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Green IoT for Eco-Friendly and Sustainable Smart Cities: Future Directions and Opportunities

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Abstract

The development of the Internet of Things (IoT) technology and their integration in smart cities have changed the way we work and live, and enriched our society. However, IoT technologies present several challenges such as increases in energy consumption, and produces toxic pollution as well as E-waste in smart cities. Smart city applications must be environmentally-friendly, hence require a move towards green IoT. Green IoT leads to an eco-friendly environment, which is more sustainable for smart cities. Therefore, it is essential to address the techniques and strategies for reducing pollution hazards, traffic waste, resource usage, energy consumption, providing public safety, life quality, and sustaining the environment and cost management. This survey focuses on providing a comprehensive review of the techniques and strategies for making cities smarter, sustainable, and eco-friendly. Furthermore, the survey focuses on IoT and its capabilities to merge into aspects of potential to address the needs of smart cities. Finally, we discuss challenges and opportunities for future research in smart city applications.

Keywords Green IoT · Smart city · Sustainability · Eco-friendly · Energy efficiency · Pollution

1 Introduction

Due to the tremendous development in communication and sensing technologies, 'things' around us are being connected together to provide various smart city applications, enhancing our life quality [1]. This connectivity between things in the smart city is commonly referred to as the Internet of Things (IoT). IoT includes everything in smart cities, to be connected at any time, anywhere, and using any medium [2, 3]. The development of IoT technologies continue to grow, making IoT components smarter through an adaptive communication network, processing, analysis, and storage. For context, some IoT devices include cameras, sensors, Radio Frequency Identification (RFID), actuators, drones, mobile phones, etc. All of these have the potential to communicate and work together to reach common goals [1, 4]. With such components and communication technologies, IoT devices are set to provide a broad range of applications for real time monitoring, as seen in environmental monitoring [5, 6], e-healthcare [7], transportation autonomy [8], industry digitalization and automation [9, 10] and home automation [11, 12]. Furthermore, IoT is an enabler of software Agents, to help share information, make collaborative decisions, and optimally accomplish tasks [10].

IoT is capable of collecting and delivering vast amounts of data using advanced communication technologies that can be analyzed for intelligent decision making. The Big data requirements of IoT needs storage capacity [13], cloud computing [14], and wide bandwidth for transmission, to make IoT ubiquitous. This big processing and transmitting of data consumes high amounts of energy in the IoT devices. However, using efficient and smart techniques could lead to a decrease in power consumption. Therefore, the combination of IoT and the practical techniques to reduce power consumption of big data processing and transmission can improve the quality of life in smart cities, and contribute to making the world greener, more sustainable, and collectively a safer place to live [15–17]. Shuja et al. summarized this relationship between green IoT and big data to create sustainable, green, and smart cities by decreasing pollution hazards and reducing energy demand and efficient resource utilization [18].

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Presently there is new potential in smart cities to become even smarter than before with the application of advanced technologies, such as Artificial Intelligence (AI). Examples of this can be seen in smart city components including sensor integrated smart transportation systems, cameras in smart monitoring systems, and so on. Vidyasekar et al. [19] introduced the critical aspects of potential smart cities in 2020, in which things are smarter through smart energy, smart building, smart mobility, smart citizens, smart infrastructure, smart healthcare, smart technology, and smart education and governance. These aspects are shown in Fig. 1.

IoT plays a tremendous role in improving smart cities, affecting in different ways with its numerous applications in enhancing public transformation, reducing traffic congestion, creating cost-effective municipal services, keeping citizens safe and healthier, reducing energy consumption, improving monitoring systems, and reducing pollution, as shown in Fig. 2. However, IoT environmental issues, such as, energy consumption, carbon emission, energy-saving, trading, carbon labeling and footprint, have attracted researchers' attention. Therefore, carbon emission reduction and energy efficiency technologies based IoT are summarized [20]. The study discusses IoT technologies to facilitate real-time intelligent perception of the environment, and generate and collect energy consumption in manufacturing the entire life cycle.

To fulfill goals of smart cities and sustainability, green IoT is a key technology to decrease carbon emission and power consumption [21–23]. The increasing number of IoT devices leads to increased energy consumption. For example, wake up protocols and sleep schedules of IoT devices are introduced for energy consumption and resource utilization [21]. The authors of [23] provided the techniques that can reduce the energy consumption in IoT via efficient energy of data transmission from IoT devices, data center efficient energy, and design energy-efficient policies. Further, authors in [22] introduced Information and Communication Technology (ICT) impacts on carbon emissions and smart cities' energy consumption.

1.1 Related work

The preliminary literature on smart cities based on greening IoT is dispersed [23–26], leading to inadequate recognition of the importance of green IoT. There is an apparent lack of depth in current literature which can explain in detail the enabling techniques for IoT systems in smart cities which

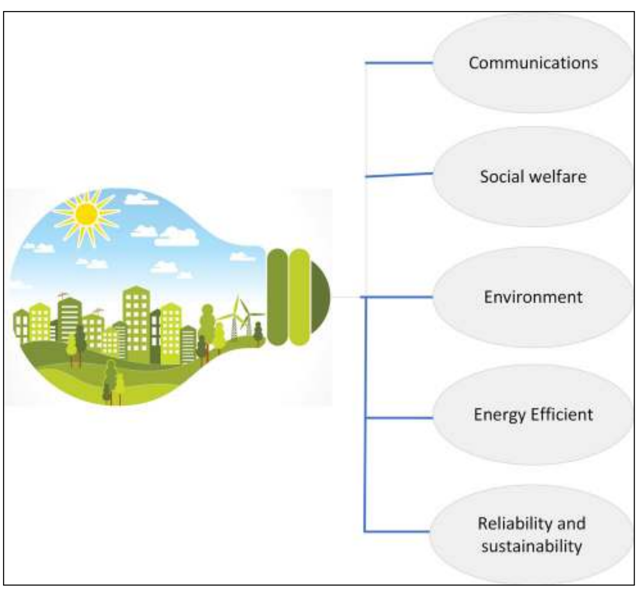

Fig. 1 Aspects of smart cities

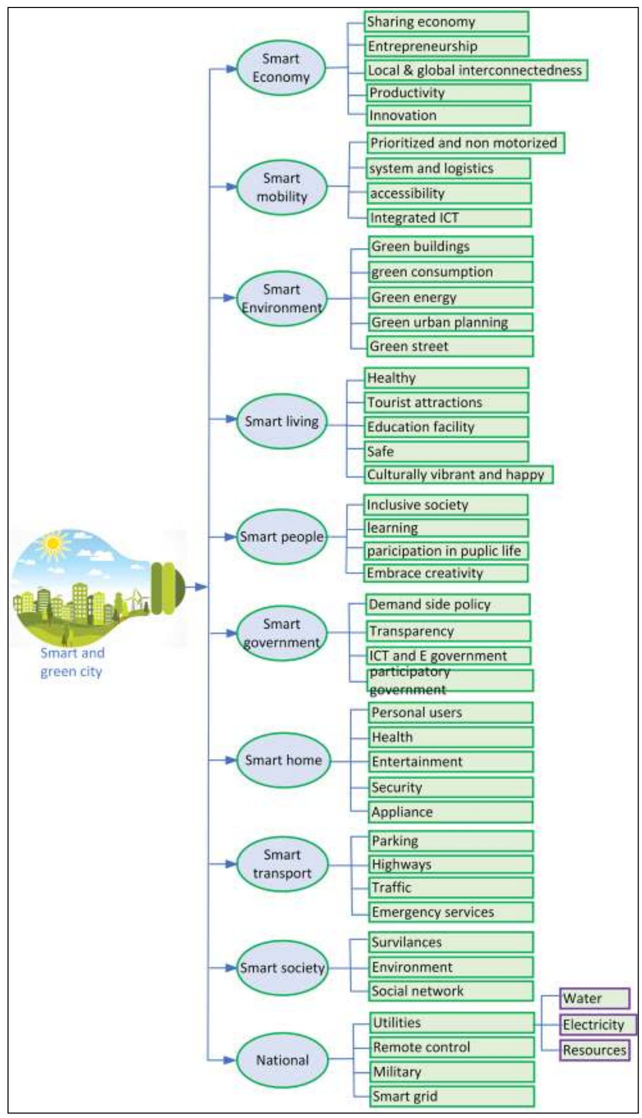

Fig. 2 Smart city applications

can reduce CO_2 emission, minimizing power consumption, enhancing QoS [27–40], and enabling ICT. Existing surveys are not comprehensively focusing on smart cities strategies strategies and techniques for enabling greener smart cities. To the best of the authors' knowledge, there is no existing survey dedicated to reviewing the strategies and techniques for greener smart cities, through enabling ICT, reducing energy consumption, reducing CO_2 emissions, reducing waste management, and improving sustainability.

