Regression Analysis in Energy Consumption Forecasting

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Abstract

With the increasing emphasis on sustainability and energy efficiency, power industry is facing growing pressure to optimize energy consumption and reduce environmental impact. The objective is to analyze the energy consumption trends, identify areas of inefficiency, and propose optimization strategies for sustainable energy management. This study delves into the energy consumption patterns within the Engineering campus, aiming to analyze trends, pinpoint areas of inefficiency, and propose strategies for sustainable energy management. Energy meter readings were collected, forecasted and analyzed to understand energy usage dynamics over time. Through rigorous examination, this research work utilizes linear regression analysis and calculated several errors like MAPE(Mean Absolute Percent Error),RMSE(Root Mean Square Error),PLAE(Peak Load Absolute Error),VLAE(Valley Load Absolute Error),EAPE(Energy Absolute Percent Error) were evaluated to encompass a range of interventions like probable patterns of changes in energy consumption during various seasons like summer, winter. From the observed patterns of energy consumption insights were specified like improvements in building design and insulation, optimal usage of energy, and the promotion of energy conservation awareness among stakeholders.

Keywords: *Energy Consumption forecasting, Regression analysis, MAPE, PLAE, VLAE, EAPE.*

1. Introduction

Energy Consumption is of global concern, as it requires to meet the energy demand and energy production. Energy forecasting is essential in power system planning [1-4],the research is carried out by Gaussian regression process, and other machine learning techniques. Energy data analytics is a field that involves the analysis of data related to energy consumption, production, and distribution. It leverages techniques from data science, statistics, and machine learning to extract insights and make informed decisions about energy usage and management. In energy data analytics, various types of data are collected from sources such as smart meters, sensors, and energy management systems. This data can include information about electricity, natural gas, water, and other energy sources[5-9]. The goals of energy data analytics typically include optimizing energy usage, improving energy efficiency, identifying patterns and trends in consumption, predicting future energy demands, and detecting anomalies or inefficiencies in energy systems. Energy data analytics plays a crucial role in industries such as utilities, manufacturing, transportation, and building management. By analyzing energy data, organizations can identify opportunities to reduce costs, minimize environmental impact, and enhance overall operational performance. The intricate process of managing energy consumption within a campus environment by integrating various buildings and optimizing local energy systems. Focused on a specific campus in Finland, the study explores strategies to enhance energy efficiency and sustainability by leveraging data analytics. By examining the interplay between buildings and local energy infrastructure, the research aims to provide insights into effective energy management practices tailored to campus settings [10]. Harness the power of data analytics to enhance both service quality and energy efficiency in residential settings. By analyzing energy consumption patterns and user behaviors, the study seeks to identify opportunities for optimization and improvement. With a focus on residential communities, the project strives to develop data-driven strategies that not only reduce energy consumption but also enhance overall service quality for residents [11]. investigating energy consumption patterns within a specific university campus in Guangzhou, China. By collecting and analyzing comprehensive energy data, the research aims to uncover insights into the factors influencing energy usage within the university environment. Through rigorous data analysis, the study seeks to identify areas for improvement and develop tailored strategies to optimize energy consumption, ultimately contributing to enhanced sustainability and cost-effectiveness within the campus infrastructure [12]. The application of machine learning techniques for optimizing power consumption in data centers. With the exponential growth of data-driven technologies, data centers have become significant energy consumers. The review explores various machine learning algorithms and methodologies employed to mitigate energy wastage and improve efficiency within data center operations. By synthesizing existing research findings, the review aims to provide a comprehensive overview of the current landscape and identify potential avenues for future research and implementation [13].

1.1 Necessity and Importance of energy consumption analytics:

a. Cost Savings: Optimizing energy usage leads to cost savings for businesses and consumers by reducing energy bills and operational expenses.

b. Environmental Benefits: Energy data analytics supports sustainability goals by promoting energy efficiency and reducing carbon emissions.

c. Grid Resilience: Analyzing energy data helps improve the reliability and resilience of energy systems, particularly in the face of increasing demand and climate-related challenges.

d. Policy Compliance: Energy data analytics assists organizations in meeting regulatory requirements and compliance standards related to energy efficiency and emissions reduction.

