ElectroAnalytica: A Comprehensive Analysis of Electricity Consumption, Rates, and Electric Vehicles Purchase across all US regions from 2016-2021

Abdur Rahman
New York University
New York
United States
ar7165@nyu.edu

Sanjana Nambiar
New York University
New York
United States
svn9705@nyu.edu

Saamia Shafqat
New York University
New York
United States
ss14758@nyu.edu

Abstract: In an era marked by rapid technological advancements and growing environmental concerns, understanding the interplay between electricity pricing, electric vehicle (EV) adoption, and electricity consumption is more critical than ever. This study delves into these dynamics across the United States from 2016 to 2021, a time frame witnessing significant shifts in energy policies and consumer behaviors toward sustainable practices. The primary objective is to unravel how electricity pricing impacts EV adoption and how these factors collectively influence regional electricity consumption patterns. Employing big data analytics, we thoroughly processed and analyzed extensive datasets, which included regional electricity rates, EV registration records, and electricity consumption data. The study's design involved rigorous data cleaning and transformation to ensure the accuracy and reliability of our analysis. This study aims to uncover the relationship between electricity demand and EV adoption, which varies significantly across different regions. Our findings reveal pronounced regional variations in electricity pricing, demand, and EV adoption rates. The study's conclusions offer valuable insights for stakeholders, including policymakers, energy providers, and automotive manufacturers. The identified trends and patterns underscore the necessity for integrated and informed strategies that support sustainable transportation and energy consumption, considering the evolving market conditions and technological advancements. This research contributes significantly to the discourse on sustainable energy and mobility, highlighting the importance of harmonizing energy policies with consumer and market trends.

Keywords: Electricity Pricing, Electric Vehicle Adoption, Energy Consumption Patterns, Sustainable Energy, Big Data Analytics, United States Energy Trends

1 Introduction: The transition towards sustainable energy sources and practices is a defining challenge of our time. This study examines a crucial aspect of this transition: the relationship between electricity pricing, electric vehicle (EV) adoption, and electricity consumption in the United States from 2016 to 2021. This period is particularly noteworthy due to the accelerated development in EV technology, alongside substantial shifts in energy policies and consumer attitudes towards sustainable practices. By examining these years, the study captures a critical phase in the evolution of energy consumption and transportation electrification.

The relevance of this research lies in its direct implications for environmental sustainability, economic growth, and the formulation of energy policies. As global efforts intensify to combat climate change, understanding the factors that drive sustainable energy practices becomes paramount. This study sheds light on the potential of electricity pricing strategies to influence EV adoption, a crucial element in reducing carbon emissions and transitioning to cleaner energy sources. Additionally, the research provides insights into how these factors collectively shape regional electricity consumption patterns, offering valuable information for energy providers, policymakers, and stakeholders in the automotive industry.

Prior to our investigation, understanding the interplay between electricity pricing, EV adoption, and electricity consumption across the entire US remained an area of ongoing research. While prior studies have explored these relationships individually and regionally, a comprehensive analysis encompassing all US regions was lacking.

Here is what we know about the individual factors and their potential interactions based on existing research:

Electricity Pricing:

- Numerous studies have established a connection between gasoline prices and EV adoption, with studies like "Energy Prices and Electric Vehicle Adoption" by Rapson (2022) highlighting a roughly four to six times stronger influence of gasoline prices compared to electricity prices.
- However, the impact of electricity pricing on EV adoption remains a subject of debate. Some studies, like "Can Electricity Pricing Leverage Electric Vehicles and Battery Storage to Integrate High Shares of solar photovoltaics?" by Kannan et al. (2020), have found limited evidence of a direct link, while others, like "Do Electricity Prices Affect Electric Vehicle Adoption?" by Davis and Knittel (2019), suggest a potential influence depending on factors like charging infrastructure availability.

EV Adoption:

- The rapid growth of EV technology in recent years has been well documented, with studies like "Global EV Outlook 2023" by the International Energy Agency (IEA) highlighting a significant increase in EV sales and infrastructure development.
- However, EV adoption rates vary substantially across regions, influenced by factors like government incentives, charging infrastructure availability, and consumer preferences.

