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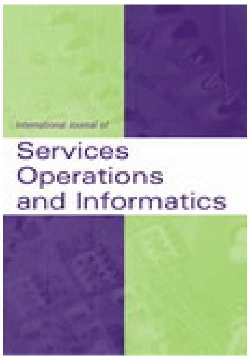

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IoT architecture for energy management in smart cities

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Abstract: In an era of rapid urbanisation, the rise of smart cities and the integration of Internet of Things (IoT) technology for smart energy management have emerged as proactive responses to multifaceted urban challenges. This paper offers a comprehensive survey that delves deep into the synergy between IoT and energy management, shedding light on their role in shaping urban landscapes and redefining energy management paradigms. The transformative impact of IoT is illuminated, with a particular focus on its revolutionary applications in shaping smart cities by revolutionising energy management and underscores the optimisation of urban functionalities and grid efficiency, while also highlighting the critical importance of data security measures and the adaptive nature of IoT system responses. By exploring the diverse applications of IoT in smart energy management for smart cities through an in-depth literature review, the potential challenges are openly discussed.

Keywords: urbanisation; smart cities; IoT technology; smart energy management; urban challenges; transformation; efficiency; sustainability; urban landscapes; paradigm; solutions and urban development.

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1 Introduction

In recent years, the concept of the Internet of Things (IoT) has gained prominence as a revolutionary approach, redefining how devices, objects, and systems engage, communicate, and share information within the digital ecosystem. IoT constitutes a network comprising physical objects infused with sensors, software, and network connectivity, enabling them to gather and exchange data (Alavi et al., 2018; Sinha and Dhanalakshmi, 2022). The rise of the IoT ushered in a new era of connectivity, transforming traditional urban landscapes into interconnected and intelligent ecosystems thus giving rise to the emergence of smart cities (Huseien and Shah, 2021; Sarkar et al., 2020). As advanced technologies in metering and digital systems keep advancing, smart cities have welcomed a variety of electronic devices, all driven by the IoT. This fusion has lifted these cities to higher levels of smarts and sophistication (Nakano and Washizu, 2021). As rapid urbanisation evolves, the modern world is confronted with a multitude of challenges, one of which is the increasing demand for energy. The IoT is rapidly transforming the global energy industry, with the potential to revolutionise the way energy is produced, distributed, and consumed (Parra et al., 2019). IoT – enabled smart energy solutions are already being deployed around the world, with a wide range of applications (Jabbar et al., 2022). For instance, smart meters gather real-time data on energy consumption, facilitating improved energy efficiency and the identification of potential areas for cost reduction (Sirojan et al., 2019). Smart grids integrate Distributed Energy Resources (DERs) like solar panels and wind turbines into the power grid. And microgrids are being used to provide reliable power to critical infrastructure during outages. The global IoT for smart energy market is expected to grow significantly in the coming years. According to a report by Grand View Research, the market is projected to reach $200 billion by 2027 (Biegańska, 2022). This growth will be driven by a number of factors, including the increasing demand for energy efficiency, the need to reduce carbon emissions, and the growing adoption of renewable energy sources (RESs).

The integration of IoT devices into the world of smart cities with smart energy solutions is not without its hurdles. Security, for instance, looms large as IoT devices connecting to the internet become vulnerable to cyber threats, spanning unauthorised access, data breaches, and even physical damage triggered by malicious intent (Habibzadeh et al., 2019). This challenge is further complicated by the puzzle of interoperability, as different manufacturers adopt a variety of communication protocols, resulting in a fragmented landscape that hinders smooth integration into a cohesive system (Lee and Kim, 2007). Financial considerations also factor in, with the upfront procurement and deployment costs of IoT devices posing potential barriers to widespread adoption, especially in financially constrained scenarios (Jabraeil Jamali et al., 2020). Simultaneously, the extensive data collection process of IoT devices raises substantial privacy concerns, given their capacity to track individuals' daily routines and behaviours, thereby amplifying the risks of privacy breaches and data security vulnerabilities, underscoring the need for robust safeguards (Al-Qaseemi et al., 2016). Balancing the transformative potential of IoT with these multifaceted challenges becomes crucial in shaping a sustainable and secure energy future.

Numerous research initiatives are actively addressing the challenges posed by IoT architecture. These efforts are centred around devising innovative solutions to overcome obstacles and pave the way for a more seamless integration of IoT devices and systems into urban environments. This involves creating more secure IoT devices and networks through innovative encryption techniques, authentication protocols, and intrusion detection systems (IDS) such as simple authentication and security layer (SASL), datagram transport layer security (DTLS) protocols, and network-based intrusion detection systems (NIDS) (Braun et al., 2018; Al-Turjman and Malekloo, 2019), which are used to shield data from interception and unauthorised access. Interoperability is another focus, where researchers are devising standards and protocols to enable the seamless integration of diverse IoT devices and systems like the IoT Protocol Suite, Open Connectivity Foundation (OCF), and AllJoyn (Nasir et al., 2019; Krčo et al., 2014). These protocols facilitate consistent communication between IoT devices (Soumyalatha, 2016; Yashiro et al., 2013). Additionally, efforts are directed towards developing affordable IoT devices like low – cost sensors and gateways, fostering the feasibility of deploying IoT solutions in smart cities. Privacy concerns are being addressed by advancing techniques like anonymisation and differential privacy, which ensure data collection while safeguarding individual privacy. As these technologies mature, they reflect a dynamic drive towards a safer, interconnected, and resource – efficient landscape, underpinned by the transformative power of IoT innovation.

