Impact of Climate Data on Energy Consumption in U.S. States from 2014–2024

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ABSTRACT

Climate change presents a significant challenge in the United States, influencing energy consumption patterns through rising temperatures, changes in precipitation, and frequent extreme weather events. This project investigates how climate change has impacted energy consumption in U.S. states from 2014 to 2024. Using datasets from the U.S. Energy Information Administration (EIA), we analyze monthly energy consumption by source and state-specific electricity consumption data. The methodology includes data cleaning, feature engineering, and the application of statistical and machine learning techniques such as linear regression and random forests. The results aim to provide insights into the relationship between climate variables and energy consumption, enabling better energy planning and resource management. Key evaluation metrics include RMSE and R-squared. Challenges include integrating datasets with varying formats and isolating the impact of climate change from other factors such as population growth and energy prices.

KEYWORDS

Climate Change, Energy Consumption, Machine Learning, Linear Regression, Random Forests

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1 INTRODUCTION

Climate change has become a pressing issue in the United States, with significant implications for energy consumption. Rising temperatures, changes in precipitation patterns, and frequent extreme weather events have altered energy demand across residential, commercial, and industrial sectors. This project seeks to understand how climate change has influenced energy consumption patterns in U.S. states from 2014 to 2024. By analyzing the relationship between climate variables and energy consumption, we aim to provide actionable insights for energy planning and resource management.

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2 PROBLEM STATEMENT

How has climate change influenced energy consumption patterns in U.S. states from 2014 to 2024? Rising temperatures increase energy demands for cooling, while changes in precipitation affect water availability, reducing hydroelectric capacity and increasing reliance on fossil fuels. Understanding which types of energy use are most affected by climate change can inform better energy planning and resource management.

3 DATASET SELECTION

The following datasets will be used for this project:

3.1 Dataset 1: Monthly Energy Consumption by Source

- **Description**: Monthly energy consumption by source for the U.S. from 2014 to 2024. It provides detailed information on retail sales of electricity, categorized by energy sources such as fossil fuels, nuclear electric power, renewable energy, and others.
- **Source**: U.S. Energy Information Administration (EIA) – `EIA.gov` [2].
- **Size and Format**: CSV format with around 130 lines of data.

3.2 Dataset 2: State-Specific Electricity Consumption

- **Description**: State-specific electricity consumption data by month, covering the years 2014 to 2024. It provides detailed information on the total energy sales of each state, broken down by different sectors such as residential, commercial, industrial, and others.
- **Source**: U.S. Energy Information Administration (EIA) – `EIA.gov` [1]
- **Size and Format**: CSV format with around 360 lines of data.

3.3 Dataset 3: Monthly Average Temperatures by State

- **Description**: Monthly average temperatures for each U.S. state from 2014 to 2024. This dataset includes temperature data in degrees Fahrenheit or Celsius, aggregated at the state level.
- **Source**: National Oceanic and Atmospheric Administration (NOAA) – `NOAA.gov` [3].
- **Size and Format**: CSV format with approximately 500 lines of data (one entry per state per month).

3.4 Dataset 4: Monthly Average Precipitation by State

- **Description**: Monthly average precipitation for each U.S. state from 2014 to 2024. This dataset includes precipitation data in inches or millimeters, aggregated at the state level.
- **Source**: National Oceanic and Atmospheric Administration (NOAA) – NOAA.gov [3].
- **Size and Format**: CSV format with approximately 500 lines of data (one entry per state per month).

4 METHODOLOGY

The methodology for this project involves data cleaning, feature engineering, and the application of statistical and machine learning techniques.

4.1 Data Cleaning and Feature Engineering

The percentage of missing data is small; therefore, any missing or inconsistent data entries will be deleted to avoid assumptions. The data will be normalized and scaled to ensure consistency and comparability across variables. For an in-depth analysis, the data will be split into seasonal categories (Winter, Spring, Summer, Fall). The national energy consumption dataset will be merged with the state-specific energy consumption dataset to provide a comprehensive view of energy consumption trends at both national and state levels. This merged dataset will then be combined with the weather dataset to compare energy consumption with state-specific weather conditions.

4.2 Statistical and Machine Learning Methods

Clustering using K-means: The K-means algorithm will be employed to identify groups of states with similar energy consumption patterns and climate characteristics. States will be grouped based on features such as average temperature, precipitation, and energy consumption across residential, commercial, and industrial sectors. The optimal number of clusters will be determined using the elbow method or silhouette score. The resulting clusters will be analyzed to uncover regional trends and similarities in how different states respond to climate variables. This approach will provide insights into which states exhibit comparable energy consumption behaviors under similar climate conditions, enabling targeted energy planning and policy recommendations for regions with shared characteristics. Additionally, the clustering results can be visualized to highlight spatial patterns and inform decision-making at both state and national levels.

Linear Regression: Linear regression will be used to model the relationship between temperature and electricity sales, considering seasonal and state-specific differences. The datasets will be split into training (80%) and testing (20%) sets. The model will be trained to learn the relationship between temperature, seasons, states, and electricity sales. Analyzing the coefficients will allow an understanding of the impact of temperature on electricity usage while considering differences in seasons and states.

Random Forests: Random forests will be used to compare the impact of climate on energy consumption across different states and seasons. Seasons and states will be converted to one-hot encoded variables. After preparing the dataset, the model will be trained, and feature importance scores will be extracted and analyzed to determine the significance of temperature and other variables.

5 EVALUATION METRICS

The success of the models will be evaluated using the following metrics:

- **Root Mean Squared Error (RMSE)**: To estimate prediction error. Lower RMSE indicates better performance.
- **R-squared**: To measure the proportion of variance explained by the model. Higher values indicate better performance.
- **Feature Importance**: For random forests, to identify the significance of each feature, particularly temperature.

6 EXPECTED CHALLENGES

- Integrating data from different datasets with varying formats and levels of detail.
- Isolating the effect of climate change on energy consumption from other factors such as population growth and energy prices.
- Making the results of the random forest model interpretable and usable.
- Creating a significant interaction between temperature, seasons, and states.

7 CONCLUSION

This project aims to provide a comprehensive analysis of the impact of climate change on energy consumption in U.S. states from 2014 to 2024. By leveraging statistical and machine learning techniques, we hope to uncover actionable insights that can inform energy planning and resource management. Future work could include expanding the analysis to incorporate additional variables such as economic indicators and policy changes.

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