Electricity Consumption:

- Studies like "Electricity Consumption Trends in the United States" by the U.S. Energy Information Administration (EIA) have identified various factors impacting electricity consumption, including economic activity, population growth, and weather patterns.
- The increasing adoption of EVs is anticipated to influence national and regional electricity consumption patterns, but the precise nature of this impact remains a subject of ongoing research.

Existing Gaps in Knowledge:

- Limited research on the combined influence of electricity pricing, EV adoption, and regional variations: While studies have explored individual factors, a comprehensive analysis encompassing all three elements and spanning various US regions was lacking.
- Need for data-driven insights: Existing research relied mainly on theoretical models and limited datasets, highlighting the need for a large-scale study utilizing big data analytics to capture the complex dynamics at play.
- Lack of understanding of the dynamic interplay between these factors over time: Existing studies often focused on static snapshots, leaving the temporal evolution of these relationships unclear.

Our study aimed to address these gaps by employing big data analytics and analyzing comprehensive datasets. This enabled us to provide a more nuanced and data-driven understanding of the complex interplay between electricity pricing, EV adoption, and regional electricity consumption patterns, contributing significantly to the existing knowledge base on sustainable energy and mobility.

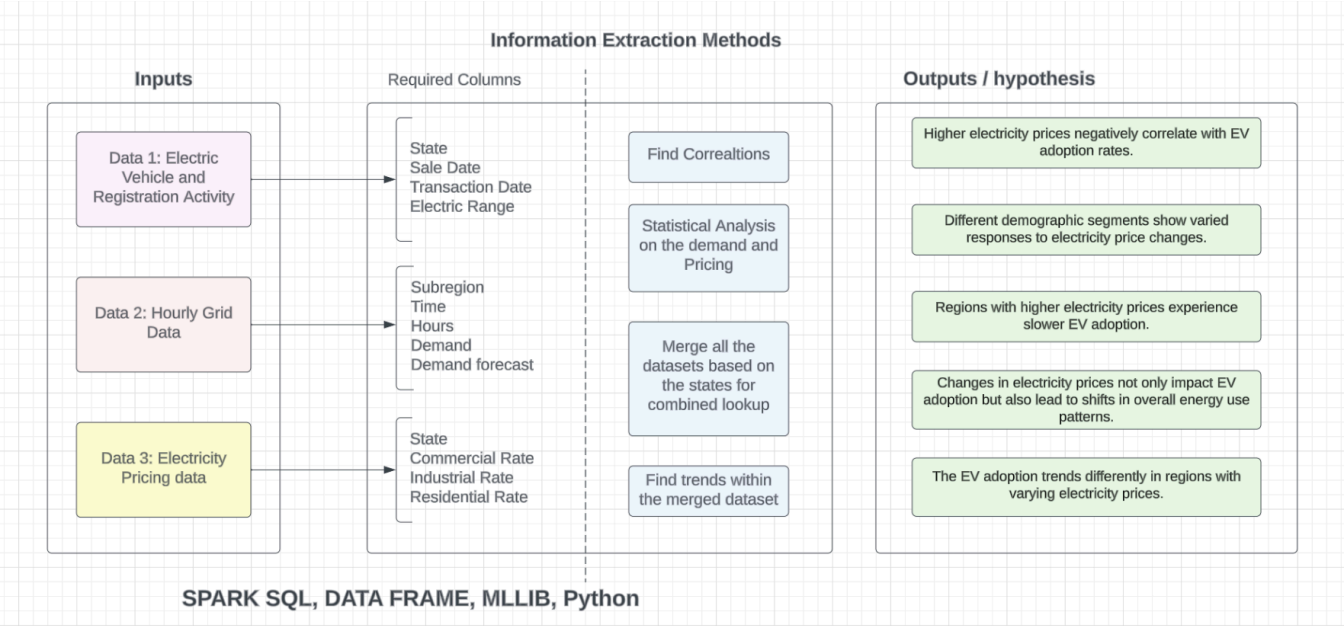


Figure 1: Data Flow Diagram of our Analysis

Figure 1 depicts a data flow diagram to elucidate the methodology of our study. This diagram, as attached above, serves as a visual representation of the data processing and analysis workflow, highlighting the data sources, the key information extraction methods applied, and the resultant outputs that feed into our hypothesis.