As a comparison, Arshad et al. [23] discussed green IoT based on minimizing energy consumption. The study focuses only on designing energy efficient policies, energy efficient policies, energy efficient data centers, and data transmission from IoT devices. However, the study does not cover all of the potential ideas, while our survey will focus on techniques and strategies, for enabling IoT to improve the eco-friendly and sustainability of smart cities. The work presented in [25] discussed the negative impact of IoT technology and suggested solutions to minimize it. Some negative impacts of IoT were included in this study, e.g., greenhouse gas emissions, and energy usage, etc. The study explored the principles of green IoT to improve life quality, economic growth, and environments in smart cities. It showed evidence that green IoT usage can support sustainable natural resource utilization in agriculture, forestry, and aquaculture. However, the authors did not fully discuss all potential negative impacts of IoT technology in various applications. As such, Our work not only includes a broader coverage of the negative impacts, but also focuses on the use of green IoT to improve eco-friendly and sustainability for smart cities.

In [24], the authors introduced IoT for smart cities, and addressed techniques for minimizing energy consumption for green IoT, and as such, introduced the green ICT principle. However, the authors did not further discuss the green ICT for IoT applications in smart cities. As such, this paper will fill this gap in the literature. Shaikh et al. [26] presented how to deploy IoT technology efficiently to fulfill a green IoT. They identified IoT applications where energy consumption can be reduced for a green environment. Several techniques were introduced for enabling green IoT to facilitate energy efficiency. The authors of [41] discussed the concept of IoT for smart cities and their advantages, benefits, and different applications. The study focused mainly on the use of IoT for smart cities such as smart homes, smart parks, smart transports, weather, and pollution management. The authors focused on the benefits and applications of IoT for smart cities applications, however, the study does not discuss the techniques for improving IoT for enhancing the eco-friendlinesss and sustainability of smart cities. A comparison of existing surveys and the present work is summarized in Table 1.

1.2 Contribution

This literature review is intended to develop smart cities' strategies and techniques based on collaborative IoT to improve life quality, sustainability, echo-friendliness, citizen safety, and the health of the environment.This work will contribute to the research literature by broadening discussions on:

1. Enabling IoT techniques for eco-friendly ICT. Specifically the significant impacts of ICT for reducing energy consumption and CO_2 emissions for a sustainable smart city,
2. Different strategies and techniques used for energy-efficiency, reduced CO_2, reduced traffic, and reduced resource usage in smart cities,
3. Waste management techniques to improve smart cities,
4. Advanced techniques used for smart city sustainability,
5. Surveyed current ongoing research works and possible future techniques for smart cities' sustainability and energy efficiency, based on collaborative IoT.

1.3 The scope of study and structure

In a smart city, IoT plays a critical role in improving the life quality, safe environments, sustainability, and ecosystem. This paper will survey the techniques and strategies used to improve smart cities to be eco-friendly and sustainable. The authors focus on techniques which lead to fewer emissions, reduce traffic, improve waste management, reduce resource usage, reduce energy consumption, reduce pollution and improve Quality of Service (QoS) of communication networks. To the authors' best knowledge, no previous research work in the survey has addressed the techniques and strategies that lead to eco-friendly and sustainable smart cities. Relevant challenges are addressed, and the solutions are conceived for other purposes, yet related work will be introduced.

The rest of this paper is organized as follows (see Fig. 3). ICT technology for smart cities is presented in Section 2. Section 3 discusses energy efficiency. In Section 4, reducing pollution hazards is considered. Waste management and sustainability are discussed in Sections 5 and 6, respectively. The future directions and opportunities are discussed in Sections 7 and 8, respectively. Finally, we conclude the paper in Section 9.

2 ICT technology for smart cities

IoT is a global, ambient communication network, immersive, and an invisible computing environment built depending on smart sensors, cameras, software, databases, and data centers

Table 1 Comparison of existing surveys and the present work

Survey	
[20] (2017)	Designing energy-efficient polities for IoT data transmission and data centers.
[21] (2012)	Exploring the principles of green IoT to enhance quality of life, safety environment and economic growth
[22] (2015)	The principle of green ICT for smart cities
[23] (2017)	Applying techniques for enabling green IoT for energy efficiency
[24] (2017)	IoT concepts and advantages for different applications of smart cities
[25] (2019)	Enabling techniques for green IoT in smart cities
[26] (2020)	Fog computing and enabling technologies for sustainable smart cities based on IoT environments.
[38] (2021)	UAV-assisted green IoT applications in smart cities based on B5G networks
Our work	Focuses on techniques and strategies which lead to reduce emissions, reduce traffic, improve waste management, reduce resource usage, reduce energy consumption, and enhance QoS of communication networks for making smart cities more livable, sustainable, and more environmentally friendly.

in smart cities [42]. In [43], the authors presented IoT for constructing a green campus environment based on energy efficiency. Despite prior evidence presented in [42], IoT elements have been presented in [4], where the benefits of IoT and how to create a green area by employing efficient techniques were discussed. In [44], the authors discussed different technical directions towards realizing future green Internet.

Consequently, IoT leads to saving natural resources, minimizing the technological impact on the environments and human health, and reducing costs. Thus, green IoT focuses on green manufacturing, green design, green utilization, and green disposal [41]. The authors in [41] discussed all of the above categories and their importance for improving smart cities.

Furthermore, Solutions for green IoT includes reducing CO_2 emissions and reducing IoT energy usage to fulfill the smart world with the sustainability of intelligent everything. Green IoT includes designing and leveraging green aspects. The design elements of green IoT include developing computing devices, energy efficiency, communication protocols, and networking architectures [45]. Leveraging the IoT element is to reduce the emissions of CO_2, and enhance energy efficiency. Uddin et al. [46] presented the techniques for improving energy efficiency and reducing CO_2 for enabling green ICT. Gathering data from smart city environments represents the essential element of smart cities that create an intelligent model for appreciated decision making.

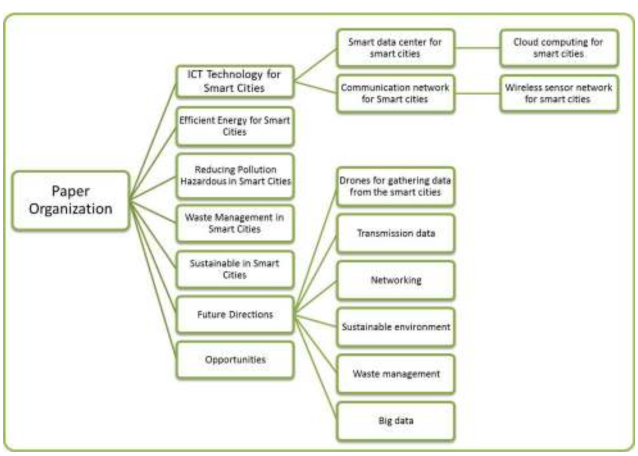

Fig. 3 Paper Organization

ICT plays an essential role in improving green IoT in smart cities to be friendly and sustainable. ICT can reduce cost, resource consumption, and pollution; interact with city services; and enhance life quality. Therefore, without ICT, the idea of smart cities cannot exist. ICT improves the smart cities' application by automated, simplified, enabling IoT, automatic security threat isolated, and scalability, as shown in Table 2. Furthermore, ICT technologies can reduce climate change globally [42–44, 47, 48], with ICT application growth with energy efficiency due to environmental awareness. Greening IoT refers to the advanced technologies that make the IoT environmentally friendly by using facilities and storage that enables subscribers to gather, store, access, and manage various information [23].

