Smart city: A review on concepts, definitions, standards, experiments, and challenges

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Nowadays, the negative effects of greenhouse gas emission, air pollution, and global warming have been increased exponentially due to population growth, especially in urban areas. To handle urbanization with minimal environmental pollution, the smart city concept has been introduced and extended significantly. Worldwide concerns on social welfare and lifestyle quality are the other important reasons that motivate cities to become smarter and more intelligent. The smart cities try to promote economic growth and improve the quality of life by providing regional development and technology utilization, especially smart-based technologies by using information and communication technology and services. In this paper, it is attempted to present the definitions, concepts, and standards to make the necessary arrangements and involved challenges in smart cities focusing on the power system requirements. Finally, by reviewing some proposed frameworks regarding the smartization road map, a sample road-map is described, especially in pioneer smart cities around the world.

keywords: *Smart city, Information and communication technology, Security, Energy, Standards.*

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1. INTRODUCTION

Urbanization is one of the main reasons for presenting the idea of a smart city (SC). Today, over 54% of the world's population live urban areas, which is expected to reach about 66% by 2050 [1] and grow to accommodate an additional 2.5 billion people over the next three decades [2]. Cities consume 75% of natural resources and produce 60-80% of global greenhouse gas (GHG) emissions [3], despite occupying only 3% of the earth's land area. The population growth rate has many threatening environmental effects by increasing the demand for energy, water, food, transportation, and so on. The huge increase in consumption leads to a scarcity of natural resources and global warming. Considering such threats, societies should provide solutions for economic, social, and environmental sustainability.

The concept of SC is suggested as one of the most effective solutions to increase the quality of life and social welfare by considering human and environmental properties. SC has six major contributions, as depicted in Fig. 1.

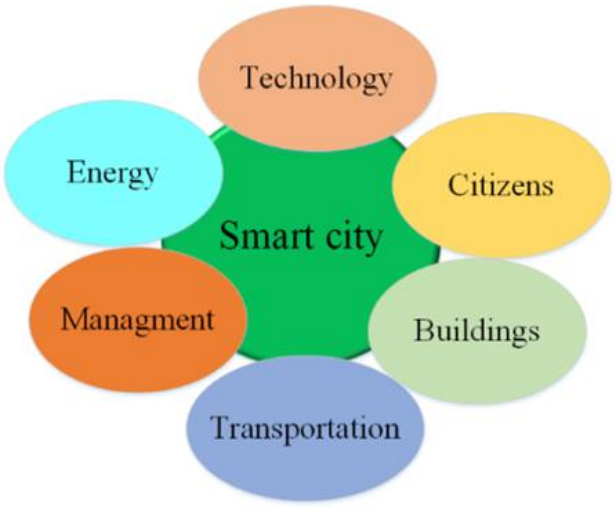

Fig. 1. Six significant parts of a smart city (SC).

SC is a metropolitan area that uses different types of instruments and sensors for supervisory, control, and data acquisition (SCADA) that are efficient for managing urban resources, services, and assets. The SC technology allows city authorities to interact directly with urban infrastructures, the community, and monitor what is evolving and what is happening. The information collected from people, devices, and city resources are processed and applied to monitor and manage traffic and transportation network, power generation units, water, waste, management, schools, systems law enforcement, hospitals, li-

braries, and the other public services. The idea of SC comes from integrating the Information and Communication Technology (ICT) and physical infrastructures connected to the Internet of Things (IoT). In this way, it is possible to make everything and everyone connected, optimize the productivity of all services, and improve urban uses and connections to citizens. SC is a framework created mainly by ICT to develop, extend, and promote sustainable development practices aimed at addressing the increasing challenges of urbanization. Much of this framework is mainly a smart grid (SG) of connected equipment and objects that transfer information using cloud computing and wireless technology. In the SC, lighting, building, parking, farming, and waste management should be conducted to be smart. Generally, ICT including smart hardware equipment (e.g., smart meters, vehicles, phones, and wireless sensors), software applications (e.g., back-office control systems, mobile apps, and big data analytical tools), mobile networks (e.g., Wi-Fi, 3G/4G/5G network), and data storage technologies (e.g., data warehouse and cloud platform) [4]. Numerous studies have been conducted on this subject since the 1980s. These works deal with aspects of this significant issue, on ICT technologies, economic issues, architectural and urban elements, energy supply, and environmental concerns.

