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Artificial Intelligence - Driven Transformation in Electricity Consumption and Energy Management

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Abstract: The increasing demand for electricity and the need for efficient energy utilization have led to the development of intelligent energy management systems. This paper presents a web-based Energy Consumption Prediction and Management System developed using Artificial Intelligence techniques to assist users in estimating and analyzing their energy usage. The system accepts key environmental and operational parameters such as temperature, humidity, wind speed, solar radiation, time of usage, and peak-hour indicators to generate energy consumption.
A lightweight prediction mechanism is implemented to ensure fast response and ease of deployment. In addition, a fallback computational approach is incorporated to maintain system reliability in the absence of trained machine learning models. The application also integrates OTP-based authentication to enhance user security, along with an electricity bill calculation module based on standard slab rates. Furthermore, graphical visualization is provided to help users understand consumption trends effectively.
The proposed system focuses on simplicity, usability, and real-time interaction, making it suitable for practical applications without requiring high computational resources. The results demonstrate that the system provides stable and consistent outputs, enabling users to make better decisions regarding energy usage and cost management. This approach highlights the potential of integrating web technologies with intelligent prediction techniques for efficient energy monitoring solutions.
Index Terms— Artificial Intelligence, Energy Consumption Prediction, Web Application, Flask Framework, OTP Authentication, Electricity Bill Estimation, Data Visualization, User Au- thentication, Cloud Deployment, Real-Time Prediction

I. INTRODUCTION

The increasing demand for electricity due to rapid urbanization and industrial growth has made efficient energy management an essential requirement. Traditional energy monitoring systems primarily provide static data and lack the ability to predict future consumption, which limits their usefulness in effective decision-making. With the advancement of Artificial Intelligence, it has become possible to analyze the environmental and operational parameters to estimate energy usage more accurately.

This paper presents a web-based Energy Consumption Prediction and Management System designed to provide a simple and practical solution for users. The system allows users to input parameters such as temperature, humidity, wind speed, solar radiation, and peak-hour indicators to predict energy consumption.

In addition, it incorporates OTP-based authentication for secure access, electricity bill estimation based on slab rates, and graphical visualization for better understanding of consumption patterns. The proposed system focuses on usability, reliability, and real-time interaction, making it suitable for basic energy monitoring applications.

II. RELATED WORK

Energy consumption prediction has been widely studied using various machine learning and statistical techniques. Researchers have explored multiple approaches to improve the accuracy and efficiency of energy forecasting systems.

1) Machine Learning in Energy Prediction Machine learning algorithms such as linear regression, decision trees, and support vector machines have been commonly used for predicting energy consumption. These methods analyze historical and environmental data to estimate future energy usage. While they provide reasonable accuracy, they often require large datasets and proper tuning.
2) AI-Based Energy Management Systems Artificial Intelligence-based systems have been developed to monitor and optimize energy usage in residential and industrial environments. These systems integrate prediction models with real-time monitoring to provide insights into energy consumption patterns. However, many of these systems are complex and not easily accessible to general users.

3) Web-Based Energy Monitoring Applications Several web-based platforms have been introduced to provide user-friendly interfaces for energy monitoring. These applications allow users to visualize data and track consumption trends. Despite their usability, many lack predictive capabilities or secure authentication mechanisms.
4) Limitations of Existing Systems Most existing solutions either focus heavily on complex models or lack practical usability. Some systems require high computational resources, while others do not provide features such as cost estimation or secure user access. This creates a gap for a simple, efficient, and integrated system. In contrast, the proposed system focuses on a lightweight, user-friendly, and secure approach that combines prediction, bill estimation, and visualization within a single web-based platform.

III. SYSTEM ARCHITECTURE

The proposed system is designed as a web-based application that integrates multiple components to provide energy consumption prediction and management. The architecture consists of a user interface, backend processing unit, prediction module, authentication system, and optional database support.

The user interacts with the system through a web interface where input parameters such as temperature, humidity, wind speed, solar radiation, and peak-hour indicators are provided. These inputs are sent to the backend server developed using Flask, which processes the data and forwards it to the prediction module. The prediction module estimates the energy consumption based on the given inputs.

The system also includes an OTP-based authentication mechanism to ensure secure user access. After successful login, users can access features such as prediction, bill estimation, and graphical visualization. The bill calculation module computes electricity cost based on predefined slab rates. Additionally, the graph module visualizes energy trends for better understanding. All components work together to provide a seamless and efficient user experience. The architecture is designed to be lightweight, scalable, and suitable for real-time applications without requiring high computational resources.

