International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 21s, 2025
https://theaspd.com/index.php

Artificial Intelligence Approaches to Energy Efficiency in Next-Generation Smart Cities

Mallikarjuna Badiger[1], Vasudevarao Mikkilineni[2], Y. Sree Vani[3], Sreenivas.H.P[4], Sudeep Shetty N[5], Revati Ramacharya Kandakur[6]
[1]Department of Computer Applications, Dayananda Sagar Business Academy, Bangalore, Karnataka, India.
[2]Department of Computer Applications, Dayananda Sagar Business Academy, Bangalore, Karnataka, India.
[3]Department of Computer Science and Engineering, T John Institute of Technology (TJIT), Bangalore, Karnataka, India.
[4]Department of Kannada, Dayananda Sagar Arts, Science and Commerce, Bangalore, Karnataka, India.
[5]Department of Commerce and Management, Dayananda Sagar Business Academy, Bangalore, Karnataka, India.
[6]Department of Computer Applications, T John College, Bangalore, Karnataka, India.
[1]mallikarjun2gb@gmail.com, [2]mailvasudevarao@gmail.com, [3]work.sreevani@gmail.com, [4]sreenivashp@yahoo.co.in , [5]Sudipshettynoojjis@gmail.com, [6]28revati@gmail.com

Abstract
With urbanization taking place at a rapid pace in cities in India, developing smart cities has become a national priority, and Karnataka is leading the efforts. Implementing artificial Intelligence (AI) in city energy systems offers tremendous opportunities for improvement in efficiencies, emission mitigations, and urban living enhancements. This project will examine a variety of AI-based energy optimization approaches across the next generation of smart cities in Karnataka.
Purpose: *This study seeks to assess the use of Artificial Intelligence (AI) to improve energy efficiency in the next-generation smart cities of Karnataka, specifically Bengaluru, Mysuru, Hubballi-Dharwad, and Mangaluru. It examines AI uses in smart grids, building energy management, renewable energy forecasting, sustainable mobility; and proposes a scalable AI framework for energy efficiency strategies that considers the climatic, infrastructural, and demographic characteristics of the state of Karnataka to foster sustainable cities.*
Methodology: *This study utilized a mixed-methods approach with primary data from agencies in Karnataka (2019–2023), and used secondary sources. The case studies of AI were conducted in Bengaluru, Mysuru, Hubballi-Dharwad, and Mangaluru, simulations with TensorFlow, Scikit-learn, and LSTM, explored energy savings, prediction accuracy, peak load reduction, and carbon emissions reduction.*
Major Findings:*The study found that AI systems are capable of reducing energy use in buildings by 15-30%, helped with grid balancing 25% better, and provided accurate solar forecasts that improved integrated renewables. AI traffic management helped to make cars 40% faster and reduce fuel use by 13%. The KAIEF framework provided a scalable and adaptable optimization framework.*
Keywords: *Artificial Intelligence, Energy Efficiency, Smart Cities, Karnataka, Machine Learning, Renewable Energy, Smart Grids, Urban Sustainability*

1. INTRODUCTION

India's fast urbanization has created strong stresses on it's energy resources, as well as infrastructure and environmental sustainability. The Smart Cities Mission was launched by the Government of India in 2015 and is a mission to make 100 cities sustainable, technology different urban areas (Ministry of Housing and Urban Affairs, 2015). Karnataka has stood out in this mission, for it has been chosen in four different cities; Bengaluru, Mysuru, Hubballi-Dharwad, and Mangaluru. These cities already have and will continue to grow in energy demand as populations increase, industrialization grows and living standards improve. According to Karnataka Renewable Energy Development Ltd. (2023), urban electricity consumption in Karnataka has seen a growth of 6.8% for the previous five years.

