Statistical Analysis of Electricity Prices in Southern Norway

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Abstract

Electricity price forecasting in Southern Norway has become increasingly complex due to a combination of fluctuating demand, supply constraints, volatile global fuel costs, and geopolitical uncertainties. This study analyzes a comprehensive dataset containing key economic indicators (oil, gas, and coal prices, exchange rates), environmental variables (precipitation, temperature, wind), hydropower storage levels, and market data (electricity spot and actual prices). A review of key market resources, including *Statnett*, *Nord Pool*, *Investing.com*, *Business Insider*, and the *U.S. EIA*, provides context for this analysis. Using descriptive statistics and correlation analysis (Pearson and Spearman Rank Correlation), the study investigates five core research questions concerning electricity pricing dynamics. Key findings indicate that (1) gas prices and electricity spot prices exhibit a stronger correlation when reservoir levels are low, (2) wind power generation has a growing negative correlation with spot prices compared to rainfall, (3) extreme electricity price spikes are more influenced by global commodity prices than local weather factors, (4) the spot market has become less reliable as a predictor of actual consumer electricity prices post-2020, and (5) fluctuations in the U.S. dollar price have a stronger impact on electricity prices than temperature and precipitation. These insights are critical for future research or market participants, policymakers, and energy-intensive industries to develop robust pricing strategies, improve risk management, and optimize energy planning in Norway's evolving electricity market.

1 Introduction

Norway's electricity market is predominantly powered by hydropower, contributing approximately 92% to the nation's total electricity generation [1]. This heavy reliance on hydropower has historically ensured stable and affordable electricity prices. However, recent developments have introduced new dynamics affecting price stability.

In the first half of 2024, Statnett reported a solid underlying result, with an increase in the number of ongoing projects from about 160 to 210, and the ongoing grid portfolio rising from around NOK 100 billion to NOK 130 billion during the same period [2]. Despite these favorable conditions, the growing unpredictability of electricity prices presents challenges for various stakeholders. Policymakers must assess whether existing regulatory mechanisms are sufficient to mitigate price shocks. Energy sector businesses require improved forecasting models to hedge against market fluctuations, while consumers seek greater transparency in price formation. Addressing these concerns requires a comprehensive understanding of the factors influencing electricity pricing dynamics.

Coal prices also play a role in electricity market fluctuations, as they influence the cost of energy imports in Europe. Recent data shows that coal prices have experienced significant volatility, reaching **$101.90** per metric ton in early 2025 [3]. While Norway primarily relies on hydropower, rising coal prices in interconnected European markets can contribute to higher electricity costs, particularly during periods of low reservoir levels when reliance on imported electricity increases.

Given these complexities, this study explores the key drivers of electricity price fluctuations in Southern Norway by addressing five core business concerns:

(1) **Gas Prices and Reservoir Levels:** How do gas prices and electricity spot prices interact under high and low reservoir levels?
(2) **Wind Power vs. Rainfall:**Has the relationship between wind power generation and electricity spot prices in Southern Norway grown stronger in comparison to the relationship between rainfall and electricity prices over the past three years? If yes, what does this change mean for the main factors affecting electricity price changes in the region as wind power increases?
(3) **Global vs. Local Price Drivers:** Are extreme electricity price spikes more strongly related to changes in global commodity prices (oil, gas, coal) or local factors (reservoir levels, temperature)?
(4) **Spot Market Reliability:** Has the relationship between electricity spot prices and actual electricity prices in Southern Norway changed significantly from before, during, and after 2020? If so, does this change mean that the spot market is becoming more or less reliable in predicting the final prices that consumers pay?
(5) **Macroeconomic vs. Meteorological Factors:** Which has a stronger influence on Southern Norwegian electricity spot prices: the U.S. dollar prices or local weather factors (temperature and precipitation)?

Through **statistical analysis**, this research investigates the complex relationships between **economic indicators, hydropower availability, and weather-related factors**. By identifying the primary drivers of price volatility, this study aims to provide valuable insights in understanding **Southern Norway's evolving electricity market dynamics**.

2 Data Description and Preparation

The dataset used in this study includes electricity market and economic data sourced from the **Nordic power market**, covering multiple years to facilitate time-series analysis. It consists of variables related to economic indicators, weather conditions, and electricity pricing, enabling a detailed examination of factors influencing electricity price fluctuations. Key variables in the dataset includes:

- **Time Stamp (datetime)**: The recorded timestamp for each observation.
- **Economic Factors:**
  - **Oil Price (€)**: Cost of oil per unit.
  - **Coal Price (€)**: Cost of coal per unit.
  - **Natural Gas Price (€)**: Price of natural gas per unit.

  - **U.S. Dollar Exchange Rate (€/$)**: Currency exchange rate.
- **Electricity Market Data:**
  - **Electricity Spot Price (€)**: The market price of electricity at a given time.
  - **Electricity Actual Price (€)**: The final price paid by consumers.
  - **Electricity Consumption (MW)**: Total electricity demand.
  - **Electricity Production (MW)**: Total electricity generated.
  - **Reservoir Level (%)**: Water levels in hydroelectric reservoirs.
- **Weather Variables:**
  - **Precipitation (mm)**: Rainfall levels.
  - **Temperature (°C)**: Air temperature.
  - **Wind Speed (m/s)**: Wind power potential.
- **Temporal Attributes:**
  - **Hour, Day, Month, Year, Week, Day of Week**: Features used to analyze seasonal trends and time-based variations in electricity pricing.

The dataset enables a multifaceted analysis of how **global commodity prices, local weather conditions, and hydropower availability** interact with **electricity market demand and pricing trends** in Southern Norway.