Based on the authors' knowledge, there is no comparative review encompassing all relevant aspects of this vast issue. This paper, as a complementary study, tries to fix this gap as much as possible.

For this purpose, first, some definitions on this subject are described in Section 2. The relevant standards for achieving this concept are detailed in Section 3. The main challenges of a SC, focusing on the power system concept, are addressed in Section 4. Some sample projects over all the world trying to implementing this issue are highlighted in Section 5. Section 6 presents the road map for a SC. Finally, the discussions are summarized in Section 7.

2. DEFINITIONS

Most of the available methods in the field of city design and planning date back to the 1800s, when the planners and engineers proposed and exposed some centralized networks to manage the water, food, and energy sources [5]. Also, other centralized systems were planned and operated to facilitate transportation and wastewater treatment. The 1980s are often regarded as the beginning of essential issues in human history. One of the most significant developments in this era is the remarkable progress made in globalization. Alongside the significant political, social, and economic challenges in that decade, which shaped the milestones of history, the conception of some small concepts such as the SC was at stake. The history of the SC goes back to the time when the field of internet use expanded into social and economic activities. The increasing growth of information technology and epidemics and sensors made institutions related to urban governance and management pay more attention to this concept. Among the many definitions of SC, one of the most important, and perhaps the most complete, is the one presented in [6]: The SC is a tool-based, interconnected, and knowledgeable city. For clarity of the definition, its three important components are described in Fig. 2.

Furthermore, introducing the new technologies and infrastructures push the city planners to apply these new trends in the planning procedure of cities. New cities designed around the private automobile, focusing on a single function. As a result, the new towns are becoming more congested, polluted, and unsafe [5]. Citizens are spending more of their valuable time commuting, and communities are becoming increasingly detached. Based on these facts, three main principles could be identified in the SC approach [6]: 1) the need to understand urban systems in time and space, focusing mainly on energy and materials, 2) the need for smart infrastructures, including smart energy grids and smart mobility systems, and 3) the need for new urban services and business models, associated with the transition to sustainable urban systems.

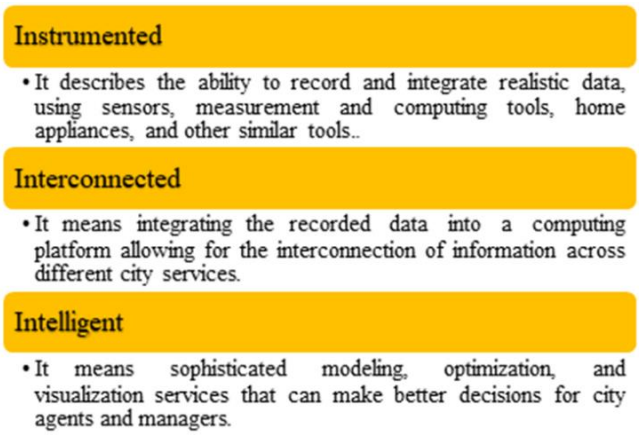

Fig. 2. Important factors in smart city (SC).

Most of the literature regarding SCs present different definitions of this context. Some references focus on either specific types of ICT. The others demonstrate the specific opportunities and challenges, or specific domains of application [7]. The presented definitions mainly emphasize different issues, such as the role of technology or ICT [8]. In [8], the authors presented a variety of definitions regarding SC in which the focus is only on the Information System (IS) and IoT subjects. As an important matter, this definition is not complete by no means and there are several issues may be extended in other studies in this field. Some definitions of the SC concept are presented in Table 1.