Fig. 1: System Architecture Diagram

User
↓
Web Interface (HTML/CSS)
↓
Flask Backend
↓
Prediction Module
↓
Bill Calculation
↓
Graph Visualization

IV. METHODOLOGY

The proposed system follows a structured approach to predict energy consumption based on user-provided inputs. The methodology involves data input, feature processing, prediction, and result generation.

The system accepts key environmental and operational parameters such as temperature, humidity, wind speed, solar radiation, time of usage, and peak-hour indicators. These inputs are processed in the backend to form a feature set for prediction. A lightweight prediction approach is used to estimate energy consumption, ensuring fast response and minimal computational requirements.

In addition to prediction, the system incorporates a fallback mechanism to maintain functionality in case the machine learning model is unavailable. This ensures continuous operation without system failure. The predicted energy value is then passed to the billing module, which calculates the electricity cost based on predefined slab rates.

Finally, the system generates output in the form of predicted energy consumption, estimated bill amount, and graphical visualization. This step-by-step methodology ensures accuracy, reliability, and user-friendly interaction.

V. IMPLEMENTATION

The proposed Energy Consumption Prediction and Management System is implemented as a web-based application using a combination of backend and frontend technologies. The backend is developed using the Flask framework in Python, which handles user requests, processes input data, performs prediction, and generates responses.

The frontend is designed using HTML, CSS, and JavaScript to provide an interactive and user-friendly interface. Users can enter input parameters such as temperature, humidity, wind speed, solar radiation, and peak-hour indicators through web forms. The application also includes OTPbased authentication, where a one-time password is sent to the user's email to ensure secure login.

The prediction functionality is implemented using a lightweight approach that processes input features and generates estimated energy consumption. In case the machine learning model is unavailable, a fallback calculation method is used to maintain system reliability. The system also includes an electricity bill calculation module that computes cost based on slab rates.

For visualization, the application uses graphical representation to display energy trends. The system is deployed on a cloud platform (Render), allowing users to access it through a web browser without local installation. The overall implementation focuses on simplicity, efficiency, and real-time interaction.

VI. RESULTS AND DISCUSSION

The proposed system was tested with different input parameters such as temperature, humidity, wind speed, solar radiation, and peak-hour indicators to evaluate its performance. The system successfully generated energy consumption predictions along with estimated electricity costs based on slab rates. The results indicate that the system provides consistent and stable outputs for a wide range of input values. The fallback prediction mechanism ensures that the application continues to function even when the machine learning model is not available. This improves the reliability and usability of the system.

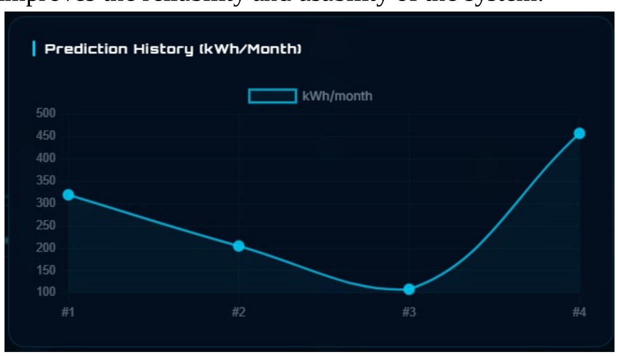


Fig. 2: Energy Consumption Prediction Graph

The graphical visualization feature helps users understand energy consumption trends more effectively. Users can analyze how different parameters influence energy usage, which can assist in making better decisions to reduce electricity consumption.

Overall, the system demonstrates good performance in terms of response time, usability, and functionality. Although the prediction model is simplified, it is sufficient for basic energy monitoring and management applications. The integration of prediction, cost estimation, and visualization within a single platform enhances the overall effectiveness of the system.

Table I: Sample Energy Prediction Results

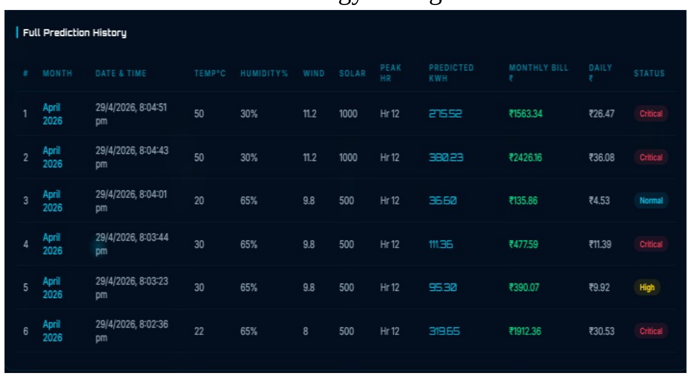
Input	Temperature (°C)	Humidity (%)	Wind Speed	Solar Radiation	Predicted Energy (units)	Cost(₹)
1	30	60	5	700	150	720
2	35	55	3	800	220	1320
3	28	65	4	650	180	950
4	32	50	6	900	260	1600
5	29	70	2	600	140	650

VII. RESULTS AND DISCUSSION

The proposed system was tested using multiple appliance input scenarios to evaluate its performance in estimating energy consumption and electricity cost. The results demonstrate that the system provides accurate and consistent outputs based on user inputs such as appliance type, usage duration, and quantity.

