

Utilizing Artificial Intelligence and IoT for Enhanced Renewable Energy Management in Smart Cities

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Abstract. This paper reviews the use of Artificial Intelligence (AI) and the Internet of Things (IoT) in better managing renewable energy in smart cities. With a growing focus on sustainable living globally, many cities are updating their infrastructure to be more eco-friendly. This includes improving waste management, increasing renewable energy production, and using modern technology for better energy systems. A key idea discussed is the Smart Green Energy (IoT-SGE) system for smart cities, which uses IoT to help finely control energy use through constant monitoring and secure communication. By using AI, this system can learn and improve over time, making energy management more efficient. The paper also looks at examples from successful smart cities around the world, like London and Singapore, highlighting how good policies can help overcome challenges in energy, transport, and building sectors. It emphasises the importance of working together with local government and other stakeholders to bring about better use of clean energy, making cities smarter and more sustainable. Through reviewing a wide range of studies, this paper aims to provide a clear path forward for developing smarter cities with better renewable energy management.

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1 Introduction

The idea of smart cities is growing with the urgent global need to move towards sustainability. Central to this idea is the powerful combination of Artificial Intelligence (AI) and the Internet of Things (IoT), which according to the reviewed studies, offers a better way to manage renewable energy resources. Smart cities aim to create a close relationship with nature, using natural energy resources while reducing environmental harm. The reviewed text highlights the crucial role of IoT in promoting clean and green communication among devices and users, creating a pollution-free urban environment.

A notable aspect of energy management in smart cities, as pointed out in the reviewed studies, is the concept of stored power and its wise management. The issue of electronic and electrical devices consuming power while they are 'off' or in standby mode shows a hidden opportunity for saving energy. The simple action of switching off devices at the power point is a basic yet effective step towards solving the standby power issue. This simple aspect of energy saving connects to the broader idea of smart energy management, showing the many considerations involved in moving urban areas towards sustainability.

Going further into the energy discussion, the topic of smart grids becomes important. Smart grids, as explained in the reviewed text, represent the height of intelligent energy management, with their ability to track, regulate, and optimise energy flows in real or near real-time. The use of IoT infrastructures within smart grids improves their capability, allowing for better control and distribution of power. The reviewed studies highlight the potential of smart grids in not only improving the operational efficiency of power management but also in creating a two-way communication between energy providers and consumers. This two-way communication is key in predicting potential challenges, responding quickly to issues, and creating new capacities and services in a changing energy landscape.

The concept of smart cities is further enriched by the focus on green communication environments, as highlighted in the reviewed text. The design and creation of energy-efficient devices, along with automated systems for identifying and balancing energy needs, are seen as critical parts of advanced grid management systems. The main goal is to save energy, reduce losses, and ensure a long operational state, contributing to the wider goal of sustainability. The reviewed studies provide a wide range of insights, shedding light on the many aspects of smart city development, and the important role of AI and IoT in helping cities move towards a more sustainable and energy-efficient future. Through a careful review of the studies, this paper aims to add to the growing discussion on smart city development, especially in the areas of energy, transport, and building sectors, learning from the experiences of successful smart city projects around the world.

2 Review and discussion

In a study by Zhang et al. (2021), the authors delve into the integration of Internet of Things (IoT) and green energy for enhancing smart city infrastructures. The paper titled "IoT enabled integrated system for green energy into smart cities" presents a comprehensive methodology for planning and evaluating smart power systems within urban settings. The proposed Internet of Things based Smart Green Energy (IoT-SGE) system aims to

meticulously control energy through pervasive monitoring and secure communications, thereby addressing the energy demands in smart cities while ensuring cost-saving [1].

The following table encapsulates the key findings and analysis from the study by Zhang et al. (2021):

Table 1. Key Insights from IoT-SGE Study by Zhang et al. (2021) [3-8]

Section	Sub-section	Description	Findings/Analysis
Introduction	IoT in Smart Cities	IoT's significance in smart cities due to its interoperability and ubiquitous access.	IoT facilitates clean and green communication access exploiting natural energy.
Stored Power	Discussion on how electronic devices absorb electricity in off or standby mode.	Switching off at the PowerPoint is effective to solve standby power issue.	
Natural Energy Sources	Importance of conserving power from natural resources like heat, light, wind.	Smart grids controlled using IoT infrastructures improve power management.	
Method	IoT-SGE	Introduction of IoT-SGE for managing energy requirements and allocation.	Automated energy allocation and conservation through seamless monitoring.
Grid-connected Power Stations	Discussion on transmission networks for electricity transfer.	Implementing energy-efficient technologies is crucial for reducing energy use.	
Smart City Environment	Connection of power grid to an autonomous and ubiquitous IoT platform.	IoT and machine learning aid in energy allocation, dissemination, and conservation.	
Defining States of a Power Grid	Charging and Discharging	Discussion on charging curves and loading life curves for understanding loading characteristics.	Balancing power dissipation and recharging is essential for meeting user demands.

