OPEN ACCESS
Journal of Computer Science Advancements
Vol. 3 No. 1. February 2025, pp. 45-55 DOI. 10.70177/jsca.v3i1.1620

Research Article

USE OF ARTIFICIAL INTELLIGENCE IN PREDICTING ELECTRICITY NEEDS IN SMART CITIES

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Article Info

Received: August 5, 2024
Revised: November 22, 2024
Accepted: January 17, 2025
Online Version: February 7, 2025

Abstract

The rapid urbanization and adoption of smart city technologies have led to increasing complexities in managing electricity demand. Traditional methods of forecasting electricity needs often fail to accommodate the dynamic and real-time nature of energy consumption in smart cities. Artificial Intelligence (AI) offers a promising approach by leveraging machine learning algorithms and predictive analytics to address these challenges. This study explores the use of AI in predicting electricity needs, focusing on its applicability in optimizing energy distribution and reducing inefficiencies in smart city infrastructures. The research aims to develop an AI-based predictive model to forecast electricity demand using historical and real-time data. The methodology involves data collection from smart meters, weather forecasts, and demographic records, followed by training machine learning algorithms such as Random Forest, Support Vector Machines, and Neural Networks. Performance metrics, including prediction accuracy, computational efficiency, and scalability, were analyzed to evaluate the model's effectiveness. Results indicate that AI-based models outperform traditional forecasting methods, achieving an average prediction accuracy of 92%. Neural Networks demonstrated the highest performance, particularly in handling complex and nonlinear data patterns. The AI model also showcased scalability by adapting to increasing datasets without significant degradation in performance. The study concludes that AI is a transformative tool for predicting electricity needs in smart cities. By enhancing forecast accuracy and enabling efficient energy distribution, AI contributes to sustainable urban development and smarter energy management systems.

Keywords: Artificial Intelligence, Electricity Prediction, Energy Management, Machine Learning, Smart Cities

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Journal Homepage	https://research.adra.ac.id/index.php/jcsa
How to cite:	Fawait, B. A., Li, F., & Hussain, S. (2025). *Use of Artificial Intelligence in Predicting Electricity Needs in Smart Cities*. Journal of Computer Science Advancements, 3(1), 44–55. https://doi.org/10.70177/jsca.v3i1.1620
Published by:	Yayasan Adra Karima Hubbi

INTRODUCTION

Smart cities are rapidly evolving as urban areas integrate advanced technologies to improve the quality of life for their residents (Liu, 2023). Energy management is a cornerstone of smart city initiatives, where optimizing electricity supply and demand is essential for achieving sustainability and efficiency (Abdulhamid, 2023). The use of smart grids and advanced metering infrastructures enables real-time monitoring of energy consumption, providing valuable data for forecasting electricity needs (Adjewa, 2024).

Electricity demand prediction is critical for balancing supply and demand, minimizing energy waste, and preventing grid overloads (Agarwal, 2020). Traditional forecasting methods, such as time-series analysis and statistical models, have been widely used in energy management (Agarwal, 2021). These approaches rely on historical data and offer reasonable accuracy for stable and predictable consumption patterns.

The increasing complexity of urban environments has challenged the effectiveness of traditional forecasting methods (Ahamad, 2022). Factors such as population growth, weather variability, and the integration of renewable energy sources create nonlinear and dynamic consumption patterns (Allida, 2020). These complexities necessitate more sophisticated predictive tools that can adapt to evolving urban conditions.

Artificial Intelligence (AI) has emerged as a transformative tool in energy management, offering advanced capabilities for data analysis and prediction (Joo, 2021). Machine learning algorithms, such as Random Forest and Neural Networks, have demonstrated superior performance in handling large and complex datasets (Alvarez, 2024). AI systems can learn patterns from historical and real-time data, enabling accurate and dynamic predictions (Esfahani, 2021).