2 Background study

The rise of IoT has brought about a significant change in how interconnected devices communicate and function. As digital communication channels spread worldwide and the internet expands exponentially, IoT has led to revolutionary advancements, especially in the field of managing smart energy. The year 2010 marked a significant turning point when cities across the globe began implementing IoT-driven solutions to tackle urban challenges efficiently (Rajab and Cinkelr, 2018).

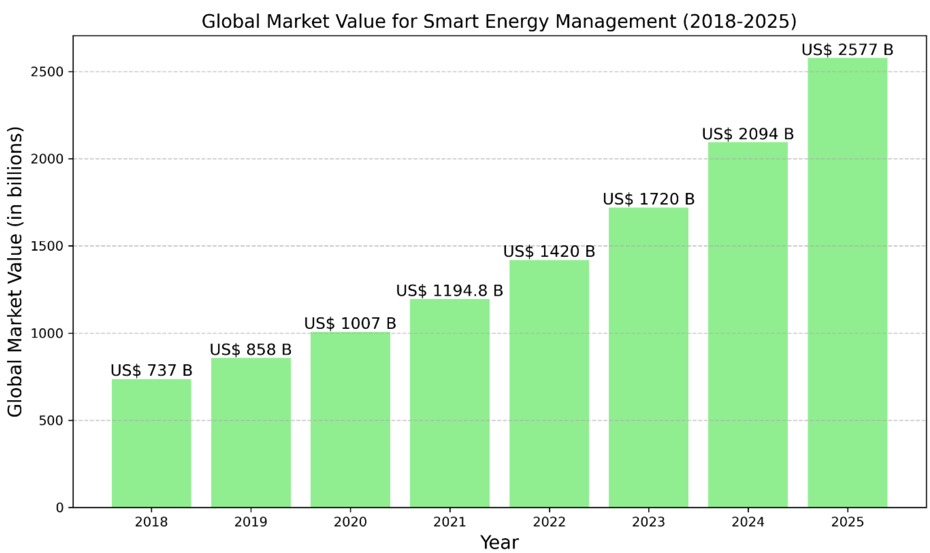
The integration of IoT architecture into energy management systems for has brought about a paradigm shift in how energy is monitored, controlled, and optimised. This innovative approach leverages the power of interconnected devices, sensors, and data analytics to revolutionise the way energy is generated, distributed, and consumed. Typically, energy management involved one-way communication, where energy was generated and supplied to consumers without real-time insights into consumption patterns. The environment has changed since the introduction of IoT. IoT technologies enable real-time monitoring, collection, and analysis of energy-related data from various sources. This data-driven approach has enabled more informed decision-making and precise management of energy resources leading towards smart energy management. The inception of smart meters marked a pivotal moment in energy consumption monitoring. These devices enabled real-time tracking and analysis of energy usage patterns, revolutionising demand-side management.

To harness the full potential of IoT in these domains, researchers have worked on refining various techniques and approaches. Techniques were developed to enhance data security, IoT solutions are designed to ensure data integrity, privacy, and interoperability. IoT devices have the capability to transmit and handle data in a visible or encrypted fashion, ensuring the protection of sensitive information against malicious entities (Guendouzi et al., 2023).

Furthermore, the concept of data entropy plays a pivotal role in optimising IoT applications. Data entropy is leveraged to determine optimal conditions for various processes within IoT systems. This approach, combined with models such as the Just Noticeable Difference (JND) model, enables a balance between the effectiveness, efficiency, and scope of IoT solutions. As a result, this approach fosters enhanced adaptability and subtlety in IoT systems, allowing them to finely tune their responses based on changing conditions (Pandey and Mishra, 2023). Ultimately, this contributes to the seamless integration of IoT into diverse real – world scenarios.

Thus, the emergence of IoT has sparked a technological revolution in the digital world. IoT is reshaping energy management paradigms in urban landscapes through enhanced connectivity and data – driven intelligence. According to Grand View Research 2018 the global market value for Smart energy was valued at USD 737 billion in 2018 and is expected to reach USD 2.57 trillion in 2025 which is shown in Figure 1. This study seeks to delve into the intricacies of IoT's applications in smart energy management in smart cities, highlighting its influence on efficiency and authenticity.