In summary, energy data analytics is essential for optimizing energy usage, improving efficiency, and achieving sustainability goals in various sectors. Despite challenges, the benefits of leveraging data analytics in the energy domain are substantial, driving innovation and progress towards a more sustainable energy future.

1.2 Types of Analytics:

a. Descriptive Analytics: Describing past energy consumption patterns and trends using statistical methods and visualization techniques.

b. Diagnostic Analytics: Identifying the causes of energy inefficiencies or anomalies through root cause analysis and correlation studies.

c. Predictive Analytics: Forecasting future energy consumption or production based on historical data, machine learning algorithms, and predictive modelling techniques.

d. Prescriptive Analytics: Recommending actions to optimize energy usage or mitigate inefficiencies based on analytical insights and optimization algorithms.

1.3 Uses and Applications:

a.Energy Efficiency: One of the primary applications is to optimize energy consumption in buildings, factories, and transportation. By picturing out energy usage patterns, organizations can identify inefficiencies and implement strategies to reduce waste.

b.Predictive Maintenance: Energy data analytics can be used to monitor equipment and predict maintenance needs. By examining energy consumption patterns, anomalies indicative of potential equipment failure can be detected early, minimizing downtime and repair costs.

c.Demand Forecasting: Predicting energy demand is crucial for utilities to ensure reliable supply and avoid overloading the grid. Energy data analytics models can forecast future demand based on historical data, weather patterns, and other relevant factors.

d.Renewable Energy Integration: Energy data analytics helps manage the integration of renewable energy sources like solar and wind into the grid. By analyzing weather data and energy production patterns, utilities can optimize the use of renewable energy and balance supply and demand.

e.Grid Optimization: Examining energy consumption and generation data helps utilities optimize grid operations, reduce transmission losses, and improve overall grid reliability.

f.Carbon Emissions Reduction: Energy data analytics can assist in tracking and reducing carbon emissions by identifying sources of emissions and implementing strategies to minimize them.

2. Methodology

2.1 Data Collection

The data used in this study was collected from various facilities within Sir C R Reddy College of Engineering campus. The data includes monthly energy consumption readings for different facilities in campus main meter readings and maximum demand.

The collected data was subjected to comprehensive analysis to derive meaningful insights into energy consumption patterns, trends, and dependencies.

2.2 Modelling Approach

Various modelling techniques may be employed to develop predictive models and optimize energy management strategies. These techniques include:

a. **Time Series Analysis**: Building time series models to forecast future energy consumption based on historical data and seasonal patterns.
b. **Regression Analysis**: Performing regression analysis to quantify the influence of different factors on energy consumption and predict future trends.
c. **Error Analysis**: Employing different methods of error calculations like MAPE (Mean Absolute Percent Error), RMSE(Root Mean Square Error),PLAE(Peak Load Absolute Error),VLAE(Valley Load Absolute Error),EAPE(Energy Absolute Percent Error) to develop predictive models with higher accuracy and complexity.

With the data collected from the college campus we are aiming to predict the future usage of energy consumption using regression analysis.

3 Linear Regression Analysis:

Regression analysis is a statistical method used to model the relationship between a dependent variable and one or more independent variables. In the context of the energy consumption data provided, we can perform regression analysis to understand how various factors influence energy consumption. The electric load is the most important input needed when carrying out an electrical load forecast. Due to wrong readings of the values and general human error, some load values were either omitted or out of range. These values were corrected using interpolation or by finding the average of the preceding and succeeding values in the daily load log. The average load consumption for each day is then calculated and added to the other values of average load consumption for the other days in a month to give the average load consumption for the particular month.

3.1 Implementation of Linear Regression on the data collected:

Data is divided into two parts, first part consisting of monthly data from Januvary to June, Second part consists of monthly data from July to December. Implementing the linear regression equation for the two parts separately, the regression coefficients are evaluated.