An overview of the various definitions shows that the definition of a SC is comprehensive in terms of engineers, researchers, and citizens as the end-users. Each of the available sources has emphasized different aspects of a SC. So, measuring the SC is a very complicated task. Given that each city has unique administrative, economic, and social features and specific priorities, it is challenging to define a fixed and generalized system concerning different characteristics of the cities. Also, given the definitions, it is best to retain the underlying structures as the basis of conceptualization and revise specific descriptions of each city based on perspectives, priorities, and content. What is emphasized is the use of ICT in public infrastructures and services, the integration of different planning and implementation systems, universal cooperation in urban development, autonomy in decision-making, participatory governance, connectivity, and integration. Creativity, learning, and resource management are all essential infrastructures of the SC. All of these factors play a role in improving the quality of life and increasing the quality of public service to citizens, who also need to be smart.

Table 1. Some definitions of SC concept

Ref. No	Definition
[4]	Developed cities which utilize a set of advanced technologies such as smart vehicles, mobile networks, and wireless sensors, smart hardware devices, incorporating software, and data storage technologies.
[9]	The main topics are SCs are related to of their smart inhabitants, quality of social interaction, educational degree, integration with public life, as well as openness to the wider world.
[10]	The sustainable city is a smart city.
[11]	The place that utilizes the ICT for improving the life quality as well as optimal management of all natural resources, through smart governance.
[12]	Each city which runs intelligently, and is sustainable would be a smart city.
[13]	The cities where ICT is combined with every object, architecture, and even the citizens to address all relevant environmental, economic, and social problems.
[14]	Smart cities are characterized by the pervasive use of ICT to smartness application in natural resources and energy, transportation and mobility, buildings, living, government, economy, and people.
[15]	An urban environment which able to improve the quality of citizens' life by using ICT systems.
[16]	A city in which the traditional services and networks based on digital technologies are made more efficient for the benefit of its businesses, services, and inhabitants.
[17]	Effective integration of human, digital, and physical systems in the built place to deliver a sustainable prosperous and inclusive future for the people.
[18]	The main features of the smart city are smart economy, smart mobility, smart environment, smart people, smart living, and smart governance.
[19]	A city that uses ICT to be more interactive, efficient, and making citizens more aware of what is happening in the city.
[20]	An urban which seeks to address all public issues applying ICT-based solutions based on a multi-stakeholder, and municipally based partnership.

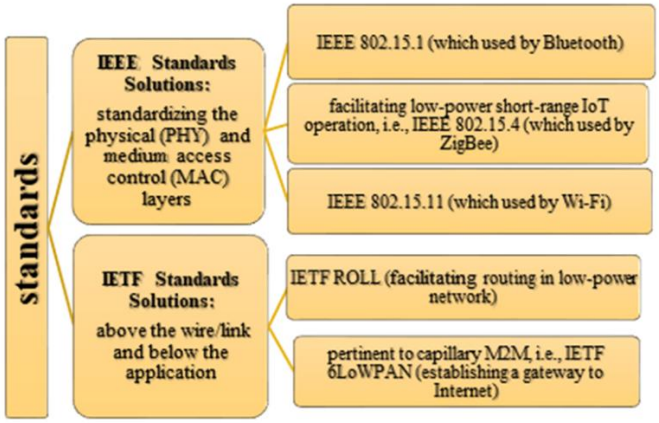

Fig. 3. Some standards on SC issue.

3. STANDARDS FOR THE SC

The standards are critical issues to evaluate the SCs so they can help adopt new technologies and create a reliable structure for various city officials, including urban planners and professionals. The main vision of SCs is to provide an urban center of the future that is safe, secure, environmental-friendly, and efficient. All the required frameworks for this purpose are planned and operating through integrated materials, sensors, and networks that interface with computerized systems [9]. Security and data privacy are the most important requirements in SCs that should be considered carefully. The primary requirements for ICT in SCs include software/hardware elements, database elements, and management information system (MIS) elements. To meet the requirements of a SC, some Machine-to-Machine (M2M) communications are suggested. The main standards in this regard are illustrated in [9]. Fig. 3 presents some useful data regarding the standards on the SC issue.