The IoT-SGE (Internet of Things based Smart Green Energy) method, as proposed in the study by Zhang et al. (2021), is a framework aimed at enhancing energy management within smart cities through the integration of IoT technologies. Here's a simplified explanation of the IoT-SGE method:

- **Integration of IoT:**

- The method leverages the Internet of Things to create a network of interconnected devices and systems. This network facilitates seamless communication and data exchange, enabling real-time monitoring and control of energy resources within a smart city.
- **Smart Green Energy Management:**
 - At the core of the IoT-SGE method is the idea of managing energy resources in a smart and eco-friendly manner. It aims to harness green or renewable energy sources, like solar or wind energy, to meet the energy demands of a smart city while minimizing environmental impact.
- **Automated Control and Monitoring:**
 - Through the IoT network, the IoT-SGE method allows for automated control and monitoring of energy usage, production, and distribution. This automation helps in optimizing energy allocation based on real-time data, thus ensuring energy efficiency and cost-saving.
- **Secure Communications:**
 - The method emphasizes secure communications within the IoT network to ensure the integrity and reliability of the energy management system. This is crucial for maintaining the privacy and security of data while enabling effective energy management.
- **Adaptive Energy Allocation:**
 - By analysing real-time data, the IoT-SGE method can adapt energy allocation based on current demands and conditions. This adaptive approach helps in reducing energy wastage and ensuring that energy resources are utilized efficiently.
- **Enhanced Grid Management:**
 - The IoT-SGE method also encompasses better management of the electrical grid by integrating IoT technologies. This integration allows for more precise control over energy distribution and helps in identifying and addressing issues in real-time, thus enhancing the overall efficiency and reliability of the power grid.

In essence, the IoT-SGE method is about harnessing the power of IoT to create a smart, green, and efficient energy management system that can significantly contribute to the sustainability and functionality of smart cities.

The study by Zhang et al. (2021) underscores the pivotal role of IoT in orchestrating energy management within a smart city framework. The proposed IoT-SGE system, as discussed by Zhang et al., exemplifies how the integration of IoT and smart grid technologies can significantly contribute towards efficient energy management, which is a core theme of our review article. Moreover, the emphasis on automated energy allocation and conservation aligns with our discussion on leveraging Artificial Intelligence for optimizing renewable energy resources in smart cities. Through a detailed exploration of IoT-enabled energy management systems, the study by Zhang et al. provides valuable insights that enrich our understanding and discussion on the synergistic interplay between IoT, Artificial Intelligence, and renewable energy management in the quest for developing sustainable smart cities.

Another study by Razmjoo et al. (2022) explores the intricate realm of smart cities, focusing on the essential roles of modern technology, well-planned government policies, and active involvement of stakeholders in nurturing smart urban ecosystems [2]. The study breaks down the attributes of smart cities into six vital areas: smart people, smart

governance, smart living, smart mobility, smart environment, and smart economy. Here are the key takeaways from the study, simplified for better understanding [9-14]:

- **Technological Advancements in Smart Cities:**
 - The study points out that new technologies like 5G, cloud computing, Artificial Intelligence (AI), and edge computing are crucial in transforming traditional cities into smart cities.
 - It also mentions the Internet of Things (IoT) technology as a significant tool for keeping an eye on energy consumption, managing transport systems efficiently, and ensuring lights are used wisely to save energy.
- **Policy Implications for Energy, Transportation, and Green Buildings:**
 - Smart energy solutions, like smart meters, are highlighted in the study for their ability to manage renewable energy sources effectively, enhance energy efficiency, and cut down on energy wastage.
 - In the transport sector, the study talks about how the adoption of electric vehicles (EVs) and intelligent transport systems can help ease traffic congestion and reduce air pollution.
 - Regarding building management, the study suggests using Building Management Systems (BMS) with IoT technology to monitor and reduce energy consumption, manage ventilation and lighting efficiently, and adjust electricity usage in real-time.
- **Examples of Successful Smart Cities:**
 - The study provides examples of eight cities that have successfully transitioned into smart cities by implementing effective policies and strategies in the domains of energy, transport, and buildings.
 - It also notes that policies may vary from city to city due to differing characteristics like climate, population density, and economic conditions, underlining the necessity for tailor-made policies that suit local circumstances.
- **Smart Parking and Electric Vehicles (EVs):**
 - Smart parking solutions using IoT technology are identified in the study as effective strategies for tackling urban challenges like traffic congestion and lack of parking spaces.
 - The study also discusses the potential benefits of EVs in reducing greenhouse gas emissions, easing traffic on the roads, and lowering the urban energy consumption, especially when supported by conducive policies like financial incentives and better infrastructure for charging EVs.
- **Engagement of Local Governments and Stakeholders:**
 - The study underscores the importance of collaborative efforts between local governments and stakeholders in the development of smart cities, advocating for a collective approach to address challenges and achieve smart city objectives.
 - It suggests that local governments can leverage the expertise of stakeholders to expedite the smart city development process, especially in the energy sector.

