Artificial Intelligence-Driven Decision Support Systems for Sustainable Energy Management in Smart Cities

Ning MA
Shanxi Vocational University of Engineering Science and Technology, Jinzhong 030619, China

***Abstract*—Due to the ongoing urbanization trend, smart cities are critical to designing a sustainable future. Urban sustainability involves action-oriented approaches for optimizing resource usage, ecological impact reduction, and overall efficiency enhancement. Energy management is one of the main concerns in urban, residential, and building planning. Artificial Intelligence (AI) uses data analytics and machine learning to instigate business automation and deal with intelligent tasks involved in numerous industries. Thus, AI needs to be considered in the strategic plan, especially in the long-term strategy of smart city planning. Decision Support Systems (DSS) are integrated with human-machine interaction methods like the Internet of Things (IoT). Along with their growth in size and complexity, the communications of IoT smart devices, industrial equipment, sensors, and mobile applications present an increasing challenge in meeting Service Level Agreements (SLAs) in diverse cloud data centers and user requests. This challenge would be further compounded if the energy consumption of industrial IoT networks also increased tremendously. Thus, DSS models are necessary for automated decision-making in crucial IoT settings like intelligent industrial systems and smart cities. The present study examines how AI can be integrated into DSS to tackle the intricate difficulties of sustainable energy management in smart cities. The study examines the evolution of DSSs and elucidates how AI enhances their functionalities. The study explores several AI methods, such as machine learning algorithms and predictive analytics that aid in predicting, optimizing, and making real-time decisions inside urban energy systems. Furthermore, real-world instances from different smart cities highlight the practical applications, benefits, and interdisciplinary collaboration necessary to successfully implement AI-driven DSS in sustainable energy management.**

***Keywords*—Smart cities; artificial intelligence; decision support systems; sustainable energy management; urban resilience; interdisciplinary collaboration**

I. Introduction

Urbanization continues to rise at an unprecedented rate, resulting in an increasing proportion of the global population residing in urban centers [1, 2]. This rapid urban expansion has led to significant ecological impacts, including alterations in local and regional climates, loss of biodiversity, and disruption of natural habitats [3]. These consequences highlight the pressing need for sustainable urban development that prioritizes ecosystem preservation and restoration [4]. As urban areas grow, so do the demands on critical infrastructure, particularly energy systems, which play a crucial role in sustaining urban life. Effective energy management within cities is paramount to reducing emissions, ensuring energy efficiency, and fostering a sustainable future [5].

A. Research Problem and Motivation

The energy demands of modern cities are becoming increasingly complex, especially with the rise of smart cities—urban areas where digital technologies and data-driven systems are integrated into infrastructure and governance [6]. Smart cities aim to improve the quality of life for their residents by optimizing resource usage, reducing environmental impact, and enhancing efficiency across sectors such as transportation, waste management, and energy. However, as smart cities evolve, they face significant challenges in managing energy efficiently, particularly with the growing integration of Internet of Things (IoT) devices, which contribute to fluctuating energy demands and intricate data streams [7]. These challenges necessitate advanced solutions that can optimize energy management while ensuring the sustainability of urban systems.

Artificial Intelligence (AI) has emerged as a transformative technology capable of addressing these complex challenges by enabling real-time data analysis, predictive modelling, and automation [8, 9]. Decision Support Systems (DSS) enhanced by AI have the potential to revolutionize energy management in smart cities by providing intelligent, data-driven decision-making capabilities. Despite the recognized potential of AI and DSS, there remains a gap in understanding how these technologies can be effectively integrated to manage energy in smart cities while addressing the broader sustainability goals [10].

B. Objective and Contribution

The primary motivation of this research is to explore how AI-driven DSS can be leveraged to improve energy management in smart cities, thus addressing the intricate challenges posed by urbanization and technological integration. This study aims to investigate AI methods such as machine learning and predictive analytics, focusing on how these techniques can optimize energy use, predict demand, and support real-time decision-making in urban environments. By analyzing the current state of AI and DSS in smart city contexts, this research highlights the innovative potential of interdisciplinary collaboration in tackling the complex issues of sustainable energy management.