Green ICT enables subscribers to gather, access, store, and manage information [24]. ICTs play a critical role in greening IoT and providing many benefits to society, i.e., saving energy used for designing, manufacturing, and distributing ICT equipment and devices. Various research have been done on green ICT technologies, such as [24, 49–53]. These are exciting, but they have been applied for limited applications and ways. In [49], the authors discussed using ICT applications and strategies to reduce CO_2 emissions and energy consumption. The authors [50] discussed green IoT principles for enhancing life quality, growth, economy, and environment. They provide the numerous benefits of reducing the negative impact of the latest technology on society, human health, and the environment. In the case of stainability, ICT can manage data centers optimization through techniques of sharing

Table 2 Advantages of enabling ICT for smart cities

Smart ICT	Advantages
Simplified and automated network management	–Allowing network to be managed as a single entity – Reducing the complexity – Improving efficiency
IoT enabled network	– Reducing wireless installations costs – Ease of deployment for IoT devices
Automatic security threat isolated	– Improving end–user experience
Scalability	– Continue to increase in number and traffic

infrastructure, which leads to energy efficiency with reduced CO_2 emissions and e-waste of material disposals [54]. Furthermore, the authors [22] discussed the enabling technologies for green IoT, which include RFID, wireless sensor networks (WSN), machine to machine (M2M), data center, cloud computing, and communication networks, as shown in Fig. 4. However, they did not consider the techniques used for greening IoT by reducing energy consumption and CO_2 emissions. Also, the authors [51] support the idea of [24] to satisfy greening IoT by transmitting the needful information, reduce the energy consumption of facilities, and use renewable energy sources. Kai et al. [53] proved that the Device to Device (D2D) communication plays a key technology to make cities greener and smarter. They investigated the combination of power allocation optimization and uplink subcarrier assignment in the D2D underlying cellular networks. Therefore, all users' power consumption in network was decreased, while guaranteeing the required throughput of both cellular user and device to the device user equipment.

ICT technologies play a vital role in reducing CO_2 emissions and energy consumption to green IoT applications in smart cities, i.e., smart transportation, smart building, smart parking, and so on [55]. The authors of [56] described the green ICT and green IoT depending on green smart grid, green communication, and green computing technologies. The benefits of greening enabling IoT are illustrated in Table 3. It shows the enhancement of green ICT technologies to reduce energy consumption, reduce CO_2 emissions, reduce costs, and change the climate.

Fig. 4 ICT technologies for smart cities

Going towards greening IoT involves finding new resources, exploiting environmental conservation, minimizing the use of available resource and costs, and minimizing negative impacts of IoT on human health and environment (e.g., CO_2 emission , NO_2 and other pollution) [45, 57–59]. The authors of [49] provided the details on how industrial emissions influence the environment over time. Therefore, reducing IoT device energy consumption is required to make the environment healthier [20]. Furthermore, greening ICT technologies help to support environmental sustainability and economic growth [45, 50], and therefore, emerging IoT technologies make the world greener and smarter. Table 4 shows the critical trends in IoT for smart cities applications domains such as smart healthcare, smart transportation, smart retail, smart, smart industries, smart house, smart grid, smart agriculture, smart wearable.

2.1 Smart data center for smart cities

Data Center is a repository and technology for smart city management, data storage, and dissemination gathered from smart cities' devices. A massive number of IoT devices need permanent internet connectivity over the smart city. However, data management and transformation of data into information over a smart city would not be possible without the data center. It consumes a huge amounts of energy [22], high costs of operation, and high CO_2 footprints due to dealing with different data from different applications. Furthermore, the production of big data is rising through various ubiquitous things, i.e., mobile devices, actuators, sensors, RFID, etc. For the energy efficiency of the data center, the authors of [24, 60, 61] discussed several techniques (i.e., renewable energy, utilizing efficient dynamic power-management, designing more energy-efficient hardware, constructing efficient, designing novel energy-efficient data center architectures, using accurate data center power models, drawing support from communication and computing techniques, and improving air management, consolidating servers, finding optimal environment, improving the processing technology and boost airflow). An eco-friendly

Table 3 ICT for enabling IoT technologies

Technology	Reduce Energy	Reduce CO_2	Reduce costs	Climate Change
Data centre	✓	✓	✓	✓
Wireless sensors	✓	✓	✓	✓
Cloud computing	✓	✓	✓	✓
Communication technologies	✓	✓	✓	✓

Table 4 Critical trends in IoT for smart cities application domains

Applications	Key trends IoT	Green IoT application domains
Smart transportation	Smart cities applications include traffic management, water distribution, waste management,environmental urban security, and monitoring.	–Health care –Managing traffic –Managing smart street –Managing car in parking area –Monitoring air pollution
Smart healthcare	Collecting healthcare data helps in analyzing personal health and provides strategies to combat illness.	– Monitoring patient – Monitoring U.V radiation – Athletes care
Smart retail	IoT supports an opportunity for retailers to connect with the customers for improving the in–store experience	–Controlling supply chain –Managing smart production –Packaging food –Shopping intelligently
Smart industries	Smart industries IoT (IIoT) is empowering industrial with smart devices, big data analytics, and software to design brilliant	–Efficient input material –Reducing waste –Reducing energy intensity –Reducing water intensity –Reducing carbon emission
Smart grids	Smart grids are used information of electricity supply behaviors in an automated fashion to enhance the reliability and efficiency and economics of electricity	–Metering infrastructure –Monitoring substations automation– –Monitoring home automation network –Monitoring power network –Demanding response –Integrating of renewables
Smart houses	Smart houses consumer needs IoT technology to increase convenience, reduce costs and converse energy.	–Detecting intrusion system –Monitoring the environment of internal building –Monitoring water
Smart wearable	Wearable devices and software are installed to collect users data.	– Human data tracking – Human big data analysis – Middleware for wearables
Smart Agriculture	Enabing farmers in smart agriculture to contend with the challenges they face.	–Farm id and sensors –Microclimate monitoring –Smart irrigation –Animal tracking –Water monitoring

datacenter comprises enhancing the airflow and processing, finding optimal environment, improving the air management, and consolidating the server.

Furthermore, the authors of [51] introduced many techniques for enhancing and predicting the energy efficiency of the data center and its components. In addition to the work of authors [51], authors in [52, 53] presented the optimization technique for the data center energy efficiency with supporting Quality of Service (QoS). The study in [62] provided a method to reduce the power consumption without degrading the data center cooling efficiency. Peoples et al. [63] explored the energy-efficient context-aware broker framework mechanisms to manage data center next-generation. However, the study in [64] offers a green data center of air conditioning via cloud techniques, consisting of two subsystems (i.e., air conditioning in the data center system and cloud management platform). The air conditioning system's data center includes environmental monitoring, air conditioning, communication, temperature control, and ventilation. Simultaneously, the cloud platform provides data storage, up-layer application, and big data analysis and prediction. Furthermore, an Ant Colony System (ACS) based virtual machine (VM) can be used for reducing the power consumption of the data center while maintaining

QoS requirements [65, 66] by a near-optimal solution, while virtual machine is considered to reduce the energy consumption of the cloud data center and maintain the desired QoS [67]. The authors of [50] discussed the mitigation of VMs for QoS constraints via bandwidth management and minimalizing energy for 5G networks [61]. Figure 5 illustrates the required impacts for greening the data center for smart cities.

The dynamic speed scaling technique plays a vital role in reducing power consumption, as discussed in details in [68]. In the case of speed scaling, various researches have addressed signal processing [69], and network devices [70, 71], and parallel processors [56] for saving energy by speed scaling. However, the authors in [72] combined sleep state and varying the speed when the tasks are processed for reducing energy usage. The study in [72] supported by Liu et al. [73], developed SleepScale for power efficiency and fulfilling QoS agreements. In addition to the work of [72, 73], the authors in [74] used hybrid technology to reduce network energy consumption by using idle periods and adapting the rate of network operators to the requested workload.

The authors in [75] proposed a centralized network power controller based on collected data of traffic. Statistic servers form, and collected data are used to perform the aggregation of transportation and VM assignment, which was used for migrating the target data center. Authors found that the bandwidth and VM reduced the network power consumption for any data center topology. To optimize the power usage in data center networks with guaranteed connectivity and bandwidth utilization, Zhang et al. [76] discussed two levels for doing the needful. These levels are core level and pod level, in which the purpose of the core level is to define the core switches, while the pod level defines the aggregation switches. They evaluated the hierarchical energy optimization for various traffic patterns, small, large, or random traffic.