The DFD has three main inputs:

- Electricity rates: This data includes the commercial, residential, and industrial electricity rates for each US state from 2016 to 2021.
- EV registration records: This data includes the EV registrations in each US state from 2016 to 2021.
- Electricity consumption data: This data includes the electricity consumption for each US region from 2016 to 2021.

The 'Outputs / Hypothesis' section of the diagram presents our initial hypotheses based on the extracted data:

- Higher electricity prices may have a negative correlation with EV adoption rates, as suggested by the preliminary trends observed in our data.
- We anticipate discovering demographic variations in response to electricity price changes, implying that different consumer segments may react differently to such economic signals.
- We expect to find that regions with higher electricity prices may experience slower EV adoption rates, indicating that pricing is a significant factor in consumer decision-making.
- We predict that changes in electricity pricing will not only impact EV adoption but also lead to broader shifts in overall energy use patterns.
- Lastly, we hypothesize that EV adoption trends will differ across regions with varying electricity prices, which may suggest the need for region-specific policies and strategies.

By integrating the DFD into our study, we aim to provide a clear and structured approach to analyzing complex datasets. The visual aid helps in understanding the logic and sequence of operations that lead from raw data to

insightful conclusions. This structure is pivotal in ensuring that our analysis is both replicable and transparent, allowing for further research based on our methodology.

2 Motivation:

The motivation behind undertaking this research paper stems from a critical gap in the current literature. While individual analyses of electricity pricing, electric vehicle (EV) adoption, and consumption patterns are available, there is a notable gap in comprehensive studies that interconnect these datasets. With the rising trend of Electric Vehicles and heightened awareness of the greenhouse effect, there is a discernible shift towards cleaner modes of transportation. In this context, it becomes imperative to delve deeper into the intricate relationships and trends among electricity pricing, EV adoption rates, and electricity consumption behaviors. The insights derived from this study are not only crucial for individuals seeking a comprehensive understanding of the evolving energy landscape but also hold significant implications for energy providers, policymakers, and stakeholders involved in shaping sustainable energy strategies. By bridging this analytical gap, the research aims to contribute valuable knowledge that can inform strategic decisions in the face of dynamic energy models.

3 Related Work:

3.1 Electricity Pricing

In recent years, several studies have investigated the relationship between electricity pricing and various factors, including consumer behavior, demand response, and Electric Vehicle Adoption.

1. "Energy Prices and Electric Vehicle Adoption" by Rapson (2022)

This paper examines the relationship between energy prices (gasoline and electricity) and electric vehicle (EV) adoption rates in California from 2014 to 2017. The authors use a panel data approach and find that gasoline prices have a significantly stronger impact on EV adoption than electricity prices. Specifically, a 1% increase in gasoline prices leads to a 0.25% increase in EV registrations, while a 1% increase in electricity prices leads to a 0.04% decrease in EV registrations. The study suggests that consumers are more sensitive to changes in gasoline prices than electricity prices when making decisions about vehicle purchases.

2. "Do Electricity Prices Affect Electric Vehicle Adoption?" by Davis and Knittel (2019)

This paper investigates the relationship between electricity prices and EV adoption in the United States using a difference-in-differences approach. The authors exploit variations in electricity prices across states and over time to identify the causal effect of electricity prices on EV adoption. They find that electricity prices have a small negative impact on EV adoption, but the effect is statistically significant only for certain groups of consumers, such as those with higher incomes and who live in urban areas. The study suggests that the impact of electricity prices on EV adoption is likely to vary depending on individual circumstances and the availability of charging infrastructure.

3. "Demand Response and Electricity Market Design" by Borenstein (2005)

This paper provides a theoretical framework for analyzing the role of demand response in electricity markets. Demand response refers to the ability of consumers to adjust their electricity consumption in response to changes in price or other signals. The author argues that demand response can play a valuable role in improving the efficiency of electricity markets and reducing the need for expensive investments in new power generation capacity. The paper discusses various mechanisms for implementing demand response programs, such as time-of-use pricing and interruptible service programs.

