Uyen Le, El Hadj Taye, Dakota Ellis, Ana Abreu

University of North Carolina at Charlotte

Marco Scipioni & Christopher Dong

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Research Question:

How did energy generation from renewable sources (solar, wind, hydro, biomass) and fossil fuels (coal, gas, oil) impact electricity prices from 2015 to 2018 in Spain ?

Energy Price Prediction (2015 - 2018)

Introduction

This research investigates the impact of various energy sources, such as solar, wind, hydro, biomass, coal, gas, and oil, on electricity costs in Spain from 2015 to 2018. It explores how the mix of these power sources correlates with changes in electricity prices. The aim is to provide valuable insights that can inform decision-making and shape future energy policies. The 2015-2018 period is significant as it marks a shift towards renewable energy, which has different cost structures and supply characteristics compared to traditional fossil fuels. For this data-driven research, we follow a systematic approach. First, we define a specific research question that can be addressed with our dataset. Next, we delve into the dataset's context, considering how our findings could be practically implemented while being aware of ethical implications and stakeholder impact. We then explain our measurement strategy and how we manipulate the dataset to glean insights. This process includes a thorough overview and visualization of our data to highlight key findings. Lastly, we discuss our primary discoveries and draw conclusions from our analysis.

Context and Implications

Renewable energy sources have now become vital worldwide, driving economic growth and development beyond merely powering homes and industries. With energy demands set to increase due to population growth and industrial expansion, the provision of sustainable and renewable energy solutions is crucial. In the 21st century, Spain has emerged as a leader in renewable energy, largely due to its strategic location and favorable weather conditions. Despite not being rich in oil, gas, or gold, Spain takes advantage of having more sunlight hours than any other EU member state, one of Europe's largest lithium deposits, and ideal conditions for wind and water power. As a result, Spain ranks as Europe's third-largest renewable energy producer.

The limitations and environmental impact of conventional sources, such as fossil fuels, have prompted a global shift towards renewable energy (Spanish Presidency of the Council of the EU, 2024). Countries worldwide are making substantial investments in renewable energy production, including solar, wind, hydro, and geothermal energy. These investments represent more than a commitment to meet current energy needs; they signify a significant step towards a stable, sustainable, and environmentally friendly energy future and changes on the market prices.

The integration of renewable energy sources into national electricity grids and their subsequent impact on market prices is an area of significant academic and practical interest, particularly in the context of Spain's energy market from 2015 to 2018. A comprehensive review of the literature reveals a complex interplay between increased renewable energy adoption and its effects on electricity pricing. For instance, research indicates that the generation of renewable sources such as wind and solar often leads to lower electricity prices, a phenomenon attributed to the merit order effect, where the lower operating costs of renewable displaces more expensive fossil fuels-based production (Mahmud, H., & Roy, J. 202). However, the extent and consistency of this effect largely depends on a variety of factors such as the scale of renewable penetration, the specific type of renewable energy used, its relative cost efficiency, and market regulations. The latter can either facilitate or hinder the integration of renewable energy into the grid, and policies that incentivize renewable energy production can significantly influence market prices. Moreover, the overall energy mix of a given region plays a crucial role in the region principal in Europe with diverse energy portfolios may experience different pricing effects compared to those heavily reliant on specific energy sources.

The publication from the *International Journal of Environmental Research and Public Health* mentions, “The increasing electricity prices have become a heavy burden on household and industrial users, making many (Truckers, farmers, auto and metal workers, hairdressers, and pensioners) go on strikes or protests on the streets. It can be concluded that energy prices are strongly related to the development of Spain's agricultural industry." This kind of event occurs due to the lack of management stability on the electricity prices market, reflecting the significant impact of rising electricity prices on various societal sectors in Spain. This unrest underscores the critical role of energy prices in Spain's economic stability, especially within its highly energy-dependent agriculture sector, one of the industries of more important economic development nationwide in Spain.The lack of stability in electricity pricing affects not only daily living and operational cost but also broader economic activities. Accurate energy price forecasts enable governments to tailor financial measures such as subsidies, tax incentives and support programs effectively. This helps buffer against fluctuations costs, maintain stable food prices, and ensures agricultural productivity is not compromised by high energy expenses.