Y= a + b*X (1)

Y is the energy consumed

X is the month

Using the present energy consumed values of 3 months data regression coefficients a, b are evaluated using the following equations

$$a = \frac{\sum Y * \sum X^2 - \sum X * \sum XY}{n * \sum X^2 - (\sum x)^2} \qquad (2)$$

$$b = \frac{\sum XY - \sum X \sum Y}{n \sum x^2 - (\sum x)^2} \qquad (3)$$

Using the regression coefficients (a=6.77, b=4.968) for Jan-Jun set of data ,(a=49.08,b=23.63) for Jul-Dec set of data, the energy consumed is Predicted from Jan to June and July to Dec shown in the following Figure 1 and Figure 2 respectively.

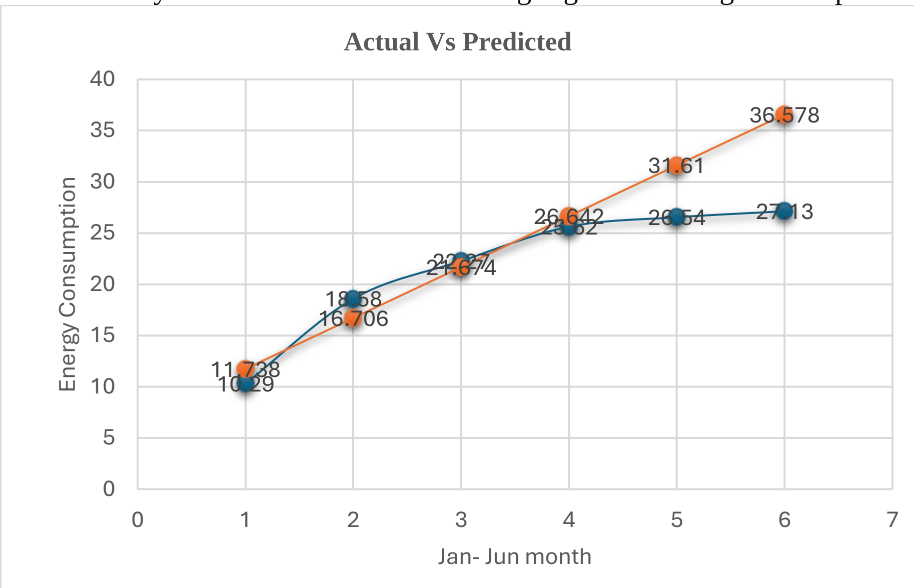

Figure 1 : Actual data vs Predicted data for the months Jan to Jun 2023 using Linear Regression

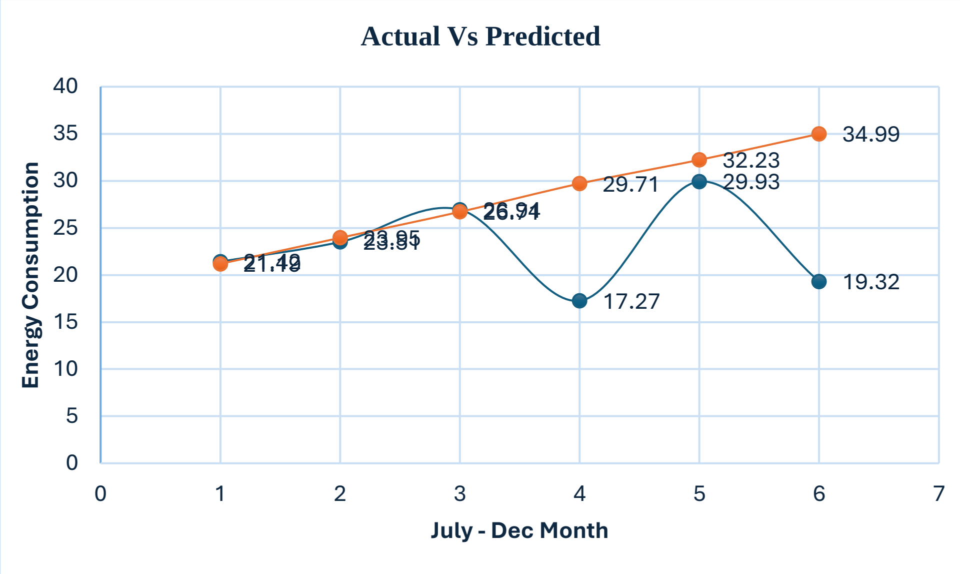

Figure 2 : Actual data vs Predicted data for the months July to Dec 2023 using Linear Regression