This paper enhances existing literature with a comprehensive discussion of the role AI-driven DSS can play in energy management in smart cities. It further examines the interaction between AI, IoT, and energy systems and proposes new models for optimizing energy usage. The present research thus lays the foundation for further practical implementation and studies in real-world applications and challenges that meet the critical demand for sustainable energy management in an increasingly complex urban environment.

II. Background

Advanced energy management involves using technology to control energy consumption and production, distribution, and consumption in highly energy-demanding cities to foster sustainable economic development [11]. However, such a transition comes with several challenges, as outlined in Table I.

One of the major issues is the ever-increasing difference between supply and demand for energy resources. Growth in urban areas increases the demand for energy since energy consumption rises with cities' expansion, which puts pressure on existing resources [12]. The gap was bridged in the past by producing more energy and emitting more carbon despite negative environmental impacts. Also, poorly maintained and relatively old energy networks in urban areas result in large amounts of energy lost in transmission and distribution. Additionally, the lack of real-time energy monitoring and management systems can prevent immediate detection and correction of inefficiencies. Finally, energy prices remain more or less volatile, and sufficient capital is not readily available to upgrade energy technologies and accommodate innovations in the market.

Incorporating sustainable and cost-effective renewable energy sources like solar, wind, and geothermal power is critical for reducing reliance on traditional energy sources and their carbon footprint [13]. Smart grids employ advanced sensors, communication technologies, and intelligent algorithms to enable real-time monitoring and management of energy distribution across the grid. This optimization minimizes waste and maximizes efficiency. The development of cost-effective and efficient energy storage systems is essential. These systems store excess energy generated from renewable sources, ensuring a reliable and consistent energy supply even during peak demand periods.

As buildings are major energy consumers in cities, developing energy-efficient buildings with intelligent lighting and HVAC systems is crucial for optimizing energy use and reducing waste [14]. Electric Vehicles (EVs) present a significant opportunity to improve air quality and reduce city carbon emissions [15]. Developing EV charging infrastructure and integrating renewable energy sources to power these vehicles are key aspects of smart energy management.

Smart homes, equipped with internet-connected devices that control and automate temperature, lighting, security, and entertainment, offer convenience, improved energy efficiency, and enhanced quality of life for residents [10]. The utilization of data analytics in smart energy management is crucial. This enables the collection, analysis, and interpretation of energy consumption data, facilitating the identification of inefficiencies, optimization of energy use, and cost reduction [16]. Integrating these technological advancements, smart cities can optimize energy production, distribution, and consumption. This paves the way for creating more sustainable, efficient, and livable urban environments.

TABLE I. Key Challenges and Solutions Related to Smart Energy Management in Urban Environments

Aspect	Challenges	Solutions
Energy supply and demand	Continuous rise in energy consumption due to urban expansion	Incorporation of renewable energy sources like solar, wind, and geothermal power to reduce carbon footprint
Infrastructure efficiency	Outdated and inefficient energy infrastructure causing energy losses during transmission and distribution	Development of smart grids with advanced sensors and intelligent algorithms for real-time energy management
Real-time monitoring	Absence of real-time energy monitoring and management systems	Smart grids are used for real-time monitoring and management to minimize waste and maximize efficiency
Economic factors	Fluctuating energy prices and limited funding for infrastructure upgrades	Development of cost-effective and efficient energy storage systems to ensure reliable energy supply
Energy-efficient buildings	High energy consumption by buildings	Development of energy-efficient buildings with intelligent lighting and HVAC systems to optimize energy use
Electric vehicles	Need for improved air quality and reduced carbon emissions	Develop an EV charging infrastructure and integrate renewable energy sources to power EVs
Smart homes	Need for improved energy efficiency and quality of life	Equipping homes with internet-connected devices for automated temperature control, lighting, and security

III. AI-Powered Decision Support Systems for Energy Management

This section comprehensively compares AI-powered DSS for energy management. Table II summarizes various approaches and their key features, challenges addressed, methodologies, applications, and outcomes based on recent studies.

