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# Enabling technologies and sustainable smart cities

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ABSTRACT

The technological interventions in everyday processes has led to the rise of Smart ecosystems where all aspects of everyday life like governance, transportation, agriculture, logistics, maintenance, education and healthcare are automated in some way or the other and can be controlled, managed and accessed remotely with the help of smart devices. This has led to the concept of Smart cities where Information Communication and Technology (ICT) is merged with the existing traditional infrastructure of a city which is then coordinated and managed using digital technology. This idea of smart cities is slowly but surely coming into reality as many countries around the globe are adopting this idea and coming up with their own model of smart cities. At the core of smart city lies the sensors and actuators embedded in the smart devices that sense the environment for facilitating effective decision making. The microcontrollers available in these devices are programmed to take decisions automatically based on the information received from the sensors. This involves integration of several information and communication technologies like artificial intelligence, protocols, Internet of things (IoT), wireless sensor network (WSN) etc. This paper discusses and extensively reviews the role of enabling technologies in smart cities. The paper further highlights the challenges and limitations in the development of smart cities along with the mitigation strategies. Specifically, three categories of challenges are identified namely technical, socio-economic and environmental giving specifics of each category. Finally, some of the best practices for attaining sustainable smart cities are provided.

## 1. Introduction

The cutting edge technological advancements in today's world has helped realize the long awaited dream of a modern utopian world that aims to balance the traditional systems with advanced technological interventions. The technologies like artificial intelligence (AI), Internet of Things (IoT), machine learning (ML), deep learning (DL), cognitive computing and big data analytics have contributed immensely in the realization of this dream (Balakrishna, 2012; Guelzim, Obaidat, & Sadoun, 2016; Obaidat & Nicopolitidis, 2016). Smart city is one such hopeful project that has been adopted globally with an aim to make the lives of the habitants more convenient and inclusive (Nam & Pardo, 2011; Su, Li, & Fu, 2011).The idea is to use modern day technologies to convert every entity of a conventional city into an autonomous object performing its operation automatically without any substantial external help. All everyday processes like governance, policies, services and feedbacks are automated and the users are able to access these with the help of smart devices from anywhere around the globe. This automation has provided a decent help in curtailing the environmental hazards by means of applying environment friendly and cost-effective techniques. The core entities of a smart city consists of smart infrastructure, smart governance, smart policies, smart transportation, smart healthcare, smart agriculture, smart education, smart economy, smart environment, smart industry, smart energy and smart feedback mechanisms that helps to truly realize the concept of a smart city ecosystem (Balakrishna, 2012; Guelzim et al., 2016; Nam & Pardo, 2011; Obaidat & Nicopolitidis, 2016; Su et al., 2011). The word "smart" refers to an automated mechanism which is adopted to perform the desired activity within a domain. For example, in a smart home all gadgets and electric equipment (like fans, tube-lights, washing machines, HVAC systems, ovens etc) are embedded with miniature sensory devices that are able to sense the surrounding environment, collect information and transfer that information to the processing hubs where decisions can be taken with the help of dynamic rules and regulations. The locking and unlocking of doors and windows, switching the devices on and off are all automated and can be controlled with the help of small hand-held smart devices. Fig. 1 presents some of the major sub-systems in the smart city ecosystem (Balakrishna, 2012; Guelzim et al., 2016; Nam & Pardo,

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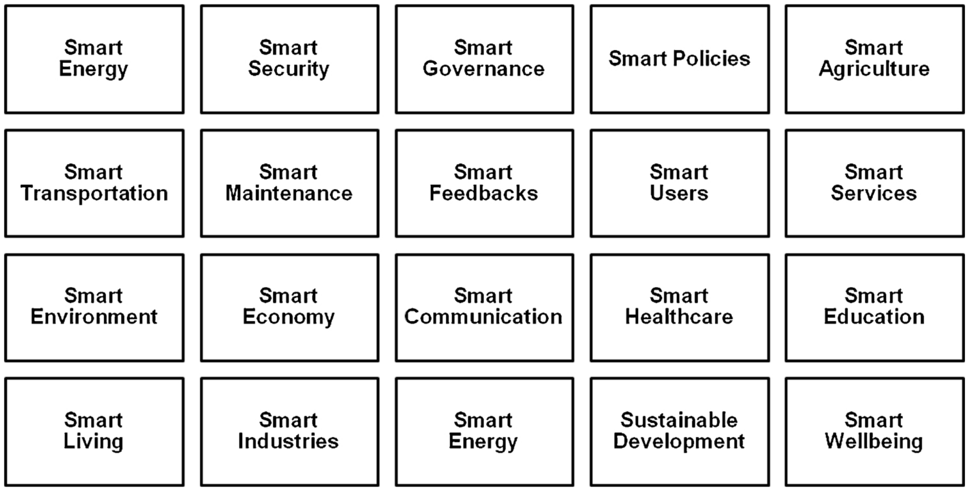


**Fig. 1.** Entities of a Smart City.

2011;Obaidat & Nicopolitidis, 2016; Su et al., 2011). Today, the notion of smart city has caught the attention of nearly every nation of the world including India. The Indian government launched the "Smart Cities Mission" in 2014 to set up 100 cities with state-of-the-art technology and infrastructure by the year 2022. According to Economic survey 2020 (Economic Times, 2020), upto 5151 projects are currently in different phases of deployment costing over rupees 2 lakh crore paving the way towards achieving India's aim of being a sustainable technology driven and highly productive nation to fuel economic growth and boost public living standards (Economic Times, 2020).

