Role of Smart Cities in Creating Sustainable Cities and Communities: A Systematic Literature Review

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Abstract. Seventeen United Nations Development Goals (UN SDG) focus on peace and prosperity for people and the planet. Smart cities can help in achieving UN SDG. This research carries out a comprehensive analysis of the role of smart cities on creating sustainable cities and communities, which is one of 17 UN sustainable goals. Current research focuses on number of aspect of sustainable environment such as renewable and green energy, energy efficiency, environmental monitoring, air quality, and water quality. This study provides a valuable synthesis of the relevant literature on smart cities by analysing and discussing the key findings from existing research on issues of smart cities in creating sustainable cities and communities. The findings of this study can provide an informative framework for research on smart cities for academics and practitioners.

Keywords: Smart cities · Literature review · Sustainable development goals

1 Introduction

The United Nation developed Sustainability Development Goals in 2015, which aim to achieve peace and prosperity for people and the planet, focusing on the present and the future. As a result 17 goals were established aiming to act as an urgent call for action for countries all over the world [1]. The SDG emphasise that ending poverty and other deprivations must go hand-in-hand with strategies to improve health and education, reduce inequality, and engender economic growth whilst tackling climate change and preserving our forests and oceans [1]. Some researchers proposed that smart cities have the potential to deliver many of the UN Sustainability Development goals [2–5].

A city is defined as smart if it "balances economic, social, and environmental development, and if it links up to democratic processes through a participatory government. A smart city involves the implementation and deployment of information and communication technology (ICT) infrastructures to support social and urban growth through improving the economy, citizens' involvement and government efficiency" [6].

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Examples of smart cities include Busan (South Korea), London (United Kingdom), Santander (Spain) to name a few. Technology spending on smart cities initiatives worldwide is currently $81 billion and predicted to reach $158 billion in 2022 [7]. The smart cities topic attracted significant attention from both academics and practitioners. This is evidenced by the growing number of research outputs within academic journals, books and conference proceedings. Some studies provided comprehensive literature review on smart cities [8–11] and barriers affecting its development [12]. Even though these existing reviews provided a timely overview of the overall subject area, there is a lack of studies focusing on the connection of the concept of smart cities and UN SDG goals. Thus this study aims to bridge this gap in the literature by conducting a comprehensive analysis of the role of smart cities on creating sustainable cities and communities, which is one of the 17 UN sustainable goals. The findings of this study can provide an informative framework for research on smart cities for academics and practitioners.

The remaining sections of this study are organised as follows. Section 2 provides a brief overview of the methods used to identify relevant studies to be included in this review. Section 3 synthesises the studies identified in the previous section and provides their detailed overview and analysis. Finally the study is concluded in Sect. 4 by discussing the key aspect of the research, challenges faced by smart cities in creating sustainable cities and communities, and outlining limitations of the current research and proposing further directions.

2 Literature Search Method

This research used a keyword search based approach in order to identify relevant studies on smart cities [4]. The following keywords were used: “Smart City” OR “Smart Cities” OR “Digital City” OR “Information City” OR “Intelligent City” OR “Knowledge-based City” OR “Ubiquitous City” OR “Wired City” in Scopus database. As a result 1473 articles were identified. By going through each of the articles manually 40 articles were selected which focused on sustainable cities and communities. The selected studies appeared in 33 separate journals, including Management Journals, Engineering Journals, and Urban studies journals. It demonstrates that smart cities attracted attention of researchers from multiple disciplines.

3 Literature Synthesis

The studies on smart cities focusing on SDG sustainable cities and communities goal were divided into the following themes: renewable and green energy, energy efficiency, air quality, environment monitoring and water quality monitoring (see Table 1). The following subsections provide overview of each theme.

Table 1. Themes in smart cities research

Theme	Studies
Renewable and green energy	[13–19]
Energy efficiency	[20–41]
Environment monitoring	[42, 43]
Air quality	[44–48]
Water quality monitoring	[2, 49, 50]

3.1 Renewable Energy

The concept of smart cities involves specifically modified infrastructure of energy, which is mainly distributed in the form of electricity. Power system provides the core functionality to many important entities of the cities such as telecom networks, wireless sensor network, water distribution, waste management, mobility, route guidance, public healthcare, information amenities and others. The power system operation has to be optimised by being intelligent and environmental friendly [13]. It can be reached by including renewable resources and green ICT systems which help to achieve greater energy efficiency. The use of renewable and efficient energy will lead to climate improvement. Number of studies focused on renewable and smart energy for smart cities [13–19].