2.1 Data Preparation

To ensure data quality and consistency, preprocessing steps included converting timestamps into datetime format for time-series analysis, handling missing values using median imputation and removing excessive gaps to prevent bias, standardizing data types for categorical and numerical variables, and detecting outliers in electricity prices, gas prices, and reservoir levels using scatterplots. Extreme outliers caused by data entry errors were either adjusted or removed while preserving data integrity, ensuring the dataset was structured and reliable for statistical analysis.

3 Data Analysis

To analyze the influence of economic and environmental factors on electricity prices, statistical techniques such as descriptive statistics, Pearson correlation analysis, and Spearman Rank Correlation were applied.

3.0.1 Correlation Analysis A key component of the study involved measuring the strength and direction of relationships between electricity prices and external variables using **Pearson correlation analysis:**

$$r = \frac{N\sum XY - \sum X \sum Y}{\sqrt{\left(N\sum X^2 - (\sum X)^2\right)\left(N\sum Y^2 - (\sum Y)^2\right)}}$$

where:

- r represents the Pearson correlation coefficient (values range from -1 to 1).
- A positive correlation ($r > 0$) indicates that two variables increase together.
- A negative correlation ($r < 0$) implies an inverse relationship.
- A correlation close to zero suggests no meaningful relationship between the variables.

Additionally, **Spearman Rank Correlation** was used to quantify nonlinear relationships and assess the relative contribution of each factor to electricity price changes. The Spearman Rank Correlation coefficient is computed as:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$

where:

- ρ represents the Spearman rank correlation coefficient.
- d_i is the difference between the ranks of corresponding variables.
- n is the number of samples.

These correlation methods help evaluate the degree to which economic variables (e.g., gas prices, exchange rates) and environmental factors (e.g., temperature, precipitation) influence electricity pricing trends.

The study applies descriptive statistics to summarize trends in electricity prices and influencing factors using measures of central tendency like mean, median, alongside the standard deviation, which quantifies data dispersion and indicates how much the values deviate from the mean. Scatter plots and regression lines visualize trends, and time-series analysis tracks price fluctuations across different periods. A two-sample Z-test assesses statistical significance in price changes, while bar charts and heatmaps provide comparative and correlation insights.

3.1 Question 1

Null Hypothesis (H_0) There is **no significant** difference in the correlation between gas prices and electricity spot prices under high and low reservoir levels.

Alternative Hypothesis (H_a) The correlation between gas prices and electricity spot prices **differs significantly** depending on whether reservoir levels are high or low.

Electricity prices in Southern Norway are influenced by multiple factors, including fuel prices, demand fluctuations, and hydropower availability. Since hydropower is a significant energy source in Norway, reservoir levels play a crucial role in determining the reliance on gas-based electricity generation. This analysis examines whether the relationship between **gas prices** and **electricity spot prices** varies under **high** and **low reservoir levels**.

3.1.1 Methodology for Classifying High and Low Reservoir Levels
A. Defining High and Low Reservoir Levels To analyze the relationship between gas prices and electricity spot prices under varying hydropower availability, we classified reservoir levels into two categories: high and low. The classification was performed using the median split statistical approach.

Median Split Method: The **median** of all reservoir levels over the dataset was computed. Reservoir levels **above the median** were classified as **high**.Reservoir levels **below the median** were classified as **low**.

Table 1: Average Electricity Spot Price and Gas Price for High and Low Reservoir Levels

Reservoir Category	Electricity Spot Price (€)	Gas Price (€)
High	41.35	27.63
Low	73.19	59.95

Using this classification, we grouped data points accordingly and computed separate Pearson correlation coefficients for each category.

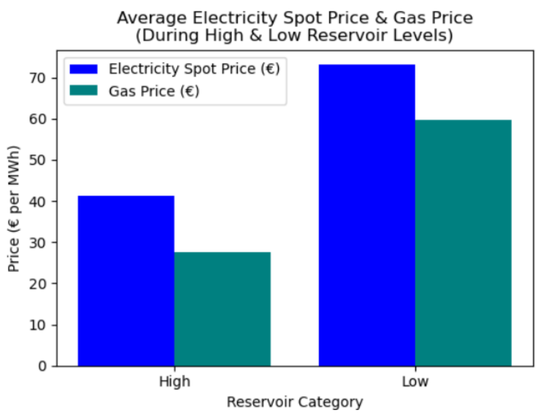

Figure 1: Average Electricity Spot Price and Gas Price During High and Low Reservoir Levels

The bar plot visualizes the relationship between reservoir levels and electricity prices.

By examining the data, we noticed that electricity spot prices tend to be significantly lower when reservoir levels are high, while gas prices also follow a similar trend.

- **Higher Reservoir Levels Reduce Prices:** When reservoir levels are high, electricity spot prices are significantly lower (€41.35) due to increased hydropower availability.
  Gas prices are also lower (€27.63), indicating less reliance on fossil fuels.
- **Lower Reservoir Levels Increase Prices:** When reservoirs are low, electricity prices rise sharply (€73.19), as hydropower generation declines and reliance on gas-powered electricity increases.
  Gas prices also rise to (€59.95), reflecting higher energy demand.
- **Market Dependence on Hydropower:** The significant price gap between high and low reservoir conditions reinforces Norway's dependence on hydropower. Policymakers and energy companies should closely monitor reservoir levels to anticipate price spikes.
- **Implications for Risk Management:**
  Energy-intensive industries should develop strategies (*e.g.*, price hedging) to mitigate risks associated with electricity price fluctuations during periods of low reservoir levels.

B. Computing Pearson Correlation for Each Group For both the high and low reservoir levels, we calculated the Pearson correlation coefficient (**r**) between **gas prices** and **electricity spot prices**.

The Pearson correlation coefficients between **gas prices** and **electricity spot prices** under high and low reservoir levels are presented in Table 2.

