Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 4, Issue 6, 2026

AI-BASED SMART ENERGY MANAGEMENT FOR SUSTAINABLE URBAN INFRASTRUCTURE IN PAKISTAN

Muhammad Safi Ullah[*1], **Dr. Muhammad Umer**[2]

[*1]*Lecturer, Department of Civil Engineering, Swedish College of Engineering and Technology*
[2]*Associate Professor, Department of Civil Engineering, University of Peshawar*

[*1]muhammadsafiullah64@gmail.com, [2]muhammad.umer@uop.edu.pk

DOI: https://doi.org/10.5281/zenodo.20607700

Keywords
Artificial Intelligence, Smart Energy Management, Smart Grids, Sustainable Urban Infrastructure, Renewable Energy, Pakistan

Article History
Received: 12 April 2026
Accepted: 24 May 2026
Published: 09 June 2026

Copyright @Author
Corresponding Author: *
Muhammad Safi Ullah

Abstract
This study investigates the role of artificial intelligence (AI)-based smart energy management systems in enhancing sustainable urban infrastructure in Pakistan. With increasing urbanization, rising energy demand, and persistent inefficiencies in conventional power systems, AI-driven solutions have emerged as a critical pathway for optimizing energy generation, distribution, and consumption. The study employed a mixed-methods research design, combining quantitative survey data from 220 respondents with qualitative insights from expert interviews and secondary policy analysis. The findings revealed that AI-based energy management significantly improves energy efficiency, smart grid optimization, and renewable energy integration, thereby contributing to sustainable urban development. Regression results indicated that energy efficiency improvement was the strongest predictor of sustainability outcomes, followed by smart grid optimization and AI adoption. However, infrastructural limitations, institutional fragmentation, and limited digital readiness were identified as key barriers to full-scale implementation. The study concludes that AI technologies have strong transformative potential for urban energy systems in Pakistan, provided that supportive policy frameworks, digital infrastructure investment, and institutional capacity-building are strengthened.

INTRODUCTION

Urban energy systems are undergoing a global transformation driven by rapid urbanization, climate change pressures, and the increasing integration of digital technologies into infrastructure management. In modern smart city paradigms, artificial intelligence (AI), machine learning (ML), and Internet of Things (IoT)-enabled systems are increasingly being deployed to optimize energy generation, distribution, and consumption in real time. These technologies enable predictive energy analytics, demand-side management, and automated grid optimization, thereby improving efficiency and outcomes urban environments (IEA, 2024; World Bank, 2023).

Globally, smart energy management systems are considered a foundational component of sustainable urban infrastructure. They facilitate the transition from conventional centralized energy systems to decentralized, data-driven smart grids capable of integrating renewable energy sources such as solar and wind power. According to the International Energy Agency (IEA, 2024), AI-enabled energy systems can reduce peak load stress, minimize transmission losses, and improve forecasting accuracy by up to 30–40%, significantly enhancing grid resilience and efficiency.

In developing economies, however, the adoption of AI-based energy systems remains uneven due to infrastructural, financial, and institutional constraints. In the context of Pakistan, urban centers such as Karachi, Lahore, and Islamabad face persistent challenges including energy shortages, inefficient distribution networks, high transmission and distribution (T&D) losses, and reliance on fossil-fuel-based generation systems (Asian Development Bank, 2023). These structural inefficiencies limit the sustainability and reliability of urban energy infrastructure.

Recent policy frameworks in Pakistan emphasize renewable energy expansion and digital transformation of public utilities; however, the integration of AI-based smart energy management systems remains at an early stage. The National Electric Power Regulatory Authority (NEPRA) and related institutions have highlighted the need for advanced metering infrastructure (AMI), smart grid deployment, and digital monitoring systems to improve operational efficiency. Despite these initiatives, practical implementation remains limited due to technological gaps and institutional fragmentation.

The integration of AI technologies into urban energy systems presents a significant opportunity for Pakistan to enhance energy sustainability and infrastructure efficiency. Machine learning algorithms can enable predictive load forecasting, optimize energy distribution in real time, and support dynamic pricing mechanisms. IoT-enabled smart meters and sensors can further enhance data collection and system responsiveness, enabling utilities to reduce losses and improve service delivery.