A study by Aamir et al. [13] focused on implementation of smart grids. Smart grid places ICN into electricity generation, distribution, and consumption. As a result, the system becomes more clean, secure, reliable, and efficient. The proposed framework can provide a simulation platform for detailed study of power system. It will help to deal with issues such as susceptibility of failure, critical situations and restoration scheme by adding renewable energy resources. Thus, the framework can be used in a simulation platform for analysing power system operation in smart cities. It can also be used to develop operational algorithms to optimize the generation, transmission and distribution schemes and taking advantage of smart infrastructure in a more effective manner. The calculation of Locational Marginal Prices is mandatory as prices vary by location in case of congestion. It will be resulted in more economic dispatch of electricity as most of the contingent conditions will be resolved in proactive manner. A study by Sanchez-Miralles et al. [18] discusses the use of renewable energy systems for distributed generation for households or districts. The authors reviewed the main renewable energies and companion technologies and investigated their current economic feasibility. As a result a simplified architecture is presented, which consists of three interconnected layers, the intelligence layer, the communication layer and the infrastructure layer.

Smart energy is one of the most important components of smart cities, which includes electricity generation, transmission and distribution [15, 51]. Main goals of smart cities are to reduce energy consumption, provide renewable energy and reduce carbon footprints. The study by Ahuja and Khosla [15] proposes a hierarchical architecture to solve the problem of lacking of necessary interoperability and integration of communication standards, which affect successful deployment of communication networks. The proposed system aims to support smart energy system infrastructure and help smart cities to provide ubiquitous communication. The system consists of two computing zones. First is fog computing which will help to reduce latency response to anomalous and hazardous events in real time. Second is cloud computing which will provide access to data from anywhere for deep analysis.

Studies on green energy focused on two types of energy: solar and wind. A study by Abdullah et al. [14] focuses on wind energy as one of the renewable sources, which has advantage such as sustainability and being environmentally friendly. The authors proposed an improved one-power-point solution maximum power point tracking algorithm for wind energy conversion system in order to overcome problems such as difficulty in getting a precise value of the optimum coefficient, requiring pre-knowledge of system parameters, and non-uniqueness of the optimum curve. The proposed solution is based on the combination of two algorithms: the particle swarm optimisation and optimum-relation based MPPT algorithms. By using MATLAB/Simulink simulation and experiments the study proved that the proposed algorithm demonstrates the improved performance in terms of tracking efficiency and energy extracted.

Wang et al. [19] focus on solar energy and wind energy, by presenting the approach of maximising their use in the cities, as there is a problem of utilization of wind turbine generators in the cities due to their large volumes and safety issues. The authors designed a hybridized nanogenerator, which includes collar cell and a triboelectic nanogenerator. It allows to scavenge solar and wind energies by installing these nanogenerators on the roofs of the city buildings. The hybridized nanogenerator has better performance than the individual solar and wind generators.

Barresi [16] also focused on solar energy. The study proposed the solutions for urban planners how to ensure that unobstructed flow of solar energy through adjacent lots when designing a particular urban area. The study also defined ordinances specifying the standards for the exact size and location of the easement and indicating limitations on buildings or structures that could prevent the passage of light through it. These solutions will increase flexibility for the integration of solar and local energy sources.

Hung and Peng [17] proposed green-energy water-autonomous greenhouse system, which is more responsive and efficient as an alternative-technology approach towards sustainable, smart-green vertical greening in smart cities. Future studies should establish a real model of prototype for conducting experimental studies.