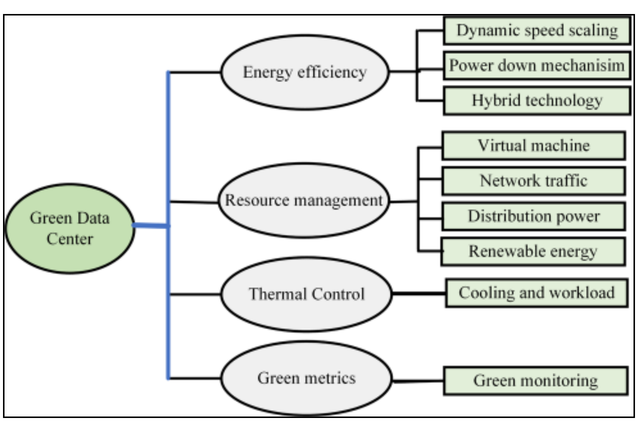

Fig. 5 Required impacts for greening the data center

Furthermore, the study [77] focused on reducing energy by two steps:(i) by allocating VM to the server to minimize the traffic amount and (ii) balancing traffic flows by reducing the number of active switches. Zheng et al. [78] used PowerNets for improving the energy savings of a data center network. The proposed technique gradually improved VM and traffic consolidation performance with lower VM migration overheads by energy savings for a data center.

For power distribution, Meisner et al. [79] developed a technique to eliminate idle power waste in servers based on the PowerNap and RAILS.The finding showed that both techniques minimized the average power consumption in the server by 74%. Therefore, the proposed methods supported transitioning quickly between near-zero-power idle and high-performance active states in response to immediate load variations. However, the authors in [80] proposed a method to reduce the utilized power in installing the infrastructure, and they used power routing across redundant power feed for schedule servers.

Renewable energy is another route towards a green data center which minimizes the negative environmental implications. Therefore, Zhang et al. [81] designed the middleware system to optimize the dynamically distributed requests through various data centers via linear-fractional programming. They found that the proposed system could significantly increase renewable energy usage at different locations without impacting operational cost budges. Furthermore, authors in [82, 83] considered the electrical grid and solar array for data center powering. They proposed two schedulers called GreenHadoop and GreenSlot for data processing jobs and parallel batch jobs, respectively. These schedules are used to predict the solar energy amount to maximize the green energy usage. Both schedulers could increase green energy consumption efficiently. Table 5 illustrates the summary of techniques and strategies for energy efficiency, resource management, thermal control, and green metrics for greening data centers.

Availability and sustainability are the factors that can determine the future of data centers. Therefore, smart cities are required for the data center with the high capacity to process big data coming from sensors dispersed in the city. To enhance the technological infrastructure and reduce the cost, the processing of big data needs communication networks, virtualization systems, and storage access. Here, the smart data center will manage the smart cities effectively and efficiently. Therefore, smart data centers represent smart cities' core, increasing access security, providing passive sensitometry, achieving balanced sustainability, taking care of the city environment, and providing sustainable development for city development. Furthermore, the smart data center will have the capability to effectively and efficiently coordinate and manage the resources required

Table 5 Summaries of data center techniques for smart cities

Improvement	Techniques	Ref.	Advantages
Energy efficient	Dynamic Speed Scaling Hybrid Technology	[71, 74, 84] (2014, 2018,2008)	–Reduce power consumption
Resource management	Virtual machine assignment	[65, 66] (2015,2017)	–Reducing power consumption of data centers –Preserving QoS
		[67] (2016)	–Maintaining QoS –Reduce power consumption
		[85] (2009)	–The trade–off between SLA and energy
	Network traffic	[60] (2015)	– Bandwidth management
		[75] (2010)	–Network power reduction by enhanced QoS parameters
		[76] (2015)	–Network power savings by connectivity, maximum link utilization
		[77] (2014)	–Network energy savings by enhancing connectivity
		[78] (2014)	–Energy savings by enhancing Packet delay
	Power distribution	[79] (2009)	–Reducing the average power consumption
		[80] (2010)	–Reduce the utilized power used in installed the infrastructure
		[86] (2020)	–Adopt decentralized
	Renewable energy access	[87] (2012)	–Maximizing the green energy usages
		[88] (2011)	–Increase the use of renewable energy
		[89] (2020)	–Optimize utilization of energy usage
Thermal control	Cooling and workload distribution	[62] (2016)	–Reduce the power consumption
Green metrics	Green monitoring	[64] (2016)	–Monitoring air condition

by smart cities. For instance, they are measuring and controlling energy from renewable resources, managing the mobility and traffic, measuring the emissions and pollutions, managing the growth of resources, i.e., air, water, light, ect., and leading other services such as recycling waste, public safety, health, etc. Smart data centers' future will help create new technologies and architectures for managing smart cities to improve citizens' quality of life.

2.1.1 Cloud computing for smart cities

Cloud computing is a critical technology for smart cities' physical infrastructure. The deployment of smart cities requires the combination of a decentralized cloud and a distributed open-source network.Cloud computing services are essential for smart city applications. Therefore, the massive amounts of heterogeneous data collected from different devices surrounding smart cities require the services of cloud computing. Smart cities refer to the high quality of life, management the natural resources, and economic development. Smart cities should intelligently provide the many facilities to improve smart city applications, such as police transport, public safety, security, electric supply, water supply, internet connectivity, smart parking, etc.

Cloud computing provides unlimited computational service delivery via the internet and unlimited storage. It is shown that different devices (i.e., tablet, camera, laptop, mobile, etc.) are connected to gather via the cloud. The combining of cloud computing and IoT together has a comprehensive research scope. The aim of cloud computing is to promote eco-friendly products, which are facilely reused and recycled. Thus, the authors of [18] proposed green computing with a focus on ICTs. Also, they discussed the trade-off between green computing and high- performance policies. Furthermore, Baccarelli et al. [90] introduced a green solution to IoT over the fog-supported network.

Therefore, efficient cloud computing plays a vital role in maximizing energy consumption, reducing hazardous materials, and enhancing old products' recyclability. Moreover, efficient cloud computing achieves product longevity resource allocation and paperless virtualization due to the management of power used. Furthermore, Sivakumar et al. [91] introduced the integration of IoT and cloud computing in various architectures, applications, protocols, database technologies, service models, and algorithms.

Further, efficient cloud computing plays a vital role in maximizing energy consumption, reducing the use of hazardous materials, and enhancing the recyclability of old products. Moreover, efficient cloud computing achieves product longevity resource allocation and paperless virtualization due to the management of power used. The idea is supported by a study in [47], which discusses the various technologies for greening cloud computing by reducing energy consumption. It focused on how the combination of cloud and sensors can be used for green IoT agriculture and healthcare domains. Furthermore, Sivakumar et al. [91] introduced the integration of IoT and cloud computing in various architectures, applications, protocols, database technologies, service models, and algorithms.

Zhu et al. [92] presented a multi-method data delivery technique for low cost, sensor-cloud (SC) users, and immediate delivery time. Multi-method data delivery includes four kinds of transportation, i.e., delivery from the wireless sensor network to SC users, delivery from cloudlet to SC users, delivery from cloud to SC users, and delivery from SC users to SC users. Minimizing utility power is the main idea of green cloud computing [93]. Thus, the authors of [93] introduced the essential technique for improving the data center's power performance. Private and public clouds required energy consumption in data processing, switching, transmission, and storage [94]. Table 6 summaries the used techniques and strategies in cloud computing for smart cities.

Despite the numerous works in [22, 81, 95, 96] which carried out on green cloud computing and provided potential solutions be shown as the adoption of software and hardware for decreasing energy consumption, power-saving using VM techniques, various energy-efficient resource allocation mechanisms and related tasks, and efficient methods for energy-saving systems. The authors in [82] explored the trade-off of the energy performance for consolidation, which resulted in the desired workload distribution across servers and saves energy. The authors of [83] summarized the strategies used for economic and green cloud based on multi-tenancy, dynamic provisioning, server utilization, and data center efficiency.