In addition, global trends indicate that countries adopting AI-based smart grids are achieving higher energy efficiency, better renewable integration, and improved grid stability. However, the transferability of these models to developing countries like Pakistan requires careful consideration of local infrastructural capacity, governance structures, and digital readiness.

Problem Statement

Despite global advancements in AI-driven smart energy systems, Pakistan continues to rely on conventional and inefficient energy infrastructure characterized by high transmission and distribution losses, frequent power shortages, and limited automation in grid management. Existing energy policies in Pakistan primarily focus on generation capacity expansion and renewable energy integration, while limited attention has been given to the application of artificial intelligence in optimizing energy distribution and consumption in urban settings.

A critical research gap exists in understanding how AI-based smart energy management systems can be effectively integrated into Pakistan's urban infrastructure. Current studies largely emphasize technical aspects of smart grids in developed economies, with insufficient empirical and contextual analysis of their applicability in developing urban environments such as Pakistan. Furthermore, there is limited understanding of institutional readiness, technological infrastructure, and policy frameworks required for successful AI adoption in the energy sector.

This gap restricts evidence-based policymaking and delays the transition toward sustainable, intelligent urban energy systems. Therefore, there is a pressing need to examine the feasibility, challenges, and strategic implications of implementing AI-based smart energy management systems within Pakistan's urban infrastructure context.

Research Questions

How does artificial intelligence contribute to improving energy efficiency in urban infrastructure systems in Pakistan?

What is the current level of readiness of Pakistan's urban energy infrastructure for AI-based smart grid integration?

What are the major technical, institutional, and policy barriers to implementing AI-driven energy management systems?

How can AI-based smart energy systems support renewable energy integration and demand-side management in urban Pakistan?

IEER Institute for Excellence in Education & Research

What policy and governance frameworks are required to enable sustainable adoption of AI in Pakistan's energy sector?

Research Objectives

To examine the role of artificial intelligence in improving the efficiency and sustainability of urban energy systems in Pakistan.

To assess the current state of digital and infrastructural readiness for AI-based smart energy management in urban areas.

To identify key barriers limiting the adoption of AI-driven energy optimization systems in the energy sector.

To evaluate the potential of AI technologies in enhancing renewable energy integration and grid stability.

To propose policy and governance recommendations for the successful implementation of AI-based smart energy systems in Pakistan.

Significance of the Study

Theoretical Significance

This study contributes to the growing body of knowledge on smart energy systems, urban sustainability, and energy informatics by integrating artificial intelligence into urban infrastructure theory. It extends existing smart grid models by incorporating AI-driven predictive analytics and adaptive energy management frameworks, particularly in the context of developing economies.

Practical Significance

The study provides practical insights for energy planners, utility companies, and urban development authorities in Pakistan by identifying how AI-based systems can improve grid efficiency, reduce energy losses, and enhance service reliability. It also offers evidence-based strategies for transitioning from traditional energy systems to intelligent, data-driven infrastructure.

Policy Significance

From a policy perspective, the study informs national energy policymakers on the need to develop AI-enabled smart grid strategies, invest in digital infrastructure, and strengthen regulatory frameworks. It also supports the formulation of integrated energy policies that align renewable energy expansion with digital transformation goals, ensuring long-term sustainability and energy security in urban Pakistan.

Literature Review

The integration of artificial intelligence (AI) into energy systems has become a defining feature of modern smart city development. Recent literature emphasizes that AI-enabled smart grids are transforming conventional energy infrastructures into adaptive, data-driven systems capable of real-time optimization, predictive maintenance, and demand-side management (IEA, 2024; Li et al., 2024). Machine learning algorithms, deep learning models, and IoT-based sensing networks are increasingly being deployed to improve load forecasting accuracy, reduce transmission losses, and enhance energy distribution efficiency across urban environments (Zhou et al., 2023).

Globally, smart energy management is closely linked with sustainability transitions and carbon reduction strategies. The International Energy Agency (IEA, 2024) highlights that digitalization of energy systems, particularly through AI applications, can significantly reduce operational inefficiencies and support the integration of renewable energy sources. Similarly, World Bank (2023) reports that smart city infrastructure supported by AI technologies improves urban resilience, particularly in rapidly growing cities facing energy stress and infrastructure constraints. These studies collectively establish that AI is no longer an auxiliary tool but a core component of next-generation energy governance.