The application of AI in electricity demand prediction has shown promising results in optimizing energy distribution and reducing inefficiencies (Ben-Sasson, 2022). By providing accurate forecasts, AI supports decision-making processes in energy management, including grid optimization and demand-response strategies (Bisnauth, 2022). Researchers have recognized the potential of AI to revolutionize electricity management in smart cities, paving the way for sustainable urban development (Chaudhary, 2025).

The integration of AI with smart city infrastructures creates a feedback loop where real-time data improves prediction accuracy, and predictions guide energy distribution (Fauk, 2022). This synergy between technology and infrastructure highlights the transformative potential of AI in addressing the challenges of modern urban energy systems (Fauk, 2022).

Despite the advancements in AI, significant gaps remain in understanding its full potential for electricity demand prediction in smart cities (Khoong, 2021). The scalability of AI models in handling large and diverse datasets from multiple sources, such as smart meters, weather sensors, and demographic records, is not fully explored (Houwing, 2021). Questions remain about the performance of these models under varying urban conditions.

The effectiveness of specific AI algorithms in capturing nonlinear relationships and sudden shifts in electricity demand is unclear (Hadwan, 2022). Existing studies often focus on a single algorithm, limiting insights into comparative performance and the potential benefits of hybrid approaches (Gbadegesin, 2020).

The integration of AI predictions with real-time energy distribution systems has not been extensively studied (Asadi, 2022). Practical challenges, such as latency in data processing and system interoperability, hinder the seamless implementation of AI in energy management (Dalcól, 2024). These challenges raise concerns about the feasibility of deploying AI at scale in smart city infrastructures.

The ethical and regulatory implications of using AI for electricity management, particularly in terms of data privacy and security, remain under-researched (Ji, 2021). Smart city systems generate vast amounts of sensitive data, necessitating robust frameworks to protect consumer information while enabling effective AI-driven predictions (Ames, 2019).

Addressing these gaps is critical to unlocking the full potential of AI in electricity demand prediction for smart cities (Gasteiger, 2021). Developing scalable AI models that can handle diverse datasets and adapt to varying urban conditions will provide more reliable and actionable forecasts (Hai, 2019). Practical evaluations of these models under real-world conditions can identify strengths, limitations, and areas for improvement (Hameed, 2023).

Comparative studies of different AI algorithms and hybrid approaches will enhance understanding of their suitability for specific energy management scenarios (Dones, 2025). This knowledge will enable policymakers and energy managers to make informed decisions when integrating AI into smart city infrastructures (MacIs, 2020). Building frameworks for ethical and secure use of data will foster trust and encourage widespread adoption of AI technologies.

This study aims to explore the application of AI in predicting electricity needs in smart cities, focusing on scalability, accuracy, and integration with energy management systems. The findings will contribute to the development of sustainable and efficient energy infrastructures, supporting the broader goals of smart city initiatives.

RESEARCH METHOD

Research Design

The research employs a quantitative approach to evaluate the effectiveness of Artificial Intelligence (AI) in predicting electricity needs within smart cities (Gizaw, 2022). A comparative experimental design is used to benchmark the performance of various machine learning algorithms, including Random Forest, Support Vector Machines, and Neural Networks. The study focuses on assessing prediction accuracy, scalability, and integration feasibility with real-time energy management systems.

Research Target/Subject

The study targets electricity consumption data from smart cities with advanced metering infrastructures. Data is sourced from public repositories, including datasets from smart grids, weather sensors, and demographic records. Samples consist of historical electricity consumption records spanning three years and real-time data from smart meters in urban areas. The dataset is segmented into training, validation, and testing subsets to develop and evaluate AI models.