Regarding green cloud computing, the relationships and similarities are discussed between service rate, packet arrival rate, and response time for efficiency improvement in power cost and server utilization [97]. However, a VM scheduling algorithm plays a vital role in greening cloud computing, which leads to energy consumption minimization [98, 99]. In the case of [98], a machine algorithm is used for migration of loads of hosts, dynamic voltage frequency scaling, and shutdown of underutilized host features. The result of using algorithms led to improving power consumption. Cloud computing availability in smart cities could help ease big data storage, transforming in real-time data processing, and analyzing in real-time. Therefore, cloud computing will enhance speed, sharpness, and cost savings by providing network access on demand for sharing computing resources, which can be scaled as required and rapidly provisioned. The combination of IoT and cloud computing plays a vital role in healthcare applications such as disease prediction intelligently in smart cities [100].

Furthermore, [101] presented an intelligent model for healthcare services in smart cities using parallel particle swarm optimization and particle swarm optimization. The proposed model solves task scheduling, reduce medical requests execution time, and maximize medical resources utilization. The economic benefits and costs were discussed in [102] based on the combination of AI, cloud computing, and IoT. The authors of [91] proposed fog, cloud, and IoT to mitigate processing loads, reduce cost and time.

2.2 Communication network for smart cities

Greening wireless communication technologies play a crucial role in making IoT greener. Green communications refer to sustainable, energy-efficient, energy-aware, environmentally aware communications. The idea of a green communication network is referring to low CO_2 emissions, low radiation exposure, and low energy consumption. In [103], the authors proposed a genetic algorithm optimization for the network planning, where the finding showed significantly CO_2 reduction cost and low radiation exposure. The idea supported by a study in [104], discussed how to maximize the data rate, minimize CO_2 emissions in cognitive WSNs. In addition to the work of authors [103, 104], Chan et al. [105] provided several models to evaluate the use-phase power consumption and CO_2 emissions of wireless telecommunication networks. The designing of Vehicular Ad hoc NETworks (VANETs) was proposed to decrease energy consumption [106].

The investigation of the energy efficiency in 5G based mobile communication networks are presented in three aspects, i.e., theory models, application, and technology developments [107]. Furthermore, Abrol et al. [108] showed the influence and the growing technologies supporting the energy efficiency of Next Generation Networks (NGN) technology. The need for adopting energy efficiency and CO_2 emission is to increase capacity, enhance data rate, and improve QoS of the NGN. Several researchers have addressed solar for saving energy and enhancing QoS, such as [27, 39, 109–112], reliable storage for saving energy [113]. Furthermore, the stochastic geometry approach is applied to achieve energy efficiency and maintaining QoS [114].

Moreover, the utility-based adaptive duty cycle algorithm proposed to reduce delay, increase energy efficiency, and keep a long lifetime [115]. However, the hypertext transfer protocol was applied to minimize delay and enhance the lifetime for providing reliability [116]. The development

Table 6 Summaries of cloud computing techniques and strategies for smart cities

Ref	Techniques and strategies	Advantages
[41] (2016)	Integration of sensor and cloud	–Reducing energy consumption
[92] (2017)	MMDD	– Lower cost – Less delivery time
[82] (2008)	A heuristic for multi–dimensional bin packing	– Energy consumption, –Satisfy performance requirements
[93] (2012)	Dynamic provisioning, multi–tenancy, server utilization, and data center efficiency	– Minimize the power consumption – Increase environmental sustainability
[94] (2012)	Energy consumption model	–Save energy and reduce adverse environmental impacts – Identify the relationship between energy consumption and running tasks
[97] (2013)	Workload Scheduling	– Maximum recommended utilization – Management cost
[98] (2011)	The virtual machine scheduling algorithm	–Minimization of energy consumption in task executions
[100] (2019)	Machine learning	– Predicting diseases in smart cities
[101] (2019)	Parallel particle swarm optimization and particle swarm optimization	– Solve task scheduling – Reduce the medical requests execution time – Reducing medical resources utilization

of wireless communication will improve a next-generation network's performance according to the requirements based on decreasing energy usage, reducing the emission of CO_2 for providing a healthy environment, and green cities.

5G focuses on reducing energy utilization and results to green communication with healthy environments. In 2020, the prediction of green communication is observed that all communication devices and objects will communicate effectively and efficiently using smart and green techniques for a healthy and green life. 5G technology is essential for enhancing the reliability and improving QoS of communication among machines and humans. Also, 5G technology supports a large area's connectivity, reduces latency, saves energy, and provides higher data rate. The services of 5G for our society are including robotics communication, e-health, interaction human and robotics, media,transport and logistics, e-learning, public safety, e-governance, automotive and industrial systems, etc.[117–120].

Many techniques have been used for energy harvesting and energy-efficient methods discussed in [121]. Regarding energy-saving methods, Wang et al. [122] proposed a resource allocation approach for minimizing the network's energy rate. Maximizing the power-efficiency was by relay station with subcarrier for an orthogonal frequency division multiple access. However, the energy efficiency was optimized by using an energy-efficient incentive resource allocation technique for enhancing the cooperation of communication networks [123], in which the combination of genetic and water drops method for improving energy consumption effectively and efficiently.

Regarding harvesting energy, many studies focus on greening the communication network based on harvested energy, such as [124–126]. In [124], the authors focused on resource allocation techniques used for maximizing the energy efficiency of the green cognitive radio network. Furthermore, Ge et al. [125] discussed the cognitive radio network secured based on multiple-input single-output using to minim transmit the information signal's power. However, Zheng et al. [126] introduced the smart grid's performance and power consumption based on analyzing IEEE802.11ah. The authors [127] introduced different techniques for greening communication networks in term of energy-efficiency metrics. The power consumption of the network equipment has taken into account transparency and accuracy [128]. Yang et al. [129] differentiated renewable and non-renewable energy for green internet routing. However, Hoque et al. [130] examined techniques to enhance mobile hand-held devices' energy efficiency. Table 7 summaries the used techniques and strategies in a communication network for smart cities.

2.2.1 Wireless sensor network for smart cities

The combination of sensing and wireless communication has led to WSNs. WSNs have been used in many applications such as fire detection [132–134], object tracking [135–137], environmental monitoring [138–142], evolving constraints in the military [143], control machine health, and monitoring industrial process [121]. WSNs represent the critical technology that has made IoT

Table 7 Summaries of the communication network techniques and strategies for smart cities

Ref	Technique	Advantages
[122] (2018)	Energy–efficient	– Maximizing the energy–efficient
[123] (2018)	Resource allocation	– Maximizing the energy–efficient – Enhancing the cooperation of communication networks
[124] (2018)	Green cognitive radios	– Minim transmit power of the information signal
[126] (2018)	Smart grid	–The enhanced power consumption of smart grid
[131] (2020)	Edge computing	–Reduces traffic flow from and to edge computing by using relying communication protocol based on node–to–node.

flourish. A sensor combines an enormous number of small, low-power, and low-cost electronic devices [139]. WSN components are including base stations or sinks and a large number of sensors nodes. The sensor node consists of communication unit, sensing unit, processing unit, and power unit [139]. Sensor nodes are used to measuring global and local environments such as pollution, weather, healthcare, agricultural fields, and so on. Sensors also communicate via wireless channels and deliver the nearest base station's sensory data using ad-hoc technology. The authors of [144, 145] introduced sleep mode for saving sensor power for a long time and supporting green IoT. For energy conservation of WSNs, Khalil et al. proposed the nearest most used routing algorithm, in which the nearest node is active (transmit and receive data), and the rest of the nodes are in sleep mode and keep sensing in idle mode [146] . Therefore, any node wanting to send data to another node, it will wake up all the nodes along to its roots and then send data accordingly.

Consequently, when the sending data finished, all the nodes will be reset to sleep mode. Sensors can utilize energy harvested directly from the environment, such as the sun, vibrations, kinetic energy, temperature differentials, etc. [147–152]. Also, the combination of WSN and energy harvested technologies plays a vital role in the green world [153], on account of energy harvesting is cost comparable with long batteries life. Many techniques are enabling sensor networks for green IoT, such as sensing selection [154], energy overheads for context-aware sensing [155], and sleeping schedule [156] to save energy, reduce the communication delay between sensors nodes.

Battery power is considered the most critical resource in WSN that directly influences network lifetime. Thus, the main goal is to reduce energy consumption and contribute reliable/robust transmission without compromising the overall QoS [203]. The idea of energy efficiency is supported by Mehmood et al. [157], which introduced routing protocols for energy efficiency. Similarly, Rani et al. [158] discussed flexible IoT and the designing hierarchical network's energy-efficiency. In addition to [58, 157], the authors in [159] introduced green WSN to improve routing and lifetime of WSN. However, the authors of [158] discussed green WSN for enabling greening IoT based on increasing energy efficiency, reducing relay nodes, extending the network lifetime, and improving the system budget.

