# Artificial Intelligence's Role in Shaping Renewable Energy for Next-Generation Smart Cities

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**Abstract.**This review article explores the perspective of artificial intelligence (AI) in shaping the future of smart cities, with a particular focus on the integration of renewable energy solutions. The smart city and AI perspective has gained significant attention in urban policy circles, yet many initiatives have faced challenges due to narrow, technology-centric approaches. In response, this paper advocates for a "green AI" approach that prioritises sustainability and equity alongside efficiency in urban development. Through a comprehensive analysis of AI and smart city literature, practices, trends, and applications, this review identifies critical research gaps, stressing the need for AI systems that promote sustainability, efficiency, and fairness in urban contexts. In light of pressing issues like climate change, overpopulation, and resource depletion, the urgency of AI-driven urban solutions is evident. The article examines Smart Cities in Spain and compares them to conventional cities, offering insights into strategic technological measures across areas such as economics, sustainability, transportation, governance, population management, and quality of life. It underscores AI's potential to transform traditional cities into smart, sustainable urban hubs, contributing to the broader discourse on AI's role in shaping the cities of tomorrow.

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# 1 Introduction

The fusion of the digital era and the fourth industrial revolution has ushered in an era of unparalleled innovation, driving technological progress across a multitude of domains. Notably, artificial intelligence (AI), characterized by algorithms emulating human cognitive functions to autonomously make decisions, has witnessed an exponential rise over recent decades. It has emerged as a transformative and disruptive technology with wide-ranging applications, spanning healthcare, finance, transportation, and beyond, positioning itself as a pivotal driver behind the global movement towards smart cities.

Smart cities have arisen as epicenters where digital technologies and data are harnessed to drive efficiencies, catalyze economic growth, elevate quality of life, and champion sustainability. Within the discourse of smart city transformation, AI has gained substantial prominence, capturing the attention of urban policymakers and planners seeking technological solutions to multifaceted urbanization challenges. The appeal of technocentric solutions lies in their potential to tackle intricate urban issues, encompassing environmental sustainability, safety, mobility, and accessibility.

Technological advancements have paved the way for the accumulation of substantial volumes of data through strategically deployed smart sensors in urban environments, marking the advent of the big data era. Coupled with recent AI techniques and ubiquitous computing, this influx of data has catalyzed improvements in the quality of life, urban operational systems, and environmental conditions. AI applications in urban settings span a broad spectrum, encompassing automated urban decision-making, infrastructure assessment, post-disaster reconnaissance, autonomous mobility, descriptive analytics, urban security, and service agent chatbots.

Governments worldwide have embarked on ambitious AI-driven initiatives at national, state, and local levels with the aim of bolstering efficiencies and public services. Nevertheless, many such endeavors have encountered challenges, grappling with the delivery of ethical, responsible, and sustainable solutions. This predicament is equally evident in the realm of smart cities, where predominantly technologically deterministic and reductionist AI approaches have often fallen short of materializing the envisioned smart urban future, sometimes resulting in project cancellations and disillusionment.

The crux of the issue stems from the prevailing technologically determined and reductionist nature of AI adoption practices, frequently neglecting the intricacies of urban, human, and social contexts, exacerbating issues of societal control, inequality, and marginalization. This perspective paper seeks to address these challenges by spotlighting the constraints of current AI conceptualization and practice. It introduces a novel paradigm - "green AI," harmonized with green sensing - that redirects the focus from short-term efficiency to a long-term vision of ethical, responsible, and sustainable AI practices. By seamlessly integrating AI into the fabric of smart cities, this approach aspires to lay the groundwork for sustainable urban futures that benefit all.

# 2 Review and discussion

In a study by Yigitcanlar et al. (2021), the impacts of human activity on the environment, the development of green AI, and policy directions for AI's role in sustainability were

explored [1]. This comprehensive investigation shed light on key findings and insights that have significant implications for our understanding of how artificial intelligence can contribute to addressing pressing global challenges. In the following table, we present a summary of these findings in a concise format for reference and analysis.