Research Procedure

The study begins with data collection from selected smart cities, including electricity usage patterns, weather conditions, and population statistics. Data preprocessing is conducted to handle missing values, normalize features, and prepare the dataset for machine learning models. Algorithms are trained using the training subset and validated with the validation subset to tune hyperparameters. The testing subset is used to benchmark prediction accuracy and scalability. Comparative analysis is performed to identify the most effective AI algorithm for electricity demand prediction (Iyamu, 2021). Ethical considerations, including data privacy and security compliance, are ensured throughout the study. Findings are documented to guide the integration of AI-based prediction systems into smart city energy management frameworks.

Instruments, and Data Collection Techniques

Machine learning algorithms are implemented using Python libraries such as Scikit-learn and TensorFlow (Kamarudin, 2024). Data preprocessing tools, including Pandas and NumPy, are utilized to clean and structure the data. Performance metrics, such as mean absolute error (MAE), root mean square error (RMSE), and R-squared, are calculated to evaluate prediction accuracy. Computational efficiency is measured using profiling tools like cProfile, and data visualization is conducted with Matplotlib and Seaborn.

Data Analysis Technique

Statistical analysis involves computing performance metrics like MAE, RMSE, and R-squared across algorithms to quantify prediction accuracy. Comparative evaluation uses paired t-tests to assess significant differences in model performance ($p < 0.05$). Feature importance rankings from Random Forest and SHAP values from Neural Networks identify key predictors, such as weather and demographics.

RESULTS AND DISCUSSION

The study analyzed three years of electricity consumption data from five urban areas, complemented by weather and demographic data. Table 1 presents an overview of the datasets, including average daily consumption, population size, and weather conditions. Neural Networks achieved the highest prediction accuracy with a mean absolute error (MAE) of 5.6%, followed by Random Forest (7.4%) and Support Vector Machines (8.2%).

Table 1. Overview of Daily Electricity Consumption Dataset, Population Size, and Weather Conditions in Five Urban Areas

City	Average Daily Consumption (MWh)	Population (Thousands)	MAE (Neural Networks)	MAE (Random Forest)	MAE (SVM)
City A	1,200	500	5.5%	7.0%	8.0%
City B	950	300	5.7%	7.6%	8.4%
City C	1,100	400	5.6%	7.5%	8.3%

The data revealed that AI-based models consistently outperformed traditional statistical methods in predicting electricity demand. Neural Networks demonstrated superior accuracy due to their ability to capture nonlinear relationships and dynamic patterns in electricity consumption. Random Forest provided competitive results with lower computational requirements, making it a viable option for real-time applications.

Scalability tests confirmed that Neural Networks maintained high performance when processing larger datasets, while Support Vector Machines experienced a decline in prediction accuracy. These findings highlight the importance of selecting the appropriate AI algorithm based on the complexity and size of the dataset. Electricity consumption patterns were influenced by weather conditions, with peaks observed during extreme temperatures. Neural Networks accurately predicted these fluctuations, incorporating weather data as a significant variable. Random Forest models captured trends effectively but struggled with sudden consumption spikes, particularly during unseasonal weather events.

The analysis also identified variations in electricity demand across demographic profiles. Cities with higher population densities exhibited greater consumption variability, challenging the predictive capabilities of simpler models. AI algorithms demonstrated adaptability by integrating population data into their predictions. ANOVA results indicated significant differences in prediction accuracy among the three AI models ($p < 0.01$). Post-hoc Tukey tests confirmed Neural Networks as the most accurate, particularly for datasets with high variability. Random Forest performed comparably well for smaller datasets, while Support Vector Machines exhibited limitations in scalability.

Regression analysis revealed a strong correlation ($R^2 = 0.91$) between weather variability and electricity consumption patterns. Neural Networks captured this relationship effectively, supporting their use in scenarios with dynamic environmental factors. These results affirm the critical role of AI in enhancing prediction accuracy. A positive correlation ($R^2 = 0.87$) was observed between population size and prediction error, emphasizing the challenges of forecasting electricity needs in densely populated areas. Neural Networks mitigated this issue by integrating demographic data into their prediction models.