On the industry side, precise energy price forecasts can drive innovation in energy efficiency and development of eco-friendly energy/technology. For instance, companies in the energy sector might invest more willingly in renewable projects if they can anticipate cost trends and evaluate potential profitability. This is crucial for transitioning to greener energy solutions, reducing carbon and combating climate change. Furthermore, predictive insights into energy pricing can facilitate a more rapid adoption of renewable energy sources, contributing to worldwide efforts to mitigate climate change. Thus, the development and utilization of advanced predictive analytics for energy pricing not only have the potential to stabilize economies and industries but also play a crucial role in the larger context of environmental conservation and sustainable development. These collective benefits underscore the importance of investing in and focusing on technological advancements in energy price forecasting, which could ultimately lead to more sustainable economic growth and environmental protection.

Explanation of the possible stakeholders that could be impacted

- Government: The Spanish Government and the European Union, which shape energy policies and market rules, could be impacted. Changes in electricity prices can influence the economy and guide policy direction.
- Energy Producers: The volatility of electricity prices can significantly affect their profitability, investment strategies, and long-term sustainability. They must navigate a complex landscape of market dynamics, technological advancements, and investment strategies.
- Consumer: Both individual and industrial consumers are directly impacted by fluctuations in electricity prices, which in turn affect their monthly expenditures and consumption behaviors.
- Environmental Groups: Advocates for sustainable and eco-friendly energy solutions. They closely monitor how shifts towards renewable energy sources are impacting electricity prices, energy market dynamics, and most importantly environmental outcomes.
- Investors: These financial stakeholders including banks and private equity firms are interested in the profitability and stability of the energy markets. Changes in energy pricing can influence their decisions regarding where and when to invest in the energy sector.

Ethical considerations

Harms: There are several potential harms associated with this dataset, two of which are particularly significant: **economic impact and social equity**. These critical ethical considerations cannot be overlooked. High volatility in electricity prices can lead to economic instability, significantly impacting energy-dependent industries like manufacturing. The unpredictability of energy costs could destabilize these sectors. Additionally, energy is a basic necessity for all households. Sudden price fluctuations could disproportionately affect lower-income households, as they spend a larger percentage of their income on energy. This situation could worsen social inequality, widening the gap between the affluent and less fortunate, even leading to a state of energy poverty. Therefore, it's essential to acknowledge these potential outcomes when analyzing and interpreting the data.

Benefits: Our research analysis delves into the ethical implications of renewable energy pricing, which brings forth a plethora of beneficial impacts. The act of predicting electricity consumption and prices, in connection to the generation from renewable and fossil fuel sources in Spain and Europe, offers significant ethical advantages, including **enhanced transparency and economic resilience.** Accurate price predictions ensure just pricing, while maintaining market transparency aids in making informed decisions. This allows policymakers to develop supportive renewable energy policies, businesses to strategize based on energy costs, and consumers to optimize their energy use. Moreover, demonstrating how renewables positively influence electricity prices encourages further investment in sustainable technologies, thus promoting a rapid transition to a low-carbon economy. Predictive insights also contribute to economic resilience by stabilizing national economies against the volatile global fuel market, thereby reducing dependence on imported fossil fuels. Importantly, affordable renewable energy facilitated by predictive pricing models can alleviate energy poverty and ensure a more equitable distribution of energy resources, thereby promoting social justice. These interconnected benefits collectively advocate for the ethical necessity of employing predictive analytics in energy pricing, underpinning a sustainable, equitable, and economically stable future for Spain.

This analysis of energy generation from renewable and fossil fuel sources uses an ethical framework that caters to various stakeholder interests and ethical considerations. This approach ensures careful ethical oversight, considering electricity pricing fluctuations' impact on parties such as governments, energy producers, consumers, environmental groups, and investors. The framework evaluates how energy price changes affect economic stability and social equity. Our project aims to show how renewable energy can stabilize electricity prices, reduce economic vulnerability to fossil fuel markets, and support sustainable economic development. By addressing these ethical aspects systematically, we emphasize the importance of integrating ethical considerations into energy market analyses for a sustainable, equitable future.