3.2 Energy Efficiency

Some of the studies focused on improving energy efficiency in smart cities [20–41]. For example, study by Peña et al. [37] proposed a new method to solve the problem of energy efficiency anomalies in smart buildings. The proposed solution is based on a rule-based system, which is developed by using data mining techniques and applying knowledge of energy efficiency experts. The result of this work provided a set of rules which can be used a part of a decision support system for the improving energy consumption and the detection of anomalies in smart buildings by controlling the activation of devices and minimising power taking into consideration different requirements of users. Battista et al. [21] aimed to define the approach for assessment of building energy savings. The study used a single building located in Rio de Janeiro. They calculated the annual energy demands through dynamic software. Additionally, different energy efficiency interventions were simulated. After this, a graph was created to summarize the energy demand percentage variations as a function of the selected parameter variation, such as solar absorbance coefficient, vertical and horizontal surface thermal transmittance and window g-value. Based on the results of this study, it will be possible to choose the most effective building intervention.

Jung et al. [30] also focus on energy efficiency of buildings in the city. However, they argue that not just energy efficient devices to equip buildings are important but also an efficient management. The study measures the energy consumption and environmental data through establishing a Building Energy Management System. The proposed technologies will integrate real-time energy consumption monitoring with Building Energy Information Modeling. By using Genetic Algorithms an optimal energy-saving method was found. The study plans to apply the proposed energy optimization tool to the micro-energy grid system in the future. A study by Sanseverino et al. [39] is focusing on sustainable territorial planning, by investigating the possibility to draft a basic structure on Municipal Building Regulations. It will help to guide local administrators and technicians and limit discretionary power of bureaucracy. Brundu et al. [23] proposed and tested an IoT software infrastructure enabling energy management and simulation of new control policies in a city district. The platforms allow the interoperability and the correlation of real-time building energy profiles with environmental data from sensors, buildings and grid models. This will simulate novel energy policies at district level and provide optimization of the energy usage. After the testing platform in real world it was found that this platform is suitable to run energy distribution policies simulations from the district level down to the building room level, with a special focus on both district energy savings and end-user comfort level.

Calvillo et al. [24] also focused on buildings, as one of the bigger energy users of the city. The paper proposed a linear programming model which finds optimal operation and planning of distributed energy sources in a residential district. The proposed model was successfully tested using data from Madrid. Another study by Caponio et al. [25] is focusing on buildings for improving their energy efficiency. The study proposed a simulation model based on System Dynamic applied to a medium-sized Italian city. The proposed model enables the testing of "what-if" scenarios and analysing the result of implementing energy efficiency policies. Obtained results demonstrate the importance of a holistic view of urban energy process. The simulation trends can be used as essential information for the city's future energy and carbon emission profiles. It will help policymakers to accomplish their goals. Carli et al. [26] proposed decision process which will help the city energy manager and local policy makers use decision from one urban sector on another.

Zhang [40] proposed a novel routing algorithm named as power controlled and stability-based routing protocol (PCSR). The proposed protocol aims to improve the energy efficiency and route stability. The power for transmitting both control packers and datagrams is reduced in PCSR. By using expensive simulations the findings show that proposed PCSR consumes less energy and extends network lifetime with guaranteed packet delivery. Alzahrani and Ejaz [20] propose a resource management scheme for cognitive IoT network with radio frequency energy harvesting in 5G networks, which can improve spectral efficiency and accommodate a large number of IoT devices. The study applies mixed linear programming and greedy approaches in order to solve the optimization problem. The proposed scheme is tested by using simulation and shows the significant positive impact on the performance of the IoT network.

Bhati et al. [22] focused on the ways how Singapore household perceive smart technology and their usage to reduce energy consumption. By suing interviews and case studies the research found that the behavioural patterns of consumers may not change in order to save energy. Some individuals will still prefer comfort and security over their concerns about environment and energy saving. As a result the study demonstrated the gap in the designing technology, which does not take into consideration people's behaviours and perceptions when designing smart home design functionality.

Kai et al. [31] studied device-to-device (D2D) communication which helps to improve data rate and reduce power consumption, D2D allows two physically nearby located user equipment to communicate directly with each other. Authors aim to achieve green communications by using D2D. Thus, they investigated the joint optimization of uplink subcarrier assignment (SA) and power allocation (PA) in D2D underlying cellular networks. Orsino et al. [35] also focused on D2D communications. The study adapted the Modulation and Coding Scheme on the communication links in order to maximise the radio resource utilization as a function of the total amount of data to be sent. As a result, the transmission power will be reduced when a robust modulation and coding scheme is applied.