Figure 1 Global market value for smart energy management, grand view research 2018 (see online version for colours)



2.1 IoT based energy management

Managing energy in a complex environment that includes distribution networks, households, buildings, and more, requires real – time transfer of various types of information emphasising the need for IoT – enabled smart energy management (Liu et al., 2019). IoT – based energy management will harness IoT technology to monitor, control, and optimise energy usage in various settings like homes, buildings, industries, and cities. Its primary goal is to boost energy efficiency, cut costs, reduce waste, and promote sustainability. This system relies on sensors and devices strategically placed to collect real – time data on energy consumption and environmental conditions. These sensors include smart meters, temperature and humidity sensors, light sensors, motion detectors, and energy – efficient appliances. They transmit data to a central platform or cloud using communication protocols like Wi-Fi, Bluetooth, Zigbee, and cellular networks (Zeinab and Elmustafa, 2017). Once collected, this data goes through processing and analysis to uncover insights, such as consumption patterns and optimisation opportunities, aided by advanced analytics and machine learning (ML). The system enables real – time monitoring and control of energy – consuming devices, supports demand response programs, offers user – friendly energy consumption visualisation through dashboards and mobile apps, and can even predict maintenance needs. Moreover, it ensures compliance with energy regulations and robust security measures to protect data and privacy.

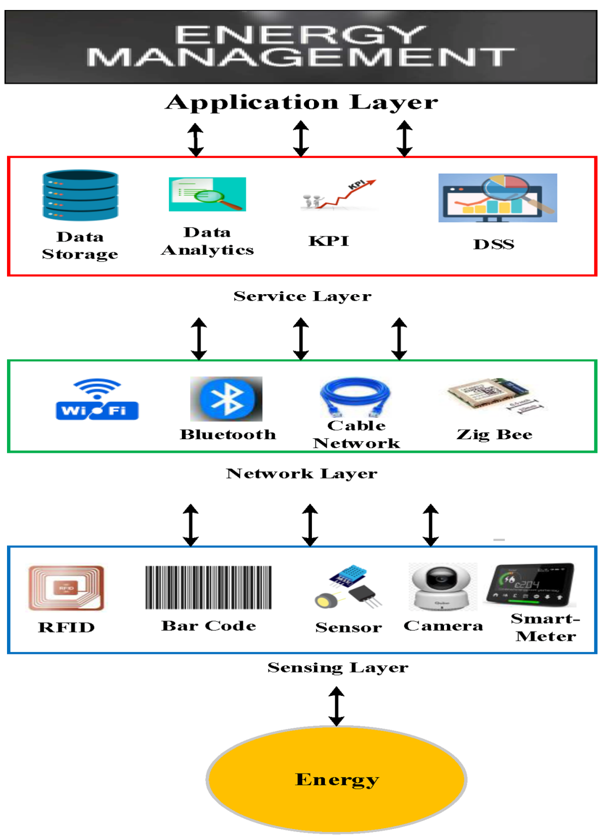
2.2 IoT architecture for energy management

The architecture of the IoT in smart energy management is a complex framework that harnesses the power of connected devices, data analytics, and automation to transform the way energy is monitored, controlled, and optimised. The architecture of IoT varies according to its functions and implementations across diverse sectors. Yet, a fundamental process flow forms the core framework for building IoT systems. The architecture is essential for ensuring interoperability, scalability, security, and efficient communication within the IoT environment (Zhong et al., 2015). It encompasses a series of interrelated layers, each serving a distinct purpose to establish a cohesive and functional IoT ecosystem.

The first layer is known as the sensing layer, which serves as the starting point for collecting data from various sources. In this layer, the sensors and actuators strategically placed in the environment. This layer includes various sensors and actuators strategically placed to collect data related to energy consumption and environmental factors. Sensors can monitor parameters like electricity usage, temperature, humidity, light levels, and more. To transmit this data, they're connected to the network layer through either wired or wireless communication protocols (Razzaq et al., 2023). The network layer within an IoT architecture assumes the crucial role of facilitating seamless communication and connectivity among devices within the IoT system. This stratum encompasses an array of protocols and technologies, which serve as the bridge enabling devices to establish connections with each other and with the broader internet. Prominent examples of network technologies employed in IoT encompass Wi-fi, Bluetooth, Zigbee, and cellular networks like 4G and 5G. Furthermore, this layer might incorporate gateways and routers acting as intermediaries, ensuring effective communication between devices and the broader internet. Security attributes, such as encryption and authentication, may also be integrated within this layer to safeguard against unauthorised access (Khan et al., 2022). The data processing layer or service layer within the IoT architecture encompasses both software and hardware components dedicated to the collection, analysis, and interpretation of data sourced from IoT devices. This layer assumes the role of receiving raw data from these devices, then proceeding to process it and render it accessible for subsequent analysis or action. Comprising a multitude of technologies and tools, the data processing layer incorporates data management systems, analytics platforms, and