The recommended standards for implementing the SG, as one of the main requirement for SCs, are categorized as USA (NIST IOP), Europe (CEN/CENELEC M/441), Japan (METI), China (SGCC), Germany (BMWi E-energy program, BDI initiative-internet der Energie), Korea (Smart grid 2030), IEEE(P2030), and Microsoft (SERA) [10].

A comprehensive review of the international measures taken to implement SC practically has been carried out by the UK National Standard Organization (NSO) in its SC document [11]. The main sections regarding the required standards for a SC are demonstrated as fields supporting smart cities, Additional ICT keywords, SC application areas, SC topics, City organizational terms, SC objectives, and project management and software management for section and the suggested standards for each category [11].

The activities related to standards can be divided into three levels [12]: Strategic focus on guiding city management,
A relevant standard to the strategic level is the ISO 37,120. It deals with sustainable development communities including urban service indicators and quality of life. This standard has been set up by the ISO 268 technical committee, which provides 100 indicators for cities that should be considered to evaluate their progress. Several cities are moving toward adopting these standards. In this regard, the World Council on City Data (WCCD) has made efforts to promote these standards and encourage cities to use them.

Process-focused procurement and management of SC projects and activities:

The IEEE emphasizes the importance of IoT as a vital trend in SCs. The organization has made efforts to develop the IEEE P2413 standard, which is the standard for having a specific architecture for IoT. The IEEE P2413 standard is being developed to provide an architectural framework to support interoperability, system collaboration and functional compatibility, and the organic growth of the IoT market.

The technical level focused on low-level details on technologies used for SC projects, which exceed IEEE standards: ISO JTC1 committee has produced useful documents regarding the technical level.

As an essential result of the study of SC standards research, it can be stated that this topic is moving quickly, and new documents, standards, and frameworks are currently under development or can be envisioned. Also, given the variety of issues involving SC concepts ranging from social to administrative for providing various energy infrastructures, more research is still needed. Strictly related security issues and network reliability in the privacy of individuals is a significant concern that many efforts are being made to complete it.

4. MAIN CHALLENGES

While the topic of SCs is getting increased attention and its various aspects are being addressed, there are some significant challenges in implementing this idea. In this section, the most critical issues in this regard are addressed.

- One of the biggest challenges for SCs is the issue of cybersecurity, which allows hackers and cybercriminals to access the electronic devices connected to the internet and smart urban infrastructures and change the information they need [13].
- The high costs of designing, implementing, and operation of SC infrastructures over popular cities is a very challenging issue. The main problem in this regard is how to provide the required investment [14].
- Urban wastewater and the need for modern systems to deal with various pollutants while meeting the relevant high standards is another critical issue. It should be noted that the growing population of SCs is a severe issue that exacerbates the crisis [15].
- Another significant challenge posed by SCs is a significant reduction in the workforce and the elimination of many job opportunities. This issue, if not handled properly, can cause major social and human crises [16].
- Due to the expansion of cities in multiple geographical areas, SCs, which are aimed at enhancing the standard of living, have led to a population surge of the less-privileged regions (non-SCs) to SCs, resulting in new cultural problems and the need to increase the facilities and infrastructures.
- An essential prerequisite of a SC, along with all the communication infrastructures and technologies, is the existence of smart citizens, a subject that requires specific cultural, social, and educational solutions [17].
- The other important challenges of SCs can be "detailed regulations," "reluctance and unwillingness of citizens to urbanize," "government funding and business models," and "development of smart infrastructures" related to different areas such as energy, water, and transportation systems [15].

