Artificial Intelligence in Sustainable Smart Cities: A Systematic Study on Applications, Benefits, Challenges, and Solutions

Simone C. dos Santos[a], Jéssyka F. F. Vilela[b], Thiago H. Carvalho, Thiago C. Rocha, Thales B. Candido, Vinícius S. Bezerra and Daniel J. Silva

Centro de Informática, Federal University of Pernambuco, Recife, Brazil

Keywords: Smart Cities, Sustainability, Artificial Intelligence, Systematic Literature Review.

Abstract: In an era marked by rapid urban growth and environmental challenges, the advent of "smart cities" holds promise for a sustainable future. Central to the operational efficiency of these cities is the role of Artificial Intelligence (AI). This Systematic Literature Review addresses the critical question: How can AI be used in sustainable smart cities? Using Kitchenham's guidelines, the review followed a three-step Planning, Conducting, and Reporting process. Through a comprehensive search in the databases ACM, IEEEXplore, Scopus, Science Direct, and Emerald, a total of 46 high-quality papers were identified. These papers were scrutinized to understand the AI services utilized in smart cities, the benefits, the challenges of implementation, and potential solutions to these challenges. Findings reveal that AI's impact is multi-dimensional, affecting transportation, energy management, and citizen engagement, among other areas. However, several challenges remain, considering ethics and data management. This review serves as an exhaustive guide for researchers and policymakers interested in leveraging AI for sustainable urban development.

1 INTRODUCTION

In an age of rapid urbanization and environmental challenges, a "smart city" has emerged as a beacon of hope for a more sustainable and efficient future. A smart city is constantly evolving and, therefore, requires constant communication and dissemination of information (Zubizarreta et al., 2016). At the heart of these smart cities lies the transformative power of Artificial Intelligence (AI), which can be defined as an information processing system capable of generating new non-trivial information processing systems (Suleimenov et al., 2020). With this in mind, AI emerges as a vital ally,- enabling municipalities to harness data-driven insights and make informed decisions that can lead to creating genuinely sustainable smart cities. In line with the original definition of sustainable development, a city can be defined as sustainable "if its conditions of production do not destroy over time the conditions of its reproduction" (Imperatives, 1987) (Castells, 2000)(Ahvenniemi et al., 2017). The fusion of AI technology and urban planning represents a paradigm shift in how cities operate, manage resources, and serve their inhabitants; intelligent machines are utilized for making smart decisions and for removing human tasks in various fields like automatic sensing applications, medical applications, automated farming, and automated vehicle driving (Wang et al., 2019)(Sharma et al., 2021). It goes beyond mere automation; it's about creating cities that are not just smart but also sustainable, livable, and resilient.

This article delves into the pivotal role of AI in shaping the future of our urban landscapes, exploring how it is helping to build greener, more efficient, and socially inclusive cities. From optimizing transportation systems to managing energy consumption and fostering citizen engagement, AI is driving a revolution that promises to redefine urban living for future generations. However, there is a need to carry out a systematic study that answers the following central research question: RQ) *How can AI be used in sustainable smart cities, considering AI-based services, its benefits, challenges, and solutions for these challenges*?

[a] https://orcid.org/0000-0002-7903-9981
[b] https://orcid.org/0000-0002-5541-5188

Santos, S., Vilela, J., Carvalho, T., Rocha, T., Candido, T., Bezerra, V. and Silva, D.
Artificial Intelligence in Sustainable Smart Cities: A Systematic Study on Applications, Benefits, Challenges, and Solutions.
DOI: 10.5220/0012617900003690

In *Proceedings of the 26th International Conference on Enterprise Information Systems (ICEIS 2024) - Volume 1*, pages 644-655
ISBN: 978-989-758-692-7; ISSN: 2184-4992

This paper is structured in five sections to discuss research results. After this brief introduction, we describe primary concepts and related work in Section 2. Section 3 details the research method based on the Systematic Literature Review. Section 4 presents the results and discusses our research secondary questions. Finally, Section 5 presents conclusions and future work.

2 BACKGROUND

2.1 AI Mechanisms and Technologies Across Industries

AI-based services harness various mechanisms and technologies, revolutionizing multiple industries (Lee Park, 2019; Li et al., 2021; Lee Yoon, 2021).

Machine Learning (ML) stands out as a cornerstone, enabling systems to learn from data, adapt, and improve performance over time (Singh, 2007). Supervised Learning trains models on labelled datasets, while unsupervised Learning discovers patterns in unlabelled data. Reinforcement learning introduces decision-making through reward-based systems.

Deep Learning, a subset of ML, utilizes neural networks with multiple layers to process complex data representations, excelling in tasks such as image and speech recognition (Mathew et al., 2021). Convolutional Neural Networks (CNNs) are pivotal for visual data (Li et al., 2021), while Recurrent Neural Networks (RNNs) excel in sequential data like language (Medsker, 2001).

Natural Language Processing (NLP) empowers AI to comprehend and generate human language. This technology underpins virtual assistants, chat-bots, and language translation services, facilitating seamless human-computer interaction. Computer Vision extends AI capabilities to interpret and understand visual information (Kothadiya et al., 2021). Image recognition, object detection, and facial recognition are prominent applications that enhance the healthcare, security, and retail sectors.

Other AI mechanisms include expert systems, rule-based systems that mimic human expertise, and reinforcement learning for autonomous decision-making (Shrestha et al., 2019). Speech recognition technology enables voice-based interactions, while robotics integrates AI for physical tasks in industries like manufacturing and healthcare. Overall, the synergy of these mechanisms fuels AI-based services, transforming industries by automating processes, improving user experiences, and fostering innovative solutions across diverse domains (Noor et al., 2022).

2.2 Related Works

This section summarizes ten systematic studies of the literature on Sustainable Smart Cities, covering various topics from energy management and transportation to governance and data security.

Alotaibi et al. (2020) examine recent literature on smart grids, highlighting their role in enhancing energy efficiency and sustainability in urban environments. Also concerning energy efficiency, Khaje Nasiri et al. (2017) investigate energy-efficient IoT applications in sustainable solutions, emphasizing reducing environmental impact in smart urban environments.

With a focus on IoT applications, Vaidian et al. (2019) explore their impact on urban mobility, providing insights into sustainable transportation solutions. Concerning smart buildings, Ejidike Mewomo (2023) explores technologies and strategies for sustainable construction and operation, contributing to eco-friendly urban development. Also relating to human well-being, Nitoslawski et al. (2019) highlight their importance in promoting environmental sustainability and residents' well-being through green spaces in smart cities.