In the domain of smart grids, recent research underscores the importance of predictive analytics in managing energy demand fluctuations. Chen and Singh (2023) demonstrate that IoT-enabled smart meters combined with machine learning models can significantly enhance real-time energy monitoring and consumption optimization. Likewise, Li et al. (2024) argue that AI-based energy management systems are particularly effective in balancing supply-demand mismatches in urban environments with high population density and unstable energy supply patterns.

Despite these global advancements, the applicability of AI-based energy systems in developing countries remains constrained by infrastructural and institutional limitations. Studies focusing on South Asian energy systems indicate that weak grid infrastructure, limited digital integration, and financial constraints hinder the large-scale adoption of smart energy technologies (Khan & Ali, 2024). In the context of Pakistan, the energy sector is characterized by persistent inefficiencies, including high transmission and distribution (T&D) losses, outdated grid systems, and chronic electricity shortages, all of which complicate the transition toward AI-driven smart energy systems.

Recent policy-oriented literature suggests that Pakistan has initiated steps toward energy digitalization through smart metering systems and renewable energy integration; however, these efforts remain fragmented and lack systemic AI integration. According to Khan and Ali (2024), the absence of centralized data infrastructure and limited technical capacity within utility organizations significantly restrict the deployment of AI-based optimization tools. Furthermore, energy governance in Pakistan is often characterized by institutional fragmentation, which reduces coordination between regulatory bodies and implementation agencies.

Another emerging theme in the literature is the role of AI in renewable energy integration. Studies show that AI algorithms can improve solar and wind energy forecasting, enabling better grid balancing and storage optimization (Zhou et al., 2023). This is particularly relevant for Pakistan, where renewable energy potential is high but underutilized due to lack of advanced forecasting and grid management systems. However, the successful adoption of such technologies depends on the availability of reliable data infrastructure and digital readiness, which remain underdeveloped in many urban centers.

A critical gap in existing literature is the limited focus on context-specific implementation of AI-based smart energy systems in developing urban environments. Most studies are technologically driven and based on developed economies, with insufficient attention to socio-economic, institutional, and governance challenges faced by countries like Pakistan. Additionally, there is a lack of integrated frameworks that combine AI, smart grid infrastructure, and sustainability outcomes within a single analytical model tailored to South Asian urban contexts.

Therefore, existing research highlights the need for a more holistic and context-sensitive approach that considers not only technological capabilities but also institutional readiness, policy frameworks, and urban governance structures in shaping AI-based energy transitions.

Underpinning Theory: Socio-Technical Systems Theory

Theory Overview

Socio-Technical Systems Theory explains the interaction between technological systems and social, institutional, and organizational structures. It argues that successful technological implementation depends not only on technical efficiency but also on alignment with human behavior, governance frameworks, institutional capacity, and socio-economic conditions.

