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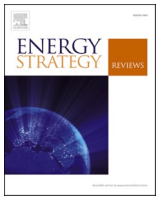

The key role of clean energy and technology in smart cities development

Armin Razmjoo [a], Amir H. Gandomi [b,*], Mehdi Pazhoohesh [c], Seyedali Mirjalili [d,e], Mostafa Rezaei [f]

[a] Escola Técnica Superior DÉnginyeria Industrial de Barcelona (ETSEIB), Universitat Politécnica de Catalunya (UPC), Av. Diagonal, 64708028, Barcelona, Spain
[b] Faculty of Engineering & Information Technology, University of Technology Sydney, Ultimo, NSW, 2007, Australia
[c] School of Engineering and Sustainable Development, De Montfort University, The Gateway, Leicester, LE1 9BH, UK
[d] Centre for Artificial Intelligence Research and Optimisation, Torrens University Australia, Australia
[e] Yonsei Frontier Lab, Yonsei University, Seoul, South Korea
[f] Queensland Micro- and Nanotechnology Centre, Griffith University, Australia

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ABSTRACT

Humanity is currently facing immense challenges related to the reduction of CO_2 emissions and satisfying energy demand whilst mitigating environmental impacts, hence, developing smart cities is one of the most important goals for every country. This paper presents a comprehensive discussion on smart city development across successful cities including London, Singapore, Barcelona, New York, Melbourne, Amsterdam, Dubai, and Helsinki, highlighting the importance of appropriate policies in overcoming barriers and creating solutions with regard to the importance of clean energy in each section. This paper focuses on three sectors: Energy, Transport, and Buildings. This research aims to illustrate fruitful pathways for smart city development based on these successful cities in using appropriate policies and strategies to overcome the relative hurdles often limiting these three important sectors in improving and achieving the necessary development for smart city status. Additionally, the stakeholder cooperation with the local government has a prominent role in carrying and executing the ideas of the politicians and the energy experts for more utilization of clean energy in different sections as a proper policy in smart city development.

1. Introduction

With humanity facing critical challenges, such as global warming and population growth, the move toward smart cities has become a necessity [1]. Despite the benefits of smart cities, the path toward developing such cities has many barriers [2] and therefore, implementation of appropriate policies and planning are crucial to its success [3]. Additionally, prudent management of urban resources, including appropriate infrastructure in energy [4], transportation, and buildings [5] are essential aspects of smart cities. In this regard, the role of clean energy is remarkable and needed to provide comfort and well-being for citizens [6]. In fact, the utilization of clean energy for the reduction of CO_2 emissions is a decisive role [7]. Furthermore, ensuring high security and quality of urban services across numerous sectors, such as housing, telecommunication, mobility, transportation, telecommunication, lighting, and leisure are also important factors for inhabitants [8]. This paper seeks to investigate the smart city development along with relative appropriate policies in terms of energy, transport as well as building sectors across nominated successful cities. In this respect, previous studies have attempted to present the appropriate policies for smart cities development in successful projects. For example, Zvolska et al. [9], studied four important subjects including city as provider, city as consumer, city as regulator, and city as an enabler. Kim et al. [10], investigated the importance of technologies for smart cities. Thornbush, M et al. [11], carried out a study on the importance of city-energy-sustainability nexus based on smart energy cities. Hoang et al. [12], conducted an analysis on the major elements of renewable energy resources such as design tools, efficiency, and the prospect of integrating renewables in a smart city. Larsen et al. [13], scrutinised the performance of initiatives that rely on a smart approach through the integration of various technologies in demand-side management for 16 Danish households. Further investigations on Effective policies to overcome barriers in the development of smart cities can be found in Kontokosta et al. [14], and Razmjoo et al. [15], the spatial and socio-economic configurations of smart city development in Mert Duyganet al. [16], recent advances, taxonomy, and open challenges in

* Corresponding author.
E-mail address: gandomi@uts.edu.au (A.H. Gandomi).