ML algorithms. These tools are employed to extract significant insights from the data, thereby facilitating informed decision – making. A pertinent example of a technology situated within the data processing layer is the data lake, serving as a centralised repository designed to house raw data procured from IoT devices (Wan et al., 2022). The application layer in the IoT architecture stands at the top, directly engaging with end – users. This layer is all about providing user – friendly interfaces and functions that make it easy for users to interact with and control IoT devices. Users, which can be consumers, utilities, or administrators, interact with the applications to gain insights into their energy consumption patterns, make informed decisions, and optimise their energy usage. It's composed of various software and applications, including mobile apps, web portals, and other interfaces that have been designed to smoothly interact with the underlying IoT infrastructure (Khanh et al., 2022). The architecture of IoT systems can vary based on specific use cases and requirements. For instance, some IoT systems may heavily rely on edge computing, where data processing occurs closer to the devices, while others might rely more on cloud – based processing. This architecture represents a pivotal advancement in how energy systems are monitored, managed, and optimised. By leveraging the capabilities of interconnected devices, data analytics, and automation, this architecture has the potential to reshape the energy landscape, making it more efficient, sustainable, and responsive to the needs of modern society. Figure 2 shows the frame work of IoT architecture for smart energy management

Figure 2 IoT architecture for energy management (see online version for colours)



3 Review on IoT – enabled smart energy management system for smart cities

The rise of IoT – enabled smart energy management is reshaping urban life, fundamentally changing how cities manage their energy resources and empowers cities to enhance efficiency and responsiveness in smart energy management while prioritising sustainability. This transformation signifies a significant leap towards a more interconnected, data – driven, and environmentally conscious urban future, revolutionising the approach to energy management in urban environments.

3.1 Improved energy efficiency and sustainability

IoT is reshaping energy management, infusing intelligence into smart cities. By melding devices and data, it optimises energy usage, boosts efficiency, and fosters sustainability, revolutionising how power is generated and consumed.

Kazmi et al. (2017) presents the comparative performance of HEM (Home Energy Management) controller embedded with heuristic algorithms, such as harmony search algorithm, enhanced differential evolution, and harmony search differential evolution. The integration of RES in SG makes the performance of hem system more efficient. The electricity consumption in peak hours usually creates peaks and increases the cost but integration of Res makes the electricity consumer able to use the appliances in the peak hours.

Santhanaraj et al. (2023) proposed a novel EAMCR-RTDM technique that mainly intends to manage the energy utilisation of nodes with the consideration of the features of the disaster region. To achieve this, EAMCR-RTDM technique primarily designs a yellow saddle goatfish-based clustering (YSGF-C) technique to elect cluster heads (CHs) and organise clusters. In addition, enhanced cockroach swarm optimisation (ECSO) based multihop routing (ECSO-MHR) approach was derived for optimal route selection. The YSGF-C and ECSO-MHR techniques compute fitness functions using different input variables for achieving improved energy efficiency and network lifetime.

Krishnan and Jacob (2022) have introduced an innovative approach by the joint implementation of deer hunting optimisation (DHO) and crow search algorithm (CSA) termed the DHOCSA technique, to enhance energy management within smart grids. This hybrid method amalgamates DHO and CSA, effectively regulating power and distribution system resources through continuous IoT-enabled data monitoring. Employing a communication framework reliant on IoT, the distribution system integrates seamlessly with data acquisition modules, forming a mesh wireless network under a single IP address. This IoT-based structure serves as a conduit for enabling demand response (DR) development in the EMS distribution system. DR data is collected from loads and transmitted to a centralised server, undergoing processing via the DHOCSA technique. The result is a heightened flexibility in the IoT distribution system, optimising resource utilisation and ensuring global energy supply and demand satisfaction.

3.2 Cost reduction with smart energy

IoT – enabled smart energy management offers substantial cost reduction opportunities by providing real – time data on energy consumption and optimising operations. By efficiently monitoring and controlling energy usage, businesses and utilities can identify wastage, reduce peak demand charges, and improve overall energy efficiency. This not only cuts operational expenses but also supports sustainability goals in an increasingly resource – conscious world.

Roslan et al. (2021) introduced a scheduling controller for microgrid energy management, employing the lightning search algorithm for optimisation. This controller utilises real-time microgrid data, including load demand, renewable energy availability, and electricity prices, to compute an optimal power generation and consumption schedule. The primary goal is to minimise electricity costs and reduce emissions. Evaluation on an IEEE 14-bus test system demonstrated impressive outcomes, with a 62.5% reduction in electricity costs and a 61.98% decrease in emissions. This study contributes significantly by proposing an innovative controller, implementing it with an efficient optimisation algorithm, and validating its effectiveness in a real – world context, advancing microgrid energy management for improved efficiency and cost – effective approach.

Hafeez et al. (2020) proposed wind-driven bacterial foraging algorithm (WBFA)-based strategy enhances effective energy utilisation within IoT-enabled residential buildings, thereby contributing to the sustainability of such buildings in smart cities. It achieves this by automatically responding to price-based Demand Response (DR) programs, which is a significant challenge in DR programs due to consumers' limited knowledge and ability to respond promptly to DR signals. The simulation results demonstrated that the proposed WBFA-based strategy outperforms the benchmark strategies in terms of the specified performance metrics. This suggests that their approach is more cost effective in managing energy in IoT-enabled smart homes under price-based Demand Response programs in smart cities.