Table 2: Correlation Between Gas Prices and Electricity Spot Prices

Reservoir Level	Pearson Correlation (r)
High Reservoir Levels	0.43
Low Reservoir Levels	0.67

The result indicate that **gas prices have a stronger influence on electricity spot prices when reservoir levels are low (r = 0.67.** This suggests that during periods of low hydropower availability, electricity generation depends more heavily on gas, making electricity prices more sensitive to gas price fluctuations.

Conversely, when reservoir levels are high (r=0.43), **hydropower stabilizes electricity prices,** reducing dependency on gas and mitigating price volatility.

3.1.2 Scatterplot and Interpretation. Figure 2 presents scatterplots of gas prices against electricity spot prices for high and low reservoir levels. The regression lines highlight the positive correlation in both scenarios.

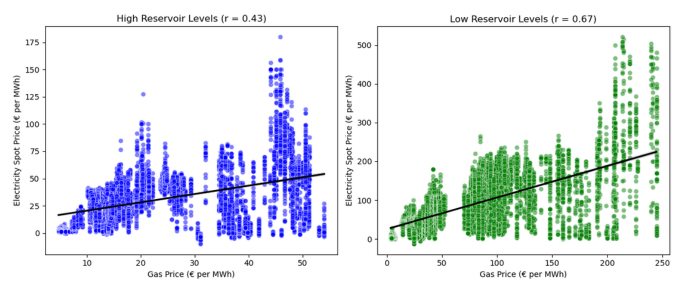

Figure 2: Scatterplots of Gas Prices vs. Electricity Spot Prices Under Different Reservoir Levels

High Reservoir Levels (r = 0.43):

- A weaker correlation suggests that when hydropower is abundant, gas prices have less influence on electricity prices.
- The blue points are more clustered, indicating price stability due to the dominance of hydropower.
- The less steep regression line shows that changes in gas prices do not translate into large fluctuations in electricity spot prices.

Low Reservoir Levels (r = 0.67):

- The stronger correlation suggests that gas prices are a major driver of electricity prices when reservoirs are low.
- The green points are more widely spread, indicating higher price volatility due to increased reliance on gas-fired electricity generation.
- The steeper regression line suggests that as gas prices rise, electricity spot prices increase more significantly.

3.1.3 Understanding the Relationship. Norway's electricity generation is predominantly sourced from hydropower, accounting for approximately **88%** of its total power production [4]. This reliance on hydropower significantly influences electricity prices, particularly in response to fluctuations in **reservoir levels**.

When **reservoir levels are high**, Norway benefits from **abundant hydropower availability**, reducing the need for gas-fired electricity generation. As a result, electricity prices remain relatively **stable** and **less sensitive** to gas price fluctuations [5].

Meanwhile, **low reservoir levels** lead to a decline in hydropower availability, forcing greater reliance on **gas-based electricity production**. This shift makes electricity prices **more volatile**, as they become increasingly dependent on **global gas market dynamics** [6].

Electricity price trends in Norway demonstrate a clear **inverse relationship** with reservoir levels:

- **Higher reservoir levels** → Increased hydropower → Lower electricity prices
- **Lower reservoir levels** → Increased reliance on gas → Higher electricity prices

This relationship shows the crucial role of **hydropower as a price stabilizer**, mitigating the impact of **gas price fluctuations** during periods of sufficient water reserves.

3.1.4 Conclusion. Gas prices significantly impact electricity spot prices, but the effect is stronger when reservoir levels are low (r=0.67).

When reservoir levels are high, hydropower reduces reliance on gas, leading to a weaker correlation (r=0.43).

The stronger correlation under low reservoir conditions confirms that electricity prices become more sensitive to gas prices when hydropower availability is limited.

Hypothesis Testing Decision: Since the correlation values differ significantly between high and low reservoir levels, we **reject the null hypothesis (H_0).** This confirms that the relationship between gas prices and electricity spot prices is strongly influenced by reservoir levels.

3.2 Question 2

Null Hypothesis (H_0): The relationship between wind power generation and electricity spot prices in Southern Norway **has not grown stronger** compared to the relationship between rainfall and electricity prices from 2021 to 2023.

Alternative Hypothesis (H_1): The relationship between wind power generation and electricity spot prices **has strengthened** over time compared to rainfall and electricity prices from 2021 to 2023.

The goal of this analysis is to determine whether wind power generation has a stronger relationship with electricity spot prices in Southern Norway compared to rainfall over the past three years (2021-2023). This helps us understand the primary drivers of electricity price fluctuations in the region as wind power capacity increases.

In this analysis, the **average correlation** was used to observe long-term trends in the relationship between wind power, rainfall, and electricity spot prices.

3.2.1 Average Correlation The yearly average correlation is computed using the **Pearson correlation coefficient**.

The **yearly average correlation** is then calculated as:

$$r_{avg} = \frac{1}{T} \sum_{t=1}^{T} r_t$$

where T is the number of days in a year, and r_t is the rolling correlation computed daily.

By taking the **average correlation** per year, we smooth out daily fluctuations and obtain a clearer understanding of long-term trends.

It also allows us to compare correlations across different years and determine whether wind power has grown in importance relative to rainfall.

Businesses and policymakers can observe trends and plan accordingly based on how or which weather factors influence electricity prices over time.

Table 3: Pearson Correlation Coefficients for Wind and Rainfall vs. Spot Prices

Year	Wind vs. Spot Price (r)	Rain vs. Spot Price (r)
2021	-0.03	-0.07
2022	-0.22	-0.08
2023	-0.15	-0.11

3.2.2 Visualizing the Relationship Between Wind Power, Rainfall, and Electricity Spot Prices. To comprehensively analyze the relationship between wind power, rainfall, and electricity spot prices in Southern Norway, both a **time-series plot** and a **line chart** were used. These visualizations highlight trends over the past three years (2021-2023) and allow us to compare their relative influences.