Lu et al. [32] investigated the joint optimization of subcarrier grouping, subcarrier pairing, and power allocation such that the transmission rate performance is maximized with the energy harvesting constraint. The joint optimization problem is solved via dual decomposition after transforming it into an equivalent convex optimization problem. Simulation results tested with the real wireless sensor networks system data indicate.

Maier [33] provides a comprehensive methodology for planning and assessing the development of 'smart' energy systems leading to complex energy provision technology networks using different on-site as well as off-site resources. The results of the study can be used to form smart energy supply solutions as an integral part for the discussion of the stakeholders (investors, city department) to guide the forming of their action plan through the development of the city quarter.

Mohapatra et al. [34] proposed dynamic cluster-head scheme and modified LEACH protocol. By using simulation it was found that the proposed system ensures minimal energy waste and consolidated a green model for smart cities. The study proposes that future research should focus on existing fault diagnosis protocols for incorporating dynamic faults in the network.

The study by Pardo-García et al. [36] presents the design and development of the innovative SuperCity Platform which makes cities sustainable. The platform is transparent and user friendly which can be used by non-technical staff, such as politicians. Also, it enables the assessment of urban policies and measures by using holistic optimisation of the whole energy system towards low carbon energy system. As the proposed model is generic it can be applied to any cities. Pardo-García et al. [36] claim that it is important to create a platform for users with different level of expertise, which can improve communication between city actors.

Pirisi et al. [38] presented the optimization of a Tubular Permanent Magnetic-Linear Generator for energy harvesting from vehicles. The optimization process is developed by means of hybrid evolutionary algorithms to reach the best overall system efficiency and the impact on the environment and transportation systems. The proposed system is experimentally validated. Zhu et al. [41] presented energy savings algorithms (network-wide energy-saving algorithms and customer-side energy-saving algorithm), which can be used by cable operators in order to enhance the energy efficiency of cable access networking using channel bonding. The numerical results of this study suggest that effective energy saving can be achieved in wideband cable access networks with the proposed algorithms, and the packet delay and protocol overhead can be reduced if the key parameters are chosen properly.

Causone et al. [27] discusses the importance of establishing appropriate key performance indicators for different aspects of the cities, such as economy, education, environment etc. The study focuses on creating KPI to assess the energy performance of cities and to determine if energy is used with appropriate and smart approaches. The study proposed exergy as an indicator of the energy quality, which offers a quantitative basis to measure the degradation of energy (the decrease of its capacity to generate useful work) in conversion process. Causone et al. [27] used data collected from European cities to access the possibilities and limitations of the proposed KPI.

Chui et al. [28] focus on artificial intelligence and by investigating ways it can provide support in providing sustainable energy in smart cities. By conducting pilot study and creating prototypes this paper examined smart metering and non-intrusive load monitoring (NILM) to propose NILM value added in context of profiling electric appliances' electricity consumption.

Colmenar-Santos et al. [29] focused on energy storage system with high power density. The authors designed an electrical and control adaptation circuit for storing energy, which consisted of three blocks (passive filter, converter system, chopper). By using simulations the study found the possibility of controlling the energy supply as well as storage. These findings enable to adapt to different contingencies which may include the wiring of the charge in the new and different types of charges. However, the disadvantages of this system can be high cost of manufacturing and maintenance in comparison with other cheaper systems.

3.3 Environmental Monitoring

Some studies focus on the importance of environment monitoring in smart cities [43]. For example Dwevedi et al. [43] identified six environmental factors, such as landscape and geography, climate, atmospheric pollution, water resources, energy resources, and urban green spaces for Smart City Mission in India. These factors should be integrated in the development of smart cities and to be included in the monitoring system, which will be available through online platform to public to ensure that the society can participate in identifying the problems and offering help with the solutions.

Bacco et al. [42] also focused on monitoring environment of cities. They proposed and successfully tested environment monitoring system in Pisa, Italy. The system was based on a cost-effective, distributed and efficient sensor network for collecting, processing and distributed data about the air quality. The system has fixed and mobile sensor nodes. To support objective information from sensor nodes the system allows the citizens to provide additional subjective information, such as comments, pictures and videos. The information from citizens is then stored on the central host of the proposed architecture and can be correlated with the data collected by nodes. The system calculates Air Quality Index, Thermal Comfort Index and Traffic Index. After, this information is available to all stakeholders interested in receiving timely updates on the air quality in the city (e.g. city governors, local authorities, citizens).