### *1.1. Our contribution*

The work presented in this paper discusses the smart city concept in light of technical, social and economical aspects. There are many published studies and researches in the area which discusses the smart city concept from the viewpoint of individual technology like IoT, blockchain, ICT etc. Our work focuses on modern day technologies and their role in the development of smart cities and provides an extensive and detailed review of state-of-the-art researches conducted in the smart city ecosystem. The paper contributes in the field by presenting a multidimensional review of the technical, socio-economic, demographical and natural-environmental factors that creates major challenges in the realization of a smart city. We also identified a comprehensive roadmap for achieving a smart city ecosystem covering its major aspects and entities. Considering the need for sustainability in today's world our work also focuses on the development of sustainable smart cities in a way where sustainability is at the centre of governance, policies, business, inhabitants and all other entities of the smart city systems. The paper further highlights the best practices that can be adopted by the various stakeholders including governments, users, manufacturers, retailers and designers for the effective implementation of smart city projects. Finally, the paper concludes by providing a detailed discussion and future research directions with respect to emerging concepts like quantum computing and nanotechnology. To the best of our knowledge this kind of review work has not yet been done in the field of smart cities ecosystem.

### *1.2. Organization of the manuscript*

The manuscript is divided into 6 sections. Section 2 provides the extensive literature review on smart cities and underlying issues and challenges. Section 3 discusses the enabling technologies in a smart city ecosystem focusing on their respective significance and associated challenges. Section 4 provides the issues and challenges associated with the development of smart cities. Section 5 highlights the concept of sustainable smart cities and discusses the concept of sustainability in multiple domains of a smart city ecosystem. The section also presents the roadmap for achieving sustainable smart cities by focusing on some of the best practices. The final Section 6 concludes the paper by providing a discussion and future research directions.

## 2. Literature review

There have been several proposals and frameworks for developing the concept of an effective smart city which emerged in recent years. This section reviews the state-of-the-art proposals and solutions for the same. The authors in (Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014) discussed about the concept of urban IoT for developing smart cities with a purpose of providing a heterogeneous set of activities to the users. The paper further discussed the "Padova Smart City" project, a "proof-of-concept deployment" of IoT ecosystem in Italy. In (Batty et al., 2012), the authors discussed the role of ICT in enabling the concept of smart cities by integrating ICT with the legacy infrastructure for providing services, developing policies and governance to the masses. The authors specifically identify seven domains regarding the urbanization and realization of a smart city and discussed how these domains can be interlinked to provide a seamless connected infrastructure necessary for the smart city. The authors in (Albino, Berardi, & Dangelico, 2015) reviewed the literature to provide clarity about the concept of "Smart" in "Smart Cities". They identified and reviewed several matrices of Smartness within a smart city and highlighted the differences, similarities and features of a smart city based on these matrices. In (Batty, 2013), the author highlighted the role of big data collected from various sources in an urban city for realizing the concept of a smart city. The paper further discussed the importance of short-term planning with respect to the rapidly changing challenges and issues in the smart cities. The author stressed that although data collected over a longer period of time is really important, but at the same time the data collected over a shorter time period is equally important for the changing dynamism of a smart city. The authors in (Jin, Gubbi, Marusic, & Palaniswami, 2014) provided an IoT based framework for developing smart cities. The framework integrated several aspects and entities of an urban smart city like infrastructure, governance, policy, sensors, networking and security encompassing a complete cyber physical system. The paper further discussed how IoT technology can be used to provide better and customized services to the inhabitants of the smart city. As more and more population around the globe is shifting towards urban cities and setups for obvious reasons, there exists a tremendous pressure on different domains and aspect of urban livings.