Furthermore, the authors of [160] investigated a cooperative approach to save energy for greening WSNs. A collaborative approach is based on the cluster technique in which multi-hop works as a relay station to ensure the communication between sensors. Furthermore, energy consumption and network resilience provisioning are discussed for enhancing green WSN for fog computing platforms [161]. Four steps implemented this work: the creation of hierarchical system frameworks, sensor/actuator nodes localization, nodes clustering, creation of optimization model to realize green IoT, and finally the computing the discovering the minimal energy routing path. The results showed that the proposed approach was pliable, energy-saving, and cost-effective. Furthermore, it applies to the different type of IoT applications such as smart city and smart farming applications.

Mahapatra et al. [162] introduced wake-up radio, error control coding, wireless energy harvesting to enhance the performance of green WSNs while minimizing the CO_2 emissions. Furthermore, the combination of WSN and cloud computing leads to a decrease in demanded high power consumption and CO_2 emission, which significantly affects the environment [163]. A balanced tree-based WSN is designed for network lifetime maximization and reduces sensor nodes' energy consumption [164]. However, the green cooperative cognitive radio was proposed in WSN [104]. Also, Araujo et al. [165] proposed cognitive WSN for reducing a large amount of power. Their work was demonstrated and evaluated in three scenarios to enable the development of power reductions and green protocols for cognitive WSN. Regarding green WSN, the following techniques could be adopted [22, 95, 116, 166] such as sleep and active sensor nodes to save energy consumption, energy depletion, optimization of radio techniques, data reduction mechanisms and energy-efficient routing techniques, hybrid transmission protocol to maximize lifetime reliability.

Table 8 summarizes the used techniques and strategies in WSN for smart cities.

Smart cities are recently suffering from several problems such as traffic, pollution, waste management, and high energy consumption. The rapid development and sustainability solutions demand increasing mobility in order to improve environmental impacts. The authors [167] introduced smart mobility with autonomous vehicles and connected and discussed smart cities' challenges. The advantages of mobility for enhancing smart cities' sustainability are discussed [168], including increasing people's safety, reducing noise pollution, reducing pollution, improving transfer speed, reducing traffic, and reducing the transferring costs. Furthermore, [169] discussed how information shared with IoT help in a sustainable value chain network.

3 Efficient energy for smart cities

The drone plays an essential role in greening IoT. It provides efficient energy utilization and hence reducing IoT device's power consumption. For sending data over long distances, IoT devices need high transmission power. Therefore, the drone can move towards closer to IoT devices to collect data, processing data, and sending data to another device that is in another place. Authors in [170] introduced a genetic algorithm for improving drone-assisted IoT devices based on energy consumption, sensor density, fly risk level, and flight time. Furthermore, Mozaffari et al. [171] evaluated the optimal values for small drone cells' altitude, which leads to the maximum coverage area and minimum transmit power.

Processing in each machine is the primary object of IoT equipment. Drone-equipped IoT devices are used to capture data, process, analyze, manage, storge, and deliver to the cloud. The combination of drones and WSN was discussed [172]. The framework of drone and WSN is composed of sensor nodes, fixed-group leaders, and drone-Sink. The finding was that the election process and energy consumption were reduced. The techniques of drone-based WSN for data collection were discussed [173]. The used procedures were able to reduce flying time, energy consumption, and latency of data collection. The authors in [174] introduced an algorithm for data collection of WSNs by using mobile agents and drones. Therefore, drones and mobile agents are contributed to save time and reduce sensor nodes' energy consumption. Also, Zorbas et al. [175] developed a mathematical model for the energy efficiency of IoT devices. The developed model's performance detects the events that happened on the ground with minimizing power consumption in the coverage area. Furthermore, Sharma et al. [176] introduced drones' cooperation with WSN to provide energy-efficient relaying for a better life.

Table 8 Summaries of WSN techniques and strategies for smart cities

Ref	Techniques	Advantages
[163]	Sensor and cloud computing	– Reduce energy consumption and harmful effects of computing resources.
[164] (2018)	Balanced tree node switching	– Counterbracing the energy consumption among the sensor nodes – Improving network's lifetime
[116] (2017)	Hybrid transmission protocol	– Save energy near the sink areas – Enhance the delay and network reliability.
[153] (2015)	WSN with an energy harvest	– Green world – Provide long life to WSN nodes
[144, 145] (2002, 2013)	Duty–cycling	– Save energy
[156] (2015)	Duty–cycling scheduling	– Save energy – Reduce the communication delay between sensors nodes.
[160] (2012)	Cluster technique	–Save energy for greening WSNs
[165] (2012)	Cognitive WSN	– Reduce a large amount of power used – Green protocols
[146] (2012)	Shortest path	– Energy conservation
[161] (2018)	Application profile and self–heal based on events	– Energy consumption – Network resilience provisioning
[24] (2019)	Intelligent transportation	– Optimize network capacity, – Reduce congestion – Increase safety – Reduce pollution

The power needed for a drone is found that energy-efficient components in emerging technologies can improve the energy efficiency [177]. Choi et al. [178] formulated the drone efficient energy based relaying by taking into consideration the traffic load and speed factors. On the other hand, the wired drone docking system was developed to perform several functions via the collaboration of drone and IoT devices for reducing wasted resources, reducing energy consumption, and ensuring transmission security [179]. Moreover, Seo et al. [180] proposed drones for IoT monitoring, security platform, and emergency response in buildings by utilizing beacons.The authors in [181] developed an automatic battery replacement mechanism of drone battery lifetime. An automatic battery was used in drones to operate without battery manual replacement.

The selection of the shortest path for packet transmission plays an important role in conserving energy and high efficiency. Engergy 4.0 fault diagnosis framework was presented based on wind turbines [182]. For improving WSN efficiency, intelligent path optimization is proposed to maximize the rate of network utilization and create the shortest routing path [183]. The proposed method shows significant improvement in traffic load and network utilization rate for enhancing network performance.

Mahapatra et al. [184] discussed smart homes' energy management for making sustainable and green smart cities. Furthermore, the authors proposed NN-based Q–learning for efficient energy management in Canadian homes by decreasing the peak load. Big data analytics represents the most critical part of developing smart city applications. IoT devices are intended to improve smart cities, where they are connected to improve life quality. Therefore, authors in [185] introduced a new protocol QoS –IoT to reduce the delay of collecting big data from sensors nodes in smart cities and enhance energy efficiency. The study in [91] discusses an essential issue related to IoT devices' hardware lifespan in smart cities and energy conservation. Table 9 summarizes the techniques and strategies for energy-efficient for smart cities.

Table 9 Advantages of energy-efficient for smart cities

Ref.	Advantages
[183] (2017)	–Select the shortest path for energy efficiency and enhancing the network performance
[185] (2018)	–Develop protocol of QoS– IoT to conceive energy for a long lifetime of sensors.
[186] (2020)	–Management energy efficiency in smart cities

4 Reducing pollution hazardous in smart cities

Recently, monitoring air pollution has become the ultimate essential issue in our environment, life and society. Smart sensors are utilized for pollution monitoring. However, their transmission power is limited for sending data in real-time. Therefore, these sensors can be carried by drones, and it will be easy for gathering data and sending to the destination in real-time. Thus, Villa et al. [187] developed the best way for gas sensors and a particle number concentration monitor onboard a hexacopter. The authors showed that developed drone system was capable of identifying the point source emissions. The study focuses on airflow behavior and evaluates CO, NO, CO_2, and NO_2 sensors for monitoring the pollution emissions in a particular area. The potential drone applications explore for interacting with sensor devices to perform remote crop monitoring, soil moisture sensing, water quality monitoring, infrastructure monitoring, and remote sensor deployment [165, 188]. The greenhouse pollution should also be considered for controlling the gas emission from the greenhouse. Hamilton et al. [189] introduced a solar-powered drone carried CO_2 sensing integrated with a WSN. The authors of [190] proposed drone for remote autonomous food safety and quality. Due to the dynamic and flexible deployment, air pollution monitoring has been found suitable as one of many applications [191, 192]. Authors in [193], reviewed the existing techniques for drone monitoring applications. Furthermore, author of [194] proposed drones equipped with off-the-shelf sensors for tracking tasks, but they ignored the guidance system. To solve this issue, few authors suggested adopting the pollution-based drone control system. It was based on the chemotaxis meta heuristic and PSO technique, which monitors certain areas on the most polluted zones [195]. Authors [196] proposed drone equipped Pixhawk Autopilot to control the drone and a Raspberry Pi for storing and sensing environmental pollution data. Furthermore, authors in [197] developed an efficient drone platform model to monitor multiple air pollutants. Also, Šmídl et al. [198] developed the idea of autonomously navigated drones for pollution monitoring. Authors remonstrated the applications of the drone platform in air pollution. It was focusing on air pollution profiling of roadside and air pollution episodes in emergency monitoring. Furthermore, Zang et al. [199] demonstrated experiences in applying drones to investigate water pollution in Southwest China because of low air pressure, high altitude, severe weather, strong air turbulence, and clouds over. Furthermore, the prediction of carbon footprint in ICT sectors was discussed in [200].