Panagoulias, et al. [17] introduced a novel development methodology for AI-powered analytics in energy management. This approach emphasizes tailored explainability, addressing the inherent lack of transparency ("black box") often associated with AI systems. It acknowledges that various stakeholders with diverse backgrounds, preferences, and goals will utilize these analytics. The methodology aligns with the Explainable Artificial Intelligence (XAI) paradigm, aiming to enhance the interpretability of AI-driven DSSs. A core feature is a clustering-based approach that customizes the level of explanation based on the specific needs of user groups. This customization fosters accuracy and effectiveness in energy management analytics while promoting transparency and trust in decision-making.

TABLE II. COMPARISON OF AI-POWERED DECISION SUPPORT SYSTEMS FOR ENERGY MANAGEMENT

Studies	Focus	Key features	Challenges addressed	Methodology	Applications	Outcomes
Panagoulias, et al. [17]	AI-powered analytics with explainability tailored to stakeholder needs	Explainable AI (XAI) and clustering-based explanation customization	Transparency and trust in AI-driven DSS	• Iterative development lifecycle • Stakeholder identification	Estimation of energy savings from building renovations	Higher adoption rates of AI systems
Selvaraj, et al. [18]	AI Technique for Monitoring Systems in Smart Buildings (AIMS-SB)	Prediction model methodologies and energy analysis, renewable energy generation, recycling assessment	Poor energy recycling, high consumption, suboptimal usage, and drain characteristics	• Eco-design monitoring systems • Effective control of energy consumption and generation	Intelligent building energy management	Enhanced precision and effectiveness compared to traditional approaches
Şerban and Lytras [19]	AI in the renewable energy (RE) sector in the EU	Conversion processes of RE and Impact of AI on RE industry and smart cities research	Development and resilience of the energy sector	• A conceptual framework for AI's impact on RE • Examination of RE efficiency from Gross Inland Consumption to final energy consumption	AI adoption trends for RE in the EU	Improved efficiency and sustainability of the RE sector
Chen, et al. [20]	IoT framework for energy-efficient street lighting	IoT sensor-equipped smart electric poles and LED bulbs with a mesophilic design	High energy consumption and inefficiency	• Intelligent decision-making based on traffic flow and occupancy data • Dynamic battery charging algorithm based on MPPT	Smart street lighting for highways, residential, and suburban pedestrian zones	Significant reduction in energy consumption and carbon emissions
Manman, et al. [21]	Cognitive Radio Sensor Networks (CRSNs) for sustainable IoT applications	Distributed artificial intelligence and cooperative communication for resource management	Efficient resource allocation and sustainability in smart city applications	• Real-time computation of resource allocation using DAI • Statistical behavior-based relationship between secondary users in clusters	Enhanced sustainability of intelligent world IoT applications	Increased energy efficiency and sustainability in smart city applications
Singh, et al. [22]	Blockchain and AI integration in smart cities for sustainability	Blockchain for risk management, IoT, financial services, and public services and analysis of security vulnerabilities in blockchain	Security vulnerabilities and challenges in blockchain implementation	• Detailed exploration of the convergence of blockchain and AI • Analysis of critical factors for successful integration of blockchain and AI	Intelligent transportation systems leveraging blockchain and AI	Paving the way for more sustainable smart cities
Li, et al. [23]	IoT and AI-assisted Smart Metering Systems (IoT–AI–SMS)	RNN model for load forecasting and customer-centric design for optimizing load scheduling	Privacy concerns and efficient energy dispatch in smart grids	• Data acquisition system using IoT and AI • Recurrent Neural Network (RNN) model for predicting energy consumption patterns	Predicting energy consumption in smart cities	Efficient and sustainable energy ecosystem in smart grids
Mahmoud and Slama [24]	Peer-to-peer energy trading and enhanced residential energy storage	Energy exchange system with a community energy pool	Local energy transactions and pricing mechanisms	• Markov decision process • Fuzzy q-learning • Real-time correlation between supply and demand	Intelligent residential energy management	Optimized energy costs and enhanced utilization of renewable resources
Malleeshwaran, et al. [25]	AI-based IoT framework for consumer electronics energy efficiency	AI models for real-time data analysis, demand forecasting, and adaptive control	Inefficient energy consumption in consumer electronics	Machine learning algorithms Real-time energy consumption analysis Anomaly detection	Energy-efficient consumer electronics	Up to 20% energy reduction compared to traditional methodologies
Miuccio, et al. [26]	Next-generation multiple access (NGMA) scheme for massive IoT deployments	NOMA technique for maximizing spectral efficiency and efficient contention-based approach for resource utilization	High-load network performance and energy consumption in IoT devices	• Dynamic UL radio resource allocation based on traffic load • AI technologies for optimizing network performance metrics	Supporting Beyond 5G and 6G networks for massive IoT deployments	Outperforming existing benchmark schemes in spectral efficiency and energy consumption under high-load conditions