Rochd et al. (2021) have presented a comprehensive Home Energy Management System (HEMS) framework that seamlessly integrates renewable energy sources, employs data – driven decision – making, utilises AI – based optimisation, and effectively balances cost savings with user comfort to promote sustainable and efficient energy management in residential buildings. Their work not only advances the integration of renewable energy but also demonstrates practical implications for the evolution of smart grid and smart home technologies, with the help of IoT.

3.3 Smart grid optimisation

The integration of the IoT in smart grid optimisation, coupled with innovative technologies, is emerging as a new trend that represents the convergence of cutting-edge solutions to address the complex challenges faced by modern energy grids.

Selvaraj et al. (Iqbal et al., 2021) proposed an artificial intelligence technique for monitoring systems in smart buildings (AIMS – SB) designed to effectively manage energy consumption, renewable energy production, and energy recycling within smart buildings. AIMS – SB employs predictive modelling strategies to forecast energy usage, analyse renewable energy generation, and evaluate recycling processes. This approach includes the development of eco – design monitoring systems that optimise energy consumption, utilisation, and discharge patterns in smart buildings. By employing efficient implementation strategies and methods for harnessing RESs, AIMS – SB enhances safety protocols, recycling practices, and the sustainable reuse of energy resources for smart building management. These solutions address the challenges associated with smart city energy management, and the system's outcomes showcase enhanced accuracy and efficiency when compared to conventional methods.

Sankarananth et al. (2023) presents a comprehensive approach combining artificial intelligence algorithm techniques with metaheuristic optimisation algorithms for anticipating and managing RESs in smart grid environments. With precision, recall, and accuracy scores of 0.92, 0.93, and 0.92, respectively, the proposed hybrid (reinforcement learning with long short-term memory) LSTM-RL model beats current algorithms in correctly forecasting energy demand patterns. With an accuracy of 0.91 for various load balancing measures, the (Reinforcement learning with simulated annealing) RL-SA algorithm efficiently measures load balancing. With mean squared error (MSE), mean absolute error (MAE), r-squared score, root mean square error (RMSE), and mean absolute percentage error (MAPE) values of 345.12, 15.07, 0.78, 18.57, and 7.83, respectively, the CNN-PSO algorithm also turns out to be the most successful at forecasting the generation of renewable energy. These discoveries help hybrid renewable energy systems in smart grid settings advance, enabling effective, dependable, and economical energy production and distribution. The suggested solution also has the potential to be used in rural and off-grid settings. Overall, this research offers a useful method for maximising the production of renewable energy and acts as a spark for additional studies into smart energy management systems

3.4 Reliability and security

Chakrabarty and Engels (2020) present a framework to secure IoT enabled Smart Cities using Black Networks and AI to protect against a broad range of current and future cyber – attacks. Smart city cyber systems carry critical data beginning with the simple sensor data captured by IoT devices up to and including providing the essential services and commands dependent upon that data. The broad reliance upon IoT in smart cities significantly increases the attack surface of the already large, complex, and heterogeneous smart city system by making each and every IoT device and its communications a potential entry point into the system. This proposed framework utilises Black Network protocols and key management to secure the most vulnerable, and typically unsecured, IoT communications. The framework utilises a hierarchical, distributed architecture with pooled resources to prevent single points of failure and to sandbox attack impacts. This hierarchy allows AI enabled management tools to be placed both near the IoT edge using localised data and in the Big Data collections.

Li et al. (2018) proposes a cybersecurity solution that emphasises the importance of IoT, decentralised energy management, SDN, and blockchain technologies in securing power distribution systems, particularly in the context of active distribution networks. It aims to create a comprehensive cybersecurity framework for active distribution networks that addresses various aspects of power distribution, from fine – grained control and security of IoT devices to the resilience of decentralised energy management. This approach is designed to improve the overall performance, reliability, and security of electricity services within these networks while considering future developments in technology and energy sustainability. And the goal is to enhance the overall performance and security of electricity services within these networks.

3.5 Review analysis

A total of 10 documents were included in the survey. Each of these documents was individually analysed, with each paper offering a range of solutions to the various challenges associated energy management. The summarised findings and insights from the discussed literature are presented in Table 1.