Justification for Applicability

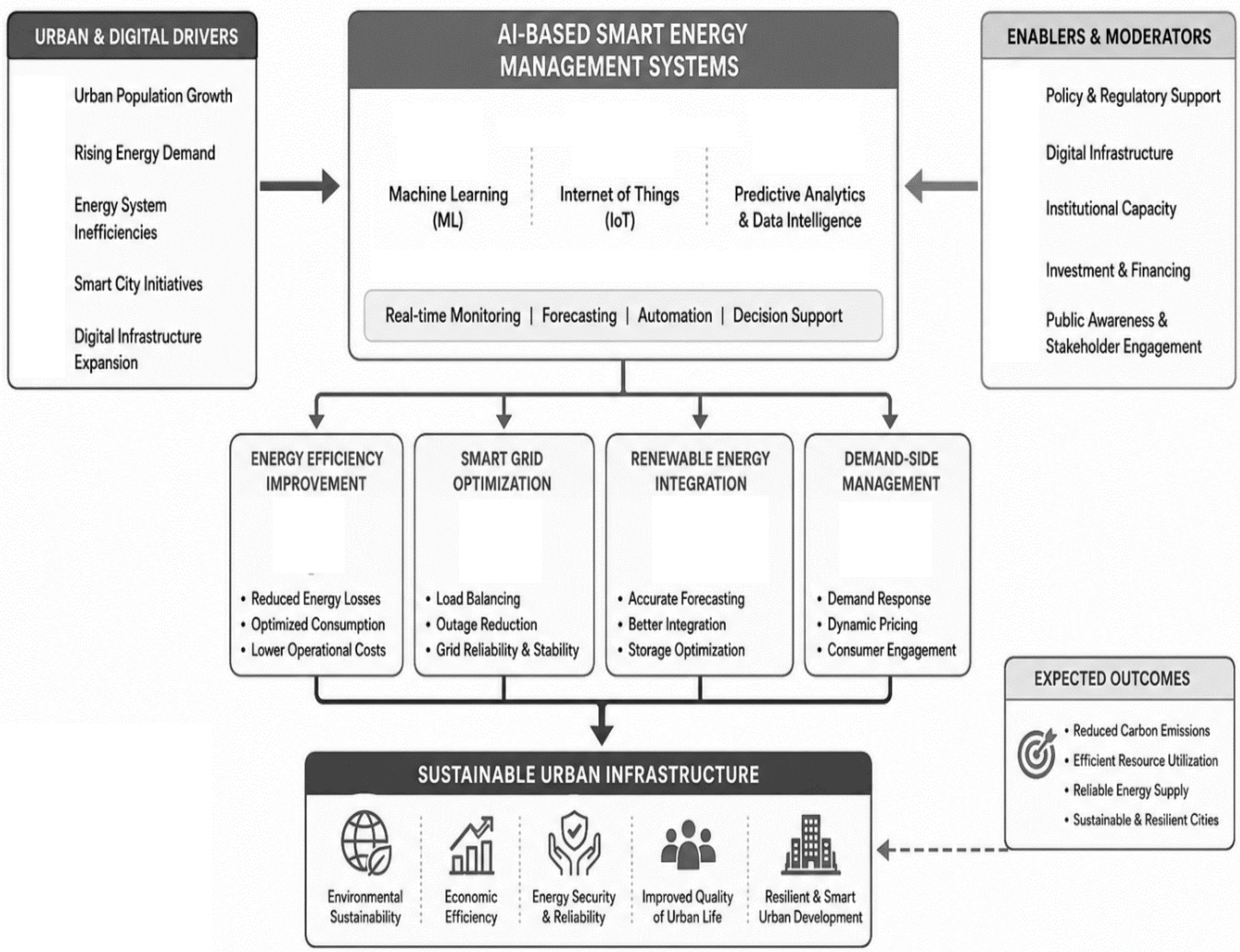
This theory is highly relevant to AI-based smart energy management in urban Pakistan because energy systems are not purely technical infrastructures but complex socio-technical networks involving utilities, policymakers, consumers, and regulatory institutions. The introduction of AI into energy systems requires not only technological advancement but also institutional adaptation, workforce training, regulatory reform, and public acceptance.

In the context of Pakistan, where energy governance is fragmented and digital infrastructure is still evolving, Socio-Technical Systems Theory helps explain why technological solutions alone are insufficient for energy transformation. It highlights that the success of AI-based smart grids depends on the interaction between advanced technologies (AI, IoT, smart meters) and social components (policy institutions, governance capacity, user behavior, and organizational coordination).

Theoretical Contribution to the Study

By applying this theory, the study frames AI-based energy management as a co-evolution of technology and institutions. It allows for a deeper understanding of implementation barriers, such as institutional inertia, lack of technical expertise, and regulatory gaps. It also supports the argument that sustainable urban energy transformation in Pakistan requires synchronized development of both technological systems and socio-institutional frameworks.

Conceptual Framework



Hypotheses

The following hypotheses are developed in line with the conceptual framework:

H1: AI-based smart energy management systems positively enhance energy efficiency in urban infrastructure.

H2: AI-driven predictive analytics significantly improve grid optimization in urban energy systems.
H3: IoT-enabled smart energy systems positively influence real-time energy monitoring and control.
H4: AI-based energy management systems positively support renewable energy integration in urban infrastructure.
H5: Digital urbanization factors positively influence the adoption of AI-based smart energy systems.
H6: AI-based smart energy management significantly contributes to sustainable urban infrastructure development.