**Table1**: Insights from Yigitcanlar et al. (2021) Study on Green AI and Sustainability

| Topic | Overview | Key Findings | Benefits | Challenges/Gaps | Insights | References |
|---|---|---|---|---|---|---|
| The Green AI Approach for Flourishing | Impact of human activity on the environment. | Catastrophic threats include pollution, biodiversity loss, and climate change. AI often prioritizes business efficiency over addressing global threats. | AI may act as an enabler for 79% of UN's SDG targets but may negatively affect 35%. Significant investment and collaboration needed for AI-supported SDGs. | AI can address sustainability challenges and global threats. Governments and the public must understand and act on these risks. | The failure to understand and act on global risks hampers AI solutions' effectiveness in addressing anthropogenic threats. | [4-6] |
| Green Sensing, Communications, and Computing | Role of sensing, communication, and computing in green AI. | Smart applications' interdependence, IoT growth, and AI's role in efficiency. Introduction of "green sensing" for sustainability. | Smart applications' enhancement of decision-making, IoT's data sensing, and efficient green sensing. Energy, privacy, and security concerns. | Green sensing and efficient computing contribute to sustainability and smart cities. The concept of "green sensing" encompasses various methods and technologies for measuring sustainability. | Sensing, communication, and computing are increasingly interdependent due to IoT and AI, driving the need for green sensing. | [7,8] |
| Policy Directions for AI | Need for a green AI approach and policy challenges. | Rapid growth and disruptive nature of AI. Urgent need for government intervention and regulation. | Legal and ethical frameworks, ethical principles, and consequences for AI ethics | Government's cautious approach to AI ethics and regulation. Timely government policy is vital for greener AI and smarter | Government intervention and regulation are essential to address the disruptive nature and risks of AI effectively. | [9-11] |

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| | | | violations. | cities. | | |

Another study by Ortega-Fernández et al. (2020) provides valuable insights into the assessment of Smart Cities, offering a practical approach through the use of a simplified data dashboard [2]. Their research illuminates the journey of cities in transitioning towards becoming Smart Cities. By visualizing and quantifying progress, they facilitate a clearer understanding of the strides made by these urban centres in embracing the concept of smart urbanization. In this context, our review article delves deeper into the implications and broader perspectives arising from studies like Ortega-Fernández's, aiming to draw connections between the findings and the larger discourse surrounding Smart Cities. We explore the significance of these findings and their potential impact on urban development practices and policies [12-14].

- **Data Dashboard Utilization:** The research team effectively employed a user-friendly data dashboard to visually gauge cities' progress. This approach made it easier to identify cities that were making strides in their transition towards becoming Smart Cities.
- **Adherence to ISO Standards:** The study placed particular emphasis on cities' adherence to international standards, particularly ISO 37120, which relates to Smart City development. Data was sourced from various outlets such as city websites and newspapers.
- **Scoring System:** Using a straightforward scoring system, each element on the dashboard received a score ranging from 1 to 6. Higher scores indicated better performance in respective areas, although some elements were excluded due to data unavailability.
- **Smart City Rankings:** The study's findings positioned Madrid as the foremost Smart City, closely followed by Barcelona, Valencia, and Malaga. In contrast, Santander received the lowest ranking, with Granada trailing Madrid.
- **Smart Initiatives:** Specific projects undertaken by cities to advance their Smart City goals were highlighted. For instance, Malaga successfully reduced CO2 emissions, Santander implemented real-time traffic monitoring, Valencia improved citizen services, and Barcelona excelled in public transportation and healthcare management.
- **Areas Requiring Improvement:** Despite successes in certain areas, all cities exhibited deficiencies. These included the need for more electric vehicle charging infrastructure, enhanced public transportation systems, improved recycling efforts, increased green spaces, and more effective healthcare services.
- **Comparison with Granada:** A comparison between Granada, the study's primary focus, and Madrid revealed significant disparities across various domains. Granada was found to require substantial improvements in multiple aspects to match Madrid's Smart City status.
- **Strategic Measures:** To address deficiencies observed in Granada, the study proposed strategic actions covering governance, transportation, environment, economy, and quality of life. These recommendations included enhancements in healthcare, public transportation, green spaces, and poverty reduction.
- **Resilience and Innovation:** The study underscored the critical role of technology and innovation, including AI, in Smart City evolution. It advocated for the use of technology to enhance city operations, effectively address healthcare and environmental challenges, and prepare for global challenges.