This is resulting in an imbalance of governance, services and management. The authors in (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014) discussed the role of sensing as a service to provide better management of various aspects of an urban smart city. The authors in (Vlacheas et al., 2013) discussed the issues and challenges in adopting IoT for providing sustainable solutions for smart cities. The primary issues that were identified in the paper were heterogeneous and unreliable nature of IoT devices. The paper further provided a framework for the cognitive management of the participating entities in the IoT ecosystem. In (Suciu et al., 2013), the researchers proposed a cloud computing and IoT based approach for realization of a smart city in which the data is managed, controlled and analyzed automatically. The authors in (Rathore, Ahmad, Paul, & Rho, 2016) proposed an IoT based data analytics model for the development of a smart city. It is a four tier architecture wherein each tier has a specific role and responsibilities. For performing the data analysis, Hadoop –MapReduce and Spark frameworks were used by the authors. In (Sun, Yan, & Zhang, 2016), the authors proposed a conceptual framework considering three dimensions viz technology, human and organizations. The idea here was to provide a blockchain based sharing of services so that it becomes secured, distributed and scalable. The researchers in (Biswas & Muthukkumarasamy, 2016) proposed a blockchain based security framework for enabling smart city environment. In any smart city, communication is considered as the backbone for its effective existence. Incorporating blockchain technology to provide secure communication was the main idea of the authors. The authors in (Sharma, Moon, & Park, 2017) provided an architecture of a blockchain based vehicular network. The core aim of the paper was to provide a "blockchain-based distributed transport management system". In (Ibba, Pinna, Seu, & Pani, 2017), the authors proposed a SCRUM based approach for capturing environmental surrounding with the help of sensors and its management using blockchain based distributed ledger technology. The authors in (Sharma & Park, 2018) proposed a hybrid network architecture for the development of smart cities using the integration of blockchain and software defined networking technologies. In order to maintain security and confidentiality in the proposed model, the concept of "Proof of Work" has been used. Finally, the proposed model was empirically evaluated on several performance metrics. Security aspects related to the existence of several devices, which make up the IoT, and which allow obtaining a lot of information for later analysis through Big Data, are covered in (Mora et al., 2018). The authors propose a case study that uses blockchain to reconcile security and privacy, as well as dealing with access control. In (Cedillo-Elias, Orizaga-Trejo, Larios, & Maciel Arellano, 2018), authors present a collaborative experience based on open-source technologies, between the government and academic entities to build a private cloud together with Software Defined Networks (SDN) technologies, thus allowing to improve the intelligent government services available. In (Ceballos & Larios, 2016), authors propose a model that aims to privilege citizen participation in the development of the city, contradicting models in which this involvement does not happen. This methodology, according to the authors, leads to greater satisfaction on the part of citizens in the model adopted for the development of cities. Standardization aspects are addressed in (Tolcha et al., 2018) by the authors. The collection of data in a smart city is then transferred to several service providers and given the lack of a standard for this transfer, there is a fragmentation of services in a smart city. In this sense, the authors propose a platform that uses the standards ratified by GS1, which stores the information in an independent repository that provides standard open interfaces for sharing resources in a smart city. In (von Son et al., 2017) authors refer to aspects of health and well-being as fundamental to the concept of a smart city. Combining genetic research with environmental monitoring, authors present a virtual platform that makes use of IT and IoT to improve citizens' quality of life and to establish correlations between the environment and the genetic information of each person. The use of spatial methods in cities has been known and used for several years, for strategic, tactical and operational reasons. Examples include Google Maps or Uber that assist citizens in different ways based on their location and proximity. The future of space computing in smart cities opens up many perspectives on the help it can provide to prevent risks (climate change, population growth) and address new opportunities (autonomous vehicles, etc.). The authors, in (Xie, Gupta, Li, & Shekhar, 2018) address these aspects through a literature review. The importance of assessing the construction of smart cities is addressed in (Liu, 2016), which reveal to be increasingly strategic for solving city problems such as energy or environmental. Authors present a case study that addresses the construction of a smart city under several aspects such as: infrastructure, economic, technological and innovation and security. The security and resilience of a smart city is studied in (Liang, Shetty, & Tosh, 2018), as a critical factor that arises from the IoT and the various devices interconnected with each other. The authors present a blockchain-based approach to ensure security and resilience in smart cities as well as analyzing the potential security concerns that exist when integrating blockchain technology into the infrastructure of a smart city. An example of connecting smart city technologies with local communities in urban environment is presented in (Wang et al., 2018) through an interdisciplinary education project that made use of art and communication to connect science with technology innovation and adopt it into smart city concepts.

## 3. Enabling technologies in smart city

The concept of technology adoption for ensuring an easy and efficient lifestyle is not new. Since ages mankind is integrating technology in the daily processes to achieve some level of automation and decision making. When the world is slowly moving towards business 4.0 and Industry 4.0, many new technologies are also being utilized for achieving a smart and sustainable lifestyle. The concept of smart cities is a way forward in this direction. Today, the modern day technological interventions have made it possible to realize the concept of smart cities. Many existing and new technologies are integrated to support the development of a connected network of devices and entities of a smart city. Fig. 2 discusses the key enabling technologies in a smart city.

Providing seamless connectivity within all the participating entities of a smart city is pivotal to any smart city project. The use of cloud/Edge computing paradigm and ICT along with dynamically changing network configurations management with the help of software defined networking (SDN) can aid in providing a seamless connected network which is self reliant and always on (Ahad & Biswas, 2019; Ahad, Tripathi, Zafar, & Doja, 2020). The data processing, management and analysis can be handled by big data management software like Hadoop, Cassandra, Quantcast etc (Ahad & Biswas, 2017, 2019). All such software has their advantages and limitations. Some are appropriate for real time processing while the others are suitable for performing historical data analytics. The devices in a smart city are embedded with sensors which are self sustainable and automated. The integration of physical devices, services and management can be realized with the help of cyber physical systems. Providing security and privacy to the users and the devices connected in the smart city ecosystem is imperative. The classical security protocols fail to complement the dynamic and heterogeneous nature of the network and devices in the smart city and thus novel security mechanisms are required for providing a holistic security and privacy to the devices and participating entities within the smart city ecosystem.

### 3.1. Cloud/edge computing

The cloud computing technology has contributed immensely in providing cost effective and faster solutions in terms of operating platforms, software, infrastructures. The users are not required to invest huge money in setting up of physical infrastructure rather these can be availed as a service from any cloud service providers like Amazon,


**Fig. 2.** Enabling Technologies in Smart City.

Microsoft and Google etc (Armbrust et al., 2010; Mell & Grance, 2011). The edge computing enables the users to perform quick and lighter computations right on the edge of a network rather than requiring to transfer the whole data on the cloud for processing (Hu, Patel, Sabella, Sprecher, & Young, 2015; Mao, You, Zhang, Huang, & Letaief, 2017). This makes the response time much faster and making the system takes decision in near real time.