The methodology follows an iterative development lifecycle for intelligent DSSs. Key steps include stakeholder identification, an empirical study on usability and explainability, user clustering analysis, and the implementation of an XAI framework. This framework incorporates XAI clusters and local and global XAI techniques, all aimed at facilitating higher adoption rates of the AI system and ensuring responsible and safe deployment. The methodology's effectiveness is tested on a stacked neural network used for an analytics service that estimates energy savings from building renovations. This application targets increased adoption rates and contributes to the advancement of the circular economy.

The issues faced in smart building energy management include poor energy recycling, high energy consumption, suboptimal energy usage, and drain characteristics. Therefore, to investigate the relationship between intelligent city management policies and energy management, Selvaraj, et al. [18] suggested the implementation of an Artificial Intelligence Technique for Monitoring Systems in Smart Buildings (AIMS-SB). This technique aims to effectively control energy consumption and generate and recycle the energy needed for a smart building. AIMS-SB utilizes prediction model methodologies to forecast energy analysis, renewable energy generation, and recycling assessment. AIMS-SB created eco-design monitoring systems for intelligent buildings to improve energy use, utilization, and drainage properties. These effective implementation strategies and techniques for using renewable energy enhance the safety procedures, recycling, and reuse of our energy resources for intelligent building energy management. AIMS-SB offers practical solutions to the increasing array of issues related to energy management in smart cities. Hence, the system's results highlight enhanced precision and effectiveness compared to traditional approaches.

Renewable Energy (RE) is a valuable asset for future global growth, particularly in light of the changing climate and the depletion of resources. AI necessitates establishing novel regulations for organizing activities to effectively address these emerging demands. To address numerous issues that will impact the development and resilience of the energy sector, it is imperative to enhance the architecture of the energy infrastructure and increase the deployment and production of renewable energy. Șerban and Lytras [19] capitalized on the latest trends in AI adoption for the RE industry in the European Union (EU). They examined the effectiveness of RE conversion processes within the energy chain, specifically from Gross Inland Consumption to final energy consumption. They also explored how this efficiency affects the composition of renewable energy sources such as solar, wind, and biomass, the productivity of the renewable energy sector compared to the overall economy, and its relationship with investment levels.

Additionally, they investigated the potential impact of adopting AI for renewable energy in future research on smart cities. The primary achievement of this study is establishing a conceptual framework that elucidates the impact of AI on the renewable energy (RE) industry in Europe. One notable addition to this study is thoroughly examining the implications for future research on Smart Cities and identifying potential areas for further investigation.

Chen, et al. [20] developed an IoT framework for an energy-efficient, intelligent, and adaptive street road lighting design. The network includes IoT sensor-equipped smart electric poles with controllers for adjusting LED bulbs. The standard metal halide lights have been replaced with mesophic design LED lamps, which consider the human eye's sensitivity. This not only results in considerable energy savings but also improves overall efficiency. The intelligent decision-making component, using data from the sensor unit on traffic flow and occupancy, calculates the intensity levels for generating pulses of varying width through a PWM dimming system.

These pulses then activate the LED power switch via the DALI controller installed inside the LED Light Controller. Sustainable power systems use PV solar panel units, battery storage systems, and smart electric power networks to harness sustainable energy supplies effectively. The charging battery system used a dynamic battery charging algorithm based on MPPT. Based on experimentation and simulated data, it was observed that the suggested energy-efficient smart street lighting system significantly reduces energy consumption during both peak and off-peak hours, not only on highways but also in residential and suburban pedestrian zones. It will ultimately reduce energy usage and carbon emissions.

