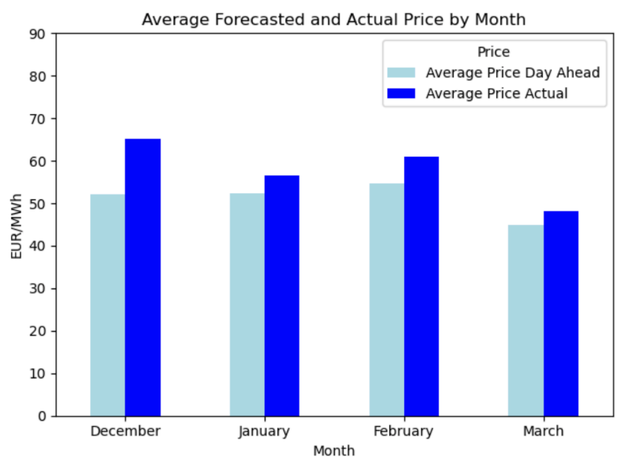


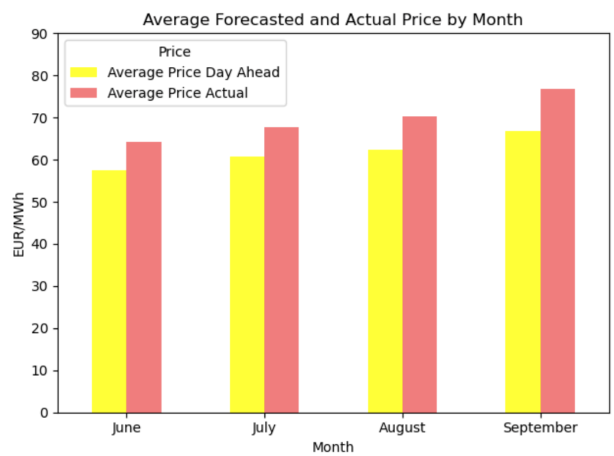
Next, we looked at the values of the correlation matrix for each dataset and found that the top 3 predictors for both models were “price day ahead”, “generation fossil”, and “total load forecast”. We combined these with the top features to test out a few different regression models: linear regression, k-nearest neighbors, random forest, and XGBoost. For simplicity in testing and analysis, we found that we were able to use the same predictors for the summer and winter models without overfitting or compromising the adjusted R^2. Using R^2, mean absolute error, mean squared error, and root mean squared error as our performance metrics, we found that XGBoost performed the best for both models using “price actual” as the response variable and “price day ahead”, “generation fossil”, “total load forecast”, “generation nuclear”, “generation other renewable”, “generation waste”, and “generation biomass” as the predictors. The model returned an R^2 of 0.9132 for the summer data and 0.8423 for the winter data.

Our next goal was to analyze each model’s ability to accurately predict the price. First we tested the winter model using the first row from the winter dataset. The actual price was 64.92 and the model predicted 59.25. We did the same with the summer model–the actual price was 54.54 and the predicted price was 57.87. This shows us that each model did fairly well with accuracy. Then we tested several lines from each dataset, and this revealed an interesting pattern. When testing the values from the summer dataset, the winter model tended to underestimate the price and the summer model tended to overestimate the price. For the testing of the winter values, the opposite was the case. This is likely due to the sources of energy that are more prominently utilized in each season.



In the winter, more wind and hydro energy is utilized, and although these variables aren't present in the model, the price difference is reflected in the "price day ahead" column. In the summer, more fossil and solar energy are utilized, which are cheaper energy sources. Because each model is trained having a different amount of knowledge on each energy source, it makes sense that they estimated differently. Each model mostly relies on "price day ahead" to estimate the actual price.





The dataset itself underestimates the actual price, so it is interesting that the models overestimated the price using their own data.

Because we know that "total load forecast", the estimated electrical demand, highly correlates with "price actual", we can assume that the fluctuations in price directly relate to the electrical demand. The graphs show that prices and demand generally decline as the weather gets warmer and increase as the weather gets cooler. We can conclude that the seasonal pricing changes depend on the type of energy consumed as well as the actual change in weather conditions. Prices are generally higher in the summer, even though more cheaper energy sources are utilized. From this we can assume that price gouging is present in the summer season.

Conclusion

The research addresses the impact of seasonal variations on electricity consumption patterns and energy prices in Spain. Climatic conditions and daylight duration primarily influence significant shifts in energy demand and source utilization between summer and winter. During summer, increased temperatures drive higher consumption due to the extensive use of cooling systems, while enhanced solar generation contributes to energy source diversification. Conversely, winter experiences elevated demand from heating systems amidst reduced solar energy production due to shorter days. This seasonal dynamic is critical in understanding the fluctuations in energy prices, as it intertwines with the types of energy sources used and the overall energy demand. The study offers insights into the operational challenges faced by energy providers. It underscores the broader implications for pricing strategies and energy policy development, particularly in transitioning towards renewable energy sources.

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