Table 1 Overall analysis of findings and insights

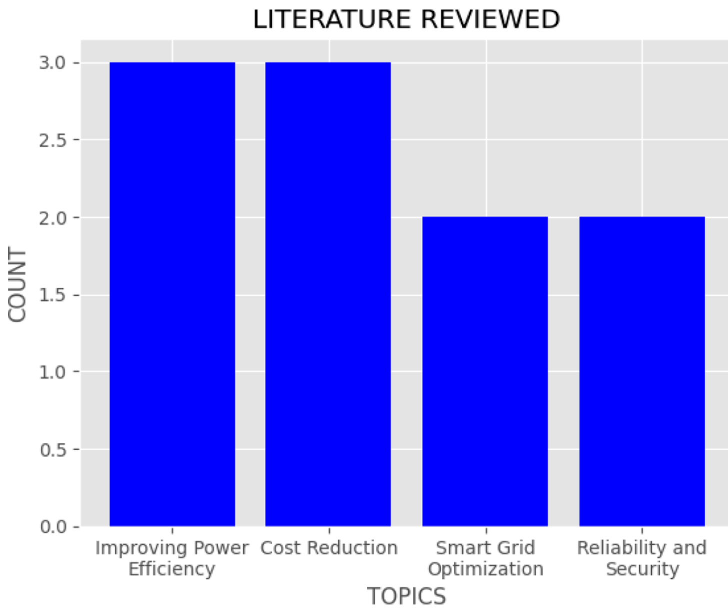
Author name	*Year*	*Algorithm or techniques used*	*Objective*	*Results*	*Application*
Kazmi et al. (2017)	2017	Harmony search differential evolution (HSDE) algorithm	To enhance the demand response management system	The proposed method shows balanced load pattern and reduction in peak to average ratio (PAR) of 17.2%	Managing demand energy management (DRM)
Santhanaraj et al. (2023)	2023	Energy aware metaheuristic clustering with routing protocol (EAMCR)	To manage energy ululation and increase efficiency	The EAMCR model has demonstrated better performance with decreased average packet loss rate (APLR) of 10.25% of 30.68 J	Increasing power efficiency
Krishnan and Jacob (2022)	2022	Deer hunting optimisation with crow search algorithm (DHOCSA)	To enhance the energy management	The proposed Method effectively consumes power and achieve a cost reduction of up to 10% compared to the baseline scenario	Managing power consumption
Roslan et al. (2021)	2021	Lightning search algorithm (LSA)	To reduce cost in energy management by scheduling power in microgrids	The proposed technique optimise the DER in the microgrid (MG) system by minimising the use of distributed generation (DGen) in the IEEE 14-bus test system	Cost reduction
Hafeez et al. (2020)	2020	Wind-driven bacterial foraging algorithm (WBFA)	To reduce cost by effective energy utilisation	The proposed method minimised cost of electricity and Par by 27.6% and 58%	Cost reduction

Table 1 Overall analysis of findings and insights (continued)

Author name	*Year*	*Algorithm or techniques used*	*Objective*	*Results*	*Application*
Rochd et al. (2021)	2021	AI and IoT Based hems	To reduce cost by a new Hems frame work	The proposed technique optimises overall cost by 26.27% compared to the fixed tariff scheme for electricity	Cost reduction
Iqbal et al. (2021)	2023	Reinforcement learning	To effectively manage energy consumption with in the smart grid	The proposed strategy using simulations and shows that it can effectively reduce the electricity consumption by up to 20% within smart grids	Smart grid optimisation
Sankarananth et al. (2023)	2023	Hybrid long short term memory reinforcement learning (LSTM-RL)	To manage renewable energy resource in the smart grid environment	The proposed model performs better than existing algorithms as regards accuracy, precision and recall rate at 0.92, 0.93 and 0.92.	Smart grid optimisation
Chakrabarty and Engels (2020)	2020	Black networks and artificial intelligence (AI) based frame work is used	To secure IoT enabled Smart Cities using Black Networks and ai	Smart cities integrated with proposed framework seems to prevent all kind of ransomware attacks in the IoT network	Reliability and security
Li et al. (2018)	2018	Cyber-secure decentralised energy management framework is used	To make a secure IoT environment for energy management	In the proposed framework the networked microgrids in ADN collaborate transparently to enhance electricity service quality	Reliability and security

Figure 3 presents a graphical overview of the overall analysis of the number of literatures reviewed in this section.

Figure 3 Graphical oversight of overall analysis (see online version for colours)