3.4 Air Quality

Air pollution is one of the main threats for developed societies [45]. Based on the data from World Health organisation, pollution is considered as the main cause of deaths for under five years old children [45]. Number of studies investigated how to monitor and improve air quality in cities using smart technologies [44–48]. Marek et al. [44] conducted a case study of monitoring air quality in post-earthquake Chirstchurch, New Zealand. The project focused on near real-time monitoring of air pollution in fine scale and its association with respiratory diseases. The intention of the project was to create the continuous air pollution surface of the city in real time and provide the data as an interactive dynamic map and the raw data stream. The data was collected using a grid of four dustmote devices and low cost IoT air quality sensors. The air quality data is designed to be provided to all citizens and interested stakeholders in primary forms and in the form of maps and tables. It aims to engage citizens to check information about air quality in the way which is easy to understand. Also, citizens can check and understand their individual exposure.

Data collection in smart cities is possible by employing sensors. However, data obtaining through sensors can have errors. As a result, it is important to develop a model which can predict values of interest in order to control air quality. Martínez-España et al. [45] analysed different machine learning techniques to predict ozone levels (Random Forest, Random Committee, Bagging and KNN) and obtained the best model which can predict ozone levels (Random Forest). As a result, if the sensors fail to record the data correctly, the model can predict with the least possible error the amount of ozone in the air to create a warning in case of the recommended thresholds levels are exceeded. The test of the proposed model was conducted in four cities at the Region of Murcia (Spain) by using real data from 4 stations for air quality measurement. This model can help to predict pollution levels and to establish thresholds and action plans for local authorities and industries. The future work can focus on automatic generation of recommendation to local authorities, drivers and other stakeholders about the impact of air-quality factors according to the alerts raised by the system.

Smart cities infrastructure provides information about air quality using data from low-cost sensors, which can report information in a timely and accurate manner. This information can be used to propose solutions to mitigation strategies to reduce pollution. Miles et al. [46] proposed a decision support system which can monitor air quality, forecast atmospheric pollution, as well as suggest and implement pollution reducing strategies in real time using IoT. This decision support system can help and improve decisions of policy makers and engineers on planning of urban landscapes. The proposed decision making system is using traffic model as the input to an atmospheric model to create predictors of traffic-related atmospheric pollution levels. Also, this system can evaluate of different scenarios of how pollution levels would change when mitigation strategies that change existing conditions are implemented. The strength of this proposed system is that all required information could be gathered for different locations and the system will not be limited to a single location. As a result, it can be generalised and used in other cities. Future research can focus of simulation of more complex areas such as street canyons. Another study by Ramos et al. [47] aims to improve citizens' awareness about air pollution by offering pollution-free routes. The study applied a technology-agnostic method using air quality sensor networks, which allows creating pollution-free routes in real time across cities depending on the level of air pollution in each zone of the city. In order to develop and validate the proposed framework the study used Madrid's air quality sensor network. The system can propose the routes for pedestrians, cyclists or any vehicle. Future studies could extend a routing application into a mobile application and try to render the interpolation layer as 3D surfaces.

In smart cities data is generated and collected by sensors, which represent what is happening in the city in real time [48]. Correct and timely analysis and use of these data is important. Zaree and Honarvar [48] argue that big data mining is the most effective method for analysing this data. The study uses a K-means clustering algorithm employing the Mahout library as a big data mining tool. By using this tool Zaree and Honarvar [48] aim to increase speed and accuracy in predicting real levels of air pollution, its location, and effects of weather conditions on density of air pollution. The results indicate that temperature, low air pressure, relative increase in moisture and wind spend are causes of low pollution density at the cleanest point of the city. In order to obtain more reliable results the study aims to employ the fuzzy clustering algorithm of the Mahout library in the future research.

Finding the most polluted and cleanest areas of the city can improve environment and citizen's quality of life [48]. To be able to control air pollution is one of the main advantages of smart cities. By identifying polluted areas in real time will help manage the city. By decreasing air pollution, cities can reduce diseases like brain stroke, cardiac diseases, lung cancer, and asthma [48].