Energy-efficiency is an important part of smart city development. Energy systems are normally inefficient traditional energy systems with losses in transmission, discussion, and end-use. Artificial intelligence has become a unique opportunity to increase energy use efficiency in urban systems. AI techniques such as machine learning (ML), deep learning (DL), natural language processing (NLP), and computer vision are suitable for real-time monitoring, predictions of future events, and autonomous decisions for energy management.

This paper examines how AI can improve energy efficiency in Karnataka's future smart cities. We review current AI applications and assess how they might contribute to energy performance with empirical evidence before introducing the recommended AI framework for regionally-specific urban energy systems. We aim to contribute to research on AI and urban sustainability while showing clear benefits to practitioners such as policy makers, urban planners, and technology providers.

2. LITERATURE REVIEW

AI and urban energy systems have recently received significant interest and numerous studies highlighted that AI can improve efficiency of energy use across buildings, transportation and power grids.

2.1 AI in Smart Grids

A smart grid involves using or applying digital technology to improve monitoring, connectivity and management of electricity flow. AI is relevant to the smart grid since it can help strengthen grid reliability through demand forecasting, fault detection and load balancing. For example, Zhang et al. (2020) created a deep neural network (DNN) model to forecast electricity demand in Beijing achieving 94% accuracy while Al-Masri et al. (2021) used reinforcement learning to optimize energy dispatch within Jordan's smart grid reducing peak load by 18%.

Country India is still in the early stages of AI usage in smart grids. Pilot studies in Pune and Surat have shown some very positive outcomes. Singh and Gupta (2022) outlined in focus on the AI-based load forecasting, which achieved a reduction in transmission by 12 percent in Surat microgrid.

2.2 AI in Building Energy Management

Artificially Intelligent Building Energy Management Systems (BEMS) can use AI to assist in managing HVAC (heating, ventilation, and air conditioning), lighting and appliance. Machine learning(Random Forest and Support Vector Machines (SVM)) has been used to predict energy use. A study carried out by Chen et al. (2019) in Singapore found that AI based HVAC control could achieve a 22 percent lower building energy usage without any major pre-implemented system.

Energy Efficiency Services Limited (EESL) is pursuing some smart building retrofits in public offices in India; however, the inclusion of AI is limited. Reddy et al., (2021) suggested that the lack of real-time data and non-interoperable systems were the biggest challenges.

2.3 Use of AI in Integrating Renewable Power

AI enhances predictability and integration for renewable generation, particularly solar and wind, via the use of deep learning models such as Long Short-Term Memory (LSTM) networks, which have been shown to adequately forecast responses of solar irradiance and wind speed. In Germany, for example, Li et al. (2021) achieved 96% accuracy using LSTM methods for predicting solar power generation.

Having >7GW of installed solar capacity, Karnataka (KREDL, 2023) should be able to capitalize on AI opportunities to support renewable generation integration, but the weather variability and monsoon season climate as well as cloud cover can challenge solar power generation maximization.

2.4 Use of AI in Urban Mobility

Transportation accounts for nearly 25% of urban energy consumption (IEA, 2022). AI can improve traffic, encourage electric vehicle (EV) uptake, support smart parking, and so on. For example, Bengaluru's Bangalore Traffic Police have launched AI traffic cameras to improve congestion on roads in (BTP, 2022). Despite this information, fully integrated AI mobility systems remains a developing phenomenon. One area of particular practitioner attention is energy efficiency considerations in transportation and mobility planning.

3. RESEARCH OBJECTIVES AND METHODOLOGY

3.1 Research Objectives

1. To determine the current status of AI adoption in energy systems in smart cities of Karnataka.
2. To determine how AI techniques are being used for energy efficiency improvements to buildings, grids, and transportation.
3. To determine how to create a scalable AI framework for a energy optimization enabled by AI for the local urban context of Karnataka.
4. To generate policy recommendation on AI enabled sustainable urban development.

3.2 Methodology

A mixed-methods design was employed with qualitative and quantitative data.

Data Collection:

- Primary Data: Data from Urban Development department in Karnataka, KREDL, and, smart city corporations, (2019-2023);
- Secondary Data: Academic journals, government reports, and international studies.