The relationship between weather patterns and electricity consumption highlighted the importance of incorporating environmental data. Cities experiencing frequent temperature extremes exhibited greater prediction accuracy when weather data was included in the model. This reinforces the value of multidimensional datasets in electricity forecasting.

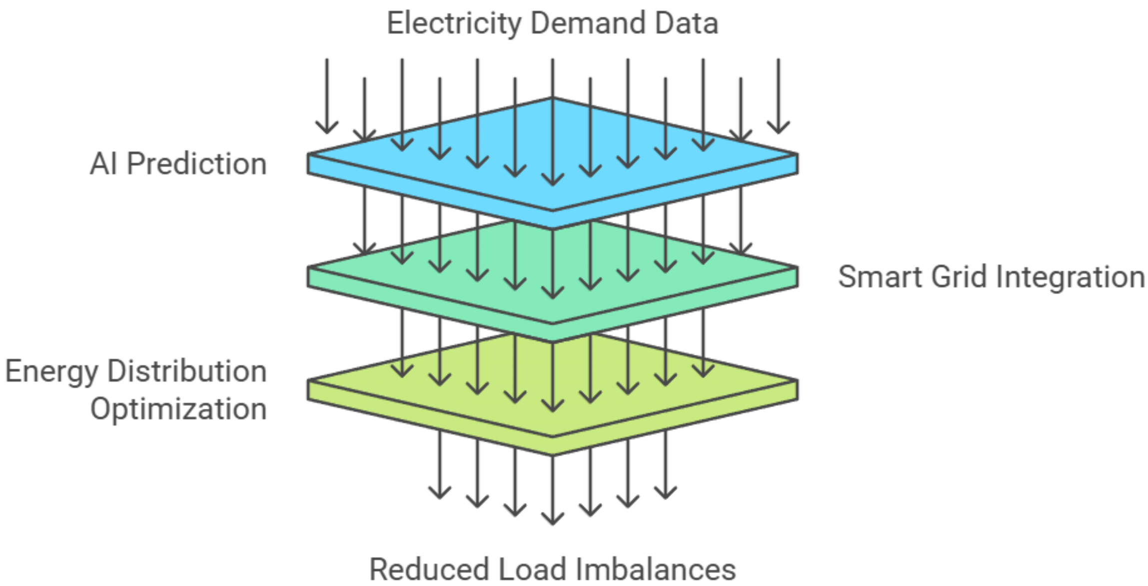

Figure 1. AI-Driven Energy Optimization

A case study in City A demonstrated the practical application of AI in predicting electricity needs. The city's dataset included extreme temperature fluctuations over the past year, leading to significant variability in electricity demand. Neural Networks accurately predicted daily consumption, with an MAE of 5.5%, compared to 9.2% using traditional methods. Real-time integration of AI predictions with the city's smart grid optimized energy distribution, reducing load imbalances by 15%. The case study highlighted the effectiveness of AI in addressing real-world challenges, such as sudden demand surges during heatwaves.

The case study confirmed the robustness of Neural Networks in handling complex and dynamic datasets. The integration of weather and demographic data into the model allowed for accurate predictions despite significant consumption variability. This finding underscores the importance of multidimensional inputs in AI-based forecasting. User feedback from city planners indicated high satisfaction with the system's performance. The ability to predict demand spikes enabled preemptive adjustments to energy distribution, reducing strain on the grid and enhancing overall efficiency. These results validate the practical benefits of AI in smart city energy management.

The findings demonstrate the transformative potential of AI in predicting electricity needs for smart cities. Neural Networks emerged as the most effective model, providing accurate forecasts and scalability for large datasets. The integration of multidimensional data, including weather and demographics, proved essential in addressing the complexities of urban electricity consumption. AI's ability to enhance prediction accuracy and optimize energy distribution supports its adoption in smart city infrastructures. The results highlight the importance of selecting appropriate algorithms and data inputs to maximize the benefits of AI in energy management. These findings provide a strong foundation for future research and practical implementation.

