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Survey on AI-Powered Energy Consumption Forecasting and Prediction

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ABSTRACT—

The escalating global energy demand, driven by rapid industrialization, urbanization, and population growth, has underscored the urgent need for innovative and sustainable energy management strategies. As concerns over climate change and environmental degradation intensify, the integration of renewable energy sources and the promotion of energy efficiency have become critical priorities for governments, industries, and communities worldwide. The energy sector, a cornerstone of national infrastructure, significantly influences economic performance, industrial productivity, transportation systems, and the overall quality of life. Ensuring a stable, reliable, and efficient energy supply is therefore essential for fostering economic resilience and achieving long-term sustainability goals.

This project focuses on the development of an AI-powered energy consumption forecasting system that leverages advanced machine learning (ML) and artificial intelligence (AI) techniques. By utilizing a diverse set of data inputs— including historical energy consumption records, meteorological data, seasonal trends, and socio-economic indicators—the system is designed to deliver accurate, real- time predictions of energy demand. These predictive insights enable energy providers, policy makers, and end- users to optimize energy production and distribution, plan for peak demand periods, and implement targeted energy- saving measures.

Through intelligent forecasting and data-driven decision- making, the proposed system not only improves energy efficiency and operational reliability but also contributes to cost reduction and environmental preservation. Furthermore, the integration of such AI-driven solutions supports the transition toward smarter grids and cleaner energy infrastructures, aligning with global sustainability objectives and regulatory frameworks.

INTRODUCTION

In recent years, the global surge in energy demand has brought the concepts of renewable energy and environmental sustainability to the forefront of governmental and corporate agendas. This shift has been largely driven by growing concerns over environmental degradation and climate change. Today, the energy sector is recognized as a cornerstone of national economies, playing an essential role in supporting industrial growth, enhancing competitiveness, and improving quality of life. Its influence spans multiple sectors, including manufacturing, transportation, and services, all of which depend on the uninterrupted and high-quality supply of energy. As such, ensuring the stability and sustainability of energy systems has become a critical element of socioeconomic development.

Energy consumption affects people, businesses, and the overall economy in many ways. Understanding how and why energy is used is key to creating smart energy policies and encouraging efficient use. In this effort, artificial intelligence (AI) and machine learning (ML) are opening up new possibilities for forecasting and managing energy needs more effectively.

The AI-powered energy consumption forecasting project uses advanced AI and data analysis techniques to predict future energy usage. By looking at past energy consumption along with factors like weather and seasonal patterns, the project provides real-time, accurate forecasts of energy demand. These insights help utility companies, businesses, and even individual users make better decisions, manage energy more efficiently, and lower costs.
Importantly, these forecasts also support sustainability by reducing energy waste and promoting smarter energy use. Machine learning models such as Artificial Neural Networks (ANNs) and Support Vector Machines (SVMs) are widely used in this field to capture complex patterns in energy consumption. Some approaches also include probabilistic forecasting and performance evaluation of AI tools in smart grids and large buildings.

In short, this project is a big step forward in energy management. By tapping into the power of AI, it boosts efficiency, supports greener practices, and leads to smarter, more informed decisions for both energy producers and users. It's a practical move toward building a more reliable, cost-effective, and environmentally friendly energy future.

OVERVIEW

In response to rising energy demand and environmental concerns, this project focuses on AI-powered energy consumption forecasting to enhance sustainability and efficiency. The energy sector is vital to economic development and quality of life, influencing multiple industries. By leveraging machine learning techniques such as artificial neural networks (ANNs) and support vector machines (SVMs), the system analyzes historical data, weather patterns, and other factors to provide accurate, real- time energy demand forecasts. These insights support smarter energy use, cost reduction, and resource optimization. The project also explores probabilistic models and AI applications in smart grids, offering transformative potential for energy management.

