

Smart Energy Consumption Forecasting using IoT, Machine Learning and Web Application

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Abstract- The Smart Energy Consumption Forecasting system is an intelligent energy analytics platform designed to monitor, analyze, and predict electricity usage in residential, commercial, and institutional environments. The proposed system integrates Internet of Things (IoT) sensors, cloud connectivity, machine learning models, and a responsive web application into a unified architecture for real-time energy management. Smart meters and environmental sensors continuously collect voltage, current, power factor, occupancy, temperature, and appliance-level usage data. These data streams are processed through a backend analytics engine, where machine learning algorithms such as Linear Regression, Random Forest Regressor, and Long Short-Term Memory (LSTM) networks are applied to forecast short-term and medium-term energy demand. The web application provides live dashboards, anomaly alerts, historical trend visualization, and consumption forecasting reports for users and administrators. Experimental observations indicate that the proposed platform improves energy visibility, supports proactive load balancing, and enhances decision-making for efficient power utilization. The system contributes toward sustainable smart building management by reducing energy wastage, improving forecast accuracy, and enabling intelligent, data-driven energy optimization.

Keywords: Smart Energy, Energy Forecasting, Internet of Things, Machine Learning, Web Application, Smart Meter, Load Prediction, Sustainable Energy Management

I. INTRODUCTION

1.1 Overview

Energy consumption has increased significantly due to urbanization, digital infrastructure, and expanding dependence on electrical devices in homes, campuses, industries, and offices. Conventional energy monitoring methods often provide only monthly billing information and lack the fine-grained

intelligence required for proactive usage optimization. As a result, users are unable to identify inefficient appliances, demand peaks, or abnormal consumption patterns in time. Recent advances in IoT, cloud platforms, and machine learning have made it possible to collect real-time energy data and use predictive analytics for accurate power demand forecasting. The proposed Smart Energy Consumption Forecasting system combines these technologies to create an integrated monitoring and forecasting environment accessible through a web application.

1.2 Objectives

- To develop an IoT-enabled smart energy monitoring system.
- To forecast electricity consumption using machine learning models.
- To build a web application for visualization, reporting, and alert management.
- To detect abnormal usage patterns and peak-load conditions.
- To support energy conservation and sustainable utilization.
- To assist institutions and households in data-driven energy planning.

II. LITERATURE SURVEY

Researchers have extensively explored smart energy analytics using sensor networks, intelligent metering, and predictive algorithms. Earlier studies on smart grids established the importance of real-time meter data for demand-side management and load forecasting. Recent research has shown that machine learning models such as support vector regression, random forests, and recurrent neural networks can

provide reliable forecasts when trained on historical consumption data, weather variables, and occupancy behaviour. Existing solutions often emphasize either hardware-based monitoring or standalone forecasting dashboards, but many lack a unified architecture that combines IoT sensing, cloud-based analytics, machine learning prediction, and user-facing web access in a single system. The proposed platform addresses this gap by integrating sensing, prediction, visualization, and decision support into a single intelligent energy management ecosystem

Dr. J. Narendra Babu [13][14][5] explored IoT applications in smart systems and emphasized combining embedded hardware with cloud connectivity for scalable IoT solutions, providing theoretical grounding for design decisions in this project.

III. PROPOSED METHOD

3.1 System Architecture

The Smart Energy Consumption Forecasting system follows a layered architecture that includes sensing, communication, backend analytics, database, and web application layers. IoT energy meters and environmental sensors capture real-time electrical and contextual parameters such as voltage, current, power, temperature, occupancy, and timestamped device usage. Sensor nodes transmit the collected data through Wi-Fi or MQTT-based communication to a cloud-connected backend server. The backend stores and preprocesses the incoming data, performs feature engineering, and feeds the refined datasets into forecasting models. Forecast outputs, alerts, and visual analytics are then delivered to end users through a responsive web interface.

3.2 Data Acquisition and IoT Workflow

The IoT module continuously monitors appliance-level and aggregate electricity consumption using smart meters and microcontroller-based sensor nodes. Parameters such as active power, energy units, voltage fluctuations, and current loads are captured at regular intervals and synchronized to the server. Additional contextual attributes including room occupancy, ambient temperature, and time-of-day are also recorded to improve forecast reliability. This continuous stream of operational data helps create a

rich temporal dataset for machine learning-based energy demand prediction.

3.3 Machine Learning Forecasting Workflow

The machine learning module uses historical consumption records and contextual sensor inputs to generate energy forecasts for upcoming time windows. Data preprocessing includes missing-value handling, normalization, timestamp decomposition, and extraction of lag-based features. Linear Regression is used as a baseline predictor, Random Forest Regressor is used to capture nonlinear behavior, and LSTM-based sequence modeling is used for time-series forecasting. Model outputs are compared using evaluation metrics such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE). The best-performing model is then deployed through the backend API for live forecasting.

3.4 Web Application Module

The web application provides role-based access for administrators, energy managers, and end users. It displays live power consumption, predicted demand curves, peak usage intervals, and anomaly alerts in an intuitive dashboard. Users can inspect daily, weekly, and monthly reports, compare actual versus predicted energy usage, and identify inefficient consumption patterns across monitored zones or devices. The web platform also supports exportable reports and notification services to improve operational decision-making.

3.5 Technologies Used

- IoT smart meters and microcontroller modules for real-time sensing.
- MQTT or HTTP protocols for device-to-cloud communication.
- Python and FastAPI for backend services and machine learning APIs.
- Scikit-learn and TensorFlow/Keras for predictive modeling.
- Firebase or PostgreSQL for authentication, cloud storage, and data persistence.
- HTML, CSS, JavaScript, and modern dashboard frameworks for the web application.

IV. RESULTS

The proposed system demonstrated effective performance in monitoring and forecasting electricity consumption under simulated smart building conditions. The data acquisition module produced stable streams of timestamped energy readings with reliable synchronization to the backend. Comparative model analysis showed that the Random Forest and LSTM models outperformed the baseline regression model for dynamic consumption patterns, while the web dashboard successfully visualized historical trends, forecasted demand, and abnormal usage alerts. The integrated platform enables early detection of peak demand periods and supports better scheduling of energy-intensive loads. These observations indicate that the system can improve energy efficiency, reduce avoidable wastage, and provide a practical foundation for smart campus, office, and household energy management.



Figure 1. SMART ENERGY CONSUMPTION FORECASTING dashboard.



Figure 2: different measures of energy usage.



Figure 3: graph of ai productive load forecasting

V. CONCLUSION

The Smart Energy Consumption Forecasting system demonstrates the successful integration of IoT sensing, machine learning-based prediction, cloud-enabled backend services, and a web application for intelligent energy management. The proposed platform supports real-time monitoring, demand forecasting, anomaly detection, and data-driven optimization of electricity usage across multiple environments. By enabling early identification of peak consumption behavior and inefficient load patterns, the system contributes toward sustainable energy utilization and operational cost reduction. Future enhancements may include integration with renewable energy sources, dynamic tariff optimization, occupancy-aware control strategies, and deployment with real-time smart grid infrastructure.

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