4 Applications of IoT enabled smart energy management in smart cities

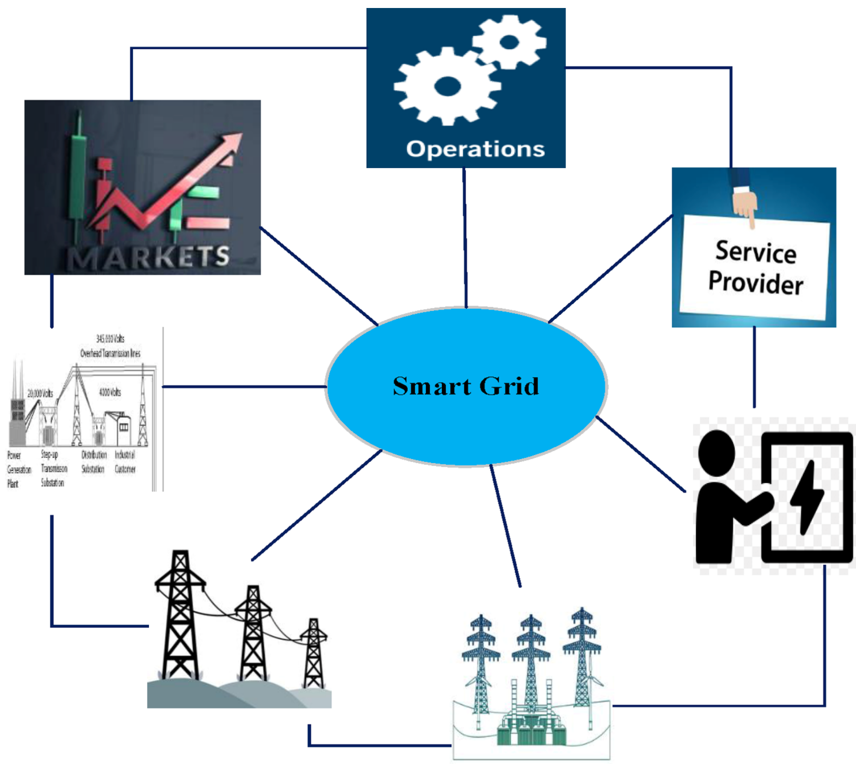
By seamlessly connecting energy management applications to the digital world, the IoT is playing a transformative role in the development of urban landscapes by efficient energy management. This technology infusion is yielding remarkable efficiencies and sustainability improvements across the entire energy ecosystem within smart cities. Through the power of real – time data and automated systems, these IoT applications are orchestrating a revolution in how cities approach energy resource management. The outcome is a significant enhancement in energy efficiency and the adoption of sustainable practices, which are pivotal for the continued growth and development of smart cities.

4.1 Smart grids and energy optimisation

The IoT offers a powerful solution for intelligently managing energy distribution and consumption across diverse environments. It also provides the foundational framework and protocols necessary for the efficient operation of intelligent systems, encompassing capabilities such as sensing, actuation, communication, and processing technologies. Additionally, the rapid technological advancements within various IoT sectors have opened up exciting opportunities for the seamless development and implementation of smart grids (Goudarzi et al., 2022). IoT nodes come equipped with capabilities like sensing and networking, which greatly enhance the potential for optimising energy supply scheduling. Furthermore, this smart energy management approach can be expanded to include contingency planning for emergency situations (Arasteh et al., 2016). Smart grids can enable efficient energy distribution and consumption by implementing demand – response mechanisms. Through IoT devices, power utilities can monitor energy demand patterns in real – time and adjust electricity supply accordingly

(Al-Ali et al., 2017). The IoT sensors can detect faults and disturbances within the grid promptly. This allows utilities to identify issues such as power outages, equipment failures, or voltage fluctuations in real time. Automated fault detection and notification systems can trigger quick responses, reducing downtime and improving overall grid resilience (Morello et al., 2017). Thus, by harnessing the power of IoT devices, data analytics, and automation, utilities can improve grid efficiency, reduce energy costs, integrate RESs, enhance grid reliability, and empower consumers to make more sustainable energy choices. Figure 4 shows the application of IoT in smart grid of Energy Management.

Figure 4 Application of IoT in smart grid (smart energy management) (see online version for colours)



4.2 *Energy consumption monitoring*

Smart energy management relies heavily on energy consumption monitoring through IoT since it offers real – time data and insights into how energy is utilised in many fields of smart cities, including residential, commercial, and industrial settings. IoT devices, such as smart meters, sensors, and energy monitoring systems, collect real – time data on energy consumption at a granular level (Jadhav et al., 2020). This data includes information about when, where, and how electricity is being used. This real – time data collection allows for more accurate monitoring and analysis of energy usage patterns. These monitoring systems can be accessed remotely via the internet. This means that energy managers and homeowners can monitor energy consumption and receive alerts or notifications about unusual usage patterns or potential issues from anywhere, using a computer or smartphone. These devices produce a large amount of data (Kaur, 2020). Advanced analytics and ML algorithms can be applied to this data to identify trends, anomalies, and opportunities for energy optimisation. This analysis can help identify energy – saving opportunities, predict maintenance needs, and optimise energy usage for cost reduction. By providing real – time insights into energy consumption, IoT – enabled systems empower users to make informed decisions about energy usage. This can lead to improved energy efficiency by identifying wasteful practices and optimising energy consumption during peak and off – peak hours.

4.3 Predictive maintenance

IoT devices are strategically placed throughout an energy system, such as power plants, substations, or building HVAC systems. These devices continuously collect real – time data on various parameters, including temperature, pressure, vibration, energy consumption, and equipment status (Cheng et al., 2020). The collected data is transmitted to a central platform or cloud – based system for analysis. ML algorithms and analytics tools are applied to this data to identify patterns, anomalies, and trends. Predictive models are developed using historical and real – time data. These models can forecast when equipment might fail, require maintenance, or deviate from expected performance levels. IoT sensors continuously monitor the condition of equipment and systems. When any deviations from normal operating conditions are detected, the system triggers alerts or notifications to maintenance teams. Predictive maintenance algorithms provide maintenance teams with recommendations on when and what maintenance tasks are needed. This allows for proactive and cost – effective maintenance scheduling. Thus IoT – enabled predictive maintenance is a powerful tool in smart energy management. It helps organisations improve reliability, reduce costs, enhance energy efficiency, and make data – driven decisions.