3.2.3 (A) Time-Series Plot: Yearly Average Correlations (2021-2023) This graph presents the trends of **wind power generation (orange)**, **precipitation**, and **electicity spot prices (blue)** in Southern Norway in 2021 to 2023. The goal is to determine whether wind power has become a more significant driver of electricity prices than precipitation over this period.

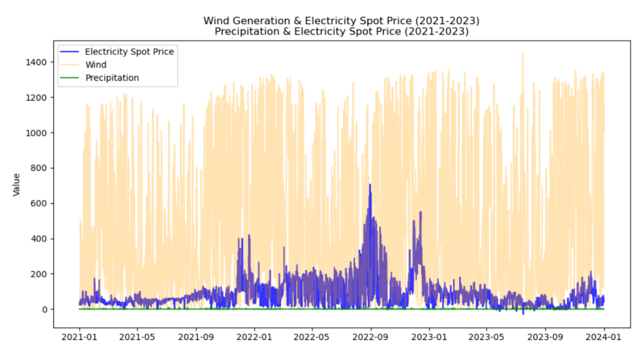

Figure 3: Yearly Average Correlations Between Wind Power, Rainfall, and Electricity Spot Prices (2021-2023)

- **Wind Power Generation (Orange Area)**
  Wind power exhibits significant fluctuations over the three-year period, indicating variability in generation levels. A noticeable increase in wind power production from 2021-2023 suggests a growing reliance on wind energy in Southern Norway. The highest wind power outputs appear to coincide with electricity price movements, particularly during 2022 and 2023, reinforcing its influence on market pricing.
- **Electicity Spot Price (Blue Line)**
  The electricity spot price experiences sharp spikes, especially in 2022 and early 2023, reflecting periods of increased market volatility. These price spikes align closely with fluctuations in wind power generation, indicating a strengthening relationship between wind energy availability and electricity pricing. This trend supports the hypothesis that wind energy is playing an increasingly significant role in determining electricity prices.
- **Precipitation (Green Line)**
  Precipitation levels remain relatively stable throughout the observed period, showing minimal fluctuations. There is no evident correlation between precipitation levels and electricity spot price movements, suggesting that rainfall alone has a limited impact on short-term electricity price variations. This finding implies that other factors, such as wind power and market conditions, have a greater influence on price formation.

3.2.4 (B) Line Chart: Yearly Average Correlations (2021-2023). The line chart provides a clearer visualization of how correlation evolved over time.

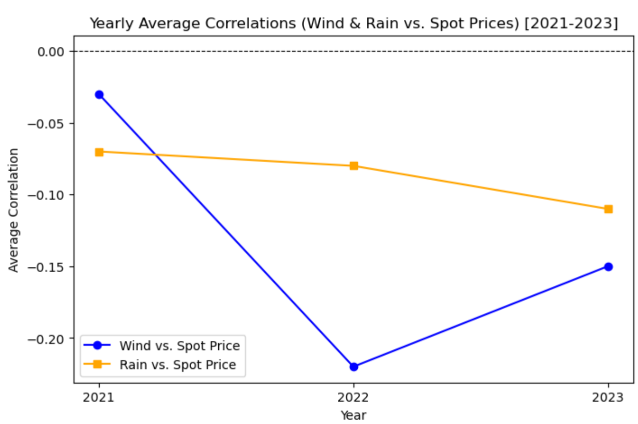

Figure 4: Trends in Wind and Rainfall Correlations with Electricity Spot Prices (2021-2023)

- The **blue line** (wind vs. spot price) shows a sharp decline in correlation in 2022, indicating wind power significantly lowered electricity prices.
- The **orange line** (rainfall vs. spot price) remains relatively stable, confirming that rainfall has a weaker impact compared to wind power.

3.2.5 Interpretation and Insights **Correlation Between Wind Power and Spot Prices (2021-2023)**

- The line chart shows that wind power consistently has a **negative correlation** with spot prices, meaning that increased wind power generation lowers electricity prices.
- The calculated Pearson correlation coefficients for wind power and electricity spot prices shown in Table 3 indicates that in **2022**, the negative correlation was at its **strongest**, suggesting that wind power significantly contributed to reducing electricity prices during that year.
- In **2023**, the correlation slightly recovered to $r = -0.15$, but it still remained negative, reinforcing the **growing influence of wind energy** in price formation.

Correlation Between Rainfall and Spot Prices (2021-2023)

- Rainfall also shows a **negative correlation** with spot prices, but its effect is **weaker than wind power**.
- The calculated Pearson correlation coefficients for rainfall and electricity spot prices shown in Table 3 shows that the line graph indicates that the impact of rainfall has remained **relatively stable** over three years, which means that although hydropower reservoirs influence prices, their immediate effect is less pronounced than wind power.
- Unlike wind power, which directly contributes to energy generation, **hydropower reservoirs store water and release it strategically**, making their influence on spot prices more delayed.

3.2.6 What does this change mean for the main factors affecting electricity price changes in Southern Norway as wind power increases? As wind power capacity increases in Southern Norway, its influence on electricity prices is becoming more pronounced. The stronger negative correlation in 2022 indicates that higher wind generation contributed to lower electricity prices during that period. This trend suggests that the electricity market is increasingly dependent on wind availability, reinforcing wind energy's role in short-term price fluctuations. [7]

In contrast, rainfall has a weaker yet stable influence on electricity prices. Hydropower generation is less sensitive to short-term rainfall variations due to reservoir management, which allows for efficient water storage. This indicates that while hydropower provides long-term stability, wind power is a more immediate driver of price changes. [8]

From an energy policy and market perspective, the growing impact of wind power highlights the need for increased investment in wind energy infrastructure. Hydropower remains essential, but its short-term effect on pricing is more limited. A diversified renewable energy strategy incorporating wind, hydro, and storage solutions will help stabilize electricity prices and reduce dependence on fossil fuel-based energy. [9]

3.2.7 Conclusion. Given the observed trends, we **reject the null hypothesis** (H_0) and confirm the **alternative hypothesis** (H_1): wind power's influence on electricity prices **has grown stronger compared** to rainfall, reinforcing its role in shaping Southern Norway's electricity market dynamics.