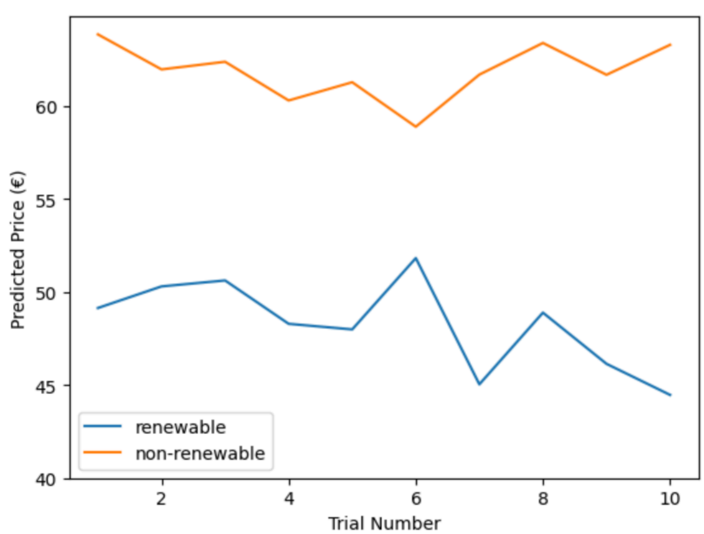
Measurement

Given the dataset provided on energy generation and electricity prices in Spain from 2015 to 2018, the operationalization of key variables involves extracting specific data points related to energy production and pricing for analysis. For energy generation, this entails retrieving data on the quantity of electricity generated from renewable sources (solar, wind, hydro, biomass) and fossil fuels (coal, gas, oil) for each year within the specified time frame. This data should include information on the amount of electricity produced from each energy source, measured in units such as megawatt (MW). Similarly, for electricity prices, the operationalization process involves obtaining data on actual market prices of electricity in Spain for the years 2015 to 2018. This data should include price data for different types of consumers with the currency being in Euros and may be presented as average prices per megawatt-hour (MWh) or as indices reflecting overall pricing trends over time.Once the relevant data has been extracted from the dataset, it can be organized and analyzed to assess the relationship between energy generation from renewable and fossil fuel sources and fluctuations in electricity prices. Statistical methods such as regression analysis may be employed to explore correlations and identify potential causal relationships between these variables. Overall, the operationalization of key variables involves accessing and processing the provided dataset to obtain the necessary information for investigating the research question regarding the impact of energy generation on electricity prices in Spain from 2015 to 2018.

Data Section

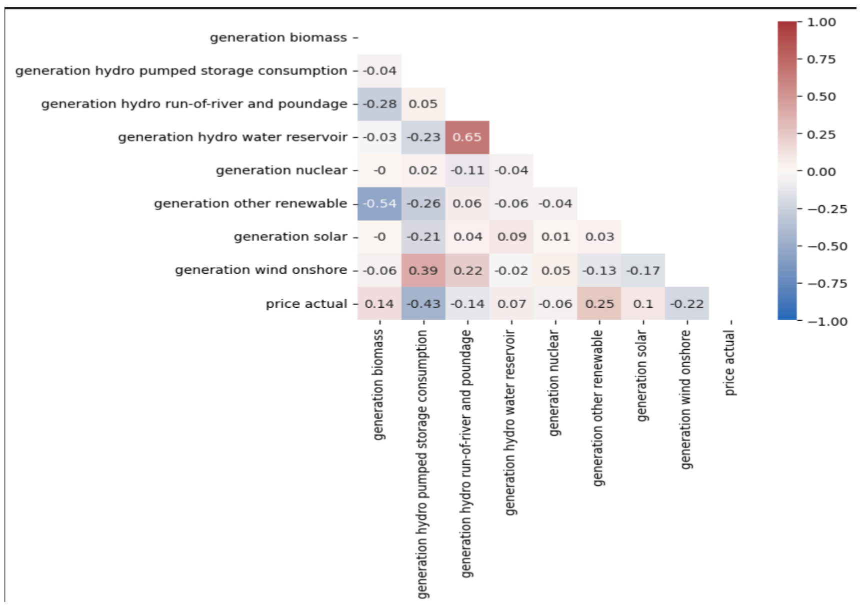
Our research project will utilize the given dataset consisting of the energy methods and their generation amounts, weather patterns, and the price of energy for Spain from 2015 through the end of 2018. This dataset includes relevant information to our research question but also has some missing information. Particularly in categories of energy production where those methods were not utilized in Spain in the specified date range. Our first step in the data analysis process will be to fill the missing data with numbers that are useful in our models. To do that, we use the .fillna() function to replace missing values with zero. Our research focuses on the relationship between generation amounts and actual energy prices, therefore we then drop the columns that fall outside of those categories(time, generation waste, weather forecast, price forecast), as well as the generation methods that yield zero overall production (geothermal, wind offshore, marine, coal-derived gas, peat, and hydro-pumped storage aggregate). The resulting data frame consists of relevant energy generation numbers and the actual price of energy. We can continue our data analysis further by training a regression model and comparing the predicted actual price based on equal production of renewable vs non-renewable generation. We start by creating three different regression models for the dataframe. Our three models constructed were linear regression, random forest, and KNN. After creating the models, we then can test the metrics of those models to find the one best fit for our data. After evaluating the models, random forest proves to be the most accurate with the lowest error metrics; Mean Absolute Error: 3.93, Mean Squared Error: 33.28, and Root Mean Squared Error: 5.77.