Regarding smart city management, Abdullah et al. (2019) examine waste management literature, focusing on smart solutions, such as IoT-enabled optimization, for efficient and sustainable urban waste management. Analyzing governance literature, Pereira et al. (2018) explore models and frameworks for effective smart city governance, contributing to sustainable urban development.

Concerning technological concerns, Wong et al. (2022) present a review investigating blockchain's potential and applications for sustainable urban development, emphasizing transparency and decentralized systems. Shehab et al. (2021) discuss connectivity, emphasizing high-speed, low-latency communication for improved urban services and sustainability. Finally, Ismagilova et al. (2020) assess the literature on data security and privacy in smart cities, addressing concerns and proposing strategies to ensure secure and responsible data management.

Considering the various aspects and themes discussed in each of these literature reviews, the current study proposes a consolidated perspective from a holistic view of how AI can be used in smart cities, its benefits, challenges, and potential solutions for these challenges. A summary of related works can be found in Table 1.

Table 1: Related works.

Ref	Title	Summary
(Alotaibi et al., 2020)	A comprehensive review of recent advances in smart grids: A sustainable future with renewable energy resources.	Focuses on the role of smart grids in enhancing energy efficiency in urban areas.
(Vaidian et al., 2019)	Impact of Internet of Things on Urban Mobility.	Explores the impact of IoT applications on sustainable transportation solutions in urban settings.
(Wong et al., 2022)	Potential integration of blockchain technology into the smart sustainable city (SSC) developments: a systematic review.	Investigates the potential applications of blockchain in promoting sustainability and decentralized systems in urban development.
(Shehab et al., 2021)	5G networks towards smart and sustainable cities: A review of recent developments, applications and future perspectives.	Examines the literature on how 5G technology contributes to improved urban services and sustainability.
(Ejidike and Mewomo, 2023)	Benefits of adopting smart building technologies in building construction of developing countries: Review of the literature.	Analyses literature on technologies and strategies for sustainable construction and operation of smart buildings.
(Abdullah et al., 2019)	IoT-based smart waste management system in a smart city.	Focuses on IoT-enabled optimization and other smart solutions for efficient and sustainable urban waste management.
(Nitoslawski et al., 2019)	Smarter ecosystems for smarter cities? A review of trends, technologies, and turning points for smart urban forestry.	Reviews literature on energy-efficient IoT ap- plications, emphasizing reducing environmental impact in smart urban environments.
(Khajenasiri et al., 2017)	A review on Internet of Things solutions for intelligent energy control in buildings for smart city applications.	Analyses governance literature, exploring models and frameworks for effective smart city governance to contribute to sustainable urban development.
(Pereira et al., 2018)	Smart governance in the context of smart cities: A literature review.	Addresses concerns and proposes data security and privacy strategies in smart cities, ensuring secure and responsible data management.
(Ismagilova et al., 2020)	Security, privacy and risks within smart cities: Literature review and development of a smart city interaction framework.	Discusses several aspects of how AI can be used in smart cities, its benefits, challenges, and potential solutions for these challenges.
Carvalho et al.	Current study.	Consolidated perspective from a holistic view of how AI can be used in smart cities.

3 METHOD

A systematic literature review (SLR) was carried out to collect data. This research has followed Kitchenham et al.'s (2009) guidelines for conducting a Systematic Literature Review. They defined an SLR as "*a means of identifying, evaluating, and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest*." This is the primary rationale for doing an SLR because if research isn't thorough on the existing literature, it is of little scientific value.

Using this method, it is possible to get a structured view of how smart cities have been implementing AI sustainably by reviewing studies written about topics related to the area. Also, a well-defined methodology makes it less likely that the results are biased, gives a wide range of information across different settings and empirical methods, and provides the possibility of turning it into real data visualization (Kitchenham et al., 2009).

This review was divided into three stages: Planning, Conducting, and Reporting.

3.1 Planning the Review

Developing research questions that could guide the search and selection processes was necessary to plan out the SLR successfully. So, we unfold the central research question (How can AI be used in sustainable smart cities?) in the following secondary questions:

- RQ1: *What AI services are used in smart cities for sustainability?*
- RQ2: *What are the benefits related to the implementation of AI in the context of RQ1?*
- RQ3: *What are the challenges associated with implementing AI in the context of RQ1?*
- RQ4: *What solutions to challenges encountered?*

The aim of the first research question (RQ1) is to establish a foundational understanding of the specific AI applications currently employed in smart cities that revolve around sustainability. The second research question (RQ2) aims to uncover the positive outcomes and advantages of incorporating AI in the pursuit of sustainability in smart urban environments. The third research question (RQ3) focuses on identifying and comprehensively assessing the hurdles and complexities that arise when implementing AI into the sustainability framework of smart cities. Finally, the fourth research question (RQ4) explores and presents potential remedies and strategies to overcome the challenges of integrating AI for sustainability in smart cities.

A generic search string was constructed to explore these research questions. It was developed to encapsulate key concepts, ensuring a focused and comprehensive retrieval of relevant literature. Specifically, it encompasses the following keywords: artificial intelligence, sustainable, and smart cities. Thus, the final search string developed was as follows:

("Artificial Intelligence" OR AI OR "Machine Learning" OR "Deep Learning") AND (sustainability OR sustainable OR green) AND ("smart cities").

3.2 Conducting the Review

The research methodology employed for this study involved an automated search conducted across five prominent research databases: ACM, IEEEXplore, Scopus, Science Direct, and Emerald. These platforms were selected for their significant representation within the computing domain. Since the topic of implementing AI in smart cities is of considerable recency (Herath and Mittal, 2022), the search scope was restricted to papers published in the last five years, considering the period from 2018 to 2023. Besides, this period was chosen, considering the analysis of this topic from a trend perspective. In the initial search, a total of 590 results were obtained across the five databases: ACM (113), IEEEXplore (79), Scopus (246), Science Direct (111), and Emerald (41).

Given the substantial volume of retrieved studies, a three-step selection process was implemented. First, a pre-selection step applied exclusion criteria based on the paper's abstract alone. The exclusion criteria encompassed studies unavailable for viewing, studies with paid content, duplicates, those outside the defined research area, early access studies, and studies with four pages or fewer. Subsequently, the second step applied inclusion criteria, which were (1) studies between 2018 and 2023, (2) studies in English, (3) studies in the field of computer science or related areas, and (4) studies that were articles, conferences, or journals.

After applying all criteria by filtering out within the title and abstract, a total of 110 studies were left, and an additional 18 more were approved after analysing their introduction and conclusion, leaving with a total of 128 papers.