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smart city governance in Zheng et al. [17],. In addition, Lausselet et al. [18], Noori et al. [19], and Ji et al. [20], explored life cycle assessment and the scenario of net-zero GHG emission neighborhoods for Norway, pathways for smart city development in smart city projects for Amsterdam, Barcelona, and Dubai, and the perceptions on smart-city services and citizens' preferences in Taiwan, respectively.

2. Motivation

To improve the quality of services, and provide market signal feedback to users, cities need to start their transition into smart cities [21]. Fortunately, appropriate measures have been taken so far in line with smart cities adoption which will, without a doubt, lead to the effective deployment of smart cities. Actions such as the utilization of the Internet of Things in order to enhance and improve energy management, municipal services or public security, traffic management, and the resilience of buildings can be considered an imperative part of improving the life quality of citizens. The novelties of the work include a comprehensive review of smart cities as a concept, investigating the key role technology that plays in energy sectors (non-renewable energy and renewable energy), transport, and building sectors. The study also explores the policies implemented across several successful smart cities and extracts the reason behind their success to make recommendations for future studies.

3. Methodology

The objective of this paper is to provide more accurate insight into smart city development with regard to the importance of clean energy. This is achieved through a review of the success of previously implemented policies across other countries in overcoming the barriers and providing appropriate solutions for various sectors. There are three significant sectors believed to be fundamental in achieving smart cities, which include energy, transport, and buildings. The work is structured as follows: First, we have introduced smart cities comprehensively through the review of relative studies. Following the literature review, the aims of this study are clarified. The key role of enabling technologies in smart cities is provided (subsection 4.1), along with the effective policies related to energy, transportation, and buildings (4.2.1). In section 5, we have a discussion section and explain about several successful cities are used as case studies where their policies and consequent success are discussed. To obtain the information required for the study, we have conducted an exhaustive review of the most recent articles published, including review papers, technical papers, and scientific reports, which are summarized in Fig. 1. These studies enhanced our knowledge and understanding of appropriate policies and required action in transitioning a city to a successful smart city.

4. Results

Six aspects of smart cities are important: smart people, smart governance, smart living, smart mobility, smart environment, and smart economy. All these divisions are equally significant and intertwined and integrating them is of vital importance in creating a smart city. Thus, this figure shows that each of these six sections needs what actions to achieve progress [22]. In this section, we first discuss the key role technology plays in smart cities, followed by the role of government and proper policy implementation in the development of smart cities relative to energy, transport, and building sectors.

4.1. The key role of enabling technologies in smart cities

With the ever-increasing population, cities of all sizes are beginning to use an array of technologies [23], including advanced data analytics, wireless communication systems, low-cost sensors, and data-actuated devices, to operate more intelligently and this approach is expected to have a remarkable role in developing them and improving the quality of life for their residents [24,25]. Therefore, the accelerated development of new technologies, such as 5G [26], cloud [27], Artificial Intelligence (AI) [28], and edge computing [29] is a leap forward to improve the evolution of smart cities. In addition, the use of technologies such as IoT is effective in monitoring energy consumption, detecting the amount of CO_2 and nitrogen, measuring pH levels and sulfur oxides, accurately monitoring transport systems, and enhancing the lighting schedule to prevent loss of energy. Traffic management assists with not only reaching a higher level of safety and punctuality but also managing ventilation, lighting,and adjusting loads across smart cities. Fig. 2 illustrates the fundamentals of technologies in smart cities. These technologies address many key challenges, such as pollution, crime, and traffic congestion which finally lead to reducing the costs of a vast array of government services and improvement of life quality for citizens.