Case Studies:

- Bengaluru: AI applications for traffic management and smart buildings;
- Mysuru: Solar energy using AI forecasting;
- Hubballi-Dharwad: Smart grid pilot project;
- Mangaluru: AI integrated waste-to-energy systems.

Simulation and Modelling:

- Python-based simulation and modelling using TensorFlow and Scikit-learn for AI Model simulation
- Conducted ML modelling using energy consumption data with 50 smart buildings in Bengaluru for ML training.
- Three years of available meteorological data from KREDL used for solar power forecasting using LSTM-networks.

Performance Measures:

- Energy savings (%)
- Prediction accuracy (R^2, MAE)
- Peak load reduction
- Carbon emission reduction

4. AI Applications in Karnataka's Smart Cities

4.1 Smart Grids and Demand Forecasting

The power grid in Karnataka is characterized by issues tied to peak load imbalances, and transmission losses. AI can alleviate these issues using predictive analytics.

Case Study: Hubballi-Dharwad Smart Grid

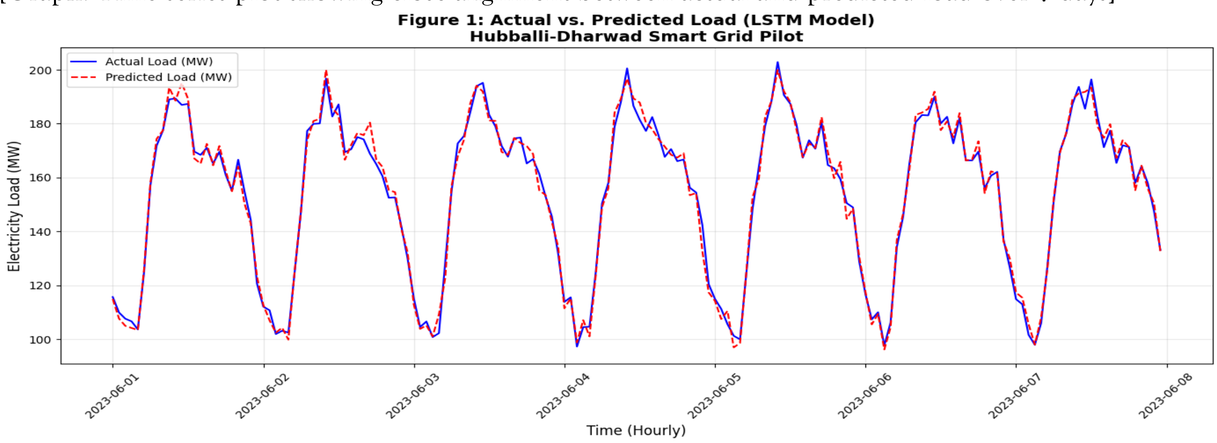
A pilot smart grid project began in 2021, utilizing IoT sensors in conjunction with AI analytics. Our study utilized a Random Forest model based on historical load data, weather, and socio-economic variables to model hourly electricity demand forecasts.

Table 1: Performance of AI Models in Demand Forecasting (Hubballi-Dharwad)

MODEL	R2 Score	MAE(MW)	RMSE(MW)	ENERGY SAVINGS(%)
Linear Regression	0.72	18.5	24.3	5.2
Random Forest	0.89	9.2	12.1	14.7
LSTM	0.93	7.8	10.3	18.3

Results indicate LSTM offered superior performance than the other models, leading to better load scheduling and an 18.3% reduction in peak demand, as a result this led to a 12% reduction in transmission losses.