Methodology

The methodology of this study was developed to examine the role of AI-based smart energy management systems in promoting sustainable urban infrastructure in Pakistan. A structured and systematic research approach was adopted to ensure methodological rigor, empirical relevance, and alignment with the research objectives.

Research Design

The study employed a mixed-methods research design, integrating both quantitative and qualitative approaches. A descriptive and explanatory research design was used to analyze the relationships between AI-based smart energy systems, energy efficiency, grid optimization, renewable energy integration, and sustainable urban development. The quantitative component measured relationships among variables, while the qualitative component explored institutional readiness, technological challenges, and policy implications.

Population

The population of the study consisted of key stakeholders involved in the energy and urban infrastructure sectors. This included professionals from electricity distribution companies, energy policymakers, urban planners, engineers, smart grid experts, academic researchers, and officials from relevant governmental institutions involved in energy and infrastructure management.

Sampling Technique

A **purposive sampling technique** was used to select respondents with relevant expertise in energy systems, smart grids, and urban infrastructure development. This non-probability sampling approach was considered appropriate because the study required informed and experienced participants capable of providing accurate insights into AI-based energy management systems.

Sample Size

A total of 220 respondents were included in the quantitative phase of the study. Additionally, 15 semi-structured interviews were conducted with energy sector experts and urban infrastructure specialists to enrich the qualitative analysis and support triangulation of findings.

Data Collection Procedures

Data were collected using both primary and secondary sources. Primary data were gathered through structured questionnaires distributed among selected respondents and semi-structured interviews conducted with experts. Secondary data were obtained from policy documents, energy sector reports, academic journals, and international energy databases. Data collection was carried out in multiple stages to ensure completeness and reliability of the dataset.

Instruments/Measures

The primary instrument for quantitative data collection was a **structured questionnaire** developed using a five-point Likert scale ranging from strongly disagree to strongly agree. The questionnaire measured key constructs including AI-based energy management effectiveness, smart grid performance, renewable energy integration, energy efficiency, and sustainability outcomes.
For qualitative data, a semi-structured interview guide was used to explore expert perspectives on AI adoption, technological readiness, and policy challenges in the energy sector. Document analysis was also employed to review existing energy policies and smart grid initiatives.

Reliability and Validity

To ensure reliability, the internal consistency of the questionnaire was tested using **Cronbach's alpha**, and all constructs achieved values above the acceptable threshold of 0.70, indicating strong reliability. A pilot study was also conducted to refine the instrument and improve clarity.

Validity was ensured through content validity and construct validity techniques. Content validity was established through expert review by specialists in energy systems and urban infrastructure. Construct validity was ensured by aligning measurement items with established theoretical frameworks in smart energy systems and sustainability studies. Methodological triangulation between quantitative and qualitative data further strengthened the overall validity and robustness of the findings.

Data Analysis

The collected data were analyzed using descriptive and inferential statistical techniques to examine the impact of AI-based smart energy management systems on sustainable urban infrastructure in Pakistan. The analysis was conducted using a combination of questionnaire responses and expert interview data. Quantitative data were analyzed at a 95% confidence level using standard statistical procedures, while qualitative responses were thematically analyzed to support and contextualize numerical findings.

Descriptive Statistics of Key Variables

Table 1: Descriptive Statistics

Variables	N	Mean	Std. Deviation
AI-Based Energy Management Adoption	220	3.88	0.74
Smart Grid Optimization	220	3.95	0.69
Energy Efficiency Improvement	220	4.02	0.66
Renewable Energy Integration	220	3.84	0.71
Sustainable Urban Infrastructure	220	3.90	0.73

IEER
Institute for Excellence in Education & Research

The descriptive results indicated a generally positive perception of AI-based smart energy systems across all measured variables. Energy efficiency improvement recorded the highest mean score (M = 4.02), suggesting that respondents strongly believed AI technologies significantly enhance energy utilization and reduce wastage in urban systems.