4.1.1. Effective policy related to energy, transportation, and green buildings

Most of the existing energy is consumed in cities. Consequently, countries are always faced with serious problems with energy generation to satisfy demand, including (but not limited to); high prices and

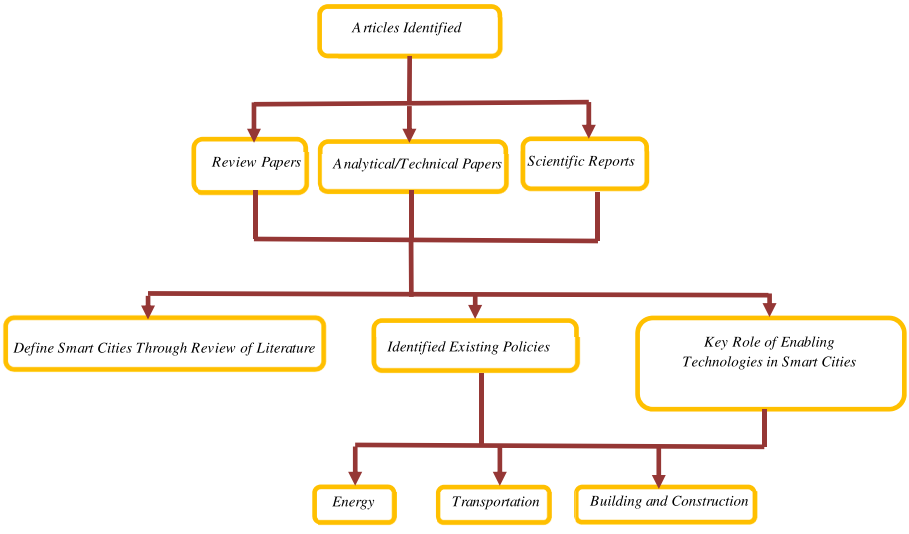

Fig. 1. Methodology of the current study.

Fig. 2. Enabling Technologies in Smart City.

CO_2 emissions [30]. On the other hand, policymakers are eager to offer safe and sustainable energy options for smart cities in order to improve environmental conditions and the health status of citizens [31]. The Energy Policy from one perspective can be categorized as Energy Access, Environment, and Energy Security. Under the Energy Access Group, it is important to address energy poverty by providing energy access to all [32]. Thus, smart energy for smart cities is provided through the use of new tools such as smart meters. This is an important and effective approach to efficiently integrating, managing, and monitoring renewables as the main source of energy, whilst advancing energy efficiency and reducing energy use [33]. Additionally, using new energy systems, such as small-scale Combined Heat and Power (CHP) with heat storage, PV-driven heat pumps for heat provision, and injecting bio-methane into grids is effective and appropriate in altering the current strategies to supply larger settlements [34]. In this regard, transportation and buildings are the two main biggest consumers in most countries. Therefore, improving the transport system across smart cities should be more considered by policymakers [35]. Because, smart transportation provides a high degree of welfare for citizens and reduces problems, such as traffic congestion and air pollution [36]. Therefore, the utilization of alternative vehicle technologies like electric vehicles (EVs) is considered to be one of the best approaches [37]. Additionally, the use of an intelligent transport system to integrate the intellect into vehicles through innovative tools allows the provision of smart communication between vehicles, which in turn permits smart transportation [38]. In fact, the utilization of an intelligent transport system is suitable for providing enhanced vehicle control, traffic management, advanced traveler information, and public rural transport [39,40]. Fig. 3 depicts the favorable sustainable transportation system in a city.

On the other hand, in new constructions, their energy consumption needs to be monitored carefully [41]. Also, new buildings can reduce energy consumption easily with monitoring systems. For example, Excess heat produced by buildings can be easily stored underground during hotter seasons and pumped back up during winter, effectively reducing energy consumption. Thereby, the utilization of such new technologies is effective in achieving this important target [42]. This can support the move in preventing energy waste, maximizing efficiencies, and reducing costs to develop energy-zero buildings with new technology [43]. In this regard, the implementation of BMS (Building