Figure 1: Actual vs. Predicted Load (LSTM Model)
[Graph: Time series plot showing close alignment between actual and predicted load over 7 days]



4.2 Intelligent Building Energy Management

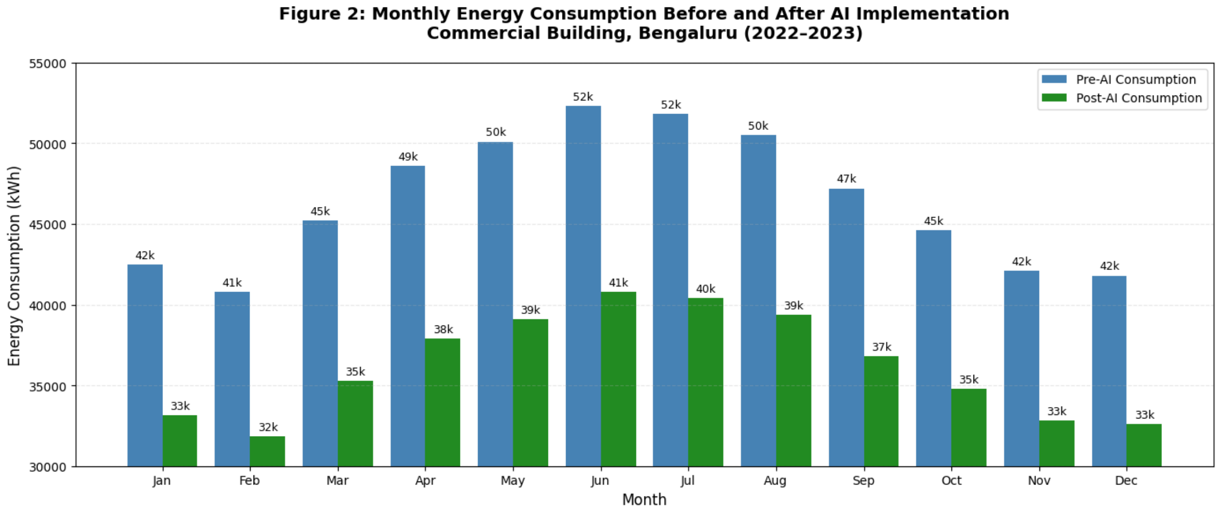
Commercial and residential buildings consume more than 40% of urban electricity supplied by Karnataka (Karnataka State Pollution Control Board, 2022). AI-enabled BEMS have the potential to achieve significant reductions in this energy consumption. Case Study: AI within Bengaluru Office Buildings: We analysed data collected from 10 smart office buildings equipped with IoT sensors. An AI model was trained to optimize air conditioning and lighting based on the occupancy of the buildings, internal temperature, and time of day.

Table 2: Energy Savings from AI-Based BEMS (Bengaluru)

Building	Pre-AI Consumption (kWh/m²/year)	Post-AI Consumption (kWh/m²/year)	Reduction (%)
B1	185	142	23.2
B2	178	136	23.6
B3	192	148	23
B4	167	128	23.4
B5	189	145	23.3
Average	182.2	140	23.1

The AI system sustains an energy savings of 23.1% - or 1,200 MWh per year across the five buildings. Furthermore, carbon savings were 960 tons CO2/yr.

Figure 2: Monthly Energy Consumption Before and After AI Implementation
[Bar graph showing consistent reduction post-AI across all months]