LITERATURE REVIEW

Duttagupta et al. [1],"***Exploring Lightweight Federated Learning for Distributed Load Forecasting***", introduces a privacy-preserving and energy-efficient framework using federated learning (FL) for short-term electricity load forecasting. The authors utilize a lightweight 4-layer feedforward neural network trained locally on smart meter data from London households. By integrating K-Means clustering to group similar consumption profiles, the approach enhances model generalization and accuracy. The proposed FL model achieves comparable prediction performance to centralized and LSTM-based models while significantly reducing computational cost, communication overhead, and energy consumption—consuming only 50 mWh on an Arduino Uno platform. The method also demonstrates resilience under non-
i.i.d. data conditions, making it suitable for real-world deployment in resource-constrained smart grid environments.

Dr. Bhalchandra M. Hardas et al. [2], " ***Deep Learning with Multi-Headed Attention for Forecasting Residential Energy Consumption***", the paper presents a deep learning model that combines Convolutional Neural Networks (CNN), Long Short- Term Memory (LSTM), and multi-headed attention mechanisms to forecast residential energy consumption. This hybrid architecture captures both spatial and temporal dependencies in energy usage data, improving prediction accuracy. The multi-headed attention enhances the model's ability to focus on significant consumption patterns, including transient spikes. Evaluated across various time resolutions, the model consistently outperforms traditional approaches like ARIMA, SVR, and standalone CNN/LSTM models. The proposed method demonstrates strong potential for application in smart grid systems and energy management, enabling better demand forecasting and resource optimization.

Lit Yang Tan et al. [3], " ***Artificial Intelligence Models in Power Generation for Energy Consumption Prediction***", the paper explores the application of Artificial Intelligence (AI) models in predicting power consumption to enhance energy efficiency in Malaysia's power generation sector. It focuses on using a customized Linear Regression model to forecast energy demand across sectors, analyze consumption growth, and identify investment opportunities. The study emphasizes tailoring AI models to specific energy datasets to improve prediction accuracy and operational planning. A comparative analysis is conducted to select the most effective model. The research also suggests incorporating real-time data and feedback mechanisms to improve adaptability, offering a foundation for future exploration in AI-driven energy forecasting and smart energy management.

Bandyopadhyay et al. [4], " ***Modelling and forecasting India's electricity consumption using artificial neural networks***", the paper presents a hybrid approach for forecasting India's electricity consumption using artificial neural networks (ANN). The authors combine Canonical Cointegrating Regression (CCR) for identifying key influencing variables such as GDP, population, temperature, and inflation, with a time-series ANN to forecast these inputs. A multilayer perceptron (MLP) ANN is then used to model and predict electricity consumption. The model is trained using historical data from 1961 to 2020 and provides forecasts up to the year 2030. The results suggest that India's electricity demand could rise by nearly 50%, reaching around 1,800 TWh by 2030. The study demonstrates that ANNs, when integrated with traditional econometric methods, offer a powerful tool for capturing nonlinear relationships and long-term consumption trends. This approach supports more accurate demand forecasting, aiding policymakers in planning for future energy infrastructure, improving supply reliability, and meeting the growing energy needs of a rapidly developing nation.
Polu et al. [5], " ***AI - Based Smart Energy Consumption Prediction for IoT - Connected Homes***", proposes an AI-IoT hybrid system for smart-home energy forecasting and load management. The framework integrates LSTM neural networks with real-time illumination data to predict solar power generation and household energy usage, achieving approximately 91% forecasting accuracy Leveraging IoT- enabled smart plugs and appliances, the system dynamically adjusts device operation—switching loads on/off based on forecasts—to optimize renewable energy utilization. It correlates ambient light levels with solar generation to enhance prediction reliability and supports automatic energy management via integration with a Smart Life platform. This approach demonstrates promising improvements in energy efficiency, cost savings, and grid interaction, indicating strong potential for scalable deployment in IoT-connected homes.