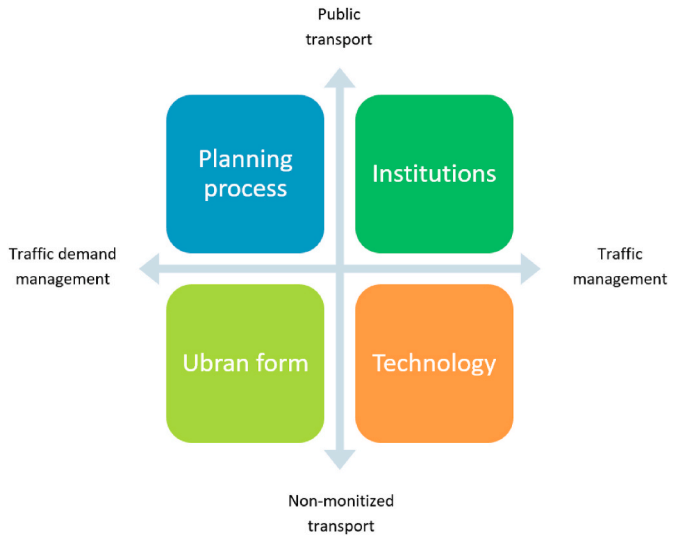

Fig. 3. Sustainable Transportation in a city .

management systems) using IoT systems to monitor the reduction in energy consumption, manage ventilation and lighting, adjust real-time electricity consumption, and adjust the loads for the energy grid are will be vital in the success of smart cities [44]. Fig. 4 demonstrates that the most important utilization of the energy, should be in the line of green energy and reduce carbon. Therefore, policies should be based on zero-carbon buildings.

5. Discussion

In this section, we describe how a city can become smart. To do so, eight successful examples of smart cities with high-quality strategies are mentioned as well as discussions on how they have succeeded in enhancing their levels and turning into a smart city.

5.1. 1. successful examples of smart cities

Successful cities are always a good example for researchers to study the transition to a smart city and highlight the policies that were implemented in this transition. In this section, we present and discuss how many cities have achieved success in smart city development. Table 1 shows several successful smart cities in implementing policies and strategies based on energy, transport, and building sections. The table presents the most important policies and strategies. Clear patterns and similarities are seen in policies and strategies across almost all cities whilst the differences are also identified and highlighted. The approaches stated in the table highlight what have been actions cities in the transition to a smart city.

Based on references [45–88], it can be inferred that the eight aforementioned cities have mainly invested in energy, transportation, and building sectors to enhance the life quality of their residents to become smart cities. In all cases, implementing suitable policies including expansion of the new technologies, improvements of infrastructure for energy sections, adoption of newest technologies related to transportation (e.g. electrical vehicles) and buildings (e.g. green buildings), increasing investment, utilization of renewable energy, expansion of energy storage systems, etc., has been regarded as important for their governments.

It is worth mentioning that the adopted policies in the eight smart cities vary case by case and depend on different situations like the climate, urban density, economy, etc. For example, Helsinki city is smaller than New York City, so the policies on higher urban density for these two cities are different. Also, the climate of London is generally cooler than Barcelona, so London needs stronger heating systems

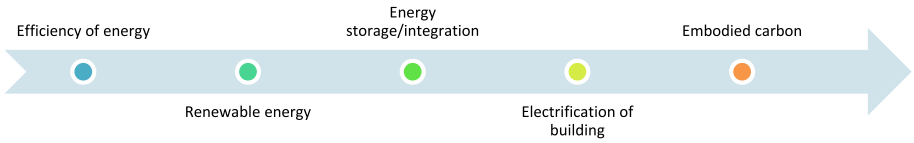

Fig. 4. The foundations of Zero Carbon Building Policies.

leading to a different policy from Barcelona in terms of household heating. For the same reason, Dubai, Melbourne, Amsterdam, and Singapore implemented different policies to become smart cities over the years. Also, to complete this table, we presented another table that shows the most important indexes in general that should be considered by policymakers and energy experts for these cities. It means that these indexes are able to improve the welfare level for the citizens in energy, transport, and building fields. Table 2 lists the key indexes in the fields of energy, transport, and buildings for the mentioned cities.