Air pollution is one of the impact of climate change.

However, drone technology currently represent the key technology for monitoring air pollution in order to improve life quality in smart cities. It is used for many scenarios to monitor air pollution and predict air pollution.

5 Waste management in smart cities

Smart cities are running to become smarter and greener. Therefore, companies and governments are searching for efficient solutions to maximize the collection level using intelligent techniques and smart devices, i.e., smart sensors, cloud platforms, IoT, etc. Therefore, Gutierrez et al. [201] introduced intelligent waste collection cyber-physical system for smart cities based on IoT sensing prototype. IoT sensing prototype measures the waste level in trash bins and sends data to the cloud over the Internet for processing and storage. Based on the collected data, the optimization process can efficiently and dynamically manage the waste collection by forwarding the worker's necessary action. The authors focused on improving the strategies of waste collection efficacy in real-time through ensuring that when the trash bins were full, the workers would collect in real-time, and therefore, the waste overflow was reduced. Thus, IoT has enabled waste monitoring and management solutions in smart cities within the connected sensors implemented in the container.

Moreover, creating a comprehensive system can help to make cities smarter, healthier, and greener. Hence, the smart waste management (SWM) system helps in decision-making and processing, ensuring the employers follow the procedures and enhance waste collection services delivery [202]. The SWM system was analyzed in the public university, such as Oradea University [203]. The designed system at Oradea University was to reduce pollution, protect the environment, and encourage recycling. Employing the SWM at Oradea University was significantly enhanced. Moreover, the authors in [204] presented ICT application for smart management in Europe and Italy's circular economy. Likewise, The authors in [205–208] [205–208] discussed SWM includes IoT technology for smart cities application.

The smart city development system is essential for automated waste collection. Companies and governments are looking for an efficient solution for collecting all kinds of waste using smart IoT devices, edge intelligence, cloud, etc. Therefore, designing, implementing, and developing an automated system to collect waste is required to increase usage, storage, and production capacity. IoT can improve automated waste collection systems by providing real-time monitoring and communication with the cloud. Furthermore, the authors in [209] focused on increasing automated waste collection systems and improved productivity and capacity. They studied how the system could be integrated with the infrastructure of the smart city. Here, IoT allowed real-time monitoring and data collection in real-time and connected with a cloud of the automated waste collection system. IoT plays a vital role in enhancing the system's performance by connecting devices and processing and analyzing data in real-time. Therefore, the proposed system could monitor the different types of waste in the containers in real-time. The proposed system helped provide the total amount of waste collected in containers, and optimal discharging equipment status, the optimized route for waste discharged storage system status. However, exploring the possibilities of increasing profit and productivity in waste collection architectures can be considered for future work. In [210], the authors introduced the existing Italian legislation tools that aimed toward sustainable waste management for smart cities. The waste management technique should foresee the hazard level and the quantity reduction of waste for sustainable development in smart cities.

To enhance environmental protection, and achieve increased efficiency, handle waste for sustainable smart cities is required. Many technologies control waste, such as automatic waste collection, recycling rate, route optimization, and renewable energy. In the case of automated waste collection, IoT devices such as sensors that produced alarms in case of the container are filled up and need to be serviced, thus mange the waste efficiently. Furthermore, smart in-vehicle monitoring makes the waste process faster and ensuring driver safety. IoT is the new technology that can be used for waste management and provide an efficient solution in different ways such as IoT software in waste management, cost efficiency, waste collection, and reduce Greenhouse gas emissions. Furthermore, advanced technologies such as AI and IoT have immensely contributed to reducing the cost and complexity of automated waste systems via improving efficiency, productivity, and safety and minimizing environmental impacts. Disposed waste represents a challenge due to health issues.

6 Sustainability in smart cities

Urban planning has become essential for our very survival in the development of sustainable and green smart cities. Maintaining the wellbeing of every citizen and health are significant factors. The areas are integrated with human right down to waste disposal. Levels of obesity are low, and then the citizens mental health is positive. The structure and design of sustainable green cities are directly connected with human health as well as wellbeing. Through smart networking and environmentally friendly habitats ecological resources are examined, maintained, and environmental benefits are immense. These technologies applications are not for making human life healthy only but also healthy trees, wildlife, and plants. Energy-efficient practices are the key in a green sustainable city. The smart and green disposal techniques help curtail the catastrophic dilemma of green-house gas emissions.

Furthermore, water and food have an impact on growing sustainable smart cities. The role of clean water is vital to the economy in smart cities' development. Integrated advanced technologies play a crucial role in creating the relationship between government, citizens, environment, ecosystems, infrastructure, and resource utilization. Therefore, sustainable and green cities lead to change in technical and social innovations. On the other hand, sustainable and green cities are also referring to green spaces and smart agricultural resources. Renewable resources, reducing the ecological footprint, and reducing pollution are necessary to keep the city smart and green. IoT plays a vital role in improving smart cities to become more livable, resilient, green, and sustainable.

IoT and smart city technology represent the critical key for developing society and improving life quality. A smart city is created on an intelligent framework and complex manner of ubiquitous networks, objects, government, and connectivity to send and receive data. The data gathered in a cloud of smart cities of any application is managed and analyzed accordingly, for decision making based on the available data, and transform action in real-time to improve the way we work and live. The study [211] finds out an analysis of the smart cities' role in making sustainable cities. It is mainly focused on air quality, green energy, renewable, energy efficiency, water quality, and environmental monitoring.

Green IoT plays a vital role in smart cities to make it a greener and sustainable place for working and living. Green IoT techniques and technologies achieve good performance in big data analysis, making smart cities significantly safer, smarter, and more sustainable. The authors of [212] discussed the big data achievements in improving life quality by reducing pollution and utilizing resources more efficiently. For managing resources utilized by IoT for sustainable and green smart cities, the authors of [213] introduced delay tolerant streaming and hybrid adaptive bandwidth and power techniques during media transmission in a smart city. Furthermore, the authors of [214] discussed a sustainable green-IoT environment. However, in [215] the authors presented greening the technologies process for sustainable smart cities by exploring the greening IoT in improving the environment, life quality, and economy while minimizing the negative impact on the environment and human health.

A smart sustainable city uses ICT to improve life quality, the efficiency of urban services and operation, and competitiveness while ensuring that it meets present and future generations' economic, social, and environmental needs. A sustainable smart city is an innovative city that uses ICT and IoT technologies to improve life quality, service quality, and competitiveness. Furthermore, it ensures meeting the need of the present and future people regarding social, economic, cultural, and environmental aspects. Due to many people shifting to live in urban and smart cities, the energy resource management, sustainability and sharing, and utilities of emerging technologies need further discussion. Furthermore, addressing the requirements are the most important such as optimizing resources management, growth of business potential, environmental impact, and improving peoples' life quality

7 Future directions

The upcoming cutting edge disruptive technologies with efficient techniques and strategies will change our future ambience to become healthier, smarter, and greener, delivering very high QoS. This tomorrow would be sustainable environmentally, socially, and economically. The following research fields will seek in depth investigation to improvise and optimize existing solutions for improving smart cities more efficiently.