3.2.Error Analysis:

Different methods of error calculations like MAPE (Mean Absolute Percent Error), RMSE (Root Mean Square Error), PLAE (Peak Load Absolute Error), VLAE (Valley Load Absolute Error), EAPE (Energy Absolute Percent Error) are carried out to develop predictive models with higher accuracy. The equations for several error calculations are given below.

MAPE: Mean Absolute Percent Error, MAPE = $\frac{1}{n}\sum_{h=1}^{n}\left|\frac{A_h - F_h}{A_h}\right| * 100$

RMSE: Root of Mean Square Error, RMSE = $\sqrt{\frac{1}{n}\sum_{h=1}^{n}(A_h - F_h)^2}$

Peak: Peak load Absolute Percent Error, Peak = $\frac{Max(A) - Max(F)}{Max(A)} * 100$

Valley: Valley Load absolute percent error, Valley = $\frac{Min(A) - Min(F)}{Min(A)} * 100$

Energy: Energy absolute percent error, Energy = $\frac{\sum A - \sum F}{\sum A} * 100$

Table 1: Actual energy Consumed Vs Predicted energy Consumed ,MAPE for Jan-Jun 2023 Data set

Month	Actual Energy Consumed	Predicted Energy Consumed	MAPE
Jan	10.29	11.378	0.140719
Feb	18.58	16.706	0.100861
Mar	22.27	21.674	0.026762
Apl	25.62	26.642	0.039891
May	26.54	31.61	0.191032
Jun	27.13	36.578	0.348249

Table 1: Analysis

During the month of february the predicted consumption is slightly lower than the actual, which results in cost saving. In the months of **March** and **April**, with MAPE below 5%, predicted values are best. Prediction accuracy worsens significantly in **May** and **June**, where MAPE exceeds 19% and 34%, respectively. This model main drawback is struggling to capture specific seasonal or external factors affecting energy consumption during summer months (May and June).

Month	Actual Energy Consumed	Predicted Energy Consumed	MAPE
July	21.42	21.19	0.010738
Aug	23.51	23.95	0.018715
Sep	26.94	26.71	0.008537
Oct	17.27	29.71	0.720324
Nov	29.93	32.33	0.076846
Dec	19.32	34.99	0.811077

Table 2: Actual energy Consumed Vs Predicted energy Consumed ,MAPE for July-Dec 2023 Data set

With MAPE consistently below 2%, during August and September month, this model effectively captures seasonal energy usage patterns during mid-summer to early fall. In November Prediction accuracy improves with MAPE at 7.68%, but the predicted value is still slightly higher than the actual consumption, indicating residual overestimations, though the error is more manageable. From July to September, the model achieves excellent accuracy, with MAPE below 2%. The model performs well in stable or predictable energy consumption patterns, which may be due to institution shutdowns during holidays, reduced demand during examinations.

Box whisker plot shown in figure 3 analysis is as follows, **MAPE1 and MAPE4**: Show high variability, with larger ranges and higher errors in specific months.

MAPE2: Most consistent with moderate errors, indicating reliable predictions.

MAPE3: Balances performance and stability, performing better in later months (May, June).

Box whisker plot shown in figure 4 analysis is as follows, the steady decline in MAPE from Jul-Dec 2023 to Jan-Jun 2024 suggests improved prediction accuracy. The increase in RMSE in Jul-Dec 2023 indicates larger deviations from actual values. The subsequent decrease to 5.12 in Jan-Jun 2024 reflects better model performance. The highest value in Jan-Jun 2023 suggests a higher frequency of large errors during this period. A consistent trend suggests no dramatic variability in error magnitudes over the periods. This sharp drop indicates substantial improvements in handling exponential error patterns, particularly over the last two periods.