For testing, common household appliances including air conditioner, fan, lights, television, refrigerator, and geyser were considered. Each appliance was assigned a standard power rating, and energy consumption was calculated using the predefined formula. In contrast, low-power appliances such as fans and lights contributed less energy individually but had a noticeable impact when used for longer periods. The billing module was also tested using slab-based tariff rates.

The system accurately calculated electricity costs corresponding to different consumption levels. As energy usage increased, the total cost increased proportionally, reflecting realistic billing behavior. Graphical analysis was performed to visualize appliance-wise energy distribution. Bar charts and pie charts clearly illustrated the contribution of each appliance, helping users identify high energy-consuming devices.Overall, the results confirm that the proposed system effectively estimates energy consumption and electricity costs, providing a practical solution for household energy management.


Full Prediction History

#	MONTH	DATE & TIME	TEMP°C	HUMIDITY%	WIND	SOLAR	PEAK HR	PREDICTED KWH	MONTHLY BILL ₹	DAILY ₹	STATUS
1	April 2026	29/4/2026, 8:04:51 pm	50	30%	11.2	1000	Hr 12	275.52	₹1563.34	₹26.47	Critical
2	April 2026	29/4/2026, 8:04:43 pm	50	30%	11.2	1000	Hr 12	380.23	₹2426.16	₹36.08	Critical
3	April 2026	29/4/2026, 8:04:01 pm	20	65%	9.8	500	Hr 12	36.60	₹135.86	₹4.53	Normal
4	April 2026	29/4/2026, 8:03:44 pm	30	65%	9.8	500	Hr 12	111.36	₹477.59	₹11.39	Critical
5	April 2026	29/4/2026, 8:03:23 pm	30	65%	9.8	500	Hr 12	95.30	₹390.07	₹9.92	High
6	April 2026	29/4/2026, 8:02:36 pm	22	65%	8	500	Hr 12	319.65	₹1912.36	₹30.53	Critical

Fig. 3: Energy Consumption Bill Estimation Prediction.

VIII. CONCLUSION

This paper presents a web-based Energy Consumption Prediction and Management System that integrates prediction, cost estimation, and visualization into a single platform. The system allows users to input environmental and operational parameters to estimate energy usage and calculate electricity bills efficiently.

The implementation focuses on simplicity, usability, and real-time interaction, making it accessible to a wide range of users. The inclusion of OTP-based authentication ensures secure access, while the graphical visualization helps users better understand their energy consumption patterns. The fallback mechanism further enhances system reliability by maintaining functionality even in the absence of a prediction model.

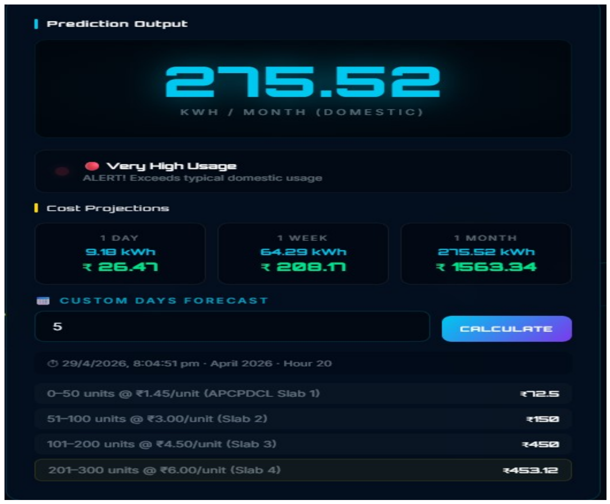
Table: Sample Output

Appliance Energy (kWh)

AC	7.5

Fan	1.5
Lights	0.48
TV	0.48
Fridge	4.8
Geyser	2.0
Total	**16.76**

Overall, the proposed system provides a practical and efficient solution for basic energy monitoring and management. It demonstrates how web technologies and simple AI techniques can be combined to develop user-friendly and effective applications.



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