IoT-enabled smart cities towards green energy systems: a review

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ABSTRACT

Integration of internet of things (IoT) in smart city management to improve various functions and living standards due to increasing population growth has dramatically evolved ubiquitous and essential services at various stages of urbanization. Hence, smart cities need to be eco-friendly by improving various sectors like education, health, and transport to provide an urban and sustainable quality of life through solving complicated green energy networks, controlling toxic pollution risks, and public safety. Linking optimized green energy systems with the production and automation of advanced applications is crucial to compose implementation strategies for smart city services. This paper aims to conduct a review on eco-friendly plans and infrastructure of IoT-enabled smart cities by exploiting green energy approaches. This study performs critical observations, ideas, and analyses of recent research in the context of our mentioned research theme. This paper points out the technical and functional challenges of an optimal performance-based green IoT-enabled smart city infrastructure. In this sense, this study organizes observations of relevant initiatives, technologies, and experiences in IoT-enabled smart cities, as well as how to embed it with green energy. Moreover, it can provide significant directions to intellectuals and authorities to develop IoT-enabled smart city applications for prospective research.

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1. INTRODUCTION

The notion of the smart city is of great significance in the present daytime, where the progressive urbanization of the world population is particularly related to the ability to assure the citizens' quality of life with all kinds of technological services and digital communication. The impact of urbanization on the rural environment is evident due to the transfer of all services from urban areas to citizens due to rapid population growth [1]. The interoperability of internet of thing (IoT) technology signifies the potential for a better life for the ubiquitous citizen to emerge as smart cities in the urban context in recent years. IoT technology is becoming more prosperous daily due to the tremendous development of new types of accessing devices and technologies, and its inclusion in smart city applications is happening. IoT-empowered smart city framework helps citizens create any kind of convenience and secure lifestyle using any medium at any time.

Operational processes used in city sub-systems and services require large amounts of energy [2]. To build a smart city paradigm on a big data scale towards green energy systems, it needs to integrate and manage all activities of academia, health, industry, land surveying, government, logistics, institutions, and citizens within an IoT-based smart city system. Integration of various renewable energy schemes into smart green [3] city systems is essential to avoid climate change and environmental instability. Cities in many developed and developing countries in the world are facing various problems, such as extensive infrastructural expansion, environmental degradation and pollution, transport congestion, increasing energy demand, unequal distribution of facilities, unequal distribution of pure water and foodstuffs, and lack of basic sanitation. Moreover, the continuous development of IoT technology in urban systems requires environmental monitoring and optimal planning accordingly in e-healthcare, industrial digitalization, transportation, automation, smart lighting, traffic monitoring, energy, electronics, and others. The prominent delineation of a smart city is to provide green and pollution-free services to citizens by harnessing renewable and clean energy to get a natural lifestyle [4].

In this case, smart cities require renewable electricity generated from various natural energy sources, for example, light, heat, wind, and water, to be used for operational aspects of power management of various infrastructures. The optimal electricity use can be controlled using IoT infrastructure for renewable power management and distribution in smart city environments [5]. In IoT-enabled smart city applications using renewable energy, numerous information on various projects related to urbanization can be shared, decisions taken, and tasks executed optimally. Smart meters can be automated by interfacing sensors with utilities used by urban citizens to meet the goal of reducing renewable energy consumption when only needed or demanded. Developing greening smart city applications requires monitoring, testing, pattern analysis, and control of overall software and devices.

However, this study offers an outstretched review of IoT-enabled smart cities towards green energy systems with full emphasis on making them more reliable, secure, and sustainable [6]. The general paradigm of an IoT-enabled smart city powered by renewable energy is depicted in Figure 1. Thus, the researchers need to also ensure connectivity in social, economic, and cultural aspects to improve and ease the quality of life of present and future generations to create green smart city frameworks considering the changing context of the global environment. The major challenge for researchers in this work is the integration of IoT technology [7] and renewable energy requirements into smart city applications where security, scalability, legitimate access, authorized resource storage, and other operational information or raw material will be protected. Furthermore, the critical analysis of this work may be favorable to intellectuals and authorities for higher-level knowledge acquisition and potential research directions.

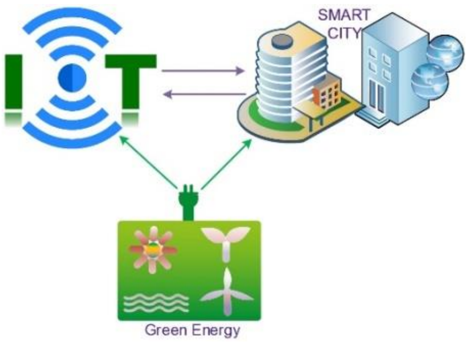

Figure 1. IoT-enabled smart city powered by green energy

The leading contributions of this study are highlighted as follows: i) this work introduces the fundamentals of IoT-enabled smart cities towards green energy and provides an updated and extensive overview of smart city domains and indicators, as well as presents the greening approach of smart cities; ii) it represents the research methodology, including research questions (RQs) and related work selection strategy in recent studies; iii) this study exposes the critical observation and appraisals in the context of our mentioned research theme by exploring existing recent methods; and iv) this work epitomizes a wide range of technical and functional challenges with directives to be addressed in the execution of IoT-based smart cities so that researchers can get a broad scope to learn how to enhance energy efficiency and gain green sustainability by using renewable sources.

The residue of this article is arranged as follows. Section 2 affords the background knowledge for IoT-enabled green smart cities, which contains the fundamental design of IoT, various smart city domains and indicators, and the greening strategy for a smart city. Section 3 explores the research methodology, formalizes research questions, and mentions a search strategy for related work on recent developments. Section 4 illustrates critical observations on some recent trends and targets of IoT-powered smart green cities. Section 5 assesses the technical and functional challenges involved in the future directions of IoT-enabled smart cities. Finally, section 6 concludes the systematic review.