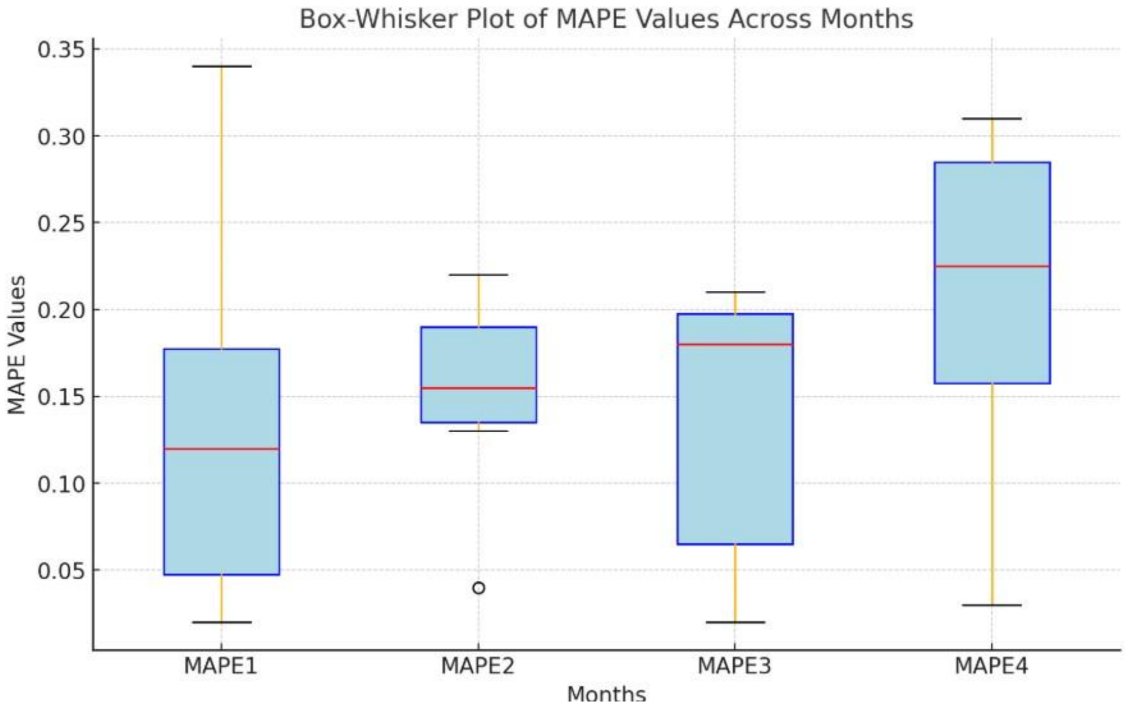

Figure 3: Box plot for MAPE calculated

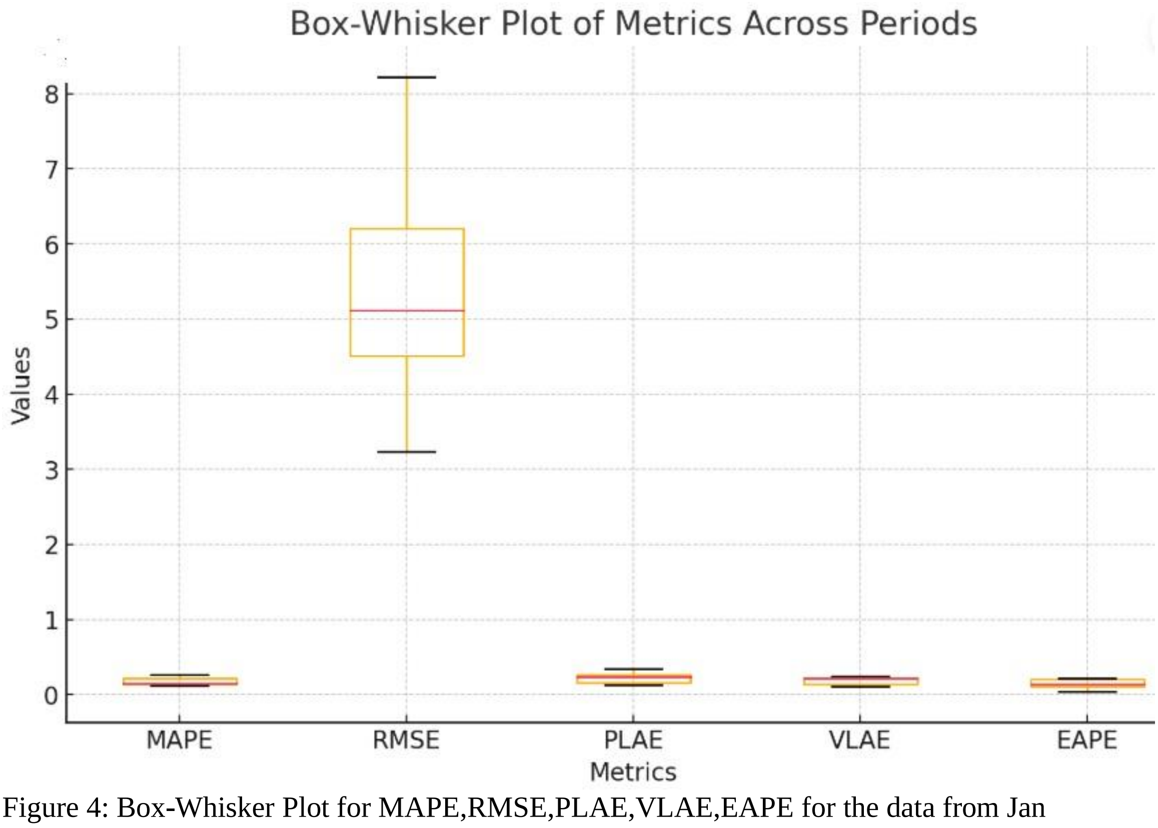

Figure 4: Box-Whisker Plot for MAPE,RMSE,PLAE,VLAE,EAPE for the data from Jan 2022 to Jun 2024.

4.Conclusion:

The study includes load consumptions and other utilities, providing a holistic view of campus resource consumption. The scope of future work includes advanced machine learning models (e.g., neural networks) for more accurate energy forecasting and Conduct lifecycle cost analysis to evaluate the financial and environmental benefits of proposed interventions. This paper highlights the importance of analyzing energy usage trends and addressing inefficiencies for sustainable energy management. By leveraging insights from the regression analysis and energy consumption patterns, the college can formulate tailored strategies to enhance energy efficiency, reduce costs, and contribute to sustainability goals. By adopting a combination of improved building design, operational strategies, and awareness campaigns, the Engineering campus can significantly reduce its energy footprint, lower costs, and set an example for sustainable practices in educational institutions.

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ETHICS APPROVAL:

This research was conducted ethically. All involved authors were consulted and asked for informed consent prior to their involvement, which meant that they were informed of the purpose and procedures of the study, the possible risks associated with it, and their right to stop at any time without repercussions. During the conduct of the research, confidentiality was maintained by adopting sound data management practices.

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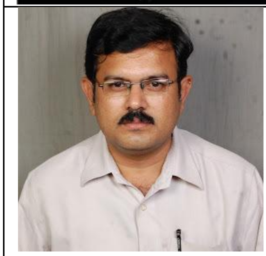	Dr. A. Srinivasa Reddy received the B.Tech degree in Electrical and Electronics Engineering from Nagarjuna University, Guntur, India in 1998, M.Tech degree from National Institute of Technology Calicut, Kerala, India in 2000 and Ph.D. degree in Electrical Engineering from Andhra University, Visakhapatnam, Andhra Pradesh, India in the year 2011. He is currently working as Professor and the Head of the Department of Electrical and Electronics Engineering, Sir C.R. Reddy College of Engineering, Eluru, West Godavari District, Andhra Pradesh, India.His research interest includes power system operation, control, and optimization, and soft computing applications. srinivasareddyalla@yahoo.co.in orcid: 0000-0002-5220-8933

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