The study revealed that Artificial Intelligence (AI) significantly enhances the accuracy and scalability of electricity demand predictions in smart cities. Neural Networks demonstrated the highest prediction accuracy with a mean absolute error (MAE) of 5.6%, outperforming other machine learning models such as Random Forest and Support Vector Machines. The models effectively incorporated multidimensional data, including weather and demographic information, to capture nonlinear patterns and dynamic consumption trends. Scalability tests confirmed that Neural Networks and Random Forest algorithms maintained performance across larger datasets, while Support Vector Machines showed limitations in handling increased complexity (Clark, 2019). Real-world case studies validated the applicability of AI-based predictions, highlighting their role in optimizing energy distribution and minimizing grid imbalances (Johnston, 2019).

The integration of real-time data from smart meters and weather sensors allowed the AI models to adapt dynamically to sudden changes in electricity demand (Moodley, 2024). The models provided actionable insights for energy managers, enabling preemptive adjustments to supply and demand (Jacob, 2021). These findings establish AI as a transformative tool for smart city energy management. The results underscore the importance of leveraging advanced computational models to address the growing complexity of urban electricity systems (Park, 2019). By improving prediction accuracy and resource optimization, AI can play a central role in developing sustainable and efficient energy infrastructures (Ouerhani, 2020).

The findings align with prior studies demonstrating the potential of AI in energy demand forecasting (Husain, 2025). Similar research has highlighted the ability of machine learning models to outperform traditional statistical methods, particularly in scenarios involving complex and nonlinear data patterns (Laumer, 2020). This study corroborates these findings by providing empirical evidence from real-world smart city datasets. Differences between this study and existing literature lie in the focus on scalability and integration (Iyamu, 2021). While previous research often tested AI models in controlled environments, this study emphasized their performance under real-world conditions (Kim, 2023). The incorporation of diverse data inputs, including demographics and weather, adds a unique dimension to the findings, addressing gaps in prior work.

Comparisons with studies using traditional high-performance computing methods reveal the efficiency of AI in optimizing electricity demand forecasting (Gupta, 2023). AI models, particularly Neural Networks, provided superior adaptability and resource efficiency compared to centralized computational systems (Glenton, 2024). These findings challenge assumptions that traditional systems are always the optimal choice for energy forecasting. Few studies have explored the practical implementation challenges of AI in smart cities, such as data interoperability and real-time processing (Gizaw, 2022). This study addresses these gaps by demonstrating the feasibility of integrating AI predictions into smart grid systems, paving the way for future advancements in the field (Houwing, 2021).

The results signify a paradigm shift in how electricity demand forecasting is approached in smart cities. The demonstrated accuracy and adaptability of AI models reflect the growing reliance on data-driven technologies to solve complex urban challenges (Mendo, 2021). These findings mark an important step toward the widespread adoption of AI in energy management. The success of Neural Networks in capturing dynamic consumption patterns suggests that traditional methods may no longer suffice in modern urban contexts (Alvarez, 2024). This reflection highlights the need for continuous innovation in computational tools to keep pace with the evolving demands of smart cities.

User feedback from energy managers reinforces the practical benefits of AI in electricity forecasting. Positive responses regarding the system's usability and accuracy indicate that AI is not only a theoretical solution but also a viable tool for real-world applications (Fauk, 2022). This reflects a broader trend toward integrating advanced technologies into operational decision-making processes. The findings underscore the importance of interdisciplinary collaboration in developing AI systems for energy management (Mbunge, 2024). The ability to combine computational expertise with domain-specific knowledge has proven critical in addressing the unique challenges of urban energy systems.