2. BACKGROUD KNOWLEDGE

2.1. IoT terminology and architecture

In the epoch of industry 4.0, the world is moving towards developing and advancing "IoT" technology everywhere, in everything, and at any time. The world is becoming more innovative and intelligent, with everything using unique and meaningful addresses, critical communication systems, and various intelligent networks. IoT connects millions of devices. IoT deals with large amounts of data, processes massive data, and performs feasible actions to make human lives smarter, safer, more convenient, and more accessible [8]. IoT applications are in various sectors, such as smart homes, healthcare, smart cities, transportation, industries, and the energy sector. IoT architectures accomplish the steps of data sensing, actuating, processing, storing, analysis, and final exploitation through fog, edge, and cloud computation using various amenities and applications for transmitting and receiving messages among appliances. Many other technologies and approaches are engaged in the improvement of IoT frameworks. Researchers use the IoT framework with different approaches, such as three, four, and five-layer, based on the open systems interconnect (OSI) model to achieve their work objectives [9]. Consequently, the elementary IoT functional architectures have been shown in Figure 2, and it comprises five layers, including the sensing or perception layer, processing layer, network layer, business layer, and application layer.

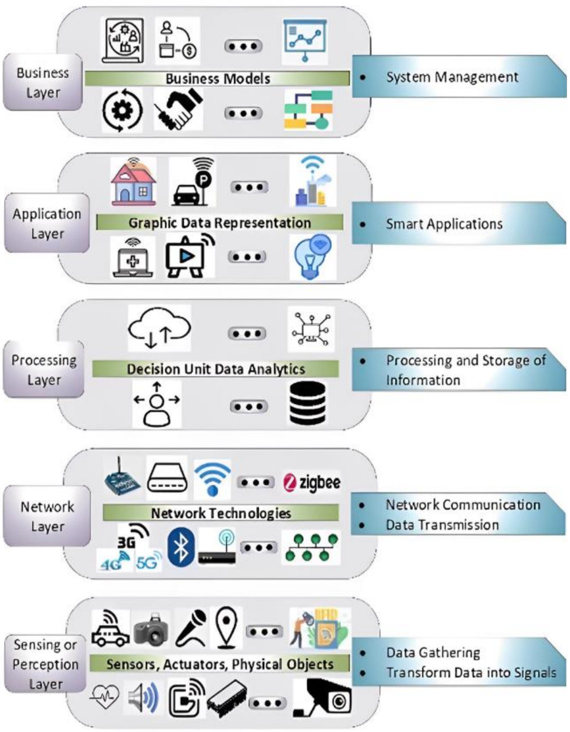

Figure 2. Architecture of IoT

The sensing or perception layer is the foundation of IoT architecture related to the physical level. It provides the interface with the tangible world by transferring and obtaining data utilizing wireless networks. Therefore, the perception layer has vital functions such as data collection, information perception, physical parameters sensed, or other intelligent objects identified, assisting in completing the control objects of perception using various sensors, actuators, and physical objects. It includes radio frequency identification (RFID) tags global positioning system (GPS), camera, sensor network, terminals, code reader-writer, 2D code labels, and all varieties of sensors. Furthermore, the network layer is the brain of IoT architecture that processes and conveys sensor-responding information from the perception layer. It operates with network devices, intelligent appliances, and servers using an internet network, convergence network, network management center, resourceful processing center, information center, and base station node.

The access strategy for this layer is Ad hoc, ZIGBEE, Mesh, 5G, WIFI, LoRaWAN, industrial bus, and Sigfox, which concede to accumulate the information by different cognitive tools or preparatory approaches and network permits. The processing layer is a significant layer of IoT structure that accomplishes many functionalities, such as storing, processing, and analyzing large amounts of transportation data and huge pieces of information on objects obtained from the network layer. Also, it can handle and process various lower layers of services and utilities. It employs a large number of primary technologies, such as big data processing, databases, innovative processing, ubiquitous computing, and cloud computing modules. Therefore, this layer contains several data storage modalities and possesses various functionalities.

The function of the application layer is based on the data processed in the process layer. This layer serves smart buildings, homes, transportation, economy, and health applications in IoT-enabled smart cities. It also customizes and delivers the output formats with specific services and applications demanded by users. It plays a vigorous role in pushing the IoT to a large-scale development for promoting and developing the diverse applications of the IoT. The fifth layer is the business layer which acts as the manager of the IoT architecture [10]. This layer is employed to classify various functions and front-end instruments that ingest vast amounts of information from the application layer for conducting developed visualization services and big data analytics, constructing business models, supportive decision-making procedures, conducting simulations, and maintaining user privacy.

2.2. Smart city domains and indicator

A smart city refers to an intelligent metropolitan area that operates in an automated manner based on IoT sensors through various electronic devices and applications. Its main objective is to analyze the collected data through data science using smart information and communication technology (ICT) to optimize various functions related to human welfare by increasing the operational efficiency of the city and driving economic growth to improve the quality of citizens' lives. It uses IoT [11] sensors and other electronic devices from various aspects of urban infrastructure, including automated large buildings, vehicles, properties, highways, trains, bridges, communications, electricity, water, and more, to collect essential data that is used later. Data is also collected, analyzed, and processed for transportation and traffic systems, power supply, power plants, waste management, and water systems. Residents are involved in data usage in smart cities because residents can genuinely participate in making smart cities more sustainable through awareness, education, and openness to data collection in case there is a problem with data use [12].

Smart cities further automate manual processes in corruption detection, information approaches, hospitals, libraries, and schools that help to improve the work environment by providing employees with more resources to accomplish their entire prospect and offer more convenient services. Furthermore, the usefulness of smart technology contributes to reducing work stress, reducing the time required for daily tasks, and making work comfortable by automating the daily tasks of city residents, allowing employees to focus on more strategic initiatives. Additionally, increasingly metropolitan environmental resources and energy efficiency are evolving to achieve an efficient, intelligent smart city and enhance its performance. Therefore, sustaining energy supply and promoting energy sustainability can be used to execute sustainable [13] policy plans to achieve significant changes in intelligent cities based on increasing metropolitan environmental resources and energy efficiency. Another critical factor in this change is identifying, committing, and integrating essential societal factors, such as governments, public-private organizations, civil society, and various private companies. According to this concept, we found different domains in the smart city framework context.