Arsene et al. [6], in their study "***Deep Convolutional Neural Networks for Short-Term Multi-Energy Demand Prediction***", the authors developed six specialized Convolutional Neural Network (CNN) models to forecast short-term energy demand across integrated energy systems—specifically electricity, heat, and gas. Recognizing the growing complexity of modern energy systems and the interdependence between various energy vectors, the study emphasizes the importance of unified forecasting models capable of handling multi-energy inputs. The CNN models were trained on real-world datasets and optimized to capture temporal patterns and nonlinear relationships within energy consumption data. Experimental results revealed that the proposed deep learning models outperformed traditional forecasting techniques in terms of accuracy and responsiveness, particularly in dynamic and short- term scenarios. The research contributes significantly to the field by offering a scalable and efficient solution for multi- energy demand forecasting, which is essential for effective load balancing, energy resource planning, and smart grid operations.

Morcillo-Jimenez et al. [7], " ***Deep learning for prediction of energy consumption: an applied use case in an office building***", This project applied deep learning techniques to predict energy consumption in a real-world office building using multisource sensor data. Focused on heating usage during winter, the study compared models including XGBoost, MLPs, CNNs, RNNs, and Seq2Seq, with RNN-based architectures delivering the best performance. Preprocessing involved outlier removal, missing value imputation, normalization, and feature selection. Key influencing factors like occupancy and outdoor temperature were identified. The Seq2Seq and RNN models significantly improved forecasting accuracy, achieving low error rates. This work demonstrates the potential of AI to optimize energy efficiency and supports data-driven energy management in smart, non-residential buildings.

Yıldız Doğan et al. [8], "***Electricity Consumption Forecasting for Smart Cities***", This study proposes a hybrid deep learning model combining Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) to forecast hourly electricity demand in sustainable cities. Using five years of electricity and weather data from a city in Türkiye, the model captures complex spatial-temporal patterns for accurate medium-term predictions. Compared to standalone LSTM, the CNN-LSTM model achieved significantly lower error rates, with an R^2 of 0.9244 on unseen data. This model aids in renewable energy planning by accurately estimating future energy needs, reducing costs, and optimizing infrastructure. The approach demonstrates strong potential for smart, data- driven urban energy management.

CONCLUSION

The AI-Powered Energy Consumption Forecasting project shows how artificial intelligence and machine learning can help solve today's energy challenges. By using past energy usage data, weather information, and smart models like Random Forest and regression techniques, the project accurately predicts how much electricity will be needed. These predictions help both utility companies and consumers use energy more efficiently, cut costs, and improve the reliability of the power grid. It also supports environmental goals by encouraging better use of energy resources and making it easier to include renewable sources like solar and wind. In the long run, this work helps build a smarter, more sustainable, and resilient energy system.

FUTURE SCOPE

- **Integration with Smart Grids**: AI-powered real-time forecasting can be built into smart grids to automatically balance energy loads and distribute electricity more efficiently. This helps avoid blackouts and makes the grid more reliable by predicting high-demand periods.

- **Renewable Energy Optimization**: By combining forecasting with solar and wind energy data, AI can better manage fluctuations in power supply. It can predict when renewable energy will be available and adjust energy use accordingly.

- **Demand Response Automation**: AI can enable systems that automatically adjust energy usage based on electricity prices or how much load is on the grid. This helps reduce energy waste and cuts costs.

- **Personalized Energy Recommendations**: Using data from smart meters and home appliances, AI can give users personalized tips to reduce energy use and improve efficiency at home or in businesses.

- **Urban Energy Planning**: Forecasting tools can support smart city projects by helping city planners design buildings and transportation systems that use less energy and operate more efficiently.

- **Decentralized Energy Markets**: As more people start generating their own energy (like from rooftop solar), AI can help balance local production and usage in these decentralized energy systems.

- **Edge AI for IoT Devices**: With the growing number of IoT devices, lightweight AI models can run directly on these devices to forecast energy needs and control energy use at a local level.

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