Smart cities are considered "smart" when the new technology can achieve the intended sustainable results. Smart city applications provide sustainable attributes characterized by reduced energy usage and optimized resource allocation. The IoT, 5G, and fog networks have been the focus of many studies owing to their wide range of applications in smart cities, which aim to achieve sustainable outcomes. The durable nature of Wireless Sensor Networks (WSNs) is crucial in implementing these technologies in real-world situations, and the effective usage of the available spectrum is a significant challenge in this context. Cognitive Radio (CR) has been integrated with WSN to form Cognitive Radio Sensor Networks (CRSNs), providing an intelligent resource management approach via cooperative communication. Manman, et al. [21] developed a strong relationship between Secondary Users/nodes (SUs) inside the same cluster based on their statistical behaviors during smart cooperative communication in CRSNs, to enhance the sustainability of intelligent world IoT applications. Distributed Artificial Intelligence (DAI) is used to compute the allocation of resources in real-time to these clusters, using their coordinator agent, which is dependent on their dynamic behaviors. To enhance sustainability in smart city applications, the time delay in predicting available channels is minimized, leading to increased energy efficiency in these systems. The efficacy of the suggested work is shown by mathematical analysis, and simulation results validate its superior sustainability compared to previous procedures.

The burgeoning adoption of blockchain technology is transforming urban environments, ushering in a novel paradigm for smart city ecosystems. This distributed ledger technology offers a promising solution to various challenges plaguing modern cities. Its applications encompass various domains, including risk management, financial services (through cryptocurrencies), the IoT, and public and social services. Furthermore, the convergence of blockchain with AI presents groundbreaking possibilities for revolutionizing smart city network architecture and fostering sustainable ecosystems. However, it is crucial to acknowledge that alongside these advancements lie opportunities and challenges in pursuing sustainable smart cities. Singh, et al. [22] conducted a comprehensive review of the security vulnerabilities and challenges hindering the implementation of blockchain systems within smart city frameworks. Their work delves into a detailed exploration of key factors that will facilitate the successful convergence of blockchain and AI technologies, ultimately paving the way for a more sustainable smart society. Additionally, they analyze existing solutions for enhancing blockchain security, outlining critical considerations for developing intelligent transportation systems that leverage the combined strengths of blockchain and AI. Finally, they identify unresolved issues and propose future research directions, including novel security recommendations and guidelines for establishing a sustainable smart city ecosystem.

Traditional smart grids can be significantly enhanced by incorporating IoT-based Smart Metering (SM) and Advanced Metering Infrastructure (AMI) technologies. These technologies bridge the gap by enabling communication between utilities and consumers during power transactions, revealing previously unavailable data about electricity usage. This granular data empowers the implementation of intelligent energy management strategies within innovative city environments. Building upon the foundation of IoT and AI, Li, et al. [23] proposed an IoT and AI-assisted Smart Metering System (IoT–AI–SMS) as a novel data acquisition system for predicting energy consumption in smart cities. The proposed system analyzes energy consumption patterns within smart cities by leveraging datasets encompassing energy efficiency metrics. The research introduces a Recurrent Neural Network (RNN) model for load forecasting based on smart meter data. This technique offers a significant advantage: a single model can be trained using data collected from all participating smart meters without exchanging local information, potentially addressing privacy concerns. Furthermore, the customer-centric design of the model allows for scheduling controllable loads and optimizing the dispatch of distributed generation within the smart grid, ultimately leading to a more efficient and sustainable energy ecosystem.

Mahmoud and Slama [24] proposed a novel energy framework featuring peer-to-peer trading and enhanced residential energy storage management. A strategic approach to intelligent residential communities is introduced, encompassing household consumers and proximity energy storage facilities. Users can access economical renewable energy by exchanging energy with the community energy pool without constructing any energy generation infrastructure. This community energy pool can acquire surplus energy from consumers and renewable sources, reselling it at a rate that exceeds the feed-in tariff yet remains below the market rate. The pricing mechanism for the energy pool is contingent upon a real-time correlation between supply and demand, facilitating local energy transactions. Within this pricing framework, electricity costs may fluctuate based on the retail price, the consumer count, and the volume of renewable energy available. This approach optimizes the benefits for consumers while enhancing the utilization of renewable resources.

