ANALYZING SEASONAL AND SECTORAL ELECTRICITY CONSUMPTION TRENDS IN SWEDEN

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ABSTRACT

This study investigates electricity consumption trends across sectors in Sweden from 1990 to 2024, with a focus on sectoral variations, seasonal influences, and the relationship between domestic consumption and electricity exports in summer. The analysis reveals an overall upward trend, with the residential sector exhibiting the highest consumption due to seasonal heating demands, whereas energy-intensive sectors, such as electricity, gas, heat, and water plants, show a decline, which reflects improved efficiency and renewable energy adoption. Seasonal analysis, supported by the Seasonality Strength Index (SSI), highlights the residential sector's sensitivity to seasonal changes, while industrial sectors remain relatively stable. Furthermore, the study identifies a weak negative correlation between domestic consumption and exports, suggesting that Sweden could leverage surplus energy for export during periods of low domestic demand. These insights inform energy planning and policymaking, supporting Sweden's transition to sustainable energy.

KEYWORDS

Electricity Consumption Trends, Sectoral Analysis, Seasonal Variations, Compound Annual Growth Rate, Correlation

1 INTRODUCTION

Electricity consumption is a crucial indicator of economic activity, energy efficiency, and environmental sustainability. In Sweden, a global leader in renewable energy, understanding how electricity consumption changes across sectors and how seasonal variations influence usage is essential for sustainable energy planning [10] . Over the past few decades, Sweden has seen significant changes in its electricity consumption patterns. This study examines the electricity consumption trends in Sweden from 1990 to 2024, focusing on long-term patterns, seasonal variations, and the relationship between domestic consumption and exports during the summer. By analyzing sector-specific data, this study aims to understand how different sectors contribute to overall consumption and how seasonal changes influence demand, which provides valuable insights for energy planning and policymaking.

Using a comprehensive dataset, the study applies analytical techniques such as the CUSUM (Cumulative Sum Control Chart) test for trend analysis [8], the Compound Annual Growth Rate (CAGR) to assess sectoral growth [3], and the Seasonality Strength Index (SSI) to quantify seasonal effects, along with correlation analysis to explore the domestic-export relationship during summer. The study examines the contribution of each sector to total electricity consumption with a focus on energy-intensive sectors, such as electricity, gas, heat, and water plants. Seasonal variations, particularly during winter and summer months, are also considered to understand how these seasonal changes affect consumption. By identifying important trends and patterns, this research helps policymakers create effective strategies, improve energy distribution, and make the energy grid stronger. Additionally, understanding how domestic consumption and exports are connected allows Sweden to use its extra energy during times of low demand, supporting both economic growth and environmental sustainability.

2 BACKGROUND/RELATED WORK

2.1 Electricity Consumption Patterns Across Sectors

Electricity consumption patterns across different sectors have been extensively studied to understand consumption behaviour and identify factors influencing demand variability. Research has shown that the residential sector is typically the largest consumer of electricity, with consumption influenced by factors like household size, energy efficiency, and climate [4]. In comparison, sectors such as railways, trams, and manufacturing show distinct consumption patterns influenced by operational hours and industrial activity [9]. Understanding these sectoral differences is crucial for developing targeted energy policies and optimizing energy use across sectors.

2.2 Seasonality in Electricity Consumption

Seasonal variations significantly influence electricity consumption patterns across various sectors. In the residential sector, electricity usage often peaks during summer and winter months due to increased demand for air conditioning and heating [5]. Studies have shown that temperature fluctuations directly impact electricity demand, with higher consumption observed during extreme weather conditions. Research also highlights that interannual climate variability plays a substantial role in explaining observed fluctuations in electricity usage [1], emphasizing the sensitivity of power consumption to seasonal changes.

The use of the Seasonality Strength Index (SSI) is common for quantifying seasonal effects on consumption, helping to identify the strength of seasonality across different sectors. Recent advancements in seasonal forecasting models, particularly those incorporating machine learning techniques like Long Short-Term Memory (LSTM) networks and hybrid models, have enhanced the precision of electricity demand predictions across various seasons [2]. These models help grid operators and policymakers allocate resources efficiently and maintain stability by anticipating demand fluctuations, highlighting the need to consider seasonal variations in energy production and distribution for reliable and efficient responses.