3.2 EV Adoption

1. "EV Adoption Trends: Not as Simple as Current Dealer Inventory Might Suggest" (2023)

   In the paper titled "EV Adoption Trends: Not as Simple as Current Dealer Inventory Might Suggest," the authors discuss the trends related to electric vehicle (EV) adoption. The study highlights the following points:

   - Growing Interest: EV sales have increased significantly, accounting for 8.2% of new vehicle sales through October 2023. The number of consumers considering an EV for their next purchase or lease has also risen to 29.2%.
   - Market Segments: While EV adoption is on the rise, there is still a lack of viable options in mass market segments. Mainstream compact SUVs have low EV penetration (only 6%), whereas compact premium SUVs see higher adoption rates (nearly 50%).
   - Unique Challenges: Selling EVs takes longer due to factors like charging infrastructure, range anxiety, and extreme weather performance.

   In summary, the paper emphasizes the need for broader EV availability and affordability to drive mass adoption.

2. "Most Americans Are Not Completely Sold on Electric Vehicles" by Megan Brenen (2023)

   In the Gallup poll titled "Most Americans Not Sold on Electric Cars," the findings reveal that electric vehicle (EV) adoption in the United States remains relatively slow:

   - Current Ownership: Only 4% of U.S. adults currently own an electric vehicle, while 12% are seriously considering purchasing one.
   - Future Consideration: 43% of adults say they might consider buying an EV in the future, but 41% unequivocally state that they would not.
   - Generational and Political Divide: The adoption of electric cars shows a generational and political divide. While the Biden administration proposes policies to increase EV uptake, some Republicans argue that these policies may make vehicles more expensive and impact U.S. energy security12.

   In summary, despite growing interest and potential benefits, a significant portion of Americans remain hesitant about fully embracing electric vehicles.

3.3 Electricity consumption

Electricity consumption is influenced by various factors such as economic, demographic, technological, climatic, and policy aspects. Understanding these factors is crucial for managing energy resources efficiently and transitioning to a sustainable future. Some of the studies exploring electricity consumption, focusing on trends, drivers, and potential solutions.

1. BP's Global Energy Statistics (2023)

This annual report provides comprehensive data and analysis of global energy consumption, including electricity. It reveals a significant upward trend in global electricity consumption, driven primarily by economic growth, population increase, and urbanization

2. The Future of Electricity Consumption by IEA (2022)

This report by the International Energy Agency explores future projections for global electricity consumption. It emphasizes the role of technological advancements, policy interventions, and socio-economic changes in shaping future electricity demand.

3. The Economics of Electricity Consumption: A Literature Review by CDES (2022) by Dr. V. Raju

This paper, published in the Journal of Development Economics and Management Research Studies (JDMS) by the Center for Development Economic Studies (CDES), provides a comprehensive review of the economic aspects of electricity consumption in India. The review discusses the impact of various factors on electricity consumption, such as the use of electronic gadgets, income level, choice of connection, size of houses, and climate change. It also addresses the dynamics between economic development and energy consumption, highlighting the potential for efficiency with the growth of residential electricity. The paper examines the challenges faced by India due to the growth in demand exceeding generation capacity, leading to energy and peak shortages. It explores pricing options for efficient use of generated capacity and equity issues. The literature review covers studies on electricity economics, household electricity consumption, and managing electricity consumption, emphasizing the need to reduce consumption and wastage across sectors and optimize resources for improved generation.

4 Datasets:

5.1 Electricity Pricing

The electricity pricing datasets are sourced from the U.S. Electric Utility Companies and Rates datasets and are available on Data.gov. The dataset integrates data from ABB's Velocity Suite, a comprehensive source of energy market data, and the U.S. Energy Information Administration's dataset EIA-861, which is a primary source of national and state-level data on electricity. This project analyzes data from a six-year period, from 2016 to 2021. This duration is significant as it covers a range of market conditions, regulatory changes, and technological advancements in the energy sector. The longitudinal dataset allows for an in-depth year-by-year analysis, enabling the identification of trends, anomalies, and patterns in electricity pricing. Each year's dataset includes detailed fields such as ZIP code (geographical identifier), EIA ID (a unique identifier for utilities), utility name, state, service type (commercial, industrial, residential), ownership (public, private), and specific rates for each sector. In our project, the datasets from 2016 to 2021 are merged to form a comprehensive schema. This schema includes regional categorization, yearly data, average rates for different consumer types, and growth rates for each sector.