In the final step, quality criteria were applied, evaluating aspects such as the adequacy of contextual description, clarity of study aims, appropriateness of research methodology, transparency of findings, relevant and consistent discussions, and that it answers at least one research question. These criteria were applied by awarding a grade (0, 0.5, or 1) for each criterion, totalling a maximum of 5 points per study.

Therefore, studies that had a score lower than three were discarded. Furthermore, the study was excluded if the score for the "Answer at least one research question" criteria was zero. Nineteen studies achieved a score of 5 points, five studies scored 4.5 points, twelve studies achieved 4 points, six studies were awarded 3.5 points, and a further four studies were given 3 points, thus leaving a total of 46 studies after all criteria. The selected papers are listed in Table 2.

Table 2: Selected studies.

EP1	(Navarathna and Malagi, 2018)
EP2	(Allam and Dhunny, 2019)
EP3	(Lee et al., 2019)
EP4	(Yoon et al., 2019)
EP5	(Rehena and Janssen, 2018)
EP6	(Ma et al., 2020)
EP7	(Schürholz et al., 2020)
EP8	(Gonçalves et al., 2020)
EP9	(Ceccarini et al., 2020)
EP10	(Liu et al., 2020)
EP11	(Yeasmin et al., 2020)
EP12	(Wu et al., 2020)
EP13	(Jafari et al., 2021)
EP14	(Grzelczak and Duch, 2021)
EP15	(Yigitcanlar et al., 2021)
EP16	(Ge et al., 2021)
EP17	(Parlina et al., 2021)
EP18	(Ghadami et al., 2021)
EP19	(Zhang et al., 2021)
EP20	(Kaya et al., 2021)
EP21	(Piccialli et al., 2021)
EP22	(Jha et al., 2021)
EP23	(DeLong and Tolk, 2021)
EP24	(Oyinlola, 2021)
EP25	(Essamlali et al., 2022)
EP26	(Anthopoulos and Kazantzi, 2022)
EP27	(Heidari et al., 2022)
EP28	(Sirmacek and Vinuesa, 2022)
EP29	(Buss et al., 2022)
EP30	(Mahamuni et al., 2022)
EP31	(Mohanty et al., 2022b)
EP32	(Ren et al., 2022)
EP33	(Mohanty et al., 2022a)
EP34	(Shah et al., 2022)
EP35	(Gohari et al., 2022)
EP36	(P.V., 2022)
EP37	(Ghahramani et al., 2022)
EP38	(Mahrez et al., 2022)
EP39	(Hsu and Tseng, 2022)
EP40	(Costa et al., 2022)
EP41	(Jain et al., 2023)
EP42	(Selvaraj et al., 2023)
EP43	(Mortaheb and Jankowski, 2023)
EP44	(Anedda et al., 2023)
EP45	(Al Hashlamoun et al., 2023)
EP46	(Tanko et al., 2023)

3.3 Limitations and Threats to Validity

Considering the classification of threats to validity (Wohlin et al., 2012), we observe some threats to validity.

While employing a Systematic Literature Review (SLR) offers a structured and comprehensive approach to synthesizing existing research (Kitchenham et al., 2009), it is important to recognize certain inherent limitations and potential threats to the validity of the findings. One notable consideration is that the decision to include only English-language studies may introduce a language bias. Valuable research in other languages may be overlooked, potentially excluding important insights from non-English sources.

Given the review's focus on studies published between 2018 and 2023, there is a temporal limitation. While this timeframe was chosen to encompass the most up-to-date research, it may inadvertently exclude older studies with relevant discussions in the field of AI in sustainable smart cities.

4 METHOD

The studies collection process involved multiple steps and criteria to ensure quality and relevance. Table 3 provides a detailed view of the process.

Initially, 590 studies were identified from various databases, including IEEE Xplore, ACM, Scopus, Science Direct, and Emerald. After applying three consecutive filters and a quality assessment, the total number of studies was reduced to 46.

We then analysed the annual trends in article publication on the subject. Fig. 1 shows the yearly evolution of the number of studies published on the subject.

Notably, there was a significant increase in publications between 2019 and 2022. The year 2019 has three publications, increasing to 8 in 2020, 12 in 2021, and reaching a peak of 16 in 2022. It's worth noting that the data for 2023 only includes six studies, considering that the research occurred in the middle of this year. This could indicate a continuing upward interest and research activity trend around the subject.

Following the quantitative reduction in studies, the quality of these studies was assessed. Table 4 offers insights into the perceived quality of studies by showing the average scores from various research databases. Science Direct leads the list with an im-impressive average of 4.50, closely followed by ACM with an average of 4.40. Despite having the most studies at 19, IEEE Xplore has an average score of 4.26. Emerald and Scopus trail with averages of 4.17 and 4.00, respectively. The overall average score across all databases stands at 4.32.

Table 3: Evolution of the studies collection process.

	Initial Numbers	Filter 1	Filter 2	Quality Filter
IEEE Xplore	79	21	12	19
ACM	113	14	0	5
Scopus	246	41	1	5
Science Direct	111	33	3	14
Emerald	41	1	2	3
Total	590	110	18	46

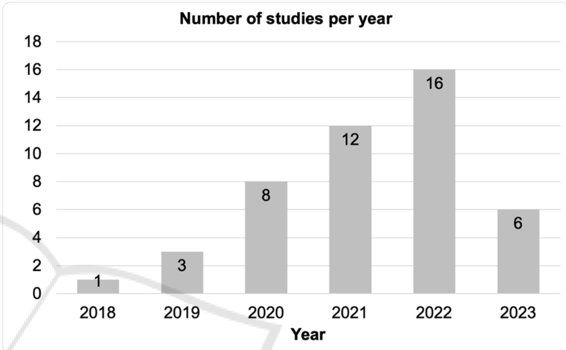

Figure 1: Yearly evolution of the number of studies.

Table 4: Average Quality Scores per Research Database.

	Number of Articles	Average Score
IEEE Xplore	19	4.26
Science Direct	14	4.50
ACM	5	4.40
Emerald	3	4.17
Scopus	5	4.00
Total	46	4.32

The types of publications in which these studies appeared also offer insights into the field's academic maturity and activity. Fig. 2 shows the distribution of the 46 selected studies based on the publication type. Among them, 18 were published in conferences and 28 in journals.

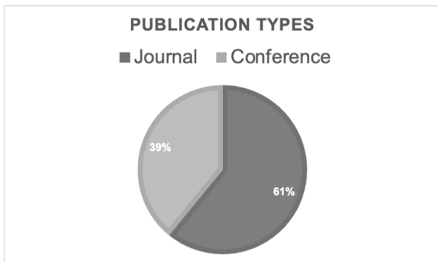

Figure 2: Types of published studies.