### 3.2. Cyber physical systems (CPS)

A typical CPS is a collection of networks, entities and devices (both physical and virtual), processing, management, computations and related physical processes. It can be thought as an umbrella term which encompasses all aspects of computing, processing, networking and storage. We can have a generic CPS and at the same time we can also have a domain specific CPS for example CPS for healthcare, robotics, transportation etc (Baheti & Gill, 2011; Lee, 2008).

### 3.3. Sensory devices and IoT

Sensory devices are at the core of a smart city. These are miniature chips embedded in the devices and components of the participating entities. These sensors are able to sense the surrounding conditions and pass this information to the network gateways for further processing. Their primary aim is to collect the data of a phenomenon (like temperature, pressure, humidity, stress, strain etc) from the surroundings or an event. The collection of such sensor embedded devices which are connected together and are able to communicate with each other as well as the external surroundings is termed as “Internet of Things (IoT) (Ashton, 2009; Gubbi, Buyya, Marusic, & Palaniswami, 2013).

### 3.4. Big data

The rate at which the data is getting generated in the current era requires new technologies for its processing and management as the existing data management setups are not able to handle such velocity of the data. The diverse nature of data further adds complexity to this. Big data holds a huge potential and if we are able to harvest this data effectively, this can open new horizons for the businesses and processes. The analysis tasks like predictive analytics and predictive maintenance are all possible with the help of big data (Ahad & Biswas, 2017, 2019; Ahad et al., 2020; Labrinidis & Jagadish, 2012; McAfee, Brynjolfsson, Davenport, Patil, & Barton, 2012).

### 3.5. Security protocols

The security and privacy is at the centre of any smart city ecosystem. It must be ensured that every entity (users, systems, sub-systems, processes etc) must be secured at all time. Since the classical security techniques are not able to cover all aspects and scenarios of a smart city because of several visible constraints like scalability, heterogeneity, power, storage and computational capabilities, new security mechanism are being developed to cover the diverse nature of the current security requirements of a typical smart city (Elmaghraby & Losavio, 2014; Zhang et al., 2017b).

### 3.6. Information communication and technology (ICT)

This technology act as a backbone for providing all the services required for creating a connection between the participating entities within the smart city ecosystem. This includes network technologies, authentication, authorization mechanisms and access privileges in consultation with security protocols (Bifulco, Tregua, Amitrano, & D'Auria, 2016; Ferro, Caroleo, Leo, Osella, & Pautasso, 2013).

### 3.7. Artificial intelligence (AI)/machine learning (ML)/deep learning (DL)

The enormous data generated by a smart city is worthless unless it is analyzed to derive sense and valuable information. AI facilitates the processing and analysis of the data generated from machine-to-machine communication in a smart city setup. Predictive and preventive decision making, holistic insights of intra and inter system settings are possible with the help of machine learning and deep learning technologies (Allam & Dhunny, 2019; Batty, 2018; Skouby & Lynggaard, 2014).

### 3.8. Wireless sensor networks (WSN)

The WSNs enable advanced sensing, translation and transmission of data making them an essential component of a smart city framework. Moreover, they are actively used for decision making in traffic management, temperature control and location sensors among many other varied applications in a smart city (Jamil et al., 2015; Wu, Ota, Dong, & Li, 2016; Yick, Mukherjee, & Ghosal, 2008).

### 3.9. Blockchain

Blockchain technology allows distributed data management and autonomous peer-to-peer connectivity between IoT devices. The incorporation of blockchain in smart city environment ensures secure, transparent, robust, immutable and authenticated data flow. This technology has enormous potential to be a promising concept for the smart city applications (Swan, 2015, Underwood, 2016).

### 3.10. G technology

5 G networks offer greater flexibility and enable more information flow to promote civic participation in a smart city. It offers enhanced connectivity, enables more data to be collected and analyzed, becoming a catalyst for digital change in a smart city setting. 5 G is capable of facilitating communities to enhance the public experience and create smart urban environments through advanced infrastructure, sustainable development, accessibility and equality (Detwiller, 2020; Skouby & Lynggaard, 2014).

### 3.11. Geospatial technology

Geospatial technology helps in the process of urban planning in a smart city system. One of the major challenges for the development of city plan is to gather the accurate location of the underlying entities and the geographical data for assisting in real time decision making. Technologies like LiDAR and remote sensing, internet mapping, GPS and GIS helps in the development of intelligent transportation, intelligent parking systems, efficient healthcare services, smart navigation systems and the management of other public utilities. Geospatial technologies plays a vital role in the development of smart city infrastructure by providing a efficient collaboration and coordination between the multiple processes and different aspects of smart city system like healthcare, emergency services, transportation, agriculture, waste management, tracking services and navigation (Al-Hader, Rodzi, Sharif, & Ahmad, 2009; Li et al., 2009). Table 1 summarizes the significance and associated challenges of the enabling technologies.