In conclusion, Ortega-Fernández et al.'s study highlights the importance of monitoring and assessing cities' progress in adopting Smart City principles. Their innovative use of a data dashboard offers a practical tool for both cities and researchers to gauge and enhance their smart urbanization efforts. As we reflect on their findings, it becomes evident that the path towards Smart Cities is multifaceted, requiring careful attention to various aspects of urban life. This study's relevance extends beyond individual cities; it contributes to the larger conversation about urban development in the digital age. By aligning these findings with our review article, we aim to provide a comprehensive perspective on the transformative journey of cities towards smarter, more sustainable futures.

In another separate study by Yigitcanlar et al. (2020), the profound influence of Artificial Intelligence (AI) on diverse aspects of smart cities was explored [3]. This article embarks on a similar journey, investigating how AI has become a driving force shaping smart cities' various dimensions, namely, the economy, society, environment, and governance.

Within the backdrop of swift urbanization and technological progress, the concept of smart cities has emerged as a beacon of hope, offering solutions to the intricate challenges associated with contemporary urban life. At the very core of this transformative vision stands Artificial Intelligence (AI), a technological dynamo with the potential to redefine urban functionality and elevate the quality of life for city dwellers. This review article delves into the profound impact of AI across a multitude of smart city facets, shedding light on its pivotal contributions to the economy, society, environment, and governance.

The authors, in their review, scrutinized 93 carefully selected articles, and discovered a conspicuous surge in interest surrounding AI technology which is apparent in recent times. This surge is vividly illustrated by the fact that nearly half of the reviewed articles were published in 2019, underscoring the burgeoning curiosity about AI's role in the evolution of smart cities. Despite the existence of articles on AI and urban development since 1990, it is noteworthy that the earliest article conforming to our selection criteria dates back to 1999. These findings closely mirror the outcomes of prior review studies and bear testament to the escalating fascination surrounding how AI systems intersect with and influence the trajectory of smart cities [15].

**AI's Role in Smart City Dimensions:**

*AI in the Economy Dimension of Smart Cities [16]:*

- Research within this domain delves into the ways AI contributes to bolstering the productivity and innovation of smart cities. This entails the automation of data management and analysis, cost reduction through pattern recognition, facilitation of data-informed decision-making, and augmentation of logical reasoning.

*AI in the Society Dimension of Smart Cities [17]:*

- Concentrating on the realms of healthcare and education, this segment delves into how AI fosters improvements in health monitoring, aids in diagnosis, and enables personalized education. It scrutinizes AI's potential to revolutionize the healthcare landscape and create more effective pedagogical experiences.

*AI in the Environment Dimension of Smart Cities [18]:*

- The exploration of AI's role within the environmental dimension shines a spotlight on its contribution to sustainable urban development. AI plays a pivotal role in monitoring environmental shifts, optimizing energy consumption, crafting energy-efficient homes, and spearheading a revolution in transportation for reduced energy consumption and environmental impact.

*AI in the Governance Dimension of Smart Cities [19]:*

- In the context of the governance dimension of smart cities, AI plays a pivotal role in augmenting governance, fortifying security, and enhancing decision-making processes. This entails AI applications in surveillance, cybersecurity, disaster management, and citizen engagement, shedding light on how AI-powered solutions contribute to safer, more efficient, and participatory urban environments.

This study by Yigitcanlar et al. (2020) unveils the multifaceted ways in which AI is reshaping the landscape of smart cities. From driving economic growth and enhancing societal well-being to fostering sustainability and elevating governance, AI assumes a pivotal role in the ongoing evolution of urban living. As smart cities continue to expand and evolve, the seamless integration of AI technologies promises to play an increasingly vital role in addressing the intricate challenges and opportunities that lie ahead. Ultimately, this integration contributes to the creation of smarter, more liveable urban environments, enriching the lives of all who call these cities home.

## 3 Future Scope of Research

As we delve into the intricate realm of artificial intelligence (AI) and its pivotal role in shaping renewable energy for next-generation smart cities, several promising avenues for future research and development come to the fore. The dynamic synergy between AI and sustainable urban energy solutions opens up exciting possibilities for further innovation and progress. Here are some key areas that warrant focused attention in future studies:

- **AI-Enhanced Renewable Energy Integration:** Investigating advanced AI algorithms and models to optimize the integration of renewable energy sources into urban grids, enabling efficient storage, distribution, and consumption of clean energy.
- **Smart Grid Resilience:** Exploring how AI-driven smart grids can enhance resilience against power disruptions, extreme weather events, and cyber threats, ensuring a continuous and secure energy supply for cities.
- **Community-Centric Energy Solutions:** Developing AI-powered systems that empower local communities to actively participate in renewable energy generation and consumption decisions, fostering energy self-sufficiency and sustainability.
- **AI for Energy Equity:** Addressing disparities in access to renewable energy benefits within urban populations, with a focus on leveraging AI to ensure equitable distribution and affordability.
- **Lifecycle Sustainability:** Assessing the environmental and economic sustainability of AI-enabled renewable energy solutions throughout their lifecycle, from manufacturing and deployment to decommissioning and recycling.
- **Urban Mobility Integration:** Exploring the synergy between AI-driven renewable energy solutions and smart urban mobility systems, such as electric vehicle networks, to create seamless, eco-friendly transportation options.

## 4 Knowledge Gaps

Despite the remarkable strides in AI's role in shaping renewable energy for next-generation smart cities, critical knowledge gaps persist, necessitating comprehensive investigations to bridge these voids. Identifying these gaps can guide future research endeavours:

- **AI-Grid Interaction Dynamics:** Understanding the intricate dynamics between AI-controlled renewable energy sources and urban energy grids, including the challenges of load balancing and grid stability.

- **Energy Storage Breakthroughs:** Investigating innovative AI-driven approaches to energy storage solutions, such as next-generation batteries and supercapacitors, to address the intermittent nature of renewable sources.
- **Community Engagement and Acceptance:** Assessing the factors that influence community engagement with AI-powered renewable energy initiatives and strategies to build trust and active participation.
- **Policy and Regulatory Frameworks:** Exploring the development of agile and adaptive policy frameworks to govern AI-driven renewable energy adoption, ensuring compliance with evolving ethical, legal, and environmental standards.
- **Data Privacy and Security:** Investigating robust AI-driven cybersecurity measures to protect renewable energy infrastructure and data from cyber threats and breaches.
- **Long-Term Sustainability Metrics:** Defining comprehensive metrics and indicators to evaluate the long-term sustainability and socio-economic impact of AI-infused renewable energy solutions in smart cities.

By addressing these future research directions and knowledge gaps, we can advance our understanding of how AI can truly revolutionize the renewable energy landscape in smart cities, driving us towards a more sustainable and resilient urban future.

## 5 Conclusion

In the journey through the multifaceted landscape of AI's transformative role in shaping renewable energy for next-generation smart cities, our exploration has yielded the below key findings that illuminate the path to urban sustainability and resilience:

- **AI as the Cornerstone:** Artificial intelligence emerges as the cornerstone of smart cities, orchestrating the seamless integration of renewable energy sources, optimising grid operations, and fostering energy efficiency.
- **Urban Energy Revolution:** The confluence of AI and renewable energy heralds an urban energy revolution, redefining traditional power paradigms, and paving the way for cleaner, greener, and more accessible energy solutions.
- **Sustainability Synergy:** AI-driven renewable energy solutions not only enhance sustainability but also contribute to economic growth, improved quality of life, and reduced carbon footprints, aligning with the broader goals of smart cities.
- **Community Empowerment:** Community-centric approaches empower urban residents to actively participate in renewable energy initiatives, democratising access to clean energy and fostering social inclusion.
- **Challenges and Adaptations:** Our exploration uncovered challenges related to grid stability, cybersecurity, and equitable access. However, AI's adaptability and potential for continuous improvement offer solutions to address these issues.
- **Uncharted Horizons:** The future of AI in smart cities and renewable energy holds uncharted horizons, with opportunities for further research, innovation, and policy development to unlock the full potential of this transformative synergy.

In summary, these six key findings paint a compelling picture of the symbiotic relationship between artificial intelligence and renewable energy, illuminating the path to a sustainable and resilient urban future. The fusion of AI's analytical prowess with the clean energy promise of renewables holds the potential to revolutionize the way we power our cities. As we delve deeper into this transformative synergy, we uncover not only technological advancements but also avenues for community engagement, economic growth, and environmental stewardship.

Looking ahead, our exploration of AI's role in shaping renewable energy for next-generation smart cities beckons us towards uncharted horizons. The journey is far from over, as opportunities for further research, innovation, and policy development continue to emerge. By harnessing the full potential of this transformative synergy, we can envisage a future where smart cities flourish in harmony with the environment, ushering in a brighter and more prosperous era for urban living—a vision that resonates with the essence of our exploration from its inception.

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