Regarding dilemmas such as traffic, air pollution, and long queues around businesses, streets, cinemas, and other places, the development of smart parking spots is one of the best strategies for policymakers in smart cities. Therefore, a smart parking solution based on IoT technology is one of the most up-to-date and newest answers to this urban problem, which greatly reduces the problems caused by the lack of parking space and allows citizens to plan and visit the desired location in a timely and hassle-free manner. In addition, systems with IoT technology are proven to be effective in waste management [89–91]. In fact, in the last years, regarding energy consumption (fossil fuels), and air pollution issue in urban zones leading to serious diseases and death, urban sustainability parameters have been changed. Therefore, today's policymakers are serious about the implementation of smart and eco-friendly solutions like mobility practices such as cycling, electrical vehicles (EVs), and smart parking. Therefore, policymakers have special attention to EVs that use Li batteries to develop smart cities provided that battery manufacturers consider sustainable materials for making EVs. In addition, smart parking solutions have potential benefits for the drivers and cities such as cost and time-efficient solutions, consumption of less fuel (it leads to less pollution), reduce search traffic on streets, and reduce parking stress. In general, it can be said, the utilization of EVs, and the expansion of smart parking can lead to less CO_2 emission, congested roads, and less urban energy use, and impressively reduce the negative feedback effects of crowded cities [92–94]. In addition, the utilization of proper policies such as allocating subsidies, improving infrastructure (EVs charging), and government initiatives, can encourage people to use EVs. Such policies lead to lowering overall urban energy use that provides by fossil fuels, and even it can correct the traffic network based on smart transportation methods. It means when people can use government support and be aware of EVs benefits, especially from the environmental point of view, will prefer the use of EVs to fossil fuels cars. Moreover, trips which are shorter in commute are easy to cover by non-motorized transport (NMT) which has also an economic Impact. All of these will lead to the correction of urban density being effective [95–98].

5.2. The critical role of local governments and stakeholders in smart city development

Without a doubt, in smart city development, engagement between the local government [99] and stakeholders is important and will affect the three important sections explained in this work [100]. In fact, stakeholders always have a tendency to have affordable energy, energy security, clean air, new transport systems, and low consumption technology, especially for buildings. In this regard, local governments with regard to their authorities and power are able to provide these [101]. On the other hand, stakeholders can help local government's further their goals by welcoming and enforcing the local governments' policies and achieving what they want easily [102]. Therefore, the decision that the municipality takes should be in support of the stakeholders [103]. Also, local government's can use the knowledge of the stakeholder easily because many of the stakeholders are experts and it can be an effective policy for local governments to the reduction of the issues and important challenges of the smart cities with their help [104]. For example, local governments agree with the investment in renewable energy in energy, transport, and buildings, and in this regard, stakeholders can if possible the more use EVs (Charging places) or public transport instead of car privates. Also, their buildings can be equipped with solar panels or small wind turbines on top (if there is a good situation). On the other hand, planning for smart city development especially in the energy field demands new stakeholders to participate although it causes the complexity of this process, there is a need for a new type of governance. In fact, stakeholders can participate in parallel activities regarding governance, and help with their responsibilities and assignments, of course after determining each contribution and responsibility. This can lead to project development without any issue in the city planning processes.

5.3. Comprehensive discussion based on findings of this work

In this section, we explore the objectives of the study and draw conclusions from reviewing the literature on the success of appropriate policies that can be suitable for future use in the transition to smart cities.