## 4. Challenges and issues in realization of smart cities

There are several inherent as well as external challenges and issues associated with the realization of an effective smart city ecosystem as presented in Fig. 3 (Baig et al., 2017; Mohammed, Idries, Mohamed, Al-Jaroodi, & Jawhar, 2014; Zhang et al., 2017a).

The issues and challenges associated with the realization of smart cities can be broadly divided into three categories.

- Technical

Security being the primary concerns of the inhabitants all other stakeholders of a smart city, it plays a major role in building trust and achieve acceptance. Several cases of data thefts and cybercrimes in recent years resulted in serious hindrance in the widespread acceptance of smart city projects. The high adoption costs of the new technologies results in high implementation costs that affects successful realization of smart city projects. The upgradation of existing infrastructure requires a huge amount of implementation costs. The diverse IoT devices involve the communication of valuable information for the effective functioning of a smart city. Interoperability across these diverse devices is pivotal for the sustenance of a smart city. The massive amount of data generated by billions of locally connected devices requires intelligent techniques for effective management and processing along with deeper and wider insights. Technical hindrances in the transition from legacy systems to smart systems further add to the complexity. Issues like backward compatibility, scalability, heterogeneity of data and devices, multiple data standards, interoperability poses inherent issues and challenges that needs to be addressed.

- Socio-Economic

The mindset of the inhabitants plays a very crucial role in realization of a smart city ecosystem. If the people are not ready to accept the digital changes around them, we cannot think of having a smart city in a true sense. For its successful implementation, the users must accept the changes and use the services for their benefits. Several governments are still not able to provide the adequate supporting infrastructure for creating the smart cities. Infrastructure provides the backbone to the smart city network, if we are not able to provide proper infrastructure, we cannot think of developing a smart city. In order to successfully implement the smart city project, a pool of well qualified and trained professionals are required. Currently we have a scarcity of such qualified professional in most of the domains of smart city ecosystem. Digital divide also poses inherent challenges in the acceptance of smart city mindset. On one hand there are users who are technology-savvy while others who are not having access to basic internet facilities.

- Environmental

We are already witnessing several hindrances in the widespread adoption of 5 G technology (Detwiller, 2020; Skouby & Lynggaard, 2014). There exists an obvious challenge of coping with the natural calamities in a smart city ecosystem. In cases of natural disasters like floods, earthquakes and landslides etc, there are high chances of underlying infrastructure getting damaged and adversely affecting the complete smart city ecosystem. Another challenge is the absence of effective management of green house gases emissions. With global warming at its peak, the sudden unavoidable changes in the weather also poses critical threats to the smart city ecosystem. Electronic waste (E-waste) is another very critical challenge that needs to be addressed. With new devices and technologies being developed at a very brisk rate, the legacy systems and devices are getting obsolete. Till date there are no standard mechanisms to dispose such old devices and system in an environment friendly manner. Most of the population in semi-urban and rural areas are not even aware of the harmful environmental and health effects of the e-waste being dumped in landfills, open-spaces and oceans.

## 5. Sustainable smart cities

Smart city ecosystem provides a means to deliver personal, social, cultural, economical, environmental and physiological wellbeing to the inhabitants with the aim to improve the “Quality of Life (QoL)”. It is imperative to provide sustainable solutions for the realization of the smart city infrastructure. A sustainable smart city may be defined as a smart city in which every aspects of the smart city ecosystem like

**Table 1**
Significance and Challenges of Enabling Technologies.

| S No | Enabling Technology in a Smart City | Significance | Challenge |
|---|---|---|---|
| 1 | Cloud/Edge Computing | Efficient data storage and processing | Managing large volumes of data in centralised manner |
| 2 | Big data | Managing large volume of real time data from IoT devices deployed across smart city | Unstructured and incomplete data |
| 3 | Internet of things | Enables a network of communicating devices | Security breaches |
| 4 | Blockchain | Trusted transactions and agreements | Infrastructural requirements and skilled task force |
| 5 | Artificial Intelligence/ML/DL | Intelligent processes | Complex processes |
| 6 | Cyber Physical System | Highly relevant technology in healthcare, agriculture, transportation domains. Automation of mechanism make it feasible for deployment in difficult terrains | Implementation costs and limited trained manpower. |
| 7 | Security Protocols | Exclusive security mechanisms and protocols serving low powered IoT devices and systems | Absence of universal standards |
| 8 | Wireless Sensor Networks | Facilitates an intelligent control system and real time data collection through different types of sensors. | Security aspects of sensors |
| 9 | 5 G | Provides strong connection to enable IoT devices to work efficiently | Environment and ecological impacts |
| 10 | ICT | Interconnects the communities with the governance and provides an Interface between the various entities of the smart city infrastructure | Security and trust |
| 11 | Geospatial technologies | Accurate location services for smart navigation, tracking, transportation and other smart city processes | Implementation challenges |

infrastructure, policies, governance, feedbacks, controlling and management is achieved by following the well-defined sustainable approaches (Al Ridhawi, Otoum, Aloqaily, Jararweh, & Baker, 2020; Höjer & Wangel, 2015; Kyriazis, Varvarigou, White, Rossi, & Cooper, 2013; Peris-Ortiz, Bennett, & Yábar, 2017; Silva, Khan, & Han, 2018). These approaches span from using clean reusable codes, using environment friendly and recyclable raw materials, optimal energy consumptions in devices, systems and sub-systems etc. The primary aim of the sustainable smart city is to provide a mechanism for fulfilling the requirements of the present as well as the future generation inhabitants.

