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Commentary

Explaining the role of reducing energy consumption in strengthening healthy cities in smart cities

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Abstract: Different dimensions and interventions can lead to the outcome of being a healthy, smart city. One