5.3.1. A review of the work

Climate change concerns [105] and environmental issues are two important issues for governments in city development [106]. In this regard, the role of smart cities is remarkable to overcome these issues. However, smart city development requires appropriate policies and strategies, thus policymakers and urban planners play a crucial role in transitioning cities [107]. The use of proper and effective policies can in fact accelerate the development of smart cities, and support the mitigation of major global challenges, such as CO_2 emission and concerns regarding the energy crisis [108]. This work has presented appropriate policies across successful cities in achieving targets of smart cities with emphasis on three important sectors: energy, transportation, and buildings energy which are believed to have the most impact on smart cities development. Across the energy sector, the use of new tools like smart meters has presented significant value in efficiently integrating, and monitoring the use of energy, whilst preventing or minimizing energy loss. Additionally, the use of the new energy systems such as small-scale Combined Heat and Power (CHP) with heat storage, PV-driven heat pumps for heat provision, and bio-methane injection into grids, has been effective and appropriate for larger settlements with high supply needs. Moreover, the utilization of air and water sensors in monitoring air and water quality to detect the amount of CO_2 and nitrogen is useful. In the transport section, the use of the internet of things, electric vehicles (EVs), and an intelligent transport system for traffic management, led to a higher level of safety and punctuality. In the building section, utilization of the IoT for monitoring purposes to reduce energy consumption, zero-energy building developments, management of ventilation and lighting, adjusting electricity consumption in real-time, and adjusting loads of the energy grid, are examples of appropriate and successful policies. However, beyond the renewable energy nature, the development of these strategies and implementation depend on policy area and needs to drive profound changes based on the terms of each country. This means that the development of clean energy

Table 1
Effective policies and strategies in the three sections are investigated across eight smart cities.

City	Energy	Transport	Building	Reference
London	Increased utilization of renewable energy, improving street lighting, use of high-speed affordable digital technology, re-usage of underground energy, smarter heating, and smart appliances, low consumers energy systems	Encourages clean and efficient transport, use of ICT systems, use of IoT technology (High-speed affordable digital), T-Charge for older more polluting vehicles, traffic lights, automatic traffic alerts	Increased utilization of cost-optimised zero-energy buildings, smarter heating, smart meters	[45–49]
Singapore	Increased use of digital technologies	Increase use of digital technologies, increased utilization of electrical vehicle	Increased use of digital technologies, development of green buildings	[50–53]
Barcelona	Increased utilization of renewable energy, smart lighting which entails sensor-controlled light-emitting diode (LED) lights, smart appliances	Utilization of global positioning system (GPS), traffic lights, automatic traffic alerts, Orthogonal bus system, Bicing, smart traffic lights	Smart meters, development of the green buildings	[16, 54–57]
New York	Increased use of renewable energy (Integrating renewable energy), green roof development, utilization of the energy-efficient streetlight system (LED)	Improved public transport using Bus (Transit Signal Priority (TSP), yellow taxis (mitigate the city's air pollution), bicycle sharing	Improved infrastructure, development of smart infrastructure, and green buildings	[58–64]
Melborne	Increased use of clean energy, expansion of the energy storage batteries	Increased use of electrical vehicle and bicycle	Improved infrastructures, development of smart infrastructure, and green buildings	[65–71]
Amsterdam	Utilization of renewable energy, development of smart grids	Smart (sensor and actuator equipped) roads, bicycles, EVs (Electric Vehicles), autonomous driving, car-sharing, improvement of digital road, car sharing	Smart meters, increase the development of energy-efficient buildings and energy storage for households	[16,45, 72–74]
Dubai	Utilization of renewable energy	Smart (sensor and actuator equipped)	Smart meters, increase energy-efficient	[16, 75–77]
Helsinki	Increased use of clean energy	Increased region intelligent traffic services, provided traffic information platform, raised the share of e-vehicles and buses, and rail transport	Smart meters, improve energy efficiency and construction of buildings, renovation of old buildings, increase public charging infrastructure, increase green roof	[45, 78–83]

Table 2
Most important indexes in the fields of energy, transport, and buildings for the mentioned cities.