Now that we have determined which model we will use, we can run two separate tests to see if there is a noticeable difference in predicted price in a renewable-heavy input vs. a nonrenewable-heavy input. Since we have 5 categories in our non-renewable and 8 categories in our renewable energy sources, we can take a test amount and divide it evenly into each subsequent category. We can take a total energy generation of 4000 MW which evenly divides into 500 MW for each renewable energy resource and leave the non-renewable categories as 0 MW. In our second test, we will fill each non-renewable category as 800 and leave the renewables as 0. This method of testing will test the impact of 4000 MW of renewable vs. 4000 MW of non-renewable energy on the actual price of energy. Our predicted price for the renewable-heavy test was €45.39 while the prediction for the nonrenewable-heavy test was €62.26. We created a loop to repeat this process ten times and generated a list of predicted values for renewable and non-renewable energy.

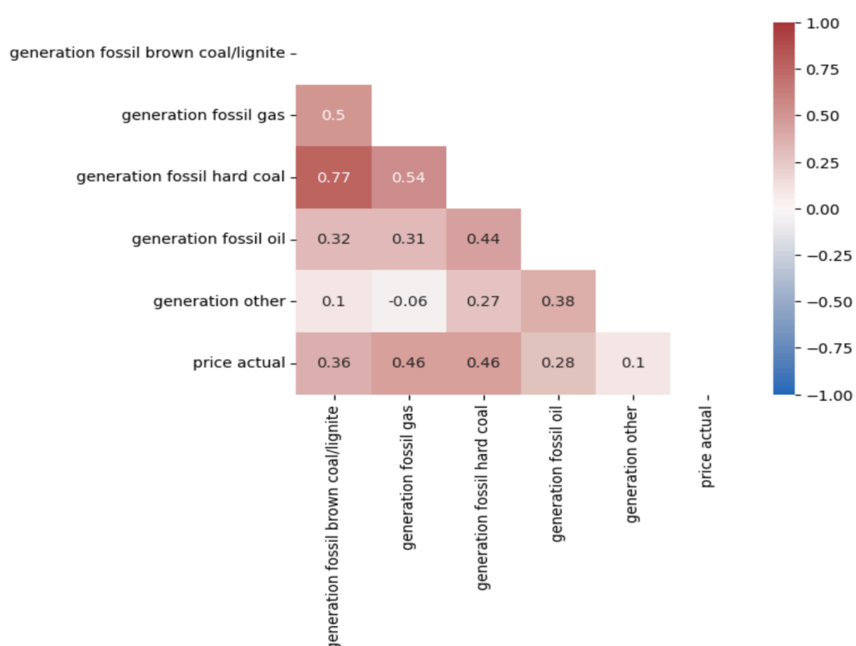


Furthermore, we can go back to our dataframe and split it into renewable and non-renewable. Splitting the data frame into the two categories allows us to separately test the generation methods for their impact on the actual price of energy. We created a correlation matrix for renewable and non-renewable generation using the separate dataframes and the built in pandas correlation function. We can visualize this information using the following heatmaps.

Renewable Generation Correlation Matrix:



Non-Renewable Generation Correlation Matrix:



Conclusion

To summarize our findings, the data suggests that in Spain from 2015-2018 ,a higher generation of renewable energy sources lead to lower energy prices compared to an equal amount of generation from non-renewable sources. The regression models trained on the dataset conducted ten trials, every non-renewable predicted price was higher than any of the renewable predicted prices. This was our first indication that there may be a measurable difference in how renewable sources and non-renewable sources impacted the actual price. We pried further by constructing the correlation matrices for both energy categories. Those matrices (expressed in the heat map visualizations) show that there is a mostly neutral but slightly negative correlation between renewable energy and price suggesting that as renewable generation increases, actual price will slightly decrease. A mostly positive correlation exists between non-renewable generation and actual price, indicating that as non-renewable generation increases, actual price also increases. It is important to note that although these findings were gleaned from a dataset that contained over 35,000 lines of information, there are external factors pertaining to our research question that are not present within our data. Some examples of exterior variables include government intervention, consumer influence, infrastructure, and resource availability in Spain. Further exploration into external costs and influences is needed to reach a more definitive conclusion.

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