3.3 Question 3

Null Hypothesis (H_0): Extreme electricity price spikes in Southern Norway are **not more strongly influenced** by global commodity prices (oil, gas, coal) than by local factors (reservoir levels, temperature).

Alternative Hypothesis (H_1): Extreme electricity price spikes in Southern Norway **are more strongly influenced** by global commodity prices (oil, gas, coal) than by local factors (reservoir levels, temperature).

To determine the influence of global vs. local factors on electricity price spikes, we used Pearson correlation analysis. The **correlation heatmap** was generated to visualize the correlation between electricity spot price spikes and various influencing factors, including global commodity prices (oil, gas, coal), local factors (reservoir levels), and temperature.

3.3.1 *Interpretation and Insights (Heatmap)*

(1) **Strongest Positive Correlation: Gas Price ($r = 0.56$)**
- Gas prices exhibit a **large positive correlation** with electricity price spikes, meaning that as gas prices increase, electricity prices rise significantly.
- This aligns with expectations since gas remains a crucial energy source in the Nordic power generation mix, particularly in balancing supply shortages.

(2) **Moderate Positive Correlation: Reservoir Levels ($r = 0.37$)**
- Reservoir levels demonstrate a **moderate positive correlation** with electricity price spikes. Typically, higher reservoirs should contribute to price stability. However, this correlation suggests other influencing factors, such as market demand, energy trading, and hydropower allocation strategies.
- The relationship indicates that in certain market conditions, high reservoir levels may coincide with price increases, possibly due to seasonal hydropower regulations.

(3) **Weak Positive Correlation: Coal Prices ($r = 0.18$) and Temperature ($r = 0.13$)**
- **Coal Prices:** A **small positive correlation** suggests that coal prices have a marginal effect on electricity price spikes in Norway. While coal contributes to power generation, its impact is significantly lower than that of gas.
- **Temperature:** The weak positive correlation indicates that electricity prices slightly increase with higher temperatures, possibly due to increased industrial or cooling energy demand.

(4) **Weak Negative Correlation: Oil Prices ($r = -0.20$)**
- Oil prices exhibit a **small negative correlation** with electricity prices, implying that oil price fluctuations have limited direct influence on Norwegian electricity pricing.
- This suggests that Norway's electricity market is primarily driven by hydropower and gas rather than oil-based generation.

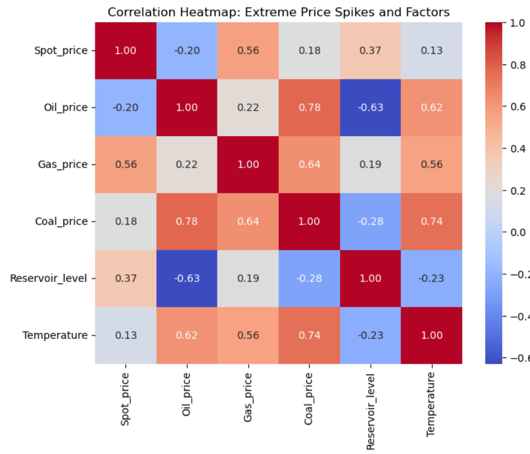

Figure 5: Correlation Heatmap: Comparing Global and Local Factors in Electricity Price Fluctuations

3.3.2 Conclusion. Gas prices have the strongest influence on electricity price spikes in Southern Norway, stressing their role as a key driver of market volatility. Energy companies should closely monitor global gas markets and implement price hedging strategies to mitigate risks associated with fluctuating gas prices. This finding aligns with previous studies indicating the dependency of electricity markets on fossil fuel price fluctuations [10].

While hydropower remains an essential stabilizing force in the Norwegian electricity market, reservoir levels do not have the most significant impact on price spikes. This suggests that external market factors, such as supply-demand imbalances and geopolitical uncertainties, may overshadow the role of hydropower storage. Coal and oil prices have a weaker correlation with electricity price spikes. While coal prices may be more relevant for long-term energy planning, oil prices appear to have a minimal direct impact on electricity spot prices in Norway due to the country's heavy reliance on hydropower and gas [11].

Temperature fluctuations have a marginal effect on electricity prices. Colder temperatures may increase electricity demand, but their influence is weaker compared to gas prices, suggesting that broader economic and geopolitical factors play a larger role in price determination.

This analysis confirms that **gas prices** are the dominant factor driving electricity price spikes in Southern Norway, surpassing local factors such as reservoir levels and temperature. Although hydropower provides long-term price stability, it is insufficient to counteract global market forces that drive extreme price fluctuations.

Since **gas prices** show the strongest correlation with electricity price spikes, while local factors have a weaker impact, we **reject the null hypothesis (H_0)** and **confirm the alternative hypothesis (H_1)**. This conclusion affirms that **global market forces**, particularly **gas prices**, are the dominant factor influencing electricity price volatility in Southern Norway.

3.4 Question 4

Null Hypothesis (H_0): The relationship between electricity spot prices and actual electricity prices in Southern Norway **has not changed significantly before, during, and after 2020.** The spot market remains a reliable predictor of actual prices.

Alternative Hypothesis (H_1): The relationship between electricity spot prices and actual electricity prices in Southern Norway **has changed significantly before, during, and after 2020.** The spot market has become a less reliable predictor of actual prices.