We emphasize the following domains such as smart governance, mobility and transportation, living and infrastructure, energy, economy, industry and manufacturing, healthcare, and environment, as shown in Figure 3, which are commonly used to represent smart city domains and indicators. Smart governance uses ICT technology to facilitate city governance's administrative and bureaucratic actions to enhance decision-making processes by nourishing smart collaboration, reliable channels, and network integration between various stakeholders and social actors [14]. In this regard, nationals can contribute to decision-making processes by participating in the data acquisition process using ICT-based tools and sociable media through their sensor-based smartphones and mobile devices. Decision-making processes based on participating actors are transformed into smart governance aids on a government-to-government, government-to-citizen (G2C), and government-to-business (G2B) basis. Government to government (G2G) aims to enhance communication between various public administration groups and entities through the interaction of actors using IoT technology, thereby keeping all processes of smart cities dynamic. IoT technologies are extensively adopted in G2B activities, which concentrate on interactions between public authorities and business companies to facilitate and enhance relationships between local governments and organizations providing services such as water management, waste, and energy.

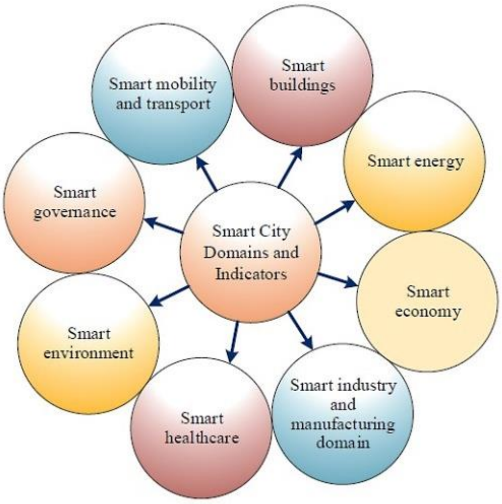

Figure 3. Smart city domains and indicators

Also, G2C uses smart mobile applications, public authority web portals, and social media to enhance interaction and communication between citizens and public administration. Moreover, RFID, smart ID cards, IoT technologies, biometric sensors for authentication and signature, and identity recognition according to various government standards are widely and increasingly adopted in smart mobile devices. These features are needed to access the services supplied and for the personal consultation of citizens. The concept of smart mobility and transport [15] refers to the transition from conventional transport procedures to mobility-as-a-service, where an intelligent IoT scheme supports distinct actors (citizens, public administration, private enterprises) and entities (sensors, individual devices, vehicles, and actuators).

Various sensors, actuators, RFID tags, mobile-to-mobile communication, and GPS services based on location are the basis of intelligent IoT-based transportation infrastructure. Even intelligent IoT-based transportation infrastructure allows the provision for managing various transportation services, for instance, public and private traffic flow, smart parking, dynamic traffic routing, sustainable mobility, and traffic solutions against traffic violations. Smart buildings and smart homes are key domains of smart living and infrastructure that use various IoT technologies for rapidly growing implementations depending on the specific use or scenario. All elements of the smart living and infrastructure domain relate to the expansion of smart cities and the advancement and management of public services, such as education, healthcare, tourism, and cultural activities. These are engaged in boosting the quality of citizen's life. IoT assimilation with construction modeling mechanisms for smart buildings supplies a high-fidelity manifestation of buildings. It has spatial features, rainwater drainage, air conditioning management, video surveillance, human activity monitoring, and security systems to manage authenticated access to buildings. It provides tools to monitor structural integrity and maintain warns for events such as gas leaks and fires.

In addition, smart homes consist of various sensors, individual devices, and actuators linked via wireless networks and are usually driven by AI-based human-machine interfaces. These afford intelligent and automatic services, such as power consumption, handling home resources and appliances, lighting management, and surveillance. In conclusion, in the smart living domain, IoT devices have extensive applications in various places and activities that improve the available living standards of competent citizens in smart cities. In addition to conventional existing energy, many types of energy, such as smart, green, clean, renewable, and sustainable, have been widely promoted and discussed for some years. Smart energy is converting conventional existing energy into new energy based on scientific and IoT technologies so that industrial structures can optimize with strong security measures, alternative energy collection, and energy conservation and contribute to the reduction of harmful gas emissions [16].

Consequently, a smart energy system consists of decentralized sustainable energy sources that can automatically integrate efficient energy distribution, energy consumption data collection, and energy consumption optimization through IoT sensors. Moreover, the eco-friendly system energy optimization platform manages home appliances for human longevity. Also, smart energy schemes are associated with various essential algorithms and historical data so that the user can become proficient and interested in optimizing, coordinating, and controlling the distribution of various energy vectors with their help. Users take a holistic view of how embedded algorithms can be widely operated at different energy levels. As a result, the development of the smart city fully reflects technological advances and energy production and consumption methods that play an indispensable role in forecasting future power demand and specifying the pricing and availability of electricity.

The notion of a smart economy facilitates the innovative interconnection of global and local trading through IoT technology. This domain corresponds to economic development, investment, business environment, and entrepreneurship. It maximizes the widespread use of human capital, including knowledge, talents, skills, and creativity. Consequently, advancements in IoT technology facilitate the rapid development and realization of many benefits and services which drives the economy smarter and improves people's quality of life [17]. Furthermore, the idea of sharing economy is also comprised in this sector, where private companies or individuals offer their services and exploit their resources through peer-to-peer marketplaces. There is also peer-to-peer labor service wherever residents and citizens offer their jobs and experiences for precise work. Machine learning and AI procedures have been performed to build predictive models and improve authorization systems for retail marketing and e-commerce. However, the smart economy domain deals with essential indicators related to the economy's strength, efficiency, and progress. It exposes a significant role in the advancement of smart cities and acts as a major driver of related dimensions.