7.1 Drones for gathering data from the smart cities

The drone is a promising technology which can improvise many real-time applications. Drone technology is a promising solution for making IoT green from both IoT power consumption and device recharging points of views. For example, drones will reduce power consumption of the IoT devices by getting closer to the nodes during data gathering, capture pollution data from agricultural farm lands, and support real-time traffic monitoring and mitigation. Therefore, drones will lead to greener IoT at low cost and with high efficiency and penetration. For pollution monitoring, few IoT devices can be carried out as payloads on a drone to capture real-time data from a large area, and cover different areas dynamically, in a time division mode for energy saving and economy in management expenditures.

Drones can contribute directly in reducing E-waste by wirelessly recharging the IoT devices, enhancing their lifetime. This is particularly useful in large IoT deployments wherein replacing batteries in the massive number of IoT devices would be impractical, thus new deployments would be considered resulting in producing E-waste.

7.2 Transmission data

The data transmission from sensors to the mobile cloud is more beneficial. Sensor-cloud model is now integrating the WSN with the mobile cloud. It is an upcoming technology for greening IoT to improve the sustainability of smart cities. Furthermore, a green social network as a service (SNaaS) may improve the system's energy efficiency, service provisioning, sensor networks, and management of the WSN on the cloud.

7.3 Networking

It may be perceived from literature that attaining outstanding performance and high QoS on the network is the future direction for green IoT. Finding suitable and efficient techniques for improving QoS parameters (i.e., bandwidth, delay, and throughput) can efficiently improve the smart city's eco-friendliness. Furthermore, researches are required to design IoT networks which help in reducing CO_2 emission and energy usage. The most critical tasks requiring urgent attention for smart and eco-friendly environment include energy efficiency, resource utilization, and CO_2 emission reduction.

7.4 Sustainable environment

While shaping up a sustainable and eco-friendly network environment for future, it will require less energy demand, newer resources and minimization of the negative impact of IoT on the health of the humankind without disturbing the environment. While machines are getting connected to machines via the Internet to reduce energy, smart devices have to be smarter and greener to enable automation in smart city. Therefore, machine based automation delays can be reduced in case of traffic and taking immediate action. Furthermore, during the machine to machine communication, energy balancing is required in which the radio frequency energy harvesting should be taken into consideration.

7.5 Waste management

Briefly, the future directions in waste management can be categorized based on enabling impacts, emerging technologies, and objectives. Waste gathering and recovery infrastructure have to focus on the automatizing process, implement the best practices with values. IoT devices and technologies have received enough attention in the smart cities domain. Waste management and smart communities need to be addressed and defined. In emerging technologies, smart cities propose to use many smart devices based on processing and computing capabilities that support green automation, monitoring and data collection. In enabling factors, planning, society, economics are essential to understand the waste management platform and creating value from the controlled collection and disposal of waste. Furthermore, the waste management and collection of smart city infrastructures should be taken into considerations. The connection between waste management and smart communities' activities need to be addressed in a coherent manner.

7.6 Big data

The challenge in the accumulated big data is the prediction and estimation of the required energy for analysis of the gathered data. Rapid analysis of big data may be taken into consideration. If the volume of big data increases, it will increase the exponential scale-up of the cost and resources required for the analysis. Hence, big data analytics may be considered to enhance the prediction of energy efficiency versus the improvement of the life quality [202]. Deep learning techniques can be applied to getting accurate estimation for energy efficiency and the ways to reduce it further to meet greener ranges of system design and deployments. Table 10 summaries the comparison of recent studies with suggestion for future improvement.

8 Opportunities

Smart cities' technologies bring many advantages by using IoT devices such as sensors, actuators, wearable devices. To improve smart cities, autonomous cars with potential services enabled by vehicle to vehicle and vehicle to internet wireless communication is a technology disruption. It will change the ways in which taxies have been run and owned thus far. For example, improving traffic flow and reducing accidents via intelligent systems and collaborative IoT devices will enhance communication with autonomous cars. Furthermore, autonomous vehicles can also get passengers in demand based on loading and unloading areas. Moreover, improving traffic flow can allow public service to optimize evacuation planning in natural disasters [225–227]. In order to make our life easier, machine learning and IoT devices are necessary for improving efficiency. Smarter waste management, using IoT technology, utilizes the consideration of our waste disposal by data gathered and how much waste is produced to collect data and then use collected data to implement models to reduce waste in the nearest future by recycling and separation. Today, IoT technology plays a vital role in making city cleaner, healthier, and happier citizens. Improving healthcare and quality of life via the monitoring of environment, air quality, and reduce health stress. Therefore, there are many

Table 10 Summaries of recent studies with suggestion for future improvement

Ref	Section	Highlighted	Suggestions for Improvement in future
[86] (2020)	ICT	Power distribution real time decision-making basis for smart cities.	Combination of advanced technologies can support
[89] (2020)		Renewable energy optimization for utilization of energy usage	smart building automation for smart cities
[100] (2019)		Daisies predication using machine learning based IoT and cloud computing	Applying machine learning edge computing leads to energy efficiency and QoS
[101] (2019)		Swarm intelligence improving smart healthcare in smart cities	Bringing swarm closer to healthcare lead to reduce energy consumption
[124] (2018)		Green cognitive radios for minimizing transmission power of the information signal	Trading QoS and energy efficiency can build green system
[131] (2020)		Edge computing for improving end-to-end nodes	Blockchain can provide high level security to improve green and smart cities
[216] (2020)		Green Smart Cities via IoT	ICT with QoS and energy efficiency improvement need to be addressed
[217] (2021)		Techniques and tools for Green and resources sustainability in smart cities	Advanced technologies such as blockchain,digital twins can be used in order to improve green and resources sustainability in smart cities.
[24] (2017)	Energy efficiency	Intelligent transportation for reducing pollution and increasing energy efficiency	Sustainability should be considered for future work
[164] (2018)		Counter bracing the energy consumption among the sensor nodes for improving network's lifetime	Identifying more real datasets in order to testout the model behavior.
[218] (2021)		electricity from renewableenergy sources	Applying energy efficiency measures wouldbe necessary.
[219] (2020)		IoT for constructing a greenWSN in smart city	ML can be used to reduce data transferring to the CHs for reducing energy consumption
[185] (2018)	Pollution	Develop protocol of QoS- IoT toconceive energy for a longlifetime of sensors	Reducing throughput variation
[186] (2020)		Management energy efficiency insmart cities	Managing energy of heterogenous grid
[220] (2020)		Identifying green zones toimprove life quality	Using drone technology to capture data and make decision in area the emission increased
[209] (2017)	Waste management	Automated Waste CollectionIn smart citiies	increase productivity and profit in wastecollection
[221] (2020)		waste management for modernsmart and green cities	green technology can only be accomplished in harmony with the well-determined behavioral attitudes of smart city residents together with the usage of green and smart city technologies
[222] (2020)		Smart Waste Bin Monitoring using IoT	Blockchain can be used to improve decentralized system
[213] (2019)	Sustainability	Green IoT for smarter and saferand sustainable cities	Green IoT and Big data
[223] (2021)		Sustainable smart cities dimension	Limited in internet radio
[214] (2020)		resource management of IoT based sustainable and green smart cities	deep learning for Green by enhancing battery lifetime in smart city during data transmission
[224] (2020)		Sustainable smart cities using AI.	Deep learning for decision-making that increases cities' perceived value.

opportunities for prospective future to create a smarter, healthier, greener, and happier citizen, leading to a cleaner, greener planet.

9 Conclusion

Tremendous developments of various technologies in the 21st century has improved life quality in smart cities. Recently, IoT technology has demonstrated heightened benefits in enhancing our life quality in smart cities. However, the technologies development demands high energy accompanied by unintentional e-waste and pollution emissions. This survey studied the strategies and techniques to improve our life quality by making the cities smarter, greener, sustainable, and safer. In specific, we highlighted the green IoT for efficient resource utilization, creating a sustainable, reducing energy consumption, reducing pollution, and reducing e-waste. This survey provided a practical insight for anyone who wishes to find out research in the field of eco-friendly and sustainable city- based on emerging IoT technologies. Based on the critical factors of enabling technologies, the smart things in smart cities become smarter to perform their tasks autonomously. These things communicate among themselves and humans with efficient bandwidth utilization, energy efficiency, mitigation of hazardous emissions, and reducing e-waste to make the city eco-friendly and sustainable. We also identified the challenges and prospective future research direction in developing eco-friendly and sustainable smart cities.

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