3.4.1 Correlation Analysis. To evaluate the strength of the relationship between spot prices and actual electricity prices, the Pearson correlation coefficient was calculated for each period.

- Before 2020: $r = 0.95$
- During 2020: $r = 0.87$
- After 2020: $r = 0.82$

These correlation values indicate that the relationship between spot prices and actual electricity prices has weakened over time, particularly after 2020.

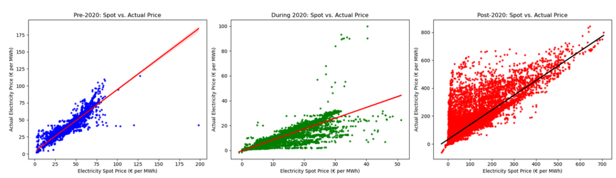

Figure 6: Scatterplots Showing the Relationship Between Electricity Spot Prices and Actual Prices Before, During, and After 2020

3.4.2 Visualization of the Relationship. The scatterplots illustrate the trend in correlation over time:

- Before 2020: A strong positive correlation with minimal dispersion suggests that actual prices closely followed spot prices.
- During 2020: A moderate weakening in correlation occurred, with increased price deviations.
- After 2020: A further decline in correlation, with greater spread in price values, indicating increased unpredictability in actual electricity prices.

A **time series analysis** of electricity sport prices before, during, and after 2020 illustrates clear changes in market volatility and price trends. The post-2020 period shows significantly higher price fluctuations, as visualized in the time series graph.

3.4.3 Mean and Standard Deviation Formulas. To further investigate price changes over time, the mean and standard deviation of electricity prices of each period were computed.

The mean (average) of a dataset is calculated as:

$$\bar{x} = \frac{\sum x_i}{n}$$

where:

- $\bar{x}$ is the mean (average value)
- x_i are the individual data points

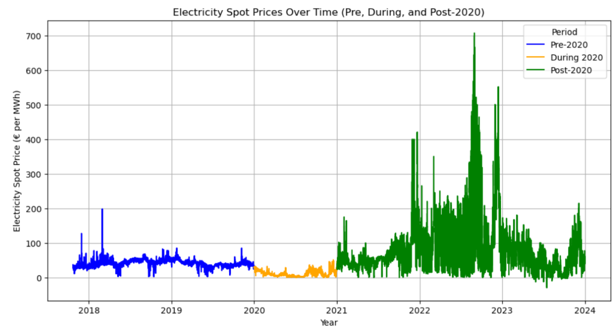

Figure 7: Time Series Analysis of Electricity Spot Prices (Pre-2020, During 2020, and Post-2020

- n is the total number of data points (sample size)

The standard deviation measures the dispersion of data points around the mean and is given by:

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

where:

- s is the sample standard deviation
- x_i are the individual data points
- $\bar{x}$ is the mean of the dataset
- n is the sample size
- $\sum (x_i - \bar{x})^2$ is the sum of squared differences from the mean

Table 4: Summary of Electricity Spot Prices Across Periods

Group	Mean ($\bar{x}$)	Standard Deviation (s)	Sample Size (n)
Pre-2020	40.56	9.70	19200
During 2020	10.93	8.25	8784
Post-2020	84.87	79.13	26280

Table 5: Two-Sample Z-Test Results for Electricity Spot Prices Before, During, and After 2020

Comparison	Z-Statistic	Critical Value	P-Value	Result
Pre-2020 vs During 2020	248.12	1.96	0.0	**H_0 Rejected**
During 2020 vs Post-2020	-87.42	1.96	0.0	**H_0 Rejected**
Pre-2020 vs Post-2020	-77.17	1.96	0.0	**H_0 Rejected**

3.4.4 Interpretation and Insights. The data indicate a sharp drop in mean electricity prices during 2020, followed by a dramatic increase post-2020. Standard deviations also increased significantly post-2020, suggesting greater price volatility.

In addition, to assess the significance of price changes, a two-sample Z-test was performed for each period comparison.

The results show that all Z-statistics are far beyond the critical value of ±1.96, leading to the rejection of the null hypothesis in all cases. This confirms that electricity spot prices have changed significantly over time, supporting the hypothesis that the spot market has become less reliable in predicting actual electricity prices.

The findings emphasize a significant shift in the relationship between electricity spot prices and actual prices. The declining correlation suggests that the spot market has become increasingly unpredictable after 2020. Several external factors appear to have contributed to this trend. First, the COVID-19 pandemic led to global economic disruptions that impacted supply chains and energy demand patterns [12]. These disruptions created financial instability within the power sector and resulted in fluctuating energy consumption trends [13].

Additionally, post-2020 market fluctuations have been influenced by factors such as fuel price volatility, geopolitical tensions, and the increased integration of renewable energy sources. The European energy crisis, exacerbated by geopolitical conflicts, particularly Russia's invasion of Ukraine, led to heightened uncertainty in electricity pricing [14].

3.4.5 Does this mean the spot market is becoming more or less reliable? The evidence strongly suggests that the spot market has become **less reliable** as a predictor of actual electricity prices. The correlation between spot and actual prices has declined from 0.95 before 2020 to 0.82 after 2020, indicating a steady weakening of predictability. Additionally, the two-sample Z-tests confirm significant changes in electricity price behavior, reinforcing the argument that external market forces have influenced price volatility.

3.4.6 Conclusion. Based on the correlation analysis, time series evaluation, and statistical testing, we **reject the null hypothesis** (H_0) and **confirm the alternative hypothesis** (H_1). The spot market has indeed become a **less reliable** predictor of actual electricity prices post-2020. This shift necessitates further research into market dynamics and potential policy interventions to address increased volatility in electricity pricing.