Indexes
Increase investment
Improve the access electricity
Improve energy efficiency
Increase EVs
Monitoring of Electricity consumption
Reduction of CO_2 emission by increase renewable energy
Improve thermal comfort in buildings
Development of IoT Systems
Development of the smart meters systems
Proper infrastructure for transportation
Renewable energy production by buildings
Improvement of energy conservation
Improvement of the lighting efficiency in buildings
Development of renewable energy use
Improvement of environmental adaptability
Architectural flexibility for energy systems, transport, and buildings
Environmental friendly design of buildings
Monitoring of water and waste in buildings

using technology like photovoltaic systems for decreasing cooling requirements inside the building and electrical power generation requires proper policy, innovation, new ideas, and technologies accepted by people, presenting beneficial business models. Concerning the importance of investment in renewable energy, having an appropriate energy strategy approach based on relevant norms, which prioritize economic rationality, will lead to attracting commercial finance reducing investment costs, and moving toward sustainability goals. Therefore, local governments with regard to existing resources, knowledge, policy, and power, can convince the high-level officials to allocate enough budget in order to improve renewable energy development. On the other hand, the development of smart parking spots to reduce traffic, and noise in cities can be considered by policymakers. Also, the expansion of IoT systems to monitor waste management and lithium batteries for electrical vehicles are two effective strategies for developing smart cities.

6. Conclusion

Important challenges introduced by the need to reduce CO_2 emission and satisfy energy demand has led to the development of smart cities. This study aimed to identify and present effective policies related to the

energy, transport, and building sectors. After a comprehensive review of smart cities, we investigated the importance of technology across these three significant sectors. The advantages of using innovative solutions (i.e., technology and smart tools) across these three sectors were presented alongside the consequent impacts, effective policies, and strategies for eight smart cities in Table 1. Previous studies have illustrated the importance of using technologies and smart tools in improving the efficiency, and effectiveness of consequent outcomes across each sector. For instance, in the energy sector, the use of new technologies like smart meters has presented significant improvement in efficiently integrating, and monitoring renewable energy, whilst preventing and minimizing energy loss. Moreover, clear improvements are observed through the implementation of other technologies, such as small-scale Combined Heat and Power (CHP) with heat storage, PV-driven heat pumps for heat provision, bio-methane injection into grids for energy systems, or the use of air to monitor air and water quality to detect the amount of CO_2 over time. The utilization of IoT to enhance the lighting schedule and switch to brighter or dimmer in order to prevent loss of energy is an example of other technologies used across smart cities that were met with success. For the transport section, the use of electric vehicles (EVs) and an intelligent transport system for traffic management led to a higher level of safety and punctuality. Across the buildings sector, the use of IoT improved monitoring, which led to a reduction in energy consumption, adjustment of electricity consumption in real-time, managing ventilation and lighting, and adjustment of energy loads for the grids. It is important to review the success and failure of previously implemented policies, strategies, and even technologies. However, the needs of each country and city vary from one and another and so what works in one region or country might not necessarily be successful in another. Each policy and strategy should be based on the individual needs, goals, and targets of a country and its corresponding city. Whilst the available resources of a country should not be overlooked in policy and decision-making progress. For instance, the economic capacity of a country would, directly and indirectly, dictate the investment capacity of a city in transition to a smart city. Pairing increases the promotion and use of EVs with traffic sensors to optimize movement which has indicated great outcomes in previous case studies but might not be an affordable and viable solution for a developing country with severely limited capital funds, and extensive fossil fuel resources available at a cheap cost. Therefore the outcomes of the study can support further research once combined with comprehension and investigation of existing resources and individual needs. On the other hand, attention to stakeholders' needs by local governments and cooperation between them, especially the use of the stakeholders' knowledge by local governments, has positive effects on smart cities' development. In fact, based on the results of this paper, in the future, we aim to focus on the results of the solutions in order to implement fruitful policies in the line of green energy development easily and attract investment for developing clean energy in the three sections investigated in this work. We also emphasized that the use of smart parking, IoT technology for waste management, and lithium batteries for electrical vehicles would be suitable strategies for smart cities development.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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