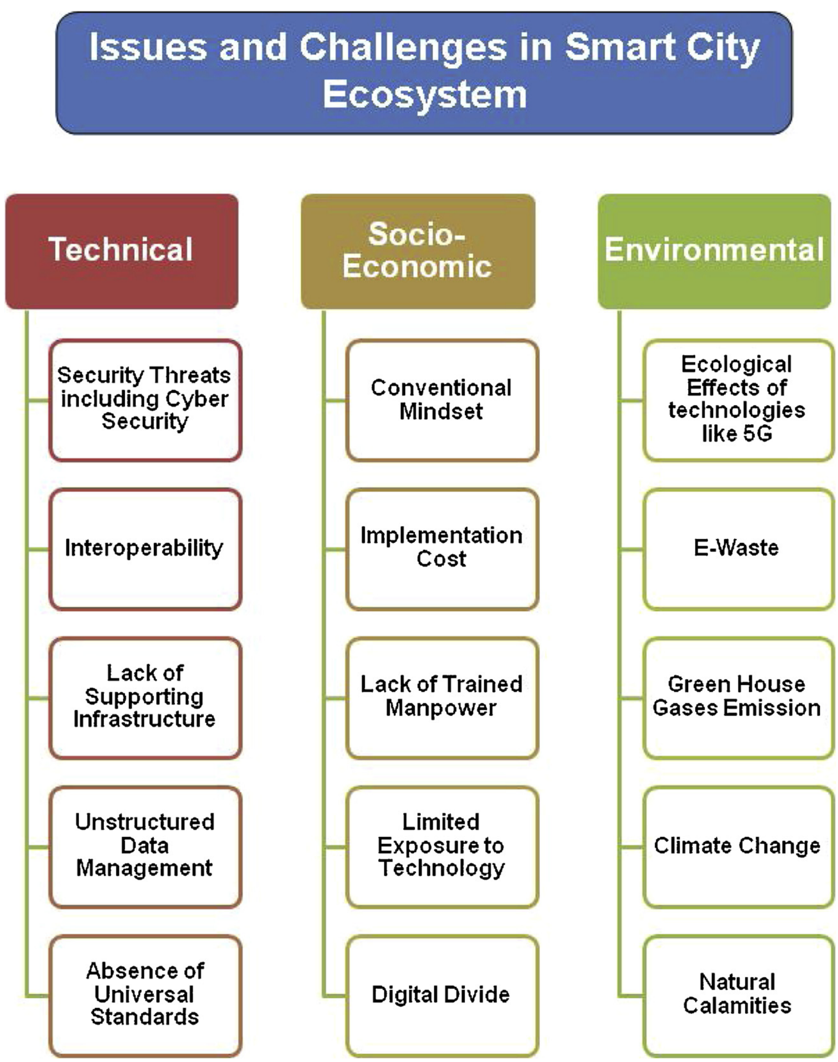


**Fig. 3.** Issues and Challenges in Smart Cities.


**Fig. 4.** Types of Sustainability in a Smart City.

There is an urgent need for devising the mechanisms so that the consumption of resources (natural and man-made) must be administered and monitored keeping in view the future generations. The United Nation's SDGs also point in the direction of achieving sustainability in every aspect of life. Another important factor which is to be considered while designing the smart city ecosystem is the optimal management of waste generated through computing or other developments (including e-waste). The underlying infrastructure of the smart city must be able to interface with the strong and dynamically evolving prediction algorithms so that the future needs and expenses are estimated well before time and preventive measures can be taken if the need arises. This predictive analysis is highly crucial for the successful implementation of the smart city ecosystem (Al Ridhawi et al., 2020; Silva et al., 2018). There exist several types of sustainability in a typical smart city ecosystem as shown in Fig. 4.

1 Inhabitant Sustainability

The degree of social engagement, opening to different societies, human capital growth, education and decreasing digital divide characterize the sustainability of smart city inhabitants. Addressing the current and future needs of inhabitants, offering equal opportunities to everyone and the perceived security to support inhabitant sustainability of a smart city must be ensured (Dempsey, Bramley, Power, & Brown, 2011).

2 Governance Sustainability

Governance sustainability is facilitated by the engagement of citizens in community decision-making, co-creation and deployment of different shared tools, technology convergence and data exchange facilities to establish an enhanced quality of life. The convergence of governance with broader societal issues is vital for stable governance in a smart city (Elkington, 2006).

3 Policy Sustainability

The pursuit of technological innovation is seen as an important part of policy sustainability. The theoretical soundness, scientific utility, social awareness, environmental innovation and relevance within and across boundaries characterize the sustainability of smart city policies (Nill & Kemp, 2009).

4 Economic Sustainability

The economic sustainability of a smart city is intertwined with the growth of a commercial environment that encourages new businesses. Factors such as innovation, market stability, entrepreneurship and self-sufficiency, as well as the global development of local economy, contribute to the economic sustainability of a smart city (Kumar & Dahiya, 2017).

5 Business Sustainability

The business sustainability of a smart city is facilitated by the management and integration of economic, social and environmental demands and issues to ensure healthy, ethical and persistent industrial development (Dyllick & Muff, 2016).