3.5 Question 5

- **Null Hypothesis (H_0)**: The dollar price **does not have a stronger influence** on Southern Norwegian electricity spot prices than local weather factors (temperature and precipitation).
- **Alternative Hypothesis (H_1)**: The dollar price has a stronger influence on Southern Norwegian electricity spot prices than local weather factors (temperature and precipitation).

This analysis aims to determine which factor—**Dollar prices** or **local weather conditions (Temperature & Precipitation)**—has a stronger influence on **Southern Norwegian electricity spot prices**.

Variable	Correlation Coefficient (r)	Strength of Relationship
Dollar Price	0.3555	Moderate Positive
Temperature	-0.0661	Weak Negative
Precipitation	-0.0627	Weak Negative

Table 6: Correlation Between Electricity Spot Prices and External Factors

The Table 6 shows the result of the Pearson correlation coefficient. In indicates that the dollar price has a **moderate positive correlation** ($r = 0.3555$) with electricity spot prices which means that as the dollar price increases, electricity spot prices also tend to rise.

In contrast, temperature ($r = -0.0661$) and precipitation ($r = -0.0627$) have **weak negative correlations** with electricity prices, suggesting that local weather factors have little impact on spot price fluctuations.

3.5.1 Visualization of the Relationship. Figure 8 presents a **heatmap** showing the correlation values between electricity spot prices, the dollar price, and local weather factors.

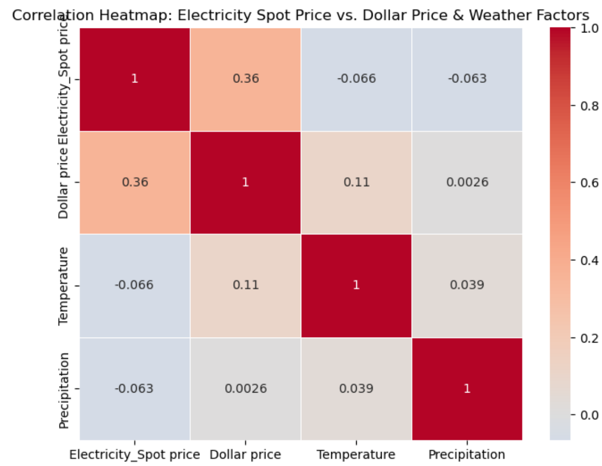

Figure 8: Correlation Heatmap: Electricity Spot Price vs. Dollar Price & Weather Factors

The heatmap illustrates that the dollar price has a stronger influence on electricity spot prices ($r = 0.3555$) compared to local weather factors like temperature ($r = -0.0661$) and precipitation ($r = -0.0627$). This suggests that fluctuations in the dollar price are more closely linked to electricity price changes, likely due to its impact on the cost of imported energy and fuel. In contrast, weather-related factors show weak correlations, indicating a lesser role in short-term price volatility.

To further analyze the influence of each factor, the **Spearman Rank Correlation** was computed and visualized in a **pie chart**. This result emphasizes relative contributions:

- **Dollar Price (41.9%)** exhibits the strongest influence, reinforcing the conclusion that global economic factors drive electricity pricing trends.
- **Precipitation (30.9%)** has a moderate impact, reflecting the role of hydropower in Norway's energy sector.
- **Temperature (27.1%)** affects electricity prices but to a lesser extent than the dollar price and precipitation.

3.5.2 Insights. Both Pearson correlation and Spearman Rank Correlation confirm that the dollar price has a stronger influence on electricity spot prices than local weather factors. However, the Spearman Rank Correlation provides additional insight by quantifying the relative contribution of each factor in a nonlinear setting, which the pie chart effectively visualizes. The consistency between both methods strengthens the conclusion that electricity prices in

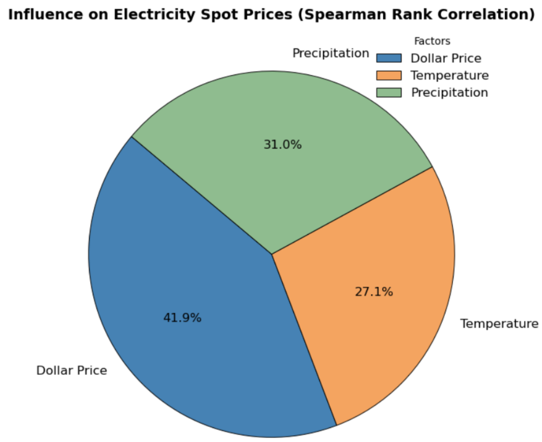

Figure 9: Pie Chart Representation of Spearman Rank Correlation Contributions

Southern Norway are more sensitive to macroeconomic variables (exchange rates and energy trade) than meteorological conditions.

3.5.3 Conclusion. The analysis confirms that **macroeconomic factors, particularly the U.S. dollar exchange rate, have a stronger influence on electricity spot prices in Southern Norway than local weather conditions**. The **moderate positive correlation** between the dollar price and electricity spot prices suggests that fluctuations in exchange rates impact energy costs, likely due to Norway's reliance on imported fuels and global market integration. In contrast, **temperature and precipitation exhibited weak negative correlations**, indicating that short-term weather variations have minimal direct effects on electricity price fluctuations.

The **Spearman Rank Correlation analysis further supports this**, with the **dollar price contributing 41.9% to electricity price variations**, while **precipitation (30.9%) and temperature (27.1%)** played smaller roles. This suggests that while hydropower remains a critical energy source, its immediate impact on price fluctuations is overshadowed by global economic conditions.

Overall, based on the statistical analysis, the **null hypothesis** (H_0) is **rejected**, and the **alternative hypothesis** (H_1) is **confirmed**, indicating that **macroeconomic factors**—such as dollar price, exchange rates, fuel prices, and global trade conditions—contribute more to electricity price volatility than meteorological conditions. The results highlight that the Southern Norwegian electricity market is more sensitive to external economic trends than to localized weather fluctuations.