4.4 Demand side management

The implementation of smart meters, provide real – time insights into energy consumption (Saleem et al., 2021). These devices empower consumers with the knowledge to actively monitor and manage their energy usage, fostering conscious decisions about when and how energy is utilised. Simultaneously, utilities benefit from granular data, allowing them to pinpoint consumption patterns, anticipate peak demand periods, and strategically allocate resources. This two – way flow of information facilitates a more balanced and efficient energy distribution. Smart appliances, another integral facet of IoT in energy management, enable seamless integration with the digital realm. These appliances, equipped with IoT capabilities, can be remotely controlled and programmed. This functionality empowers users to optimise energy consumption by scheduling tasks during off – peak hours, capitalising on lower energy rates and reducing strain on the grid during high – demand periods. Moreover, smart appliances provide real – time feedback on energy usage, contributing to heightened awareness and facilitating continuous improvements in energy efficiency (Natarajan et al., 2022). The concept of demand response underscores IoT's role in bolstering grid stability and resource optimisation. By collecting real – time data on energy demand, IoT technology facilitates the deployment of demand response programs. These initiatives incentivise consumers to curtail their energy consumption during peak periods, mitigating the risk of grid overloads and potential blackouts. The ability to remotely manage and automate these responses ensures a swift and effective implementation of demand reduction strategies. IoT is fostering the growth of Ders, encompassing solar panels, wind turbines, and battery storage systems. These localised energy generation and storage solutions are empowered by IoT sensors that monitor their performance and optimise their output (Nikam and Kalkhambkar, 2021). By integrating these Ders into a smart grid which enables the seamless integration of diverse Ders into the grid infrastructure, IoT facilitates a more decentralised and resilient energy ecosystem, lessening dependence on centralised power sources and reducing transmission losses.

5 Challenges and future trends

In terms of smart energy management, the deployment of IoT infrastructure offers a myriad of possibilities, ranging from optimising energy consumption to enhancing grid reliability. However, this innovation is not without its own set of challenges. As IoT devices gather extensive data to monitor and manage energy systems, substantial concerns regarding security and data privacy arise (Rekha et al., 2023). Moreover, the diverse array of IoT devices and systems employed in energy management often operate on disparate communication protocols and standards. The cost of implementing and maintaining such an extensive IoT ecosystem can be prohibitive, especially for large – scale energy management initiatives, making interoperability and data sharing complex (Belli et al., 2020). Looking forward, the continued development of 5G and other wireless technologies presents promising solutions for addressing these challenges. The high – speed, low – latency connectivity of 5G is poised to support the multitude of IoT devices in energy management systems, ensuring seamless communication and operation (Shafique et al., 2020). Additionally, the fusion of AI with edge computing holds significant potential for analysing the substantial volume of data generated by IoT devices. This innovation enables predictions about energy consumption patterns, grid optimisation, and reduces the need to transmit excessive data to the cloud. This not only enhances the sustainability of energy management systems but also ensures low latency and improved overall performance (Zhang et al., 2021; Naveen and Kounte, 2019). Furthermore, the integration of blockchain technology can contribute significantly to enhancing data security and privacy for IoT – enabled energy management. Blockchain provides a robust framework for safeguarding sensitive energy – related data and maintaining privacy, especially in scenarios involving energy trading and data transactions. As the landscape of IoT – enabled smart energy management evolves, these technological advancements promise to address challenges and unlock the full potential of IoT, paving the way for more efficient, sustainable, and secure energy management systems.

6 Conclusion

As urbanisation continues, the rise of smart cities and the advent of smart energy management driven by IoT technology emerge as a proactive response to multifaceted urban challenges. This integrated approach holds the potential to enhance urban efficiency, sustainability, and quality of life. This paper presents a comprehensive review that offers insights into the integration of IoT enabled energy management systems and its role in enabling smart energy management along with its various application. The transformative influence of the IoT, highlighting its revolutionary applications in energy management for smart cities were discussed by highlighting the optimisation of urban functionalities and grid efficiency, while also underscoring the importance of data security measures and the adaptive nature of IoT system responses. A thorough literature review was done to explore the various application of IoT in the field of energy management for smart cities and the challenges and future trends was discussed and hence, this paper intricately portrays the progression towards smarter cities and the establishment of resilient energy management systems, culminating in a future characterised by elevated urban living standards.

Data availability statement

All the data is collected from the simulation reports of the software and tools used by the authors. Authors are working on implementing the same using real world data with appropriate permissions.

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