The significant number of conference studies suggests that the study area is active and possibly emerging, with new findings being frequently debated. On the other hand, the more significant presence in journals also suggests academic maturity of the topic. This scenario indicates a subject with a good balance, reflecting both innovation and consolidation in the field of research.

Lastly, Fig. 3 illustrates the distribution of the 46 selected studies by research database. IEEE Xplore leads the pack with 19 studies, suggesting that this database might be a primary source for research in this field. It is followed by Science Direct, which contributed 14 studies. Scopus and ACM have equal contributions, each with 5, and Emerald has 3 studies.

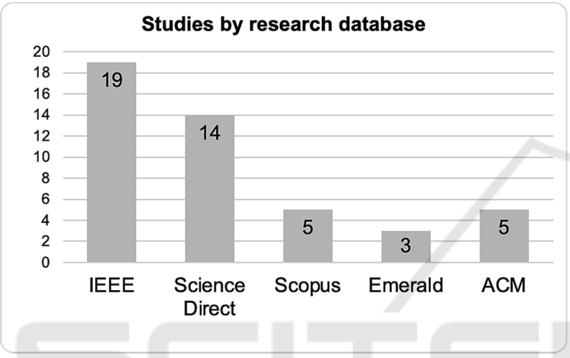

Figure 3: Concentration of studies by research database.

4.1 The Potential of AI for Industrial Applications

The field of sustainable smart cities has witnessed a burgeoning interest in various AI concepts, each of which plays a pivotal role in bolstering urban sustainability and the overall quality of urban life. This research paper delves into a selection of the most promising AI concepts within this domain, particularly emphasizing their applications and implications. In the context of smart cities striving for sustainability, diverse artificial intelligence (AI) services emerge as critical contributors to achieving environmental goals. As outlined in Fig. 4, these AI services are evaluated and ranked based on their significance.

At the forefront of this spectrum is Environmental Monitoring and Management, scoring the highest at 8. AI's capabilities are harnessed to continuously monitor and regulate various environmental factors, such as air quality, water quality, and overall ecosystem health. By doing so, these AI systems not only facilitate the identification of pressing environmental and mental issues but also enable timely interventions to mitigate and manage these challenges.

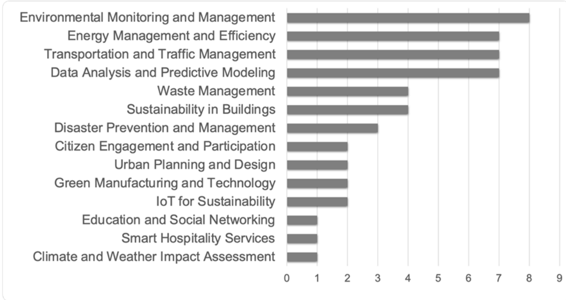

Figure 4: Concentration of benefits related to AI in smart cities collected in studies.

The second-most important AI service, with a score of 7, is Energy Management and Efficiency. AI technologies are indispensable in optimizing energy consumption and promoting energy-efficient solutions within smart cities. These systems help reduce energy consumption and emissions and encourage the adoption of sustainable energy technologies, contributing significantly to environmental sustainability and urban liveability. Similarly, Transportation and Traffic Management, with a score of 7, leverages AI to streamline traffic flow, minimize congestion, and enhance transportation systems, ultimately reducing emissions and improving mobility in urban areas.

Data Analysis and Predictive Modelling, rated at 7, enable informed decision-making processes for sustainability initiatives and urban planning. By harnessing AI-driven data analysis and predictive modelling, smart cities can better address environmental challenges and optimize resource allocation for maximum impact. In contrast, AI's role in Waste Management, Sustainability in Buildings, Disaster Prevention and Management, Citizen Engagement and Participation, Urban Planning and Design, Green Manufacturing and Technology, IoT for Sustainability, Education and Social Networking, Smart Hospitality Services, Climate and Weather Impact Assessment, and Synergies between Techno-Scientific Domains, all receiving varying scores, illustrate the diverse applications of AI in promoting sustainability across different facets of urban life. These applications collectively contribute to the development of smart cities that are not only environmentally sustainable but also energy-efficient and responsive to the needs of their citizens, all while minimizing their ecological footprint.

In summary, integrating AI services into smart cities is a multifaceted and powerful approach to addressing environmental challenges and enhancing urban living while prioritizing sustainability. This research underscores the critical role AI plays in shaping the future of cities, where technology and data-driven solutions work in tandem to create more resilient and environmentally conscious urban environments.

4.2 What Are the Benefits Related to Implementing AI in Smart Cities for Sustainability?

Integrating Artificial Intelligence (AI) into the infrastructure of smart cities holds substantial promise in advancing sustainability across a broad spectrum of domains. As elucidated in Fig. 5, this implementation offers multifaceted advantages.

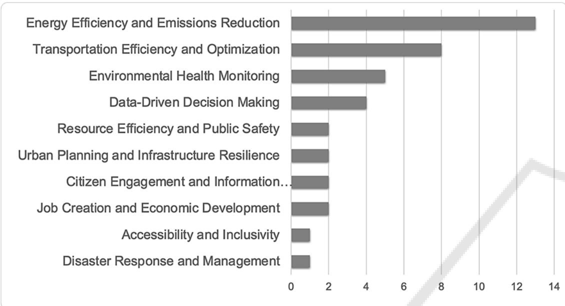

Figure 5: Concentration of benefits related to AI in smart cities collected in studies.

Firstly, in Environmental Monitoring and Management, AI can revolutionize real-time monitoring, enabling cities to vigilantly track pollution levels, air quality, and water quality, thereby facilitating the prompt implementation of remedial measures to mitigate environmental harm. The application of AI-driven systems in Energy Management and Efficiency stands to optimize energy consumption in buildings, street lighting, and public facilities, manifesting as reduced energy wastage and a subsequent decrease in greenhouse gas emissions.

Additionally, the utilization of AI in Transportation and Traffic Management promises improved traffic flow, reduced congestion, and enhanced public transportation systems, ultimately leading to lower fuel consumption and decreased air pollution. In Data Analysis and Predictive Modelling, AI is indispensable for data-driven decision-making, harnessing its ability to analyse vast datasets to predict future trends and optimize resource allocation. These applications collectively contribute to the overarching goal of sustainability in smart cities.

Moreover, AI's role in Waste Management streamlines waste collection routes, curtails overflows, and augments recycling processes, thereby minimizing landfill usage and fostering recycling. In terms of sustainability in buildings, AI-driven building management systems hold the potential to optimize energy usage, lighting, and temperature control, resulting in tangible energy savings and reduced carbon footprints in urban buildings.

Furthermore, AI can lend its capabilities to Disaster Prevention and Management by bolstering early warning systems and enhancing disaster response, ultimately bolstering resilience and mitigating the environmental impact of disasters.

AI's influence extends into fostering Citizen Engagement and Participation, utilizing AI-powered platforms to promote citizen involvement in sustainability initiatives, bolstering awareness, and encouraging responsible behaviours among residents.

In urban planning and design, AI's role is to optimize land use and reduce resource consumption, aiding in designing more sustainable urban layouts. The convergence of AI and the Internet of Things (IoT) yields remarkable potential for sustainability, with real-time monitoring and control of critical aspects such as water and energy usage. AI-driven educational platforms and social networks contribute to sustainability awareness and education among city residents, while in the domain of Smart Hospitality Services, AI enhances energy efficiency and resource management in hotels and hospitality facilities, aligning with sustainability objectives. Moreover, AI can assist in Climate and Weather Impact Assessment, supporting the evaluation of climate change impacts and predicting extreme weather events, which aids in proactive preparation and adaptation.

Lastly, AI catalyses synergies between Techno-Scientific Domains, facilitating collaboration and knowledge sharing among diverse scientific disciplines, leading to innovative and sustainable solutions. Incorporating AI into smart cities is a pivotal catalyst in advancing sustainability goals. Its manifold applications optimize resource usage, enhance environmental monitoring, and stimulate citizen engagement, collectively fostering the development of more efficient, eco-friendly, and resilient urban environments.

4.3 What Are the Challenges Associated with Implementing AI in Smart Cities for Sustainability?

Pursuing sustainability and smart city goals through integrating AI technologies is undoubtedly a promising avenue, but it is not devoid of significant challenges. Fig. 6 summarizes the challenges found.

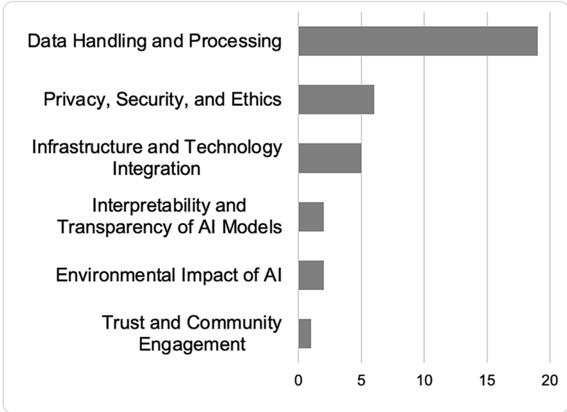

Figure 6: Concentration of challenges by collected studies.

Firstly, the heightened expectations placed on AI solutions in the context of smart cities necessitate a robust urban infrastructure capable of accommodating and sustaining these technologies (S. Wu et al., 2020). Although imperative, this infrastructure requirement is a formidable challenge, often requiring substantial investments in physical and digital systems.

Implementing and evaluating AI algorithms in the smart city environment introduces complexity. Algorithms, particularly those designed for traffic management, exhibit intricate behaviours that defy simple assessment. Comparing the performance of traffic controllers by merely controlling the average vehicular flow at intersections with and without them belies the intricacies that lie beneath. While promising for enhancing urban operations, the application of reinforcement learning techniques faces hurdles. The inherent complexity of the algorithms, combined with the stochastic nature of factors like quest location generation, impedes the convergence of reinforcement learning processes. Consequently, achieving the desired outcomes in AI applications for smart cities becomes daunting.

AI's contribution to increased electricity consumption in terms of computational power and data transmission has raised legitimate environmental concerns. The carbon emissions associated with this heightened energy usage are substantial and merit careful consideration (Yigitcanlar et al., 2021). Furthermore, the potential for errors in AI-driven critical decision-making processes, driven by user and data bias, poses another formidable challenge that demands rigorous mitigation measures. Processing vast volumes of transit data to extract actionable insights presents a multifaceted challenge (Zhang et al., 2021). The pre-processing required to cleanse and transform this data into valuable information can be resource-intensive and time-consuming, impeding the timely utilization of insight for urban planning and management.

Additionally, limitations in data collection can undermine the relevance and accuracy of research findings. For instance, the study's data aggregation concluded in August 2020, rendering it incapable of capturing subsequent developments, such as the COVID-19 outbreak that began in December 2019. These temporal gaps can compromise the efficacy of AI models in responding to dynamic urban challenges.

Lastly, the domain of energy demand prediction, which relies heavily on machine learning and statistical models, poses challenges. Implementing these models effectively and ensuring their accuracy and adaptability to changing circumstances is a non-trivial endeavour that requires ongoing attention and refinement.

In the corpus of studies, particular challenges emerged as recurrent themes, underscoring their critical importance. Data Handling and Processing stood out as a ubiquitous challenge, emphasizing the need for efficient and streamlined data management processes. Privacy, Security, and Ethics resurfaced consistently, highlighting the imperative of establishing robust frameworks to address these ethical and security concerns. Furthermore, the intricate task of seamlessly integrating Infrastructure and Technology emerged as a persistent challenge, signifying its central role in successfully adopting AI in smart cities for sustainability.

4.4 What Solutions to the Challenges Encountered?

Fig. 7 shows the proposed solutions for integrating artificial intelligence (AI) into smart cities. These present a transformative potential, positively impacting a range of identified problems. The correspondence between the issues and solutions is presented in Table 5.

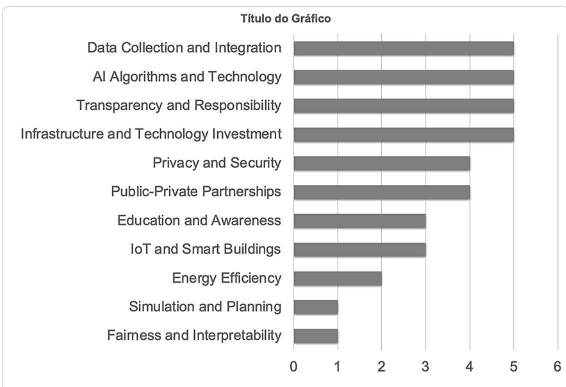

Figure 7: Concentration of solutions by collected studies.

Table 5: Solutions found.

Challenges	Solutions
Algorithmic complexity and lack of interpretability	Enhanced AI architectures allowing visualization of critical classification regions.
High energy consumption	Using more efficient algorithms to reduce computational resource demand and electricity consumption.
Minimizing errors in decision-making.	Adopting explainable AI methods, such as SHAP, to provide insights for optimizing energy consumption.
Integration and efficient shar- ing of data.	Streamlining data analysis and improving predictions, including energy demand, through effective data inte- gration and sharing.
Limitation in collecting data for dynamic events.	Implementing a real-time data collection system for a more holistic view of the urban environment and improved energy demand prediction.
Accurately predicting energy demand.	Continuous improvement of AI-based energy demand forecasting models, leading to more efficient resource allocation and energy use.

For example, the approach to enhancing the interpretability of AI algorithms addresses algorithmic complexity and tackles concerns about the transparency and comprehensibility of decision-making processes. By visualizing crucial regions for classification, gains are made in performance and confidence in the results, facilitating the acceptance and utilization of these advanced technologies.

Another crucial problem is high energy consumption, a considerable barrier to widespread AI implementation. The proposal to use more efficient algorithms has a direct positive impact, reducing the demand for computational resources and, consequently, electricity consumption. Moreover, by reducing energy consumption, efforts are made to mitigate carbon emissions, aligning with environmental sustainability objectives.

Pursuing to minimize decision-making errors is another challenge that the solutions address. By adopting explainable AI methods, such as SHAP (SHapley Additive exPlanations), that provide insights into the factors influencing predictions, optimizing decisions to improve energy consumption is possible (Lundberg & Lee, 2017). This more transparent understanding of decision-making processes allows for more precise and targeted adjustments, resulting in more efficient energy management.

The integration and efficient sharing of data, a proposed solution for complexity in traffic data analysis, also resonates with other challenges. In addition to optimizing traffic management, this solution provides more precise data on travel patterns, facilitating the prediction of energy demand. This accurate prediction is crucial for efficiently allocating energy resources, enabling a more rational and sustainable use of the available energy. Regarding the limitation in data collection related to dynamic events, the proposal to implement a real-time data collection system solves this problem, contributing to a more holistic and real-time view of the urban environment. This means that the collected data addresses energy demand and assists in traffic management and various other areas, enabling more informed and dynamic urban planning.

Finally, the proposed solutions directly address the issue of accurately predicting energy demand, considering its importance for energy efficiency. The continuous improvement of AI-based energy demand forecasting models optimizes resource allocation and contributes to more efficient energy use. The adaptability of these models to variations in circumstances and urban energy demands means more agile and effective energy management, leading to tangible benefits in terms of efficiency and sustainability.

In an extensive review of studies conducted, several recurrent themes emerged as fundamental solutions to the challenges encountered in integrating artificial intelligence (AI) into the fabric of smart cities. Data Collection and Integration, as a cornerstone, enables a more precise understanding of urban dynamics. Complementing this, advancements in AI Algorithms and Technology were highlighted, paving the way for optimized energy management, and streamlined traffic flow. Simultaneously, emphasizing Transparency and Responsibility in AI systems underscored the necessity of building trust and comprehension among stakeholders.

A parallel focus on Infrastructure and Technology Investment signified the essential role of financial backing for sustainable implementation. Additionally, ensuring privacy and security in data handling proved to be a non-negotiable aspect. Lastly, fostering collaboration through public-private partnerships and driving awareness via Education and Awareness initiatives were integral to sustainable progress. These intertwined solutions collectively present a roadmap for developing smarter and more efficient cities.

Thus, the outlined solutions address the challenges in isolation and interconnect to amplify positive impacts across a broader spectrum of problems, contributing to more sustainable and resource-efficient cities.

5 CONCLUSIONS

This paper has conducted a comprehensive review of the literature, highlighting the multi-faceted applications of Artificial Intelligence in the context of Smart Cities. The synthesis of information presented here underscores the potential for AI-driven solutions to tackle complex urban challenges and improve city dwellers' overall quality of life. By harnessing the power of AI to analyze and utilize Big Data effectively, Smart Cities can optimize resource allocation, enhance infrastructure, and provide innovative services that cater to the ever-evolving needs of their populations. Nevertheless, these advancements must be accompanied by robust ethical frameworks and stringent data privacy measures to safeguard individuals' rights and security. The responsible development and deployment of AI in Smart Cities should be guided by a commitment to transparency, fairness, and accountability. In essence, this paper highlights the promising synergy between Artificial Intelligence and the burgeoning realm of Big Data in Smart Cities. As we navigate the path forward, it is crucial for researchers, policymakers, and stakeholders to collaboratively address the ethical and legal challenges while harnessing the full potential of AI for the benefit of urban communities worldwide. By doing so, we can realize the vision of truly smart and sustainable cities that prioritize the well-being and prosperity of their residents.

Future research could explore AI's ethical, legal, and data management aspects in Smart Cities, focusing on privacy, fairness, and accountability. Collaborative efforts are needed to integrate AI with Big Data for sustainable urban development, ensuring technology benefits all residents while responsibly addressing complex urban challenges and people's rights.

REFERENCES

Abdullah, N., Alwesabi, O. A., and Abdullah, R. (2019). Iot-based smart waste management system in a smart city. In Proceedings of the IRICT 2018, pages 364–371, Springer International Publishing.

Ahvenniemi, H., Huovila, A., Pinto-Seppa¨, I., and Airaksinen, M. (2017). What are the differences between sustainable and smart cities? Cities, 60:234–245.

Al Hashlamoun, N., Al Barghuthi, N., and Tamimi, H. (2023). Exploring the intersection of ai and sustainable computing: Opportunities, challenges, and a framework for responsible applications. In 2023 9th International Conference on Information Technology Trends (ITT), pages 220–225. IEEE.

Allam, Z. and Dhunny, Z. A. (2019). On big data, artificial intelligence and smart cities. Cities, 89:80–91.

Alotaibi, I., Abido, M. A., Khalid, M., and V., S. A. (2020). A comprehensive review of recent advances in smart grids: A sustainable future with renewable energy resources. Energies, 13(23):6269.

Anedda, M., Fadda, M., Girau, R., Pau, G., and Giusto, D. (2023). A social smart city for public and private mobility: A real case study. Computer Networks, 220.

Anthopoulos, L. and Kazantzi, V. (2022). Urban energy efficiency assessment models from an ai and big data perspective: Tools for policy makers. Sustainable Cities and Society, 76:103492.

Buss, E., Rabbel, T.-L., Horvat, V., Krizmancic, M., Bogdan, S., Wahby, M., and Hamann, H. (2022). Phytonodes for environmental monitoring: Stimulus classification based on natural plant signals in an interactive energy-efficient bio-hybrid system. In Proceedings of the ACM GoodIT ’22, pages 258–264. Association for Computing Machinery.

Castells, M. (2000). Urban sustainability in the information age. City, 4(1):118–122.

Ceccarini, C., Delnevo, G., and Prandi, C. (2020). Frugar: Exploiting deep learning and crowdsourcing for frugal gardening. In Proceedings of the 1st Workshop on Experiences with the Design and Implementation of Frugal Smart Objects, pages 7–11, New York, NY, USA. Association for Computing Machinery.

Costa, D. G. et al. (2022). A survey of emergencies management systems in smart cities. IEEE Access, 10:61843– 61872.

DeLong, S. and Tolk, A. (2021). Sustainable computing and simulation: A literature survey. In 2021 Winter Simulation Conference (WSC), pages 1–12. IEEE.

Ejidike, C. C. and Mewomo, M. C. (2023). Benefits of adopting smart building technologies in building construction of developing countries: Review of literature. SN Applied Sciences, 5(2):52.

Essamlali, I., Bahnasse, A., Khiat, A., and Ouajji, H. (2022). Machine learning in the service of a clean city. Procedia Computer Science, 198:530–535.

Ge, L., Sarhani, M., Voß, S., and Xie, L. (2021). Review of transit data sources: Potentials, challenges and complementarity. Sustainability, 13:11450.

Ghadami, N., Gheibi, M., Kian, Z., Faramarz, M. G., Naghedi, R., Eftekhari, M., Fathollahi-Fard, A. M., Dulebenets, M. A., and Tian, G. (2021). Implementation of solar energy in smart cities using an integration of artificial neural network, photovoltaic system and classical delphi methods. Sustainable Cities and Society, 74:103149.

Ghahramani, M., Zhou, M., Molter, A., and Pilla, F. (2022). Iot-based route recommendation for an intelligent waste management system. IEEE Internet of Things Journal, 9(14):11883–11892.

Gohari, A., Ahmad, A. B., Rahim, R. B. A., Supa’at, A. S. M., Razak, S. A., and Gismalla, M. S. M. (2022).

Involvement of surveillance drones in smart cities: A systematic review. IEEE Access, 10:56611–56628.

Gonc¸alves, D., Sheikhnejad, Y., Oliveira, M., and Martins, N. (2020). One step forward toward smart city utopia: Smart building energy management based on adaptive surrogate modelling. Energy and Buildings, 223:110146.

Grzelczak, M. and Duch, P. (2021). Deep reinforcement learning algorithms for path planning domain in grid-like environment. Appl. Sci., 11:11335.

Heidari, A., Navimipour, N. J., and Unal, M. (2022). Applications of ml/dl in the management of smart cities and societies based on new trends in information technologies: A systematic literature review. Sustainable Cities and Society, 85:104089.

Herath, H. and Mittal, M. (2022). Adoption of artificial intelligence in smart cities: A comprehensive re- view. International Journal of Information Manage- ment Data Insights, 2(1):100076.

Hsu, H. and Tseng, K.-F. (2022). Facing the era of smartness: constructing a framework of required technology competencies for hospitality practitioners. Journal of Hospitality and Tourism Technology, 13(3):500–526.

Imperatives, S. (1987). Report of the world commission on environment and development: Our common future. Accessed Feb, 10:1–300.

Ismagilova, E., Hughes, L., Rana, N. P., and Dwivedi, Y. K. (2020). Security, privacy and risks within smart.

Jafari, S., Shahbazi, Z., and Byun, Y.-C. (2021). Improving the performance of single-intersection urban traffic networks based on a model predictive controller. Sustainability, 13:5630.

Jain, A., Gue, I. H., and Jain, P. (2023). Research trends, themes, and insights on artificial neural networks for smart cities towards sdg-11. Journal of Cleaner Production, 412.

Jha, A. K., Ghimire, A., Thapa, S., Jha, A. M., and Raj, R. (2021). A review of ai for urban planning: Towards building sustainable smart cities. In 2021 6th International Conference on ICICT, pages 937–944. IEEE.

Kaya, K., Ak, E., Yaslan, Y., and Oktug, S. F. (2021). Waste-to-energy framework: An intelligent energy recycling management. Sustainable Computing: Informatics and Systems, 30:100548.

Khajenasiri, I., Estebsari, A., Verhelst, M., and Gielen, G. (2017). A review on internet of things solutions for intelligent energy control in buildings for smart city applications. Energy Procedia, 111:770–779.

Kitchenham, B., Brereton, O. P., Budgen, D., Turner, M., Bailey, J., and Linkman, S. (2009). Systematic literature reviews in software engineering–a systematic literature review. Information and software technology, 51(1):7–15.

Kothadiya, D., Chaudhari, A., Macwan, R., Patel, K., & Bhatt, C. (2021). The convergence of deep learning and computer vision: Smart city applications and research Challenges. In ICIIC 2021, pp. 14-22. Atlantis Press.

Lee, S. H., Lee, T., Kim, S., and Park, S. (2019). Energy consumption prediction system based on deep learning with edge computing. In 2019 IEEE ICET, pages 473–477, Chengdu, China.

Li, Q., Wen, Z., Wu, Z., Hu, S., Wang, N., Li, Y., ... & He, B. (2021). A survey on federated learning systems: Vision, hype and reality for data privacy and protection. IEEE Transactions on Knowledge and Data Engineering, 35(4), 3347-3366.

Liu, H., Li, Y., Fu, Y., Mei, H., Zhou, J., Ma, X., and Xiong, H. (2020). Polestar: An intelligent, efficient and national-wide public transportation routing engine. In Proceedings of the 26th ACM KDD ’20, pages 2321–2329, New York, NY, USA. Association for Computing Machinery.

Lundberg, S. M., & Lee, S. I. (2017). A unified approach to interpreting model predictions. Advances in neural information processing systems, 30.

Ma, Y., Ping, K., Wu, C., Chen, L., Shi, H., and Chong, D. (2020). Artificial intelligence powered internet of things and smart public service. Library Hi Tech, 38(1):165–179.

Mahamuni, C. V., Sayyed, Z., and Mishra, A. (2022). Machine learning for smart cities: A survey. In 2022 IEEE IPRECON Conference (IPRECON), pp. 1–8.

Mahrez, Z., Sabir, E., Badidi, E., Saad, W., and Sadik, M. (2022). Smart urban mobility: When mobility systems meet smart data. IEEE Transactions on Intelligent Transportation Systems, 23(7):6222–6239.

Mathew, A., Amudha, P., & Sivakumari, S. (2021). Deep learning techniques: an overview. Advanced Machine Learning Technologies and Applications: Proceedings of AMLTA 2020, 599-608.

Medsker, L. R., & Jain, L. (2001). Recurrent neural networks. Design and Applications, 5(64-67), 2.

Mohanty, P. K., Das, P., and Roy, D. S. (2022a). Predicting daily household energy usages by using model agnostic language for exploration and explanation. In International Conference OCIT, pages 543–547. IEEE.

Mohanty, P. K., Roy, D. S., and Reddy, K. H. K. (2022b). Explainable ai for predicting daily household energy usages. In International Conference on Artificial Intelligence and Data Engineering, pages 182–186.

Mortaheb, R. and Jankowski, P. (2023). Smart city reimagined: City planning and geoai in the age of big data. Journal of Urban Management, 12:4–15.

Navarathna, P. J. and Malagi, V. P. (2018). Artificial intelligence in smart city analysis. In 2018 International Conference on Smart Systems and Inventive Technology (ICSSIT), pages 44–47, Tirunelveli, India.

Nitoslawski, S. A., Galle, N. J., Van Den Bosch, C. K., and Steenberg, J. W. (2019). Smarter ecosystems for smarter cities? a review of trends, technologies, and turning points for smart urban forestry. Sustainable Cities and Society, 51:101770.

Noor, N., Rao Hill, S., & Troshani, I. (2022). Recasting service quality for AI-based service. Australasian Marketing Journal, 30(4), 297-312.

Oyinlola, T. (2021). Energy prediction in edge environment for smart cities. In 2021 IEEE 7th World Forum on Internet of Things (WF-IoT), pages 439–442. IEEE.

Parlina, A., Ramli, K., and Murfi, H. (2021). Exposing emerging trends in smart sustainable city research using deep autoencoders-based fuzzy c-means. Sustainability, 13:2876.

Pereira, G. V., Parycek, P., Falco, E., and Kleinhans, R. (2018). Smart governance in the context of smart cities: A literature review. Information Polity, 23(2):143–162.

Piccialli, F., Giampaolo, F., Prezioso, E., Crisci, D., and Cuomo, S. (2021). Predictive analytics for smart parking: A deep learning approach in forecasting of iot data. ACM Transactions on Internet Technology, 21(3):1–21.

Rajkumar, P. V. (2022, December). Gauging Carbon Footprint of AI/ML Implementations in Smart Cities: Methods and Challenges. In FMEC (pp. 1-5). IEEE.

Rehena, Z. and Janssen, M. (2018). Towards a framework for context-aware intelligent traffic management system in smart cities. In Proceedings of WWW '18, pages 893– 898, Republic and Canton of Geneva, CHE.

Ren, Y., Xie, R., Yu, F. R., Huang, T., and Liu, Y. (2022). Green intelligence networking for connected and autonomous vehicles in smart cities. IEEE Transactions on Green Communications and Networking, 6(3):1591–1603.

Schu ̈rholz, D., Kubler, S., and Zaslavsky, A. (2020). Artificial intelligence-enabled context-aware air quality prediction for smart cities. Journal of Cleaner Production, 271:121941.

Selvaraj, R., Kuthadi, V. M., and Baskar, S. (2023). Smart building energy management and monitoring system based on artificial intelligence in smart city. Sustainable Energy Technologies and Assessments, 56.

Shah, D. K., Singh, R., Gehlot, A., Khantwal, S., Ahmad, A. J., and Akram, S. V. (2022). Smart kitchen: Real time monitoring of kitchen through iot. In 2022 3rd International Conference on Intelligent Engineering and Management (ICIEM), pages 718–722. IEEE.

Sharma, A., Podoplelova, E., Shapovalov, G., Tselykh, A., and Tselykh, A. (2021). Sustainable smart cities: convergence of artificial intelligence and blockchain. Sustainability, 13(23):13076.

Shehab, M. J., Kassem, I., Kutty, A. A., Kucukvar, M., Onat, N., and Khattab, T. (2021). 5g networks towards smart and sustainable cities: A review of recent developments, applications and future perspectives. IEEE Access, 10:2987–3006.

Shrestha, Y. R., Ben-Menahem, S. M., & Von Krogh, G. (2019). Organizational decision-making structures in the age of artificial intelligence. California management review, 61(4), 66-83.

Sirmacek, B. and Vinuesa, R. (2022). Remote sensing and ai for building climate adaptation applications. Results in Engineering, 15:100524.

Suleimenov, I. E., Vitulyova, Y. S., Bakirov, A. S., and Gabrielyan, O. A. (2020). Artificial intelligence: what is it? In Proceedings of the 2020 6th International Conference on Computer and Technology Applications, pages 22–25.

Tanko, B., Essah, E., Elijah, O., Zakka, W., and Klufallah, M. (2023). Bibliometric analysis, scientometrics and metasynthesis of internet of things (iot) in smart buildings. Built Environment Project and Asset Management, 13(5):646–665.

Vaidian, I., Azmat, M., and Kummer, S. (2019). Impact of internet of things on urban mobility. In Proceedings of the Innovation Arabia, pages 44–47.

Wang, K., Dong, J., Wang, Y., and Yin, H. (2019). Securing data with blockchain and ai. Ieee Access, 7:77981–77989.

Wohlin, C., Runeson, P., Ho ̈st, M., Ohlsson, M. C., Regnell, B., and Wessle ́n, A. (2012). Experimentation in software engineering. Springer Science & Business Media.

Wong, P. F., Chia, F. C., Kiu, M. S., and Lou, E. C. (2022). Potential integration of blockchain technology into smart sustainable city (ssc) developments: a systematic review. Smart and Sustainable Built Environment, 11(3):559–574.

Wu, S. et al. (2020). Evaluation of smart infrastructure systems and novel uv-oriented solution for integration, resilience, inclusiveness, and sustainability. In 2020 5th International Conference on Universal Village (UV), pages 1–45, Boston, MA, USA.

Yeasmin, S., Syed, S. N. J., Shmais, L. A., and Dubayyan, R. A. (2020). Artificial intelligence-based co2 emission predictive analysis system. In 2020 International Conference on Artificial Intelligence Modern Assistive Technology (ICAIMAT), pages 1–6, Riyadh, Saudi Arabia.

Yigitcanlar, T., Mehmood, R., and Corchado, J. (2021). Green artificial intelligence: Towards an efficient, sustainable and equitable technology for smart cities and futures. Sustainability, 13:8952.

Yoon, G. et al. (2019). Prediction of machine learning base for efficient use of energy infrastructure in smart city. In International Conference on Computing, Electronics Communications Engineering, 32–35, London, UK.

Zhang, Y., Geng, P., Sivaparthipan, C., and Muthu, B. A. (2021). Big data and artificial intelligence based early risk warning system of fire hazard for smart cities. Sustainable Energy Technologies and Assessments, 45:100986.

Zubizarreta, I., Seravalli, A., and Arrizabalaga, S. (2016). Smart city concept: What it is and what it should be. Journal of Urban Planning and Development, 142(1):04015005.