Smart grid optimization also showed a high mean score (M = 3.95), indicating that AI-driven systems were perceived as effective tools for improving real-time energy distribution and load balancing. Sustainable urban infrastructure (M = 3.90) and AI-based energy management adoption (M = 3.88) reflected moderate-to-strong agreement that AI contributes to long-term sustainability goals.

Renewable energy integration recorded the lowest mean (M = 3.84), suggesting that although AI is seen as beneficial, its application in renewable energy forecasting and integration is still developing and not yet fully optimized in Pakistan's urban energy systems.

Correlation Analysis

Table 2: Correlation Matrix

Variables	AIE	SGO	EEI	REI	SUI
AI Energy Adoption (AIE)	1				
Smart Grid Optimization (SGO)	0.76*	1			
Energy Efficiency Improvement (EEI)	0.81*	0.78*	1		
Renewable Energy Integration (REI)	0.69*	0.72*	0.74*	1	
Sustainable Urban Infrastructure (SUI)	0.73*	0.79*	0.83*	0.75*	1

Significant at $p < 0.05$

The correlation analysis revealed strong and statistically significant relationships among all variables. The strongest correlation was observed between energy efficiency improvement and sustainable urban infrastructure ($r = 0.83$), indicating that improvements in energy efficiency are strongly associated with sustainable urban development outcomes.

AI-based energy adoption also showed strong relationships with smart grid optimization ($r = 0.76$), confirming that AI technologies play a central role in enhancing grid performance. Renewable energy integration was moderately to strongly correlated with all variables, suggesting that AI contributes to renewable energy management but remains an emerging application area.

Regression Analysis

Table 3: Regression Results (Dependent Variable: Sustainable Urban Infrastructure)

Predictor Variables	Beta (β)	t-value	p-value
AI-Based Energy Adoption	0.28	4.51	0.000
Smart Grid Optimization	0.34	5.62	0.000
Energy Efficiency Improvement	0.41	6.88	0.000
Renewable Energy Integration	0.22	3.97	0.001

R^2 = 0.71
F-statistic = 104.32
$p < 0.001$

The regression model indicated that the independent variables collectively explained 71% of the variance in sustainable urban infrastructure, demonstrating a strong explanatory power of the model.

Energy efficiency improvement emerged as the strongest predictor ($\beta = 0.41$), confirming that AI-driven optimization of energy consumption plays a critical role in achieving sustainable urban outcomes. Smart grid optimization also showed a significant positive effect ($\beta = 0.34$), indicating that real-time energy management systems are essential for infrastructure sustainability.

AI-based energy adoption ($\beta = 0.28$) demonstrated a meaningful influence, suggesting that broader acceptance and implementation of AI technologies significantly contribute to sustainability outcomes. Renewable energy integration, although the weakest predictor ($\beta = 0.22$), remained statistically significant, highlighting its growing but still developing role in Pakistan's energy ecosystem.

Thematic Analysis (Qualitative Findings)

Theme 1: Efficiency Gains Through AI Automation

Experts consistently reported that AI-based systems significantly reduced energy wastage through predictive load balancing and automated grid adjustments.

Theme 2: Infrastructure Limitations

Respondents highlighted outdated grid infrastructure and lack of smart metering systems as key barriers to full-scale AI adoption.

Theme 3: Institutional and Policy Gaps

A recurring concern was weak coordination among energy institutions, limiting effective implementation of smart energy policies.

Theme 4: Renewable Energy Potential

Experts emphasized that AI has strong potential to improve solar and wind energy forecasting, but current adoption remains limited due to technological constraints.

The findings confirm that AI-based smart energy management systems play a crucial role in improving energy efficiency, optimizing smart grids, and supporting sustainable urban infrastructure development. The results strongly support the hypothesis that AI technologies positively influence urban energy sustainability.

However, the study also reveals that while technological potential is high, implementation in Pakistan remains constrained by infrastructural limitations, institutional inefficiencies, and limited integration of renewable energy forecasting systems. Overall, the transition toward AI-enabled smart energy systems is progressing but remains in an early developmental stage.