5.2 EV Adoption

5.3 Electricity consumption

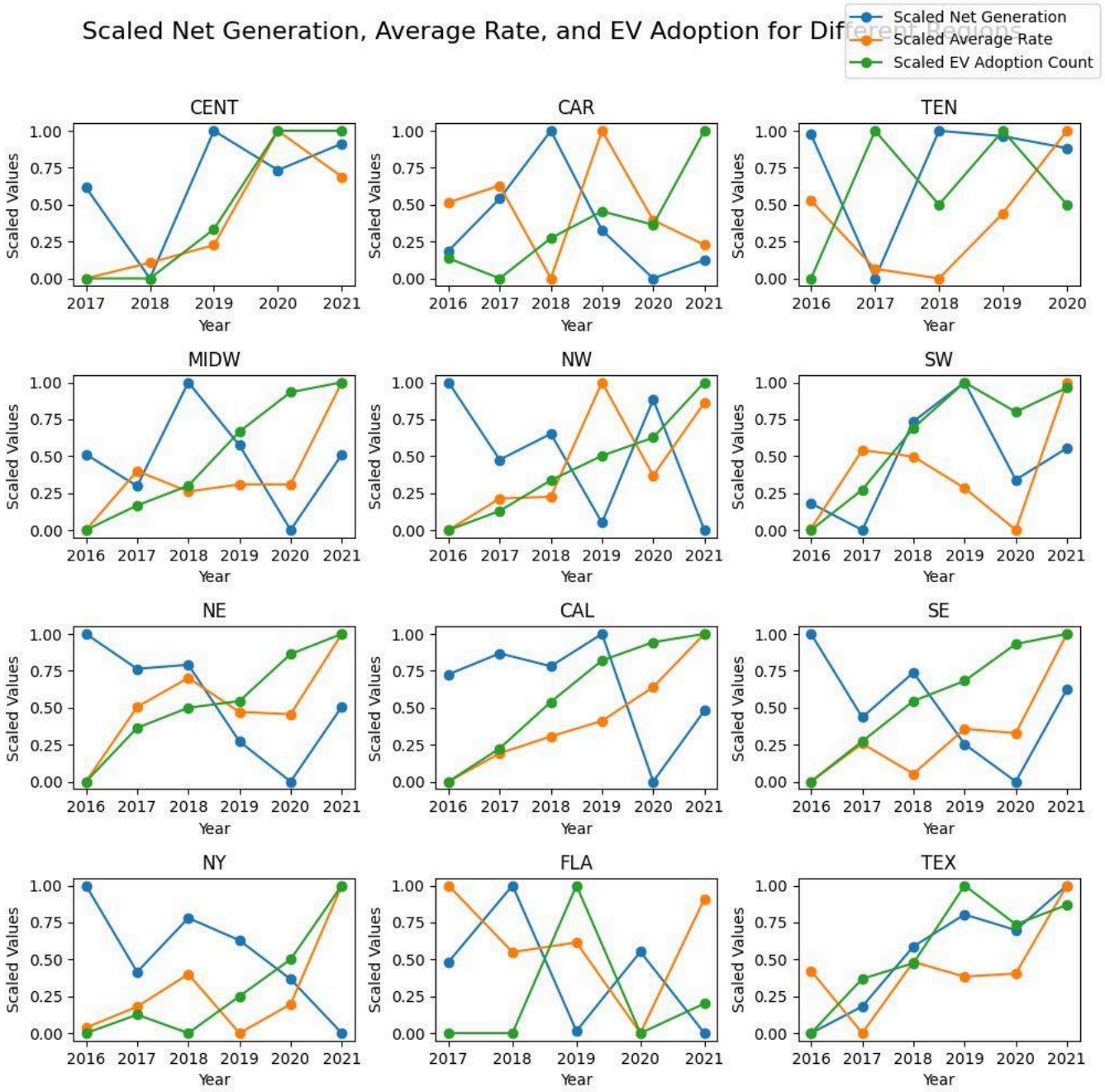
The electricity consumption datasets sourced from the U.S. Energy Information Administration (EIA) provide a comprehensive view of hourly grid consumption in the United States from 2016 to 2021. Each year's data is divided into two segments, covering January to June and July to December, resulting in a total of twelve CSV files. These datasets include critical information such as the Balancing Authority (the entity responsible for electricity balance in a region), Data Date, Hour Number, Local and UTC Time at the end of each hour, Demand Forecast in megawatts (MW), Actual Demand (MW), Net Generation (MW), Total Interchange (MW), and a detailed breakdown of Net Generation by various fuel sources. Additionally, the datasets contain regional information, providing insights into geographical electricity consumption patterns. This rich dataset is used to conduct statistical analysis to understand central tendencies and variability in electricity demand and generation, aggregating data on a yearly basis to identify consumption trends, perform regional analysis to explore geographical differences in electricity usage, and lastly calculate growth rates in demand and generation to provide insights into the evolving dynamics of electricity consumption. This thorough analysis is crucial for