The smart industry and manufacturing domain for industry 4.0 transforms a conventional industry and manufacturing into a less human-dependent and innovative AI-based IoT technology, various communication approaches, cloud-based manufacturing, and productive environments [18]. This domain can automate smart cities using sensor technology in areas ranging from manufacturing processes, shipment tracking, real-time data collection, and utilization of production and manufacturing. IoT technology and ubiquitous cloud computing are broadly used in smart healthcare. These are helpful for distant health monitoring, telenursing and telemedicine services, community health care, and gaining knowledge about detailed drug reactions. This is more relevant to the recent global COVID-19 pandemic. For instance, the body sensor network with wireless sensor network technology plays a role in incorporating disparate data sources using AI-based IoT healthcare applications in distant patient monitoring. Using smart healthcare [19] based on IoT technology, medical attendants in hospitals can provide various services by collecting biometric and physiological data of patients with the help of intelligent medical appliances.

Smart cities use smart environment schemes to contain environmental information to develop an IoT-based environment-friendly system conception, layout, and protocol. The applications, usefulness, and services of the smart environment usually depend on various sensors used to estimate environmental conditions and parameters, such as pressure, humidity, temperature, and different types of pollutants [20]. Moreover, intelligent sensing and visualization methods (LiDAR, satellites) are employed for land usage and greenhouse gas (GHG), where geographic information systems (GIS) data and location-based services are also utilized. The scheme is also linked to the control of pollution, freshwater reserves, water quality, and meteorological and climatic conditions. In this consideration, air level monitoring is an essential factor for air pollutants tracking grades, which convey a severe issue to people's health generated by the vehicle, waste, industrial emissions, and heating. Even smart waste management is incorporated in this domain as it has many environmental implications. Control approaches for waste generation are managed with smart waste bins, which are settled with sensor devices and are able for real-time exploration of directly available capabilities.

2.3. Greening approach in smart city

IoT-based smart cities connect digital devices through networks, offering several new services in various domains. A smart city uses ICT technology and sensor-based IoT devices to green the entire city environment through a pervasive and fundamental transformation. Also, progressive technological solutions that have evolved from conventional to modern will help a city become smarter, greener, and more sustainable [21]. Smart cities have the challenges of saving energy, lessening carbon dioxide (CO_2) emissions, and decreasing water and pesticide use. Even increased need for preliminary energy and water scarcity are still severe impediments to the sustainability of the existing manufacturing system. Consequently, renewable energy repositories, the solar, wind, and allocated resources can skillfully integrate into a smart city.

Greening the smart city can expand greening quantities, diminish the urban warmness impact, enhance the grade of indoor and outdoor air, lower indoor temperature, beautify urban geographies, raise energy efficiency, defend building establishments, and lessen noise. Again, a greenhouse system addresses various facets of the difficulties of traditional greening. It minimizes water use, and energy could develop by increasingly multidisciplinary and sophisticated strategies to reach an optimum balance between proficient environmental governance and manufacturer use of functional resources. The Greening approach impresses to be much more intellectually justifiable, adjustable, and creative and assembles it much more effortless to be sustainable and green in a smart city.

3. RESEARCH METHOD

In this study, the purpose of a systematic literature review on IoT-enabled smart cities toward green energy systems is to conduct a comprehensive exploration by logically defining, analyzing, and classifying relevant areas of recent research. Moreover, this paper seeks to reveal the future areas of smart city architecture by evaluating and investigating the status of existing works, clearly guiding the search and selection criteria. Findings and evaluated findings of related developments and applications from existing papers can be used by researchers and scholars more confidently in their own research. Through these reviews, one can comprehend the challenges and issues of all kinds of data management methods for smart cities and present very innovative ideas.

The methodology of the literature review process of this paper is depicted in Figure 4, which involves several distinctive operations. This research considers issues such as review planning, review process management, analysis, and reporting of findings to facilitate the literature review process. In general, research questions and answers can be derived by collecting recent research papers using search engines for systematic and systematic reviews and, at the same time, selecting appropriate and reasonable documents based on their inclusion/exclusion criteria. For the review planning, subsections 3.1 and 3.2 discuss how this study has shaped the research questions, search procedures, and paper selection. These crucial elements have been carefully considered to ensure a comprehensive and effective review process. For accomplishing the review process, it provides the details of the records screened, inclusion and exclusion criteria, and critical observations in subsections 3.2 and 3.3. The details of the quality and evaluation process with statistical analysis in section 4 and challenges with directions in section 5 are presented for developing IoT-enabled smart cities towards green energy systems.

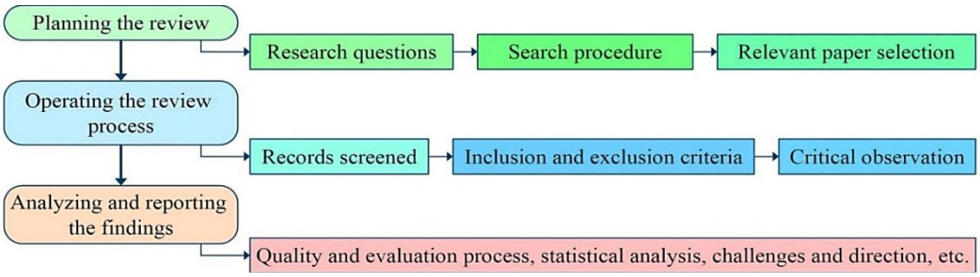

Figure 4. The methodology of literature review process

3.1. Formalizing research question criteria

For the specific purpose of reviewing recently published research on smart city-based green structures and understanding their core content, some specific and functional research questions can be considered in this article. This type of research question helps in synthesizing the intelligibility, need, and clarity of the elements involved in building a smart city. This paper records the selected questions on the smart city paradigm in Table 1, following the relevant methodology, sustainability, and benefits to sustain the proposed study objectives.

Table 1. Research questions criteria to extract the recent work

RQ. N.	Research question approach
RQ-01	What are the main obstacles in handling related services in smart city applications and how are those services implemented in different sectors?
RQ-02	What methods or techniques should be used to apparently appraise different types of data in IoT-enabled smart city structures?
RQ-03	How will renewable energy sources be incorporated into this framework to ensure a better environment for present and future generations in cities?
RQ-04	How will smart city applications be integrated with new technologies to enrich people's quality of life?
RQ-05	What kind of relationship or synergy should smart city applications have with city administrative governance?
RQ-06	How to specify the concepts, open issues, and future directions of iot-enabled smart cities and environmental sustainability in green urban development?