A. Power system challenges in the SC

The energy and environment responsibility will increase along with the rapid urban population growth and makes cities prone to confronting various challenges. In this respect, it is necessary to manage sustainable cities and control the resources, including infrastructure and energy efficiently [18]. The energy, as one of the six essential structures in the SC, has a vital and undeniable role in this process and needs to be addressed seriously. Notably, this section has a structural and fundamental role in achieving the other goals of the SC and is the leading platform in this regard. The assessment of energy performance in urbanization can be divided into two main categories: (1) urban system performance evaluation and optimization for efficient energy supply and (2) urban design performance measures for energy demand reductions [18]. Technological advances, however, have led the energy system in recent decades to undergo enormous changes from restructuring to privatization, the presence of distributed generations (DGs), micro-grids (MGs), SGs, energy hubs, and so on. Ironically, all these subjects are themselves some of the requirements of SCs and facilitate this process. The most important challenges related to the energy sector, which are somehow rooted in current power systems, are addressed as follows.

- Choosing appropriate designs and architecture for the building plays a fundamental role because they are key components in SC because of their significant contribution is about more than 40% energy consumption [18].
- The need to reduce environmental pollution and to use alternative energy or renewable energy sources (RES), which in many cases are not economically advantageous for non-state users, is the other significant challenge. In the United States, it is predicted that energy consumption from RESs reaches 4.5 quadrillions Btu by 2040, of which 39% and 7.5% will be obtained from wind turbines (WT) and photovoltaic (PV) generators, respectively [19]. The volatile nature of these sources has challenged the power system scheduling to remain reliable and economical.
- Accurate and integrated management of all energy sources, including electrical, thermal, and other types of energy and using the appropriate tools and equipment, is the different major challenge. It is even more important to remember that integrated energy systems, or energy hubs, are still in the early stages of design and operation, and implementation.
- The renewable energy resources and the Combined Heat and Power (CHP) would be effectively used together for supplying the required energy of residential and tertiary purposes in the SC. Notably, the present structure of low voltage (LV) distribution networks are inadequate to comply with this goal for the simultaneous installation and operation of renewable energy resources consisting of PV modules, Wind power plants, and CHP systems (as the cogeneration processes) or CCHP systems (as the tri-generation processes), and plug-in hybrid electric vehicles (PHEV) [20].
- In SCs, new concepts are emerging that signify the integration of different systems to meet the needs of citizens. One of these concepts is NEXUS, which is defined as an approach that adopts a transparent structure for determining and assessing the trade-offs on the use of water for food and energy production, without compromising sustainability [21]. The security of NEXUS is one of the most challenging issues. Furthermore, design, planning, and operation subjects should be investigated and analyzed carefully.
- Natural disasters and acts of sabotage are rare, unpredictable, and unlikely phenomena that have devastating effects and can cause severe damage to energy infrastructures and systems. The need to pay attention to these disasters has led to the introduction of a novel concept known as the resiliency of the power grid, which means the capacity to recover from sustained difficulty and its self-healing ability [22, 23]. It also introduces the ability of the existing networks and systems to predict, adapt to, and retrieve such an event quickly [24]. In general, resiliency includes a set of capacities that help the system in difficult situations to overcome unexpected situations with minimal damage and to respond to extremely adverse conditions and return to a normal position, quickly. In SCs, this concept and its importance have a special place. In particular, the integration of different energy systems and the importance of their sustainability against a variety of natural or subversive events are of great interest. Therefore, analyzing the conditions and providing economical and practical solutions to this concept would be crucial.