6 Environment Sustainability

The environmental sustainability in a smart city necessitates the elimination of emissions, preservation of natural resources and safeguarding of natural habitat by effective utilization of resources. Smart


**Fig. 5.** Roadmap for Sustainable Smart Cities.

cities must integrate state-of-the-art technologies and solutions to tackle the issues of clean water shortage, depleting air quality, diminishing natural resource reserves and ecological imbalance (Tanguay, Rajaonson, Lefebvre, & Lanoie, 2010).

### 5.1. Roadmap for sustainable smart cities

This section describes the roadmap for attaining a sustainable smart city ecosystem in a true sense. Fig. 5 presents the roadmap focusing on all necessary aspects for a holistic sustainable smart city experience (Calvillo, Sánchez-Miralles, & Villar, 2016; Charmes & Keil, 2015; De, Sikarwar, & Kumar, 2019; Deelstra & Girardet, 2000; Khan, 2015; Lepsinger & Lucia, 2009; Martos, Pacheco-Torres, Ordóñez, & Jadraque-Gago, 2016; McDonnell & Hahs, 2013; Microsoft Releases Sustainability Calculator, 2020; Mohammad, 2019; Mora, Deakin, & Reid, 2019; RMM, 2020; Shahidehpour, Li, & Ganji, 2018; Smart Cities & Infrastructure, 2016; Umar & Uhl, 2016).

1 Localization of Resources and Services using Local Hubs

The local relevance of services and response to development needs using local resources need to be included in smart city policies. The inclusion of local hubs in a smart city infrastructure improves awareness and operational control and optimizes the use of limited resources in the city. The localization of resources and services using local hubs facilitates the possibility of capturing and disseminating information promptly so that the city can take steps before a crisis starts to intensify (Tanguay et al., 2010).

2 Improved Last Mile Connectivity

Improved last mile connectivity ensures that people reach their destination or vice versa from a transportation hub by connecting them directly to the main public transport network. The right networking solutions for the last mile connectivity issues will assist in crime prevention and safeguarding smart city residents (De et al., 2019; Smart Cities & Infrastructure, 2016; Tanguay et al., 2010).

3 Promoting Environment Friendly Commuting (Smart Mobility)

Smart mobility focuses on methods to reduce congestion, support faster, greener, sustainable and cheaper transport at local, national and international levels by means of utilizing data collected from a variety of sources regarding traffic patterns (Khan, 2015).

4 Transparent and Single Window Clearance System for Essential Services

The Single Window Clearance System will provide smart city residents a single gateway to access essential services in a transparent manner. The complex operational structures surrounding the provision of essential services will be transparent for the residents, contributing to reduced transaction costs for the consumers of services (Shahidehpour et al., 2018; Smart Cities & Infrastructure, 2016).

5 Promote Sustainable Collaborations

Smart city citizens, technology merchants and city authorities need to collaborate to ensure urban sustainability within the city. Fostering the understanding of scientific, social and personal behaviour, and upgrading of smart urban infrastructures will promote more collaboration between residents, technology and the government (Charmes & Keil, 2015; Khan, 2015; Shahidehpour et al., 2018).

6 Densification of Inhabitants

Urban densification has been widely used as a sustainable city strategy, as ground space is fixed but the population and their needs grow. A dense city is essentially a sustainable city since most of the residents are typically nearer to the centralized services of a community, hence the energy needs (such as fuel for vehicles) are substantially reduced and this lifestyle mitigates any detrimental environmental impact (Charmes & Keil, 2015).

7 Promote and Sensitize about alternative sources of energy

A smart city is a sustainable and productive community that offers its people a high quality of life through effective resource management. Smart cities need to move progressively into a comprehensive renewable energy strategy by means of alternative sources of energy such as photovoltaic panels, thermal collectors, wind turbines, biomass and geo-thermal energy (Calvillo et al., 2016).

8 Promote Localized Urban Farming

Smart cities should gradually focus on the development of localized urban farming, greater self-reliance on local foodstuffs and leveraging local resources for sustainable urban development. The combined effects of environmental sustainability and human welfare include awareness of local influences with localized urban farming leading to enhanced climate and soil protection, minimization of urban waste, improved water management and maintenance of ecological balance (Deelstra & Girardet, 2000).

9 Improve Biodiversity

To create a sustainable and resilient smart city, the biodiversity can be improved by understanding the effects of urbanization on biodiversity and urban ecology, and then integrating this knowledge into the planning, development and maintenance of the smart city (McDonnell & Hahs, 2013).

10 Innovative Waste Management and Decomposition Mechanisms

Novel waste management and decomposition programs in addition to developing municipal solid waste landfill facilities for recycling plastic, glass, biomass and hazardous waste, should be established for minimizing environmental impact of the wastes generated in a smart city (Martos et al., 2016).

11 Remote Monitoring and Management

Remote monitoring and management would provide real-time data to effectively manage resources for improving the lives of smart city residents. This could assist in efficient government decision-making, waste reduction, smart parking and smart mobility, including many others (RMM, 2020).

12 Localized Water Management

Localized waste management would tackle water management concerns through the incorporation of ICT devices, technologies and programs in the water management and treatment system of a smart city. This would facilitate the continuous analysis of water resources, recognizing issues in the water system and effective addressing of maintenance problems, as well as the gathering of information required to optimize all facets of the municipal water supply and provide information to residents and water facility operators (Umar & Uhl, 2016).