3.2. Related work selection procedure on recent developments

In this subsection, this study clarifies related work selection procedures in the recent developments of smart cities and IoT technology for our review process. The existing papers selection creates a scope to determine and gather acquaintance of this domain. We have considered three (3) cases for recent paper selection.

In the first case, the paper selection process is performed by applying the search engine Google Scholar using a search strategy. We select some famous academic publishers such as Springer, IEEE, ScienceDirect, Wiley, and Taylor and Francis to collect the current publishing paper from their digital databases. For collecting the research paper, this study has conducted search keywords such as smart city, IoT, IoT-enabled smart city, green energy system, smart city towards green energy, and renewable energy in IoT. Additionally, relevant new technologies and algorithms are taken into account for searching published research papers. This study manages search results based on adding the whole or a part of a related word by mentioning keywords.

In the second case, search queries are assembled based on recent articles published, and we have tried to find these papers from 2017 to 2022. Related and relevant keywords of our study are conducted on journal citation reports (JCR), Science Direct, Scopus, and ACM digital library databases. Search criteria for research papers are based on focused on the nature of recent available and crucial papers. Due to complexity and ambiguity, non-English language-based articles, review papers, conference papers, book chapters, and review papers were excluded from our study. Besides, to provide more focus on relevant issues, articles that did not fully provide text on IoT-enabled smart city architecture toward green energy systems were not accepted in our review process.

We have successfully collected a total of 217 articles from reputed databases on applications supported by smart city infrastructure from the main objective of the systematic review. The inclusion and exclusion criteria of the collected existing studies are presented in Table 2. We did not consider non-published articles in English, non-clear, and non-specific goals in this study of IoT-based green smart city infrastructure papers. Articles related to innovative city applications were filtered by removing duplicate, irrelevant, and reported articles. A final 65 papers were selected by eliminating the inconsistent papers with inappropriate criteria based on full literature type and text.

Table 2. Inclusion and exclusion criteria for filtering research paper

Inclusion criteria	Exclusion criteria
1. Include recent publications from 2017 to 2022	1. Exclude publications prior to 2017
1. Include searching keywords based on our paper title	2. Exclude non-clear keywords and non-specific goals of full-text publications
2. Include relevant new technologies and algorithms based on IoT-enabled green smart cities	3. Exclude duplicate, irrelevant, and reported articles
3. Include high-level published literature and highly reputable journals	4. Exclude non-English writing and non-related academic journals

3.3. Critical observation of recent methods and targets

Various researchers have reviewed various strategies in the field of IoT-empowered smart cities toward green energy systems. Recently, multiple processes or appliances have been tried to resolve, including usability evaluation methods in intelligent city applications. In this part, we have attempted to observe recent approaches and goals critically. An organized review of various fields of selected articles can provide cognitive ideas for future researchers to further improve smart city applications.

Table 3 exposes the effective reflections on the smart city, IoT, and green energy keywords in existing studies. This table uses 21 research studies to perform a thorough review of existing work and the process of deriving evaluation criteria. The existing publications were thoroughly read to assess the effectiveness of the research work, and the relevant strategies of those publications were decided upon.

In this case, we have used shortened forms such as IoT, smart city (SC), green energy (GE), preeminent targets, architecture-based mode (ArBM), algorithm-based mode (AlBM), [2] real skill test (RST), simulation (Sim), and observation to describe the validity of the evaluated terms used in most studies to facilitate tabulation. The main motive of this paper is to include the measurement of operational strategies in research that will have a more decisive role in building smart city infrastructure. In this portion, we have attempted to mark recent suggested approaches and directions. The approaches and directions presented in the selected articles will recreate an essential role in conceptualizing the entire phase of future smart city infrastructure.

Table 3. Effective reflections on the smart city, iot, and green energy keywords in existing studies