2.3 Analytical Techniques for Electricity Consumption Analysis

Various analytical techniques are employed to understand electricity consumption patterns and identify underlying trends. One common method is the use of time series analysis, which helps in identifying temporal patterns, seasonal variations, and long-term trends in electricity usage [6]. The CUSUM (Cumulative Sum) test is widely used for detecting shifts in consumption trends over time [8]. Additionally, compound annual growth rate (CAGR) is employed to assess the rate of change in electricity consumption across sectors or regions over a specific period [3]. Time series analysis is particularly suitable for electricity consumption analysis due to its ability to capture temporal dependencies, seasonal fluctuations, and long-term trends effectively.

3 RESEARCH QUESTION

How has electricity consumption evolved over time across different sectors in Sweden, and how do seasonal variations influence sectoral electricity usage?

4 METHODOLOGY

4.1 Overview of the Research Approach

This study employs a quantitative analysis approach to evaluate electricity consumption trends across sectors in Sweden, focusing on long-term trends, seasonal variations, and the relationship between domestic consumption and exports. The methodology involves preprocessing the data, applying statistical and computational techniques to analyze the trends and seasonal impacts, and exploring the relationship between domestic consumption and exports during summer months. The results provide insights into sectoral consumption patterns, seasonal influences, and the trade-offs between domestic consumption and exports.

4.2 Dataset and Preprocessing

The dataset used in this study, titled "Electricity consumption by usage area. Monthly 1990M01 - 2024M12", was sourced from the Statistics Sweden (SCB) database [7]. This dataset provides monthly electricity consumption data from January 1990 to December 2024, categorized by usage areas such as mining and manufacturing, electricity, gas, heat and water plants, railway, trams and bus traffic, exports, residential and other services. The dataset was selected for its comprehensive coverage of sectoral electricity consumption over a long time period, making it suitable for analysing trends and seasonal variations.

To prepare the data for analysis, months were categorized into seasons based on the meteorological definition of seasons in Sweden:

- Winter: December (12), January (1), February (2)
- Spring: March (3), April (4), May (5)
- Summer: June (6), July (7), August (8)
- Autumn: September (9), October (10), November (11)

4.3 Data Analysis Techniques

The following quantitative analysis techniques are applied for the analysis:

• Trend Analysis Using CUSUM Test: The CUSUM (Cumulative Sum Control Chart) test was performed to detect the structural breaks or significant shifts in total electricity consumption patterns over time. A time-series plot was generated to visualize the results.

• In Sectoral Analysis, a bar graph was plotted to show average electricity consumption for each sector. The Compound Annual Growth Rate (CAGR) was calculated to evaluate the long-term trends in sectoral consumption [3].

$$\text{CAGR} = \left(\frac{\text{End Value}}{\text{Start Value}}\right)^{\frac{1}{\text{Years}}} - 1$$

Additionally, the contribution of plants (electricity, gas, heat, and water plants) to total electricity consumption was analyzed, revealing that the contribution of this sector had decreased over time. A 12-month moving average was plotted for this sector to visualize its decreasing contribution overtime.

• In Seasonal Analysis, a grouped bar graph was plotted to show the average electricity consumption across seasons for each sector. The Seasonality Strength Index (SSI) was computed to quantify the strength of seasonal effects for each sector. This index was useful in identifying which sectors experienced significant fluctuations in electricity consumption compared to others.

• The relationship between domestic consumption and exports was analyzed using T-test and Mann-Whitney U-test to compare mean exports during high and low domestic consumption periods and to measure the correlation, Pearson and Spearman Correlation was used.

5 RESULTS

5.1 Overall Electricity consumption trend

The CUSUM test was performed to detect significant shifts in total electricity consumption patterns over time [8]. The results are visualized in Figure 1, the plot reveals an overall increasing trend in electricity consumption from 1990 to 2024, despite some fluctuations.

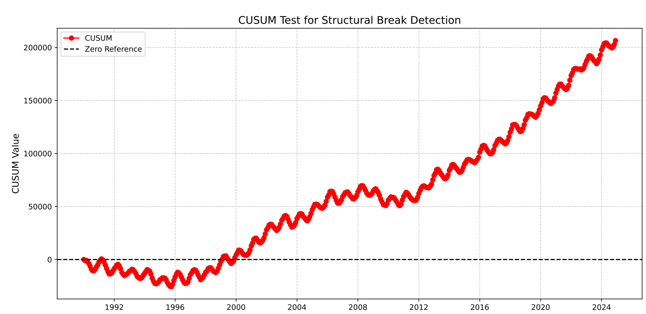

Figure 1: CUSUM Test for Overall Electricity Consumption Trend.