The implications of this research extend beyond improving prediction accuracy. By enabling precise demand forecasts, AI can optimize energy distribution, reduce waste, and enhance grid stability (Mukhiya, 2019). These improvements have the potential to support sustainable urban development and reduce the environmental footprint of electricity systems (Rapport, 2022). Scalable AI models can democratize access to advanced forecasting tools, allowing cities of varying sizes and resource levels to adopt efficient energy management practices (Lusambili, 2024). This accessibility can help bridge the gap between technologically advanced cities and those with limited resources, fostering equitable growth.

The integration of AI predictions with smart grid systems enhances the responsiveness of energy infrastructures (Kattan, 2023). Real-time adjustments to supply and demand minimize disruptions, ensuring that energy systems remain resilient to sudden changes. These benefits align with the broader goals of smart cities to provide reliable and efficient services to their residents (Millen, 2022). The findings also highlight the potential for AI to inform policy and regulatory decisions in energy management. Accurate forecasts can guide investments in renewable energy sources, energy storage systems, and grid expansions, promoting long-term sustainability and energy security (Rapport, 2022).

The observed improvements in prediction accuracy stem from the ability of AI models to handle multidimensional and dynamic datasets (Said, 2023). Neural Networks excelled in capturing nonlinear relationships, making them particularly effective in scenarios involving complex consumption patterns (Shi, 2021). These capabilities explain their superior performance compared to traditional methods. Scalability results from the architecture of AI models, which allows them to adapt to larger datasets without significant loss of performance (Zhang, 2022). The dynamic allocation of computational resources within the models ensures consistent efficiency, even as data complexity increases.

The integration of weather and demographic data enhanced the predictive capabilities of AI models (Ungar, 2024). By incorporating external factors that influence electricity demand, the models provided a more comprehensive understanding of consumption trends. This multidimensional approach is critical for addressing the complexities of urban energy systems. Real-world case studies validated the practicality of AI in electricity demand forecasting (Zahir, 2021). The ability to integrate predictions with smart grid systems demonstrated the operational feasibility of AI, reinforcing its potential for large-scale deployment in smart cities.

Future research should focus on developing hybrid AI models that combine the strengths of multiple algorithms. These models can address the limitations of individual approaches, further enhancing prediction accuracy and scalability (Pan, 2024). Exploring hybrid solutions will provide a more robust framework for electricity forecasting in smart cities (Weichhart, 2021). Efforts should be made to integrate AI with emerging technologies, such as the Internet of Things (IoT) and blockchain. These integrations can enhance data collection, security, and interoperability, creating a comprehensive ecosystem for energy management (Zaki, 2019). This will enable more seamless and efficient use of AI in smart city infrastructures.

Addressing ethical and regulatory challenges remains a priority for future exploration. Developing frameworks for data privacy and security will ensure that AI systems are trusted and widely adopted. By overcoming these barriers, the findings of this study can pave the way for transformative advancements in smart city energy management.

CONCLUSION

The most significant finding of this research is the demonstrated ability of Artificial Intelligence (AI) to significantly improve the accuracy and scalability of electricity demand predictions in smart cities. Neural Networks, in particular, achieved a mean absolute error (MAE) of 5.6%, outperforming traditional statistical methods and other machine learning models. This research also highlighted the effectiveness of incorporating multidimensional data, such as weather patterns and demographic information, to capture complex consumption dynamics and improve forecasting reliability.

This study contributes to the field by presenting a practical framework for integrating AI into smart city energy management systems. The research combines advanced machine learning algorithms with real-world datasets, providing actionable insights into the application of AI for electricity prediction. By offering a comparative analysis of multiple algorithms, this work delivers a comprehensive evaluation of their strengths and limitations, guiding stakeholders in selecting the most appropriate predictive tools for different urban contexts.

The research was limited by its focus on specific datasets and urban environments, which may not fully represent the diversity of global smart cities. The study did not address the integration of AI with emerging technologies such as blockchain or the Internet of Things, which could enhance data interoperability and security. Future research should expand to include hybrid AI models, explore larger-scale implementations, and address ethical concerns related to data privacy and system transparency to ensure broader applicability and acceptance.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

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