4 Discussion

The analysis of electricity price fluctuations in Southern Norway highlights the dynamic interplay between hydropower availability, global commodity markets, and market volatility. While hydropower remains the dominant energy source, the influence of global fuel prices, particularly gas, has increased significantly, making Norway's electricity market more sensitive to external economic conditions [8].

Hydropower stabilizes electricity prices, yet fluctuations in reservoir levels introduce price volatility. During periods of low reservoir levels, reliance on gas-fired power generation increases, driving up electricity costs [8]. This aligns with findings from Nord Pool, which indicate that electricity imports from European markets become necessary during hydropower shortages, further influencing price surges [15]. Similarly, Statnett's power flow analysis confirms that hydropower fluctuations affect cross-border electricity trading, impacting overall price stability [15].

Although surplus hydropower can lower electricity prices, market constraints limit its efficiency. For instance, Norway's record-high hydropower reserves in 2020 did not prevent price fluctuations due to export limitations and strong wind power production in neighboring countries [16]. This highlights the challenge of integrating surplus energy into broader market mechanisms.

Electricity prices show a strong correlation with global gas prices, with moderate effects from coal prices. Gas price fluctuations significantly impact electricity costs, particularly when hydropower reserves are low [17]. The European energy market's dependence on fossil fuels and geopolitical uncertainties, such as those affecting Dutch TTF gas futures, further amplify price volatility [10]. Coal prices, while secondary, still contribute to overall pricing trends, especially when European coal-fired plants operate at higher capacities during hydropower shortages [18].

Post-2020, the correlation between electricity spot prices and actual prices has weakened, reducing the spot market's reliability as a predictor of consumer electricity costs. The 2020 hydropower surplus demonstrated this shift, as prices did not solely reflect local hydropower availability but were instead shaped by global trade constraints, fuel costs, and energy market instability [16]. These findings emphasize the need for new forecasting models that incorporate both local and global factors.

Surprisingly, weather conditions such as temperature and precipitation exhibit weak correlations with electricity prices. Despite expectations that hydropower generation would be directly influenced by rainfall, statistical analysis indicates that macroeconomic and geopolitical factors have a far greater impact [19]. Even in years with extreme precipitation, electricity prices continued to follow global fuel price movements rather than local hydrological changes [16].

Limitations: This study is based on historical data, limiting its predictive power regarding future market trends, especially under evolving energy policies or economic shifts. While correlation analysis identifies statistical relationships, it does not establish causation, necessitating further econometric modeling for deeper insights. Additionally, the study relies on aggregated regional data, which may not capture localized variations in electricity demand and production.

5 Conclusion

To put it briefly, this study explored the key factors driving electricity price fluctuations in Southern Norway, particularly the influence of global economic trends compared to local weather conditions. The findings indicate that while hydropower remains a crucial stabilizing factor, macroeconomic variables—especially the U.S. dollar exchange rate—have a stronger correlation with electricity spot prices than temperature and precipitation. The results from

Spearman Rank Correlation suggest that exchange rate fluctuations play a more significant role (41.9%) in price variations compared to weather-related factors such as precipitation (30.9%) and temperature (27.1%). These findings align with research on Norway's growing exposure to international energy markets and exchange rate dependencies [15, 8].

The relationship between reservoir levels and electricity prices was also evident. When hydropower availability is high, electricity prices remain relatively stable. However, during periods of low reservoir levels, reliance on gas-fired power generation increases, leading to greater price volatility. This pattern has been observed in Nord Pool data, which stresses price surges during hydropower shortages that require increased electricity imports from European markets [8]. Similarly, Statnett has reported that fluctuations in hydropower reserves affect cross-border electricity trading and overall market stability [15]. These findings suggest that Norway's electricity prices are not only shaped by domestic hydropower conditions but also by external market forces.

One of the key takeaways from this report is that traditional forecasting models focusing only on meteorological variables may no longer be sufficient for predicting electricity price movements. Instead, incorporating macroeconomic indicators—such as fuel prices,dollar prices, exchange rates, and global energy market dynamics—could improve forecasting accuracy. This aligns with recommendations from previous studies emphasizing the need for multi-factor energy price prediction models in volatile markets [9].

From a policy perspective, these findings highlight the importance of risk mitigation strategies for electricity price stability. Policymakers could explore measures such as hedging mechanisms against fuel price volatility, strengthening cross-border energy agreements, and investing in energy storage solutions to reduce dependence on short-term electricity imports. While Norway's hydropower system provides long-term stability, its limitations during dry periods indicate a need for diversification in energy planning. The International Energy Agency (IEA) has suggested that integrating renewable energy storage solutions alongside hydropower could enhance resilience in energy markets [10].

From a data-driven perspective, this research highlights the importance of statistical techniques such as correlation analysis and hypothesis testing in understanding electricity price fluctuations. However, as correlation does not establish causation, future studies could explore more advanced predictive methods, such as regression analysis, machine learning, and time-series forecasting, to better capture trends and dependencies in energy pricing.

These methods have been widely recognized in electricity price prediction research. For instance, Weron (2014) discusses how statistical and machine learning models, particularly time-series forecasting techniques, play a crucial role in energy price modeling [20]. Expanding on such approaches in future research could improve predictive accuracy and provide deeper insights into the complex dynamics of electricity pricing.

As Norway's electricity market becomes more interconnected with global financial and energy systems, future research should continue examining the evolving relationship between macroeconomic factors, energy trade policies, and hydropower variability. By integrating both economic and environmental insights, market participants, policymakers, and researchers can develop more effective strategies to manage electricity price fluctuations and ensure long-term energy security.

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