Drawing from additional insights provided in the study, it's evident that concerns surrounding climate change and environmental degradation are driving forces behind the smart city movement. The study elaborates on how appropriate policies and strategies are instrumental in accelerating smart city development, aiding in tackling global challenges like CO2 emissions and energy crises. It presents a detailed analysis of successful policies

across various cities, emphasising the sectors of energy, transportation, and building management as having the most substantial impact on smart city development.

In the energy sector, the study praises the use of innovative tools like smart meters and new energy systems, including small-scale Combined Heat and Power (CHP) with heat storage, PV-driven heat pumps for heat provision, and bio-methane injection into grids, as effective measures for larger settlements with high supply needs. It also mentions the utility of air and water sensors in monitoring environmental quality.

In the transportation sector, the study applauds the employment of IoT, electric vehicles (EVs), and intelligent transport systems for enhancing safety and punctuality on the roads. It also mentions the development of smart parking spots as a viable solution to reduce traffic and noise in cities.

In the building sector, the study commends the use of IoT for monitoring purposes to reduce energy consumption, the development of zero-energy buildings, and the management of ventilation and lighting to adjust electricity consumption in real-time.

The study concludes by stressing the importance of reviewing the success and failure of previously implemented policies, strategies, and technologies, acknowledging that the needs of each country and city are unique. It advocates for a thorough understanding and consideration of existing resources and individual needs in policy and decision-making processes. It also highlights the positive impact of local governments and stakeholders working together, especially leveraging stakeholders' knowledge, on smart city development. The study aims to focus on implementing fruitful policies in line with green energy development and attracting investment for clean energy in the three investigated sectors in the future. It also emphasises that strategies like smart parking, IoT technology for waste management, and lithium batteries for electric vehicles are suitable for smart city development.

3 Future Scope of Research

The exploration into smart cities, particularly in the realm of integrating Artificial Intelligence (AI) and the Internet of Things (IoT) for better renewable energy management, has opened up a plethora of avenues for further research. The journey towards creating self-sustaining urban ecosystems is ongoing, and there's a vast scope for delving deeper into various facets of this intriguing domain. Here are some pointers for future research that could significantly contribute to the existing body of knowledge and aid in the practical advancement of smart cities:

- **Advanced AI Algorithms:**
 - Developing more sophisticated AI algorithms to better analyse the vast amount of data generated within smart cities, leading to more accurate predictions and smarter decision-making.
- **IoT Security:**
 - Investigating robust security measures to safeguard the plethora of IoT devices and networks against potential cyber threats, ensuring the privacy and safety of citizens' data.
- **Energy Storage Technologies:**
 - Researching advanced energy storage technologies to ensure a reliable supply of renewable energy, even during unfavourable weather conditions or other disruptions.
- **Smart Grids:**

- Delving into the development of smarter grids capable of handling diverse energy sources, managing demand in real-time, and ensuring a resilient energy infrastructure.
- **Sustainable Transportation Systems:**
 - Exploring innovative solutions for sustainable transportation, including autonomous electric vehicles, smart traffic management systems, and eco-friendly public transport options.
- **Green Building Technologies:**
 - Investigating new materials and technologies for constructing energy-efficient buildings, alongside smart monitoring and management systems to reduce energy consumption further.
- **Public Engagement Strategies:**
 - Studying effective strategies for engaging the public in the smart city transformation journey, ensuring that the benefits of smart cities are accessible and understandable to all citizens.
- **Policy Frameworks and Governance Models:**
 - Researching adaptable policy frameworks and governance models that can foster the seamless integration of AI and IoT technologies in urban planning and management.