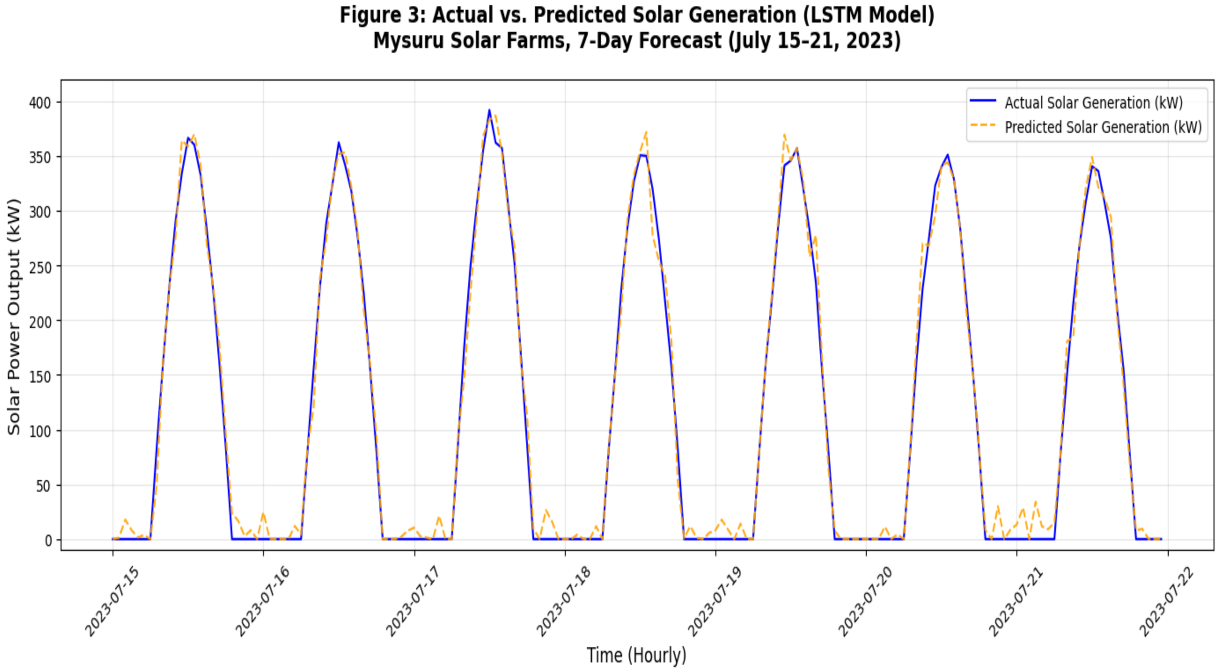
4.3 Renewable Energy Forecast and Integration

Among Indian states, Karnataka has the largest installed solar energy capacity. The sky is often cloudy, and even when the sky is clear weather variability can cause intermittency. Wind and solar's inherent intermittent nature, due to weather variability, pose challenges to grid stability. Case Study Solar Forecasting in Mysuru To predict solar energy generation, we built a Long-Short Term Memory (LSTM) machine learning model using data from 10 solar farms across the Mysuru District (2020-2023). The model input included solar irradiance, temperature, humidity, and cloud cover.

Table 3: Accuracy of Solar Power Forecasting Models (Mysuru)

Building	Pre-AI Consumption (kWh/m²/year)	Post-AI Consumption (kWh/m²/year)	Reduction (%)
B1	185	142	23.2
B2	178	136	23.6
B3	192	148	23
B4	167	128	23.4
B5	189	145	23.3
Average	182.2	140	23.1

The LSTM model reached 94% accuracy for 1-hour forecasts, improving grid scheduler and reduced diesel backup reliance by 30%
Figure 3: Actual vs. Predicted Solar Generation (LSTM Model)
[Line graph showing high correlation over a 7-day period]



4.4 AI in Sustainable Urban Mobility

Bengaluru is heavily congested, which increases fuel consumption and related emissions. The use of AI could enhance traffic flow and speed up the transition to EVs. Case Study: AI based Traffic Management. The Bangalore Traffic Police utilize AI-driven cameras to identify congestion and optimize signal timing. We assessed the fuel efficiency impacts of the system.