A Markov decision process (MDP) illustrates suggested power allocation to maximize consumer benefits, augment renewable energy usage, and present optimal energy trading options. The reinforcement learning methodology identifies the most advantageous choices within the renewable energy MDP and the energy exchange process. The fuzzy inference system, which accommodates an infinite array of possibilities for energy exchange, facilitates the application of Q-learning in continuous state space scenarios (fuzzy Q-learning). The evaluation of the proposed demand-side management system yielded positive results. The effectiveness of the advanced demand-side management framework is quantitatively assessed by contrasting the energy costs before and after implementing the proposed energy management system.

Malleeshwaran, et al. [25] have presented a novel AI-based IoT framework to enhance energy efficiency in consumer electronic devices. This framework is designed to autonomously adjust energy consumption in response to device context, user interactions, and environmental factors. It incorporates state-of-the-art AI models and algorithms to analyze real-time data streams from IoT devices. Furthermore, the framework synergizes real-time energy consumption metrics from interconnected devices with AI algorithms for demand forecasting, anomaly identification, and adaptive control. Additionally, the utilized components and technologies exemplify the role of machine learning in refining decision-making processes to achieve maximal energy efficiency. Empirical studies conducted in simulated and real-world settings reveal substantial energy reductions of up to 20% when juxtaposed with traditional methodologies. The proposed framework provides a scalable and flexible approach to advancing sustainable energy practices within consumer electronics.

Miuccio, et al. [26] proposed a novel and efficient Next-Generation Multiple Access (NGMA) scheme to address the anticipated challenges of massive IoT deployments characterized by many energy-constrained devices. This scheme integrates several innovative solutions to optimize network performance in IoT scenarios. The scheme employs a suitable NOMA technique to maximize the spectral efficiency of the Physical Uplink-Shared Channel (PUSCH). NOMA allows multiple data streams to be transmitted simultaneously on the same frequency resource, improving spectral utilization compared to traditional orthogonal access schemes. The scheme introduces an efficient contention-based approach to exploit unused PUSCH resources for data transmission. This approach helps to further enhance spectral efficiency by utilizing idle channel time. The proposed scheme dynamically adjusts the uplink (UL) radio resource allocation based on the current traffic load. This optimization aims to strike a balance between two competing factors.

By allocating sufficient resources to the physical random access channel (PRACH), the scheme seeks to minimize the likelihood of collisions during device access attempts. The scheme ensures enough PUSCH resources are allocated to accommodate data transmission from all successfully granted access requests. The scheme incorporates strategic procedures to enable accurate traffic load estimation even when the PRACH is overloaded. This capability is crucial for efficient resource allocation under heavy network traffic conditions. The scheme leverages AI technologies to optimize overall network performance metrics. The proposed NGMA scheme is compared against existing benchmark schemes from the literature. The results demonstrate that the scheme outperforms existing solutions regarding spectral efficiency and energy consumption, particularly under high-load conditions. These performance improvements are critical for supporting the demands of Beyond 5G and 6G networks, which are expected to accommodate a massive influx of IoT devices.

IV. Future Research Directions

The use of AI for energy management is mature, but many aspects still need to be developed to make these solutions efficient in practice and to promote the adoption of these technologies in smart cities. Future efforts should focus on developing AI solutions for scalability that can be easily deployed into existing city infrastructure. Compatibility with legacy systems is one of the most common barriers to deployment. Scalability is a minor but ever-growing problem due to the increasing complexity of city-based solutions and the growing amount of data generated. Further exploration of methods to optimize the use of AI models in large-scale situations while simultaneously processing the larger load of trackers in modern urban environments with relatively low latency will be extremely useful. Research that proposes scalable architectures (e.g., distributed/federated) is valuable for managing large data sets while ensuring robust AI model performance for intelligent energy management in heterogeneous urban environments. If studied, exploring the implications of the federated approach will also be valuable for research and energy management in urban environments.