3.5 Water Quality Monitoring

Safe drinking water is a life-enabling resource, but it is a difficult task to manage its quality in crowded cities [52, 53]. Nowadays cities are faced with challenges such as old water infrastructure, expensive maintenance costs, new contaminants, and increasing water demand due to rising population level [53, 54]. As a result, cities need an effective water management system. Some researchers investigated how advanced ICT based systems can improve the quality of drinking water around the word [2, 50]. For instance, a study by Corbett and Mellouli [2] developed conceptual model, which expands the role of IS in building smart sustainable cities. The model was developed based on the data from interviews. The model explains the interactions between three interrelated spheres such as administrative, political and sustainability. After, to demonstrate the applicability of this model the study used two real-word scenarios. Also, this study focused on public green spaces, which are an essential part of sustainable cities as they provide different types of benefits, including aesthetic, environmental and health to name a few. Sun et al. [50] introduced a Bayesian network model for water controlling system. The model was successfully tested by using experiments. Another study by Chen and Han [49] proposed the quality monitoring system for Bristol is Open using wireless communication and data processing, storage and redistribution. The system includes data acquisition, data transmission, data storage and data visualisation with the help of cloud computing.

4 Conclusion and Limitations

The aim of this research was to provide a systematic review of the literature on the role smart cities play in achieving the UN SDG sustainable cities and communities goal. From the growing literature on smart cities it can be seen that the development and growth of smart cities can help to achieve many UN development goals. Based on the reviewed literature it is suggested that sustainability within smart cities is covered within the smart environmental theme. Current research reviewed the number of studies which focused on these issues. The studies focused on energy for smart cities, particularly on renewable and green energy [13–15], and energy efficiency [20–22]. Also, the reviewed studies paid attention to the environment monitoring [42, 43], air quality [44–46], and water quality [2, 49, 50]. For the city environment to be sustainable it is important to monitor the quality of water and air and also use energy resources efficiently. Thus monitoring, management, evaluation and use of the smart environment are important and can be achieved by using information and communication technologies, such as IoT and cloud computing. The following are a summary of the key observations emerging from this literature review:

- Most of the studies on sustainability of smart cities are focusing on energy efficiency, particularly on energy efficiency of buildings.
- In systematically reviewing 40 publications on smart cities it was observed that many do not rely on case related empirical data. Studies generally base they results on simulations.
- IoT and cloud computing are the technologies discussed in relation to sustainability of smart cities.
- The concept of smart cities has the full potential to deliver the UN SDG sustainable cities and communities goal.

Cities are facing multiple challenges while trying to become sustainable. Most of the proposed systems to monitor the environment are not publicly available and require expert knowledge to use and understand them. Future research should develop more user friendly systems so citizens can be informed about the environment in the places they live and be able to participate in the decision making process about future actions connected to the planning, development and improvement of smart cities infrastructure. Also, policymakers should be able to use this information for policy formulation and making the decision about the environment of the city.

Some of frameworks for improving environment in the cities as proposed by a number of studies, can be limited to their application in particular cities and/or regions [22, 42]. Future studies should try to propose solutions which can be generalised and used by a large number of cities. Additionally, there can be some technological challenges for all cities to implement and adopt the proposed solutions for sustainable environment. The level of technology development, technological skills and readiness to adopt new technologies and solutions can impact the implementation of sustainable technologies especially in case of emerging market countries. Thus, it is important to propose solutions for these countries.

Also, current studies focused mostly on parameters that can influence air quality such as temperature, humidity, and wind [42, 45–48]. Future studies should focus on other parameters such as sulphur dioxide, PM10 Particles, and Nitrogen Dioxide. Finally, with the increasing number of natural hazards and climate-related challenges [43], it is important to find a way of using resources and provisioning for the future generations.

This study has a number of limitations. Only publications from the Scopus database were included in literature analysis and synthesis. Additionally, this research focused on 1 UN sustainable goal. It is recommended that future research will conduct systematic literature review (adapting approach from [4, 55–61]) around the remaining 16 UN sustainable goals, to provide a comprehensive and informative framework for research on smart cities for academics and practitioners.

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