5.2 Sectoral Analysis

A bar graph of average electricity consumption by each sector was plotted to observe sectoral contributions, as shown in Figure 2. The residential sector had the highest average consumption, followed by mining and manufacturing. The Compound Annual Growth

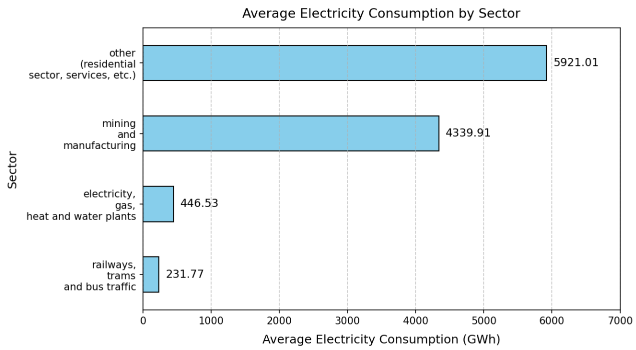

Figure 2: Sectoral Electricity Consumption Analysis

Rate (CAGR) was calculated to evaluate long-term trends in sectoral consumption. The CAGR values indicate whether a sector's electricity consumption has increased or decreased over time.

Interpretation of CAGR:

- Residential Sector (+0.68%): Indicates a steady **increase** in electricity consumption over time.
- Railways, Trams, and Bus Traffic (+0.53%): Suggests **moderate growth** in electricity usage within the transportation sector.
- Mining and Manufacturing (-0.54%): Reflects a **gradual decline** in electricity consumption in industrial operations.
- Electricity, Gas, Heat, and Water Plants (-1.96%): Represents a significant **decrease** in electricity usage in this sector.

In addition, the contribution of electric, gas, heat, and water plants to total electricity consumption was analyzed. A 12- month moving average was plotted, as shown in Figure 3, revealing a decreasing contribution over time.

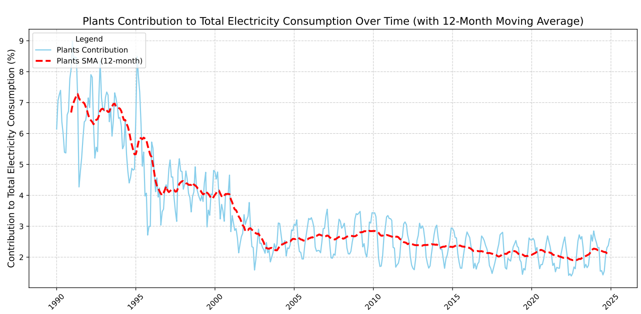

Figure 3: Contribution of Power Plants Over Time

5.3 Seasonal Analysis

To examine the role of seasonality, the Seasonality Strength Index (SSI) was calculated for each sector, along with a grouped bar graph to show the average electricity consumption for each sector between seasons, as shown in Figure 4.

The residential sector exhibits strong seasonal variations, with higher consumption in winter and lower in summer. The mining and manufacturing sector showed the least seasonal variation.

The Seasonality Strength Index (SSI) for each sector:

- Residential sector: SSI = 0.83 indicates **strong seasonality.**
- Electricity, Gas, Heat, and Water Plants: SSI = 0.70 indicates **moderate seasonality.**
- Railways, trams, and bus traffic: SSI = 0.56 indicates **moderate seasonality.**
- Mining and Manufacturing: SSI = 0.28 indicates **weak seasonality.**

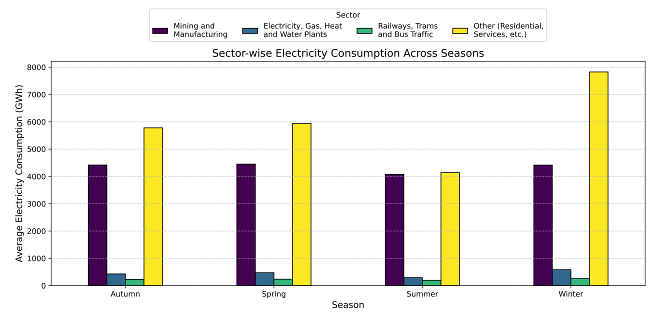

Figure 4: Seasonal Distribution of Electricity Consumption

5.4 Domestic Consumption and Exports Relationship in Summer

Using T-test, Mann-Whitney U-test, Pearson Correlation, and Spearman Correlation, the relationship was analyzed. The results are summarized below:

- Mean Exports (Low Domestic Consumption): 2098.04 GWh
- Mean Exports (High Domestic Consumption): 1731.19 GWh
- T-test p-value: 0.039
- Mann-Whitney U-test p-value: 0.044

The mean exports during periods of low domestic consumption were significantly higher than during high domestic consumption. The p-values for both tests were less than 0.05, indicating that the difference in exports between high and low domestic consumption periods is statistically significant. This suggests that when domestic consumption is lower during summer, exports tend to increase. The lower domestic demand may free up electricity for export. Correlation Analysis:

- Pearson Correlation Coefficient: -0.23
- Spearman Correlation Coefficient: -0.24

Both correlation coefficients indicate a weak negative relationship, this means that as domestic consumption decreases, exports tend to increase slightly, but the relationship is not strong.

6 DISCUSSION

6.1 Analysis

The findings reveal an overall increasing trend in electricity consumption, as indicated by the CUSUM test, despite sectoral variations. The residential sector showed highest average consumption, reflecting increased energy use for heating and household appliances. In contrast the electricity, gas, heat, water plants sector exhibited a significant decline, likely due to improved efficiency and renewable energy adoption. Seasonal trends were particularly evident in residential sector, with consumption peaking in winter, while transport and industrial usage remained relatively stable. Correlation analysis indicated a moderate inverse relationship between domestic consumption and exports, with exports increasing slightly when domestic consumption was lower during the summer months.

6.2 Seasonal and Sectoral Insights

The residential sector's strong seasonal variations highlight the need for demand-side management strategies, such as incentivizing energy-efficient heating systems and promoting off-peak energy use. The decline in energy-intensive sectors like electricity plants and mining reflects progress towards sustainability, but the overall increase in consumption underscores the need for continued efforts to promote renewable energy and efficiency. The relationship between domestic consumption and exports suggests that Sweden can use its energy surplus during low-demand periods to support international markets, thereby contributing to global energy security and economic growth.

6.3 Ethical and Societal Implications

The growing demand in the residential sector raises concerns about energy equity, as increased consumption may lead to higher costs for vulnerable populations. While the decline in energy-intensive sectors reflects progress towards reducing emissions, the overall consumption increase highlights the need for sustainability efforts. The domestic consumption-export relationship offers economic benefits, but ethical considerations must ensure that exports do not compromise domestic energy security or disproportionately benefit specific groups.

6.4 Threats to Validity

While the dataset provided valuable insights, the analysis is based on historical data and may not fully capture future trends influenced by emerging technologies or policy changes. The analysis does not account for external factors such as economic conditions, policy shifts or energy prices, which could influence consumption trend. Additionally, although the Seasonality Strength Index (SSI) quantified seasonality, it does not capture finer details such as extreme weather events.

7 FUTURE WORK

To build on this study, future research could:

- Explore the role of external factors, such as economic conditions, energy prices, and policy changes, in shaping electricity consumption trends, providing a more comprehensive understanding of consumption drivers.
- Analyze the impact of extreme weather events on seasonal electricity consumption, particularly in the residential sector, to improve grid resilience and energy planning.
- Develop predictive models to forecast future consumption patterns and inform energy policy decisions, considering emerging technologies like smart grids, energy storage, and electric vehicles.

8 CONCLUSION

This report has examined the evolution of electricity consumption in Sweden, identifying key sectoral and seasonal trends. Despite fluctuations across sectors, overall consumption has increased, with the residential sector showing the highest consumption during winter months due to heating demands. In contrast, energy-intensive sectors such as electricity, gas, heat, and water plants have experienced a decline, reflecting advancements in energy efficiency and the adoption of renewable energy sources. The decline in energy-intensive sectors signals progress toward sustainability, but the overall rise in consumption underscores the need for continued efforts to enhance renewable energy integration and energy efficiency. Seasonal variations were most significant in the residential sector, while industrial sectors like mining and manufacturing remained relatively stable throughout the year. The study also revealed a weak negative correlation between domestic consumption and electricity exports, with exports slightly increasing during summer when the domestic consumption decreases. However, this inverse relationship is not strong, suggesting that while surplus energy during low-demand periods can be utilized for export, the impact is limited. These insights contribute to a clearer understanding of Sweden's electricity consumption patterns, offering valuable guidance for policymakers and energy planners in shaping sustainable energy strategies.

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