Ref.	SC	IoT	GE	Preeminent targets	ArBM	AlBM	RST	Sim	Observation
[22]	✓	✓	×	Big data applicability in smart cities	✓	✓	✓	✓	Using public tram service data and collecting building-used energy and environmental data
[23]	✓	✓	×	Privacy-preserving data in smart cities	×	✓	×	✓	Achieved privacy-preserving views of IoT appliances in smart cities
[24]	✓	✓	×	Real-time crowd management in smart cities	✓	×	×	✓	Crowd behaviour assessed in AI-aided IoT based crowd control systems using Wi-Fi frames analysis
[25]	✓	✓	×	Design full lifecycle management of dumb devices for smart cities	✓	×	✓	✓	Automatically and periodically context awareness data processing on narrow-band IoT
[26]	✓	✓	×	Boost urban tasks by deriving intelligence and optimal policy	×	✓	×	✓	Significant time reduction using learning methods in sensible data to get the best urban services
[27]	✓	✓	×	Allow automated translation between source and target IoT networks for global smart cities.	✓	×	×	✓	Using semantic interworking in smart cities provides the flexibility and dynamic adaptation required by the environment.
[28]	×	✓	✓	Improve energy skills in managed resources by connecting channels and devices in IoT deployment.	×	✓	×	✓	Allow using optimal renewable energy at LoRa wireless grid using reinforcement learning.
[29]	✓	×	✓	To make reliable the smart city load demand using renewable energy.	✓	×	×	✓	Microgrid system with smart battery storage control to ensure maximum renewable energy.
[30]	✓	×	×	To improve data rates and reduce power costs in all-over network services for smart cities.	×	✓	×	✓	The iterative power control process was conducted to improve energy consumption for device-to-device communications.
[31]	✓	×	✓	Reducing workload and application-level time energy costs in the energy internet for green cities.	×	✓	×	✓	Evaluate both energy and work optimization objectives used in smart cities using multiaction deep reinforcement learning methods.
[32]	✓	×	✓	To transfer cooperative energy and data in wireless green sensor networks of smart cities.	✓	✓	×	✓	Controlling collaborative energy and data transfer protocols by joint optimization based on subcarrier pairing, grouping, and power allocation.
[33]	✓	×	✓	Connected and automated vehicles in smart cities collect data from sensors and make automated decisions.	✓	×	×	✓	Demonstration of evaluation to efficiently operationalize smart city metadata and reduce energy consumption for them.
[34]	✓	✓	✓	Making smart cities green and sustainable by applying security, cyber defence, forensics and cyber threats intelligence in IoT devices.	✓	✓	×	✓	Powerful computing and storage capabilities enable IoT devices to realize low latency and efficient detection.
[35]	✓	✓	✓	Making smart cities green and sustainable by applying security, cyber defence, forensics, and intelligence in IoT devices.	✓	×	×	✓	Notably the system of managing and evaluating the utilities of smart city through the integration of energy sources.
[36]	✓	✓	✓	Transferring large amounts of data in a sustainable and green manner by interconnecting smart city digital devices.	✓	×	×	✓	Estimating battery lifetime, delay, power drain, and packet loss ratio using HABPA and DSA algorithms in optimal resource management in smart city systems.
[37]	✓	✓	✓	Providing a promising platform for parking space sharing to adjust emissions and energy consumption in smart cities.	×	✓	×	✓	Intelligent and affordable car parking sharing system for driver using game theory reservation model.
[38]	✓	×	✓	Conduct green energy consumption strategy for smart cities.	✓	×	✓	✓	Green energy consumption policy verifies data size, response time, and packet time by Bluetooth data transmission.
[39]	✓	✓	×	Apply immune authentication technique in various IoT devices for smart city.	×	✓	×	✓	Performing security authentication policy, analyze best computational cost, and energy consumption.
[40]	✓	✓	×	Optimize energy consumption to operate smart city's interconnected devices.	×	✓	×	×	Evaluating mathematical model and calculating entropy to reduce energy waste.
[41]	✓	×	✓	Optimize energy consumption to make smart city applications accessible via IoT to reduce environmental impacts.	×	✓	×	✓	Energy used in smart cities is based on renewable energy systems and energy storage systems using optimization methods.
[42]	✓	✓	×	Developing traffic modelling concepts and its patterns for IoT applications in fifth generation technologies.	✓	×	×	✓	To maintain various traffic profiles in IoT using target tracking, telemetry, video espial, or other urgent operations in city.

Table 4 reveals the latest research for controlling IoT-enabled services in the smart city. This table uses 18 recently published research studies to guide the process of developing an intelligent city services regulation and assessment criteria of existing work. We have tried to specify the potential criteria for building smart city service infrastructure from existing publications. In this regard, we have used concise forms such as propound platform, optimization (Opt), time cost (TC), security (Secu), heterogeneous nature (HN), reliability (Rel), intelligent control (IC), and future direction to categorize the explored parameter used in most studies. These explored parameters will support the researchers in testing the accuracy, efficiency, and correctness of building real smart city infrastructure.

Table 4. Recent research into the ability to control smart city services

Ref.	Propound platform	Opt	TC	Secu	HN	Rel	IC	Future direction
[43]	Smart environment platform	×	×	✓	✓	×	✓	Feasibility study of automatic ontology alignment in smart cities
[44]	Mobile crowdsourcing scheme with intrusion identification	✓	✓	✓	×	×	✓	Measures the formulated security of futuristic IoT based intelligent city applications
[45]	Intelligent learning domain architecture for smart city	✓	✓	✓	✓	×	✓	Enhance the learning domain with behaviour detection by deploying skilled embedded sensors and tools
[46]	IoT sensor-based facts monitoring and forecasting model of urban economic control	✓	✓	×	✓	×	✓	Improve the structure of information availability, impact checks in many areas for the stabilized economy
[47]	An integrated framework of IoT based electronic cane for urban visually impaired.	×	✓	✓	✓	✓	✓	Increased sensor nodes, and actual node location identification, enhance the quality of speech messages and beeps for a large-scale domain
[48]	Optimized greenhouse climate control design in IoT	✓	✓	×	×	×	✓	Extend the scheme in a real environment with essential greenhouse parameters
[49]	Software-defined–IoT network design in smart city	✓	×	×	✓	✓	✓	Solve the load-balancing problem for a distinct topology on large smart city networks using the clustering approach
[50]	Smart small cell infrastructure for IoT-enabled smart city	✓	✓	×	×	×	×	Simplify the approach for smart cities in real-time networking services and communications
[51]	Green Wi-Fi management model for smart cities at the access point	✓	✓	×	×	×	×	Not mentioned
[52]	Food supply chain control in a sustainable smart city network	✓	✓	×	×	×	✓	Conducting cloud computation jobs, best power consumption, and delay optimization
[53]	Deep learning-based cyberattack detection framework in smart city	×	✓	✓	×	✓	✓	Explore engineered features of adversarial attacks and improve performance
[54]	Ontology-based IoT scheme with privacy-preserving in smart city	×	✓	✓	✓	×	✓	Evaluate the scheme on different operating systems and release useless data from the IoT devices
[55]	Deep learning based IoT oriented structure with software defined networking (SDN) and blockchain for smart city	×	✓	✓	×	✓	✓	Enhance automatic confirmation of transactions and direct participation in the transaction
[56]	Energy-efficient and IoT-enabled smart street lighting controlling scheme	✓	✓	×	×	×	✓	Ensure security and reliability performance of roles of the critical street lighting scenario
[57]	LilaSCI scheme on Living Lab Platform for the smart city	✓	✓	✓	✓	✓	✓	Not mentioned
[58]	Multimodal large-scale service support scheme in IoT-based smart city	×	✓	×	✓	×	✓	Design exploitation and availability of large-scale services in governance, industries, small and medium enterprises (SMEs), and academia
[59]	Distributed secure network and energy-aware model in smart city	✓	✓	✓	×	✓	×	Manage advanced security, use other machine learning and artificial intelligence (AI) approach, and feasibility test of the platform
[60]	Privacy-preserving and energy conserving policy in mobile edge computing-based smart city	✓	✓	✓	✓	×	✓	Consider and enrich realistic social impact modelling for service providers and remote cloud collaboration using deep reinforcement learning