Furthermore, since the SCs should be smart, they will face all the SG challenges in the energy sector. Some of the most substantial features are as follows:

- Implementation of metering and monitoring systems in SGs requires a significant initial investment in telecommunication infrastructure as well as the replacement investment of metering equipment to new ones, which are updated after a few years.
- Ensuring data security in measurement, monitoring, and data transfer systems and economic data exchanges is a further challenge [25].
- The need to train different citizens on how to use some SG features such as demand response programs and separate pricing tariffs [26]
- Challenges regarding the implementation of automation in the distribution system and even transmission [27].
- Electric vehicles and their applications (different charging and discharging strategies), their ability to be used as energy storage systems, optimal parking placement, data transfer, and proper modeling as uncertain non-linear loads [28].
- Emphasis on the use of renewable energy resources, which due to their uncertain and unpredictable nature, pose severe challenges in the operation, control, and planning of the power system; thus, it is necessary to apply appropriate and robust uncertainty modeling methods. The negative impacts of these sources can be mitigated by real-time monitoring and implementing effective energy storage strategies [29].
- Increasing the penetration of hybrid AC/DC power networks, which requires the development and application of appropriate standards in the various areas of planning, operation, protection, and control.

5. TOP SMART CITIES

One of the most significant studies in this field was conducted by [30] in which Eden Strategy Institute and ONG&ONG (OXD) address a ranking of the Top 50 SC Governments over 140 cities. The main criteria in this study were: leadership, vision, budget, support programs, financial, policies, people-centricity, ecosystems, track record, and talent-readiness. Based on this investigation, the 10 top cities in the world are ranked as London, Singapore, Seoul, New York, Helsinki, Montreal, Boston, Melbourne, Barcelona, and Shanghai. However, the other research centers and institutes have introduced SCs around the world based on relatively similar criteria and highlighted almost the same cities, with a slight difference in ranking. For example, the Bismart Company introduced the 7 top SCs around the world like New York, Singapore, London, Barcelona, Oslo, Toronto, and Tokyo [31]. However, according to the Gigabit Institute reports this ranking has been changed for the 10 top cities in the world as New York, London, Paris, Tokyo, Reykjavik, Singapore, Seoul, Toronto, Hong Kong, and Amsterdam [32].

6. SMARTIZATION ROAD MAP

In [33], smartization was divided into macro, mezzo, and micro dimensions. The macro level includes the strategic and multidisciplinary resources; the mezzo level is related to strategy implementation and actor appropriation, and the last one regards to different technologies. The mentioned levels correspond to the five main stages of the SC model, including strategy, multidisciplinarity, appropriation, roadmap, and technology.

Also, reference [34], as a supplementary work in this field, has divided the SC development into eight phases, including planning, demand identification, service identification, device identification, technology identification, roadmap drafting, roadmap adjustment, and follow-up stage.

Generally, there are four significant steps in making cities smart and measuring the smartness of cities, as follows [35]:

- Marketing: To inform and introduce the stakeholders and citizens to the SC features and requirements, cities such as Frankfurt are at this stage.
- Pilots: the implementation of pilot projects in the field of intelligent design to create a visible image; cities like Berlin are at this stage.
- Vertical: integrated management system to achieve the smartization of cities; Luxembourg is an example of these cities.
- Platform: in the final phase, a unified platform is created for integrated management systems using all the mechanisms to accomplish the objectives of a SC. London and New York are examples of cities in this category.

It should be emphasized that the roadmap for achieving the SC is not unique and will change according to the specific circumstances of society and the locations of cities.

7. DISCUSSION

The idea of the ideal city is ambiguous and clear at the same time. Humans desire to eliminate all the deficiencies experienced in social life. It seems that introducing the idea of a SC, at least physically, is an attempt to reach more prosperity and improve living standards, on the way to the ideal city. The main question in this regard is whether the smart city is in line with the ideal city.

In this study, we tried to introduce some basic concepts and definitions regarding SCs based on the literature and different experiences. Also, the main challenges and some necessary steps for implementing a SC concept are detailed. Despite many previous efforts, there is still a long way to attain the different objectives of the SC. Some feasible strategies to deal with this issue include using high-speed internet systems, appropriate standards, integrated energy systems, smart governments, competitive economics, transparency in financial transactions, and data security. However, the essential infrastructure that can make the existence of such cities possible is smart citizens.

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