Establishing standardized protocols for AI and IoT systems in energy management is crucial to improving interoperability and integrating different technologies. As smart cities deploy AI-driven systems with different functionalities from multiple vendors, common standards must be in place that enable seamless communication and data sharing between these systems. Future studies should explore paths to universal standards and schemes that promote interoperability between systems using different AI. Ultimately, interoperability is about creating a connected ecosystem of different AI systems that work together and leverage cross-system efficiencies.

Exploring more advanced data analysis techniques (e.g., deep learning and advanced predictive modeling) will improve the accuracy and reliability of AI-powered energy management systems. Advanced analytics reveal hidden complexities in large database datasets, helping to predict and optimize. Future research needs to focus on developing effective algorithms/models that enable real-time data processing and analysis and provide important analysis and suggestions for energy management.

Strategies to protect AI-supported energy management systems from potential threats must be sufficiently powerful. Future work should aim to develop secure, resilient protection frameworks that protect these systems from potential cyberattacks. This strategy may include advanced encryption strategies, intrusion detection mechanisms, or secure communication protocols that ensure the integrity and confidentiality of data in smart energy networks.

Robust cybersecurity measures are vital for protecting AI-driven energy management systems from potential threats. Future research should prioritize the development of secure and resilient frameworks to safeguard these systems against cyberattacks. This includes exploring advanced encryption techniques, intrusion detection systems, and secure communication protocols to ensure the integrity and confidentiality of data within smart energy networks.

By concentrating on human-centered AI methodologies that apply user experience principles and provide opportunities for stakeholder collaborations, AI tools will likely improve acceptance and output in energy use management. Further research should examine how to represent and design AI techniques that work seamlessly for human users with varying levels of technical knowledge. This development should also include reporting user evidence and human experts in the design process and establishing and delivering explainable AI models that facilitate trust in explanatory models and assurance of transparency in energy use management decision-making and action.

Examining the role of policy and regulatory frameworks in facilitating the adoption of AI-powered energy management systems can provide valuable insights for governments and policymakers. Research should explore how regulatory measures can incentivize the deployment of AI technologies, address ethical and privacy concerns, and ensure equitable access to smart energy solutions. Additionally, studies should assess the impact of different policy approaches on the scalability and sustainability of AI-driven energy management systems.

Another promising area for future research is the development of sustainable energy innovations that integrate AI for optimized performance. Research should focus on creating new materials and technologies that enhance the efficiency and sustainability of energy systems, such as advanced photovoltaic cells, wind turbine designs, and energy storage solutions. Additionally, investigating the role of AI in managing microgrids and decentralized energy resources can provide new insights into creating resilient and sustainable energy networks.

Future research also needs to acknowledge the value of public engagement and education in the uptake of energy management systems powered by AI. In particular, understanding how the public views these systems and how to ease concerns through clear communication and education will be essential to broader buy-in for such technologies. Research should explore how to communicate benefits effectively and highlight risks (if any). Engaging with research interested in how scientists engage with stakeholders or policymakers, or vice-versa, could be especially beneficial to research on AI in energy management systems.

V. Conclusion

This study has demonstrated the significant potential of AI-driven DSS to enhance energy management in smart cities. Our research highlights the effectiveness of integrating AI technologies, such as machine learning and predictive analytics, into energy management frameworks to improve efficiency, sustainability, and resilience in urban environments. Key findings include the identification of innovative methodologies, such as XAI frameworks, IoT-enabled smart metering systems, and AI-powered energy trading models, which collectively address the pressing challenges of optimizing energy consumption, reducing environmental impact, and managing the increasing complexity of energy systems in smart cities. The primary contributions of this study are twofold: first, we provide a comprehensive analysis of state-of-the-art AI applications in energy management, illustrating how these technologies contribute to more intelligent, more efficient urban energy systems. Second, we propose a pathway for future research, emphasizing the need for scalable and interoperable solutions, enhanced data analytics, and robust cybersecurity to ensure the effective deployment of AI in energy management. Furthermore, we advocate for developing human-centric AI approaches, public engagement, and education to ensure transparency and foster the broader adoption of sustainable energy practices.

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