13 Better Engagement of Inhabitants

A well-functioning smart city requires sincere participation, collaboration and partnership among the public authorities, private sector, charitable organizations, schools and the citizens. The involvement of different stakeholders in decision making and public services, especially the citizens, is an essential element of a thriving smart city (Lepsinger & Lucia, 2009; Mohammad, 2019).

14 Degree Feedback Mechanism

360 degree feedback mechanism should be deployed in smart cities to measure the satisfaction of residents by analyzing the performance of diverse sectors. This anonymous feedback mechanism would help uncover the loopholes and improve the public experience of smart city services (Lepsinger & Lucia, 2009).

15 Multi-tiered global and localized security mechanism

A comprehensive multi-tiered security mechanism with multiple layers of defence will protect smart city utility systems against local and global security attacks. Moreover, the security framework could use human expertise to combat unseen threats through intrinsic defence mechanisms (Mohammad, 2019; Mora et al., 2019).

### *5.2. Best practices in sustainable smart city ecosystem*

The following section presents some of the best practices that need to be followed in order to achieve the distant dream of a true sustainable smart city (Falconer & Mitchell, 2012; Microsoft Releases Sustainability Calculator, 2020; Mora et al., 2019; Naden, 2020; Sustainability in buildings & civil engineering works, 2020; Teoh, Schumann, Majumdar, & Stettler, 2020).

- Geographical distribution of Sustainable Energy Generations Hubs
- Minimizing Carbon Emissions
- Sensitizing the inhabitants about green house effects.
- Including climate change and Environmental Science at every level of Education (Practical and Theory both).
- Promoting carbon-neutral living spaces.
- Developing More Stringent Rules and Regulation on Climate Change.
- Incentivising and generously supporting individual efforts and innovations.
- Making climate protection as a legal, individual and social norm.
- Heavily Penalizing over-usage of service and resources.
- Alleviating the carbon footprint by means of tools to measure the carbon emissions resulting from technology consumption (Falconer & Mitchell, 2012).
- Imposing sustainability fees for visitors.

## 6. Conclusions, discussion and future directions

The utopian world of a smart city is still a distant dream for several developing nations but with the advent of modern technological advancements these nations have a built-in platform to work in this direction of achieving this. Several innovative technologies are coming up to cater the dynamic and diverse nature of requirements and challenges of a smart city. Security is considered as a major pillar of a smart city. Novel lightweight security protocols and regulations are being developed for securing the entities of the smart city ecosystem. The CPS plays an important role in the development and sustainability of a smart city. Novel CPS frameworks and architectures are already being developed by researchers around the globe. Keeping the Sustainable Development Goals (SDGs) in mind, the development companies and enterprises are coming up with cost effective, inclusive and environment friendly solutions for a smart city. Thus it can be concluded that the role of various enabling technologies in the development of smart cities is critical for proving a holistic environment which is transparent, automated, inclusive, extensible, secured, flexible and easily manageable. The newly introduced ISO 20,887 standards is one of the pioneering steps for reducing the carbon footprints from the building constructions. The standard aims at promoting "sustainability in building and civil engineering works" which includes optimal usage of existing buildings, minimal waste disposal in the landfills, effective energy management, optimal reuse and disposal mechanism of resource and services (Casini, 2016; Nield, 2020; Sustainability in buildings & civil engineering works, 2020; Teoh et al., 2020). One of the recent researches shows that by slightly modifying the altitude of the flights in air can reduce the climate impact of contrail energy forcing by upto 59 % (Nield, 2020; Teoh et al., 2020).

Nanotechnology has emerged as one of the most promising technology which is finding its widespread adoption in every domain of human lives. Various products and applications like "nano-clothes", "nano-tubes", "nano-fertilizers", "nano-chips", "nano-sensors", "nano-food", "nano-medicines", "nano-material" and "nano-emulsions" etc, are a reality now and slowly helping in achieving a sustainable environment in several ways like lowering carbon emission, lower energy consumption, lower space requirements, lowering health hazards etc (Casini, 2016; Jain & Jain, 2016; Markovic, Zivkovic, Cvetkovic, & Popovic, 2012).

Quantum computing technology is another promising technology which can be helpful in development of a smart city. The provision for real-time decision making and analysis can be made possible with faster computing capabilities that quantum computing exhibits. Future research must be focused on extensive role of nanotechnology and quantum computing in achieving sustainability in various spheres of daily chores of lives and environment friendly computing (Hahanov, 2018; Person, Tech, & Policy, 2004).

Sustainability can be thought as a relative term. It should not be considered by global parameters rather it must compose of localized factors within the nation. For example, sustainability parameters can be set very high for a well-developed nation however such stringent factors should not be imposed on smaller underdeveloped or developing nations. There are several factors which are considered while measuring and quantifying sustainability of a nation. These factors include population, mortality rate, literacy rate, GDP, personal, social and economic well-being of inhabitants etc (Albino, Berardi, & Dangelico, 2013; Sikdar, 2003). In future a sustainability matric may be proposed considering all these factors so that a quantifiable definition of sustainability can be defined with respect to the nation's capacities and capabilities.

## Declaration of Competing Interest

Authors declare no conflict of interests.

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