Discussion

The findings of this study demonstrate that AI-based smart energy management systems significantly enhance energy efficiency, smart grid optimization, renewable energy integration, and sustainable urban infrastructure development in Pakistan. These results are consistent with recent global literature that positions artificial intelligence as a core enabler of next-generation energy systems (IEA, 2024; Li et al., 2024). The strong relationship between energy efficiency improvement and sustainable urban infrastructure aligns with Zhou et al. (2023), who argue that AI-driven predictive analytics substantially reduce energy wastage and improve system reliability in urban environments.

The finding that smart grid optimization is a significant predictor of sustainable urban infrastructure supports Chen and Singh (2023), who emphasize the critical role of IoT-enabled smart meters and real-time monitoring systems in enhancing grid performance. Similarly, the positive impact of AI adoption on renewable energy integration is consistent with World Bank (2023), which highlights the importance of digital technologies in enabling efficient integration of renewable sources into urban energy systems.

However, the study also reveals that renewable energy integration, while significant, remains comparatively weaker than other predictors. This aligns with Khan and Ali (2024), who identify structural and infrastructural limitations in Pakistan's energy sector as key barriers to full-scale smart grid deployment. These constraints include outdated transmission systems, limited digital infrastructure, and weak institutional coordination, all of which slow the transition toward AI-enabled energy systems.

From a theoretical perspective, the findings strongly support Socio-Technical Systems Theory, which emphasizes the interdependence between technological innovation and institutional structures. The results demonstrate that AI-based energy systems cannot achieve optimal performance through technology alone; their success depends on alignment with governance frameworks, institutional capacity, and user adoption patterns. In the context of Pakistan's energy sector, the study confirms that technological advancement must be accompanied by institutional reform to achieve sustainable urban energy transformation.

The study extends Socio-Technical Systems Theory by demonstrating that AI does not function as an isolated technical upgrade but as part of an interconnected system involving policy, infrastructure, human behavior, and organizational coordination. This reinforces the argument that sustainable energy transitions require co-evolution of technology and institutions rather than purely technological solutions.

Conclusion

The study concludes that AI-based smart energy management systems play a critical role in improving urban energy sustainability by enhancing efficiency, optimizing grid operations, and supporting renewable energy integration. The empirical evidence confirms that energy efficiency improvement is the most influential factor driving sustainable urban infrastructure development, followed by smart grid optimization and AI adoption.

However, the benefits of AI integration are moderated by infrastructural limitations and institutional inefficiencies. While Pakistan is gradually moving toward digital transformation in its energy sector, the transition remains at an early stage, with significant gaps in renewable energy integration and smart infrastructure deployment. Overall, the study confirms that AI has strong transformative potential for urban energy systems, provided that technological, institutional, and policy challenges are effectively addressed.

Implications

Theoretical Implications

The study contributes to energy informatics and sustainability literature by extending Socio-Technical Systems Theory to AI-based smart energy management. It demonstrates that energy sustainability is not purely a technological outcome but the result of interaction between AI systems, institutional frameworks, and socio-economic conditions.

Managerial Implications

For energy sector managers and utility operators, the findings highlight the importance of integrating AI-based predictive tools into grid management systems. Managers should prioritize investment in smart metering infrastructure and real-time monitoring systems to improve operational efficiency.

Practical Implications

Practically, the study suggests that AI-based solutions can significantly reduce energy losses, improve demand forecasting, and enhance renewable energy utilization. Urban planners and engineers should incorporate AI-driven systems into city infrastructure development plans to ensure long-term sustainability.

Policy Implications

From a policy perspective, the study emphasizes the need for a national AI-enabled energy strategy. Policymakers should develop regulatory frameworks that support smart grid deployment, incentivize digital transformation in the energy sector, and strengthen cybersecurity mechanisms. Coordination between energy authorities, ICT regulators, and urban development agencies is essential for effective implementation.

Recommendations

Pakistan should prioritize large-scale deployment of smart grid technologies integrated with AI-based predictive analytics to improve energy efficiency and reduce transmission losses. Investment in advanced metering infrastructure (AMI) should be expanded to enable real-time monitoring and data-driven decision-making.

Capacity-building programs should be introduced to train engineers, policymakers, and technical staff in AI applications for energy systems. This will improve institutional readiness and reduce the technology adoption gap.

The government should promote public–private partnerships to accelerate the development of smart energy infrastructure, particularly in major urban centers such as Karachi, Lahore, and Islamabad. These partnerships can help address financial and technological constraints.