enhancing the understanding of energy usage patterns, aiding in efficient energy management, and informing policy and infrastructure planning in the energy sector.

5 Algorithm:

6 Analytics Stages:

7 Graphs:



The graph displays scaled values for Net Generation, Average Rate, and EV Adoption Count across nine U.S. regions over the years 2016 to 2021. Each region is represented in a separate panel, and within each panel, three lines represent the scaled values of the three different metrics. The lines are color-coded with Scaled Net Generation in blue, Scaled Average Rate in orange, and Scaled EV Adoption Count in green.

Here's an analysis of potential correlations and observations for each region as depicted in the graph:

1. CENT:
    - There appears to be a positive correlation between Net Generation and EV Adoption in 2021, both increasing as the Average Rate decreases.
2. CAR:
    - The relationship between the metrics is less clear, with notable fluctuations. However, there will be a sharp decrease in Net Generation and EV Adoption from 2020 to 2021 as the Average Rate increases.
3. TEN:
    - The data shows a strong positive correlation between Net Generation and EV Adoption from 2019 to 2020, suggesting that an increase in energy production is accompanied by an increase in EV adoption.
4. MIDW:
    - The Average Rate and EV Adoption seem to correlate between 2018 and 2020 inversely; as the Average Rate decreases, EV Adoption increases.
5. NW:
    - EV Adoption Count steadily increased over the years despite fluctuations in Net Generation and Average Rate, suggesting that factors other than electricity rates and generation might be influencing EV adoption in this region.
6. SW:
    - A potential positive correlation is observed between Net Generation and EV Adoption in 2021, but the Average Rate seems to be inversely related to Net Generation between 2020 and 2021.
7. NE:
    - Net Generation and EV Adoption appear to have a positive correlation from 2020 to 2021, increasing together as the Average Rate decreases.
8. CAL:
    - A potential inverse correlation between the Average Rate and EV Adoption is seen in 2021, where a sharp increase in the Average Rate corresponds with a decrease in EV Adoption.
9. SE:
    - The region exhibits a positive correlation between Net Generation and EV Adoption from 2020 to 2021, with both increasing while the Average Rate decreases.
10. NY:
    - There seems to be an inverse relationship between Average Rate and EV Adoption between 2020 and 2021.
11. FLA:
    - A potential inverse correlation is observed between the Average Rate and EV Adoption in the years 2020 to 2021.
12. TEX:
    - There's a marked positive correlation between Net Generation and EV Adoption from 2019 to 2021, both increasing as the Average Rate decreases.