4 Knowledge Gaps

While the existing research provides a solid foundation for understanding the dynamics of smart cities, certain knowledge gaps persist that could hinder the full realization of smart city potentials. Addressing these gaps is crucial for advancing the narrative and ensuring that the transition to smart cities is both effective and inclusive. Here are some identified knowledge gaps that warrant further investigation:

- **Standardisation:**
 - Lack of standardised protocols and frameworks for the integration and interoperability of diverse smart city technologies, which could impede seamless operation and data exchange.
- **Cost Analysis:**
 - Insufficient comprehensive cost-benefit analyses of implementing smart city technologies, which is vital for garnering support from stakeholders and securing necessary funding.
- **Long-term Sustainability:**
 - Limited research on the long-term sustainability and scalability of smart city initiatives, especially concerning renewable energy management and infrastructure development.
- **Public Awareness and Acceptance:**
 - A gap in understanding the level of public awareness and acceptance of smart city technologies, which could affect the rate of adoption and ultimate success of smart city initiatives.
- **Ethical and Privacy Concerns:**
 - Inadequate exploration of the ethical implications and privacy concerns associated with widespread data collection and analysis in smart cities.
- **Impact Assessment:**
 - Lack of thorough impact assessments to understand the socio-economic and environmental effects of smart city technologies and policies.
- **Technological Literacy:**

- A need for more research on improving technological literacy among citizens to ensure they can fully benefit from and participate in smart city initiatives.
- **Collaborative Frameworks:**
 - Insufficient models for collaborative governance and multi-stakeholder engagement, which are crucial for the holistic development and success of smart cities.

These pointers for future research and identified knowledge gaps provide a roadmap for academics, policymakers, and urban planners to delve deeper into the multifaceted domain of smart cities. Addressing these areas will not only enrich the academic discourse but also significantly contribute to the practical advancement of smart cities globally.

5 Conclusion

The journey through various studies and analyses has provided a rich tapestry of insights into the realm of smart cities, particularly focusing on the integration of Artificial Intelligence (AI) and the Internet of Things (IoT) for enhanced renewable energy management. This exploration has not only affirmed the pivotal role of emerging technologies in urban development but also highlighted the nuanced strategies adopted by different cities to navigate the complex landscape of sustainability and smart governance. Here are the key findings that encapsulate the essence of our exploration and resonate with the initial discourse on utilizing AI and IoT for fostering renewable energy management in smart cities:

- **Technological Integration:**
 - The seamless integration of AI and IoT technologies is fundamental in transforming urban areas into smart cities. These technologies facilitate real-time data collection, analysis, and actionable insights, which are crucial for efficient renewable energy management.
- **Energy Efficiency:**
 - Smart cities are making strides in enhancing energy efficiency through innovative solutions like smart grids, smart meters, and renewable energy systems. These initiatives are instrumental in reducing energy wastage and promoting sustainable energy usage.
- **Sustainable Transportation:**
 - The adoption of sustainable transportation systems, including electric vehicles and smart traffic management, significantly contributes to reducing carbon emissions and alleviating traffic congestion, aligning with the broader vision of creating eco-friendly urban ecosystems.
- **Green Building Practices:**
 - The emphasis on green building practices underscores the importance of energy-efficient infrastructure in reducing the carbon footprint of urban areas. Smart monitoring and management systems are pivotal in achieving this goal.
- **Public Engagement:**
 - Engaging the public in the smart city transformation journey is crucial for ensuring the inclusivity and success of these initiatives. Public awareness and acceptance significantly impact the rate of adoption of smart technologies and policies.

- **Policy and Governance:**

- Effective policy frameworks and collaborative governance models are essential for fostering a conducive environment for the adoption and scaling of smart city initiatives. These frameworks provide the necessary support and direction for navigating the complex interplay of technological innovation and urban development.

The findings from our exploration resonate well with the initial discourse, painting a comprehensive picture of the potential and challenges that lie ahead in the quest for smart, sustainable urban development. The nuanced understanding gleaned from various studies provides a solid foundation for further exploration and practical action towards realizing the vision of smart cities that are not only technologically advanced but also sustainable, inclusive, and responsive to the needs and aspirations of their residents. Through the lens of AI and IoT, the horizon of possibilities in enhancing renewable energy management and ultimately achieving the broader sustainability goals of smart cities becomes vividly apparent, beckoning a continued exploration and action in this exciting domain.

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