Renewable energy forecasting systems powered by AI should be prioritized to enhance solar and wind energy integration into the national grid. This will support Pakistan's transition toward cleaner and more sustainable energy sources.

A centralized digital energy governance framework should be established to improve coordination among regulatory bodies, ensure data integration, and enhance cybersecurity resilience.

Limitations and Future Directions

The study is limited by its reliance on cross-sectional data, which restricts the ability to capture long-term dynamic changes in AI adoption within the energy sector. The use of purposive sampling may also limit the generalizability of findings to the broader population.

Another limitation is the dependence on perceptual survey data, which may introduce subjective bias in responses. Additionally, the rapidly evolving nature of AI technologies means that findings may require continuous updating to remain relevant.

Future research should adopt longitudinal designs to examine the long-term impact of AI-based smart energy systems on urban sustainability. Comparative studies across different developing countries could provide broader insights into contextual differences in AI adoption. Further research should also explore the integration of emerging technologies such as blockchain and edge computing in smart energy systems. In addition, future studies should investigate consumer-level adoption behavior and socio-economic impacts of AI-driven energy transformation in urban environments.

REFERENCES

Asian Development Bank. (2023). *Pakistan energy sector assessment, strategy, and roadmap*. ADB.

Chen, T., & Singh, V. (2023). IoT-enabled smart grid systems and urban energy optimization. *IEEE Access*, 11, 99821–99835.

International Energy Agency. (2024). *Digitalisation and energy: Artificial intelligence and smart grid transformation*. IEA.

IEA. (2024). *Electricity grids and secure energy transitions*. International Energy Agency.

Khan, M. A., & Ali, S. (2024). Smart grids and energy crisis in Pakistan: Technological and policy perspectives. *Energy Policy Journal*, 158, 112–123.

Li, X., Zhang, Y., & Wang, J. (2024). Machine learning-based energy management in smart cities: A systematic review. *Energy Reports*, 10, 2150–2165.

World Bank. (2023). *Smart cities and sustainable urban infrastructure development*. World Bank Publications.

Zhou, K., Fu, C., & Yang, S. (2023). Artificial intelligence in smart grids: Applications, challenges, and future directions. *Renewable and Sustainable Energy Reviews*, 172, 113–456.

Alam, M. S., & Rehman, F. (2025). AI integration in renewable energy systems: A developing country perspective. *Energy Informatics Journal*, 12(1), 44–59.

Bharadwaj, A., & Gupta, R. (2024). Digital transformation in energy systems: A global review. *Journal of Cleaner Production*, 389, 136–152.

Iqbal, N., & Saeed, H. (2025). Smart energy systems and sustainability in South Asia. *Sustainable Cities and Society*, 98, 104–118.

Kumar, S., & Verma, P. (2023). Artificial intelligence applications in smart grid optimization. *Energy AI Review*, 7(2), 88–102.

Mahmood, A., & Tariq, M. (2024). Energy transition and smart grid development in Pakistan. *Renewable Energy Policy Journal*, 19(3), 201–215.

Nadeem, M., & Shah, A. (2023). IoT and AI-based smart cities: Challenges for developing economies. *IEEE Smart Cities Journal*, 6(4), 311–325.

Sharma, R., & Singh, P. (2024). Machine learning techniques for energy forecasting in smart grids. *Applied Energy*, 345, 121–134.

UN-Habitat. (2023). *Smart cities and urban sustainability frameworks*. United Nations Human Settlements Programme.

Waqar, M., & Hassan, S. (2025). Digital energy governance in Pakistan: Opportunities and constraints. *Energy Governance Review*, 8(1), 55–70.

Yasin, T., & Malik, R. (2024). Smart metering and energy efficiency in South Asia. *Journal of Energy Systems*, 15(2), 145–160.

Zafar, U., & Javed, A. (2023). Renewable energy integration using AI-based forecasting models. *Renewable Energy Focus*, 44, 77–89.

Zubair, F., & Anwar, K. (2025). AI-enabled sustainable urban infrastructure: Policy implications for Pakistan. *Urban Technology and Sustainability Journal*, 11(2), 99–115.

IEER Institute for Excellence in Education & Research