4. DISCUSSION AND ANALYSIS OF EXISTING STUDIES

This section organizes the recent paper publications with the year and extracts the foremost thought and appraisement of the IoT-enabled green smart city from the information in Tables 3 and 4. It aims to examine the status of reflection-based research on complementary services in the infrastructure of IoT-enabled smart cities implementing renewable green energy. Figure 5 manifests the ordination of publications according to year based on the concept of smart city. The graph evidently demonstrates that there is a considerable number of published research papers from 2017 to 2022. However, fewer works in this sector were revealed in the earlier years, or 2017 and 2018. Since then, the number of publications of this work has significantly increased for the improvements of related smart cities. The year 2022 witnessed the highest number of articles published so far, which indicates the interest and focus of researchers on the quality and evaluation of smart city projects. It is expected that more research articles will be published in the coming years as the concept of smart cities is gaining more attention and becoming increasingly popular among researchers and professionals.

Figure 6 exposes the foremost thought of the IoT-enabled green smart city in the prior literature. As stated in Table 3, the assessment considerations of the foremost thought for the IoT-enabled green smart city are presented in the figure through statistical work determination. The statistic percentage based on recent works in mentioning table exhibits handling green energy at 15%, connection setting of IoT at 19%, architecture-based plan at 17%, algorithm-based plan at 17%, real skill test at 4%, and simulation at 28%.

Figure 7 visualizes the recent study's appraisal of the intelligent green city with IoT. As mentioned in Table 4, the appraisements of recent opinions in the work of renewable IoT-enabled smart cities are introduced in the appearance through statistical work anticipations. The statistic percentage based on current studies in the citing table shows optimization at 18%, intelligent control at 22%, heterogeneous nature at 13%, security at 15%, time cost at 23%, and reliability at 9%.

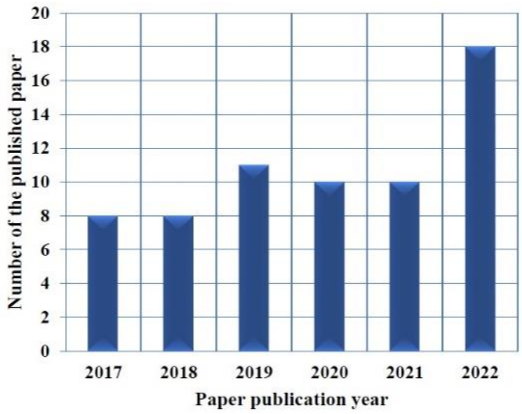

Figure 5. Ordination of publications according to year

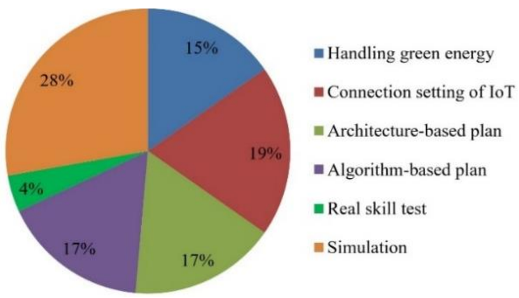

Figure 6. Foremost thought of the IoT-enabled green smart city in the existing literature

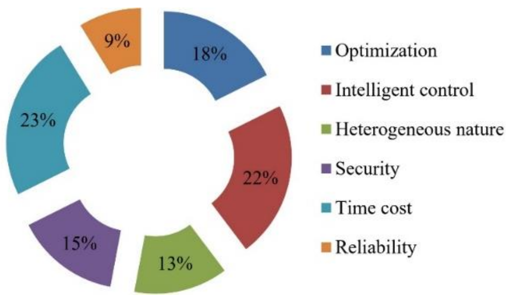

Figure 7. Recent studies appraisement in the smart green city with IoT

5. TECHNICAL AND FUNCTIONAL CHALLENGES AND DIRECTION OF IOT-ENABLED GREENING SMART CITY

A smart city application uses rich digital technology as its primary ingredient. A smart city contains a giant data management strategy that is constituted by various types of sub-information methods. It is equipped with sensors and is digitally linked. The service providers can use the urban data collected to use limited resources better to promote sustainability. However, IoT is one of the leading technologies to enable innovative city development. Technical knowledge of IoT-based smart cities and their applications is rapidly extending to real-world scenarios. Some of the significant technical, functional, and nontechnical challenges for trendy IoT-enabled smart greening cities can be used to define the requirements of different data providers. In this case, it works with various data formats and protocols, ensures scalability and interoperability, and supports component sharing. It is important to sidestep redundant data acquisition, repository, and investigation, thereby diminishing functional costs and increasing the sustainability of the city. Additionally, in a smart city, the most often occurring challenges concern privacy, interoperability, and security.

For instance, there are heterogeneous environments and interoperability issues in a smart city due to many different IoT protocols, formats, and frameworks. Resolving these two problems could bring financial blessings toward economic sustainability. In fact, reaching the highest grade of interoperability [61] and generating a heterogeneous environment among appliances, services, and applications implicates reducing costs for constructing wholly new and distinct deployments of decisions. It allows the exploitation of existing approaches and backward compatibility through integration and incremental deployment. In addition, from a technology perspective, the evolution of ICT infrastructure, from transmission media to various actuators and sensors [62] in tangible space, is a significant challenge in considering an IoT-based intelligent city enterprise. A high-speed, scalable, and trustworthy network connectivity-based structure is a crucial basis for developing a smart city. Such a structure must be in place before smart city amenities are accessible to stakeholders. Thus, acceptable, satisfactory, reliable infrastructures pave the way to perceive the city and operate through sensors and actuators.

In IoT-based smart cities, acquiring the highest scalability expresses the prospect of efficiently gathering and processing growingly significant volumes of data, which usually conducts a more increased exactitude in facts evaluation and promotes real-time processing. An effectual big data managing scheme is needed to operate different data types at different speeds. This system must be scalable, trustworthy, and consistent without downtimes. The successive collection, accumulation, generation, and processing of vastly miscellaneous data from various smart sensors have inherent challenges. However, big data aggregated across cities is beneficial and critical to attaining intelligent urban objectives. For instance, GPS sensors connected to automobiles can deliver useful data about traffic flow but produce enormous amounts of highly-rated information. The technical and operational challenges and directions for an IoT-connected infrastructure green smart city framework are demonstrated in Figure 8.

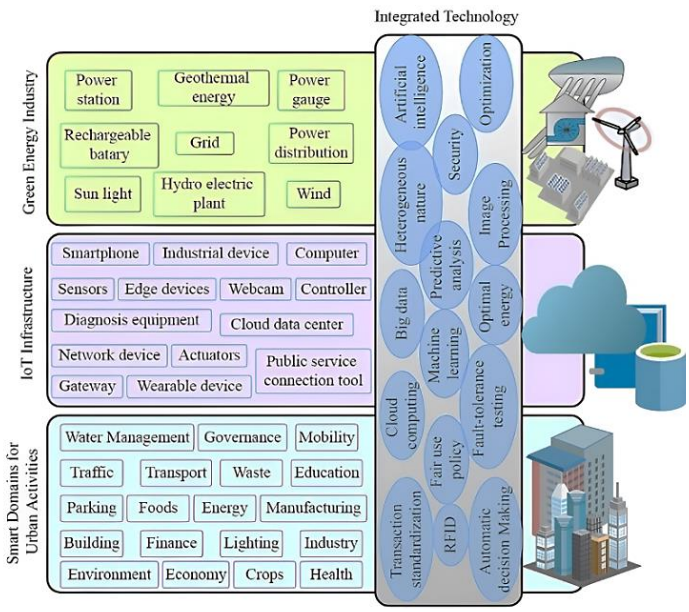

Figure 8. Technical and functional challenges and direction for smart green city throughout IoT

Again, the task of fulfilling the availability is straightly proportional to the system's complexity and size with the urban technological intelligent infrastructure. A vast amount of data engendered across the metropolis makes scalability, efficiency, and availability a vital challenge. Maintaining the efficiency of such a large approach should be mandatory. Proficient planning, execution optimization, efficient utilization of resources, and instantaneous reaction to inquiries are a few critical assistances of the smart city. As the trend moves towards IoT-based data collection for smart cities, confidentiality and security [63] matters are increasing day by day. Because an IoT-based smart city incorporates various devices and applications for our everyday lives, for instance, a smart traffic control application, which operates on user information about traffic jamming, will involve that area of the operator assembled. Meeting the safety and secrecy provisions is a significant challenge for IoT-enabled smart cities that implicate processing a large volume of sensitive data. Threats from intruders, hackers, viruses, Trojans, and worms have the massive prospect of disrupting the services and bringing down the entire procedure resulting in tremendous damages. Protecting sensitive records at the IoT architecture level requires comprehensive security mechanisms for collection, processing, storage, and dissemination. Privacy and security are essential in producing data and facilities available and making citizens' trust and confidence in utilizing these procedures.

Since IoT-enabled smart cities require essential technical infrastructure, a substantial financial investment must be needed to put the system in place. This investment is not confined to a period only; the functioning and maintenance expenses [64] of such a sizeable real-time design are high. Thousands of actuators, sensors, computing equipment, and networking appliances need for end-to-end connectivity. Likewise, the necessity of information technology (IT) professionals, consultancies, and skilled specialists will compromise a considerable cost. In order to meet the demanding efficiency and trustworthiness requirements, the need for additional resources leads to high overhead. Moreover, an IoT-based smart city is a superior solution to overcome the existing problems in the city with the rapid improvement of new, dynamic, and advanced applications and social adaption. Slow application development is a great problem in city management. For instance, one of the significant causalities behind the achievement and widespread adoption of Android is its Play Store, where numerous applications are uploaded daily. However, researchers have also specified challenges to social adaptability regarding inequality, digital sharing, and modifying cultural practices. Community adaptation of such systems involves changes in the social practices of citizens in general and those related to managing cities in particular.

Finally, the environmental and energy factors of IoT-enabled smart cities show a crucial role in the evolution toward sustainable urban life. Tremendous technological development in the IoT-based smart city has changed how we work and live, but this consumes energy and embraces toxic pollution and E-waste. In order to expand the benefits and lessen the harm of IoT, the environmental and energy issues are considered to move toward green IoT that is considered environmentally friendly. So, it is necessary to put many measures to diminish carbon footprint, reduce energy consumption, increase energy conservation, mitigate climate change, conserve fewer resources, and facilitate efficient techniques for energy usage should focus on energy efficiency [65]. Furthermore, using renewable green sources for the energy systems of smart cities depicts noteworthy assistance in decreasing energy consumption, reducing contaminant emissions, and improving the quality of living circumstances based on technical, environmental, and economic criteria.

6. CONCLUSION

This paper introduces an exhaustive review of methodologies in serviceability and quality assessment of IoT-enabled smart city systems toward green energy strategies. This review investigates various operational dimensions of smart cities from existing papers that have the potential to offer sustainable insights for future research. Prospective qualitative articles were selected from recent studies for the purpose of devising IoT-based green smart cities considering inclusion and exclusion criteria. The most important criteria and information are recorded by analyzing the solutions proposed by the researchers. The evaluation dimensions of the published articles are categorized in the table to support the overall research findings. In this context, checkmarks (✓) were used for published articles that supported the evaluation parameters or dimensions; otherwise, cross marks (×) were treated for unsupported articles. It delivers a holistic idea of IoT-enabled smart cities toward green energy operation. Recent paper publications have been plotted as years, and researchers' thoughts and evaluations of those publications have been demonstrated as percentages. Parameters or dimensions that have been worked more in recent times from the displayed evaluation are presented as percentages. This research paper highlights the technological and functional challenges and directions for IoT-enabled greening smart cities. Furthermore, this study can help researchers to plan sustainable and innovative strategic frameworks for IoT-enabled smart cities through green energy systems.

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