Overall, while there are individual variations in each region, several patterns suggest a potential inverse relationship between electricity pricing (Average Rate) and EV adoption. Higher electricity prices could be associated with lower EV adoption in some cases. Conversely, an increase in Net Generation is often associated with an increase in EV Adoption Count, suggesting that as regions produce more power, the adoption of electric vehicles also rises. Notably, a consistent inverse relationship emerges between electricity pricing (Average Rate)

and EV adoption across various regions. Higher electricity prices appear to correlate with lower EV adoption, implying that cost considerations may influence consumers' decisions regarding electric vehicles.

Furthermore, the examination of electricity demand unveils a nuanced scenario. The negative correlation coefficient of approximately -0.29 between electricity demand and pricing suggests a moderate inverse relationship. This implies that, on average, as electricity demand increases, pricing tends to decrease, and vice versa. This dynamic may be attributed to supply and demand dynamics, where increased demand might prompt adjustments in pricing. The correlation between electricity demand and EV adoption, represented by a coefficient of approximately -0.16, indicates a weak inverse relationship. While the impact is subtle, it suggests that as electricity demand rises, there is a slight tendency for EV adoption to decrease. This finding prompts further exploration into the factors influencing consumer choices in regions with varying electricity demands. Lastly, the correlation coefficient of approximately -0.30 between pricing and EV adoption signifies a moderate inverse relationship. As pricing increases, there is a discernible tendency for EV adoption to decrease. This underlines the significance of pricing as a factor influencing the adoption of electric vehicles, with potential implications for policymakers and industry stakeholders seeking to foster widespread EV adoption.

8 Conclusion:

In summary, this paper presents a dynamic relationship between electricity pricing, electric vehicle (EV) adoption, and consumption patterns from 2016 to 2021. It highlights a moderate inverse relationship between electricity demand and pricing, suggesting that as electricity demand increases, pricing tends to decrease, and vice versa. Moreover, a weak inverse relationship was observed between electricity demand and EV adoption, indicating that an increase in electricity demand slightly corresponds to a decrease in EV adoption. Also, a more pronounced moderate inverse relationship was found between pricing and EV adoption, showing that higher pricing is associated with a decrease in EV adoption. Our findings contribute to the existing body of research by providing a comprehensive, data-driven analysis that spans all US regions over a significant period. This approach allowed us to capture the evolving dynamics in the energy sector, offering a broader perspective than previous studies that often focused on individual factors or specific regions. The insights gained from this study are invaluable for policymakers, energy providers, and automotive manufacturers. They offer a data-driven foundation for developing strategies that encourage EV adoption and manage electricity demand effectively.

Our research highlights the necessity for integrated approaches that consider both energy policies and consumer trends. This is particularly crucial in the context of global efforts to combat climate change and transition to cleaner energy sources. The study opens avenues for exploring how different pricing models, such as time-of-use rates, could influence EV adoption and electricity consumption patterns. Future research could delve into the impact of emerging technologies, like smart charging infrastructure and battery storage, on the relationship between electricity pricing and EV adoption. There is also scope for investigating the role of consumer education and awareness in shaping the adoption of EVs and the response to electricity pricing strategies.

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Unwanted stuffs

4. "The Smart Grid and the Future of Electricity" by Faruqui et al. (2010)

This paper discusses the potential of smart grids to improve demand response and manage electricity consumption. Smart grids are intelligent electricity networks that use advanced technologies to improve the efficiency and reliability of the electricity grid. The authors argue that smart grids can enable a wider range of

demand response programs and provide consumers with more information about their electricity consumption, which can help them save energy.

5. "Dynamic Pricing and Demand Response in Electricity Markets" by Sioshansi (2012)

This paper reviews the literature on dynamic pricing and demand response and discusses the implications for electricity markets. The author discusses the various types of dynamic pricing programs and the potential benefits of demand response. The paper also discusses the challenges of implementing demand response programs, such as customer acceptance and privacy concerns.

6. "Can electricity pricing leverage electric vehicles and battery storage to Integrate High Shares of solar photovoltaics?" by Kannan et al. (2020)

This paper investigates the potential of electricity pricing to encourage the integration of solar photovoltaics and battery storage into the electricity grid. The authors use a simulation model to study the impact of different pricing schemes on the adoption of these technologies. They find that dynamic pricing can be effective in encouraging the integration of solar photovoltaics and battery storage, particularly when combined with other policy measures.