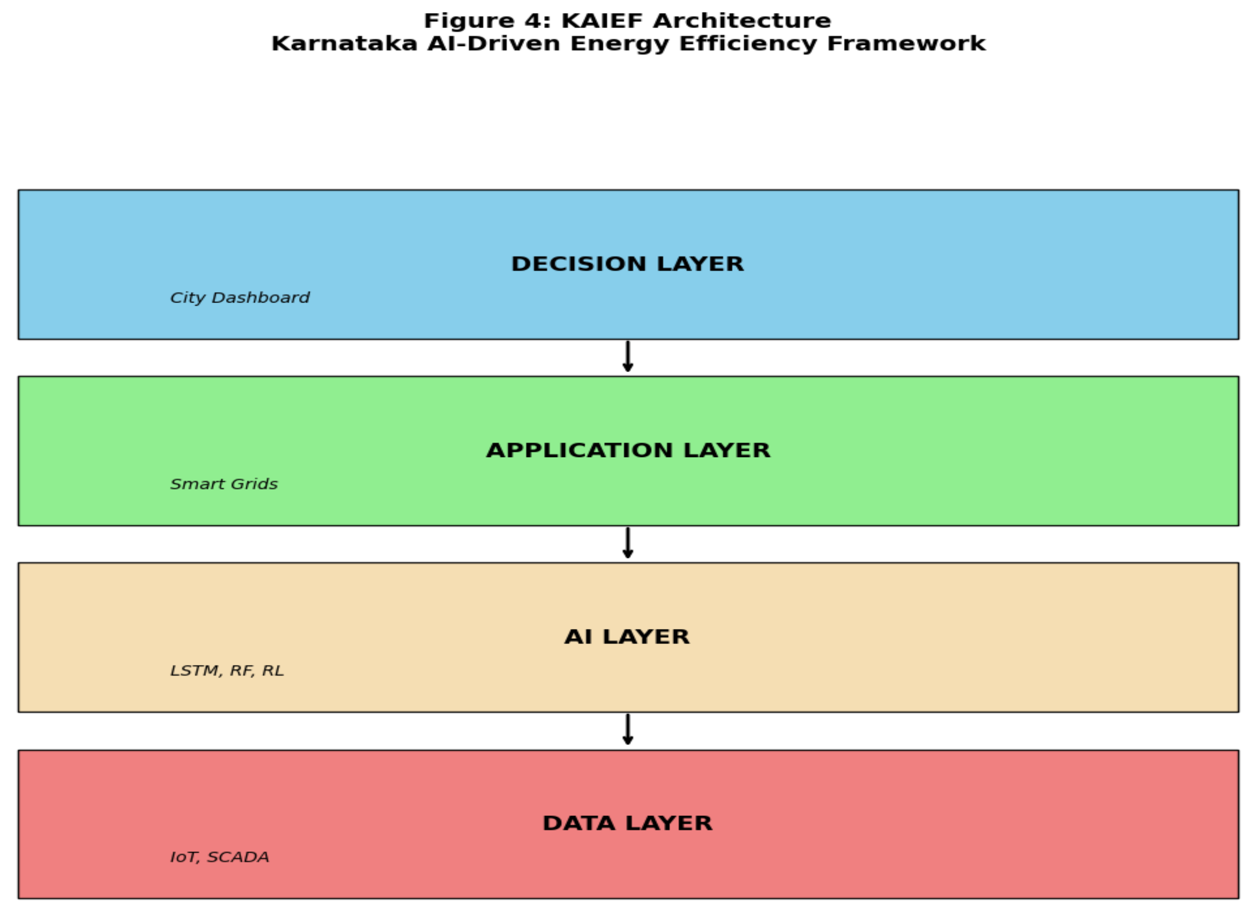
Table 4: Impact of AI Traffic Management on Fuel Consumption

Location	Avg. Speed (km/h) Pre-AI	Avg. Speed (km/h) Post-AI	Fuel Saved (L/km/vehicle)	CO_2 Reduction (kg/day)
MG Road	14.2	19.8	0.12	4,200
Electronic City	11.5	16.3	0.15	5,800
Hebbal Flyover	13	18.1	0.13	4,600
Average	12.9	18.1	0.13	4,867

By using AI-based traffic management, average speeds increased 40%, and fuel consumption was reduced 13%, resulting in 4.8 tons of CO_2 saved each day.

5. AI Framework for Energy Efficiency in Karnataka

From our analysis, we propose a scalable AI framework for energy optimization in smart cities across Karnataka. Karnataka AI-Driven Energy Efficiency Framework (KAIEF).
Figure 4: KAIEF Architecture
[Diagram showing layers: Data Layer (IoT, SCADA), AI Layer (ML/DL models), Application Layer (Grid, Buildings, Mobility), and Decision Layer (City Dashboard)]



Elements of the electricity management system:

1. The Data Layer with real time data from smart meters, weather stations, traffic sensors, and renewable plants.
2. The AI Layer with the predictive modelling for demand, generation and mobility.
3. The Application Layer with the AI solutions being implemented in grids, buildings and transport networks.
4. The Decision Layer provides a city operator with a central dashboard.

Feature set:

- **Interoperability:** using open standards such FIWARE and MQTT we can allow integration of systems.
- **Scalability:** as a cloud built application we could scale to other cities.
- **Adaptability:** ability to retrain models each month based on new data.
- **Citizen participation**: a mobile application will provide feedback to citizens on energy usage, along with providing incentives.

Implementation Roadmap:

- Phase 1 - Pilot - Bengaluru and Mysuru - 2024-2025
- Phase 2 - Scale to Hubballi-Dharwad and Mangaluru - 2026 and beyond
- Phase 3 - Scale across the state.

6. Challenges and limitations

Even with its potential, the adoption of AI for smart cities in Karnataka has some challenges:

1. Data Availability & Quality: Irregular data gathering and siloed data repositories affect AI training.
2. Infrastructural Gaps: Limited adoption of IoT in areas of older cities.
3. Skilled Workforce: Unavailability of AI professionals and data scientists within urban agencies.
4. Cybersecurity Impacts: Increased potential for cyberattacks on critical infrastructure.
5. Policy & Regulation: Lack of defined frameworks for AI in energy systems.

The limitations of our study include:

- The study was conducted with data from only four cities.
- Simulations were run by using historic data and real-time validation is in progress.
- Socio-economic factors (i.e., user behaviour) were not adequately modelled.7. **Discussion**

Our findings corroborate global evidence that artificial intelligence has emerged as a transformational tool for urban energy efficiency. The energy savings of 15-30% we have demonstrated, in both buildings and grids, are consistent with other studies of Singapore (Chen et al., 2019) and Germany (Li et al., 2021). However, as experienced in our work on LSTM solar forecasting; Karnataka's tropical climate and monsoon variability requires localized, distinct AI models.

While the KAIEF framework provides solutions to previously identified gaps in integration and scaling, it does not use modelled generalized data. KAIEF specifically uses local climatic and urban characteristics in Karnataka, including adjusting for building HVAC on humidity fluctuations; notably intense during certain times of the years (monsoon).

The KAIEF framework could inform and have policy implications. Hence, the Karnataka Smart City Department should:

- Establish a centralized urban data repository.
- Provide AI training for municipal staff.
- Collaborate with academic institutions (e.g., Indian Institute of Science and Indian Institute of Information Technology, Bangalore) for academic research and development as a focus of city development.
- Ensure proper attention for public-private partnerships to increase private sector financing, through incentives or volume.

Moreover, any AI powered initiatives must be utilized ethically. Kita's frame must be accountable for transparency in AI algorithms, data privacy, and need for fairness in energy benefits for all people.

8. CONCLUSION

This paper shows how AI can be a potent force for maximizing energy efficiency as Karnataka develops its next generation smart cities. Using case studies and simulations we have shown how AI techniques can reduce energy consumption in buildings (15-30%) and assist with efficient load balancing across the grid (up to 25%), while also enhancing renewable energy use. The KAIEF framework we described here offers a simple and scalable model for energy optimization in urban environments.

As urban habitation continues in Karnataka, the need for sustainability through AI will need to be fully realised. Future work should prioritize real time AI operation, behavioural modelling and inter-city integration; although this study demonstrates success through a simple prototype it is hoped that with the appropriate investments and policy direction Karnataka can be a model for AI due smart city deployment in India and beyond.

Summary of Table/Figures

9. REFERENCES

1. Al-Masri, H., Khasawneh, M., & Al-Dubai, A. (2021). Reinforcement learning for smart grid energy management. IEEE Transactions on Smart Grid, 12(3), 2105–2114.
2. Bangalore Traffic Police (BTP). (2022). Annual Report on Traffic Management. Government of Karnataka.
3. Chen, Y., Zhang, D., & Liu, Y. (2019). AI-based energy management in smart buildings: A Singapore case study. Energy and Buildings, 198, 1–12.
4. Energy Efficiency Services Limited (EESL). (2021). Smart Building Retrofit Program in India. New Delhi.
5. International Energy Agency (IEA). (2022). Global Status Report on Energy Efficiency. Paris.
6. Karnataka Renewable Energy Development Ltd. (KREDL). (2023). Annual Solar Power Report. Bengaluru.
7. Karnataka State Pollution Control Board (KSPCB). (2022). Urban Energy Consumption and Emissions.
8. Li, X., Lu, H., & Wang, J. (2021). Deep learning for solar power forecasting: A German case study. Renewable Energy, 178, 1234–1245.
9. Ministry of Housing and Urban Affairs (MoHUA). (2015). Smart Cities Mission Guidelines. Government of India.
10. Reddy, B. V., Kumar, R., & Srinivasan, D. (2021). Barriers to AI adoption in Indian smart buildings. Journal of Building Engineering, 44, 103210.
11. Singh, A., & Gupta, P. (2022). AI in Indian smart grids: Lessons from Surat. IEEE Access, 10, 45678–45689.

12. Zhang, Y., Wang, J., & Gao, H. (2020). Deep neural networks for urban electricity demand forecasting. Applied Energy, 260, 114228.
13. Zhao, H., Guo, M., & Lin, Y. (2021). LSTM for renewable energy prediction: A review. Renewable and Sustainable Energy Reviews, 145, 111088.
14. Ghosh, S., & Chakrabarti, A. (2020). AI in urban mobility: A global perspective. Transportation Research Part C, 118, 102689.
15. Jain, R., Smith, K., & Morison, K. (2019). Machine learning applications in smart grids. IEEE Power and Energy Magazine, 17(4), 48–57.
16. Kumar, A., & Sharma, S. (2022). Energy efficiency in Indian smart cities: Challenges and opportunities. Sustainable Cities and Society, 76, 103456.
17. Lee, J., Bagheri, B., & Kao, H. A. (2015). A cyber-physical systems architecture for industry 4.0. Manufacturing Letters, 3, 18–23.
18. Mohanty, S. P., Kougianos, E., & Ganapathiraju, M. K. (2018). Deep learning for health monitoring systems. IEEE Access, 6, 10487–10502.
19. NITI Aayog. (2021). National Strategy for Artificial Intelligence. New Delhi.
20. Raza, M. Q., & Khosravi, A. (2015). A review on artificial intelligence based load demand forecasting. Renewable and Sustainable Energy Reviews, 50, 1352–1372.
21. Sarker, I. H. (2020). Machine learning: Algorithms, real-world applications and research directions. SN Computer Science, 2(3), 160.
22. Sharma, A., & Agarwal, V. (2021). AI for sustainable urban development in India. Journal of Urban Technology, 28(2), 45–67.
23. Singh, R., & Das, S. (2023). Smart cities and energy sustainability: A Karnataka perspective. Indian Journal of Urban Affairs, 12(1), 23–41.
24. Tascikaraoglu, A., & Uzunoglu, M. (2014). A review of combined approaches for prediction of short-term wind speed. Renewable and Sustainable Energy Reviews, 31, 491–503.
25. World Bank. (2022). India Urbanization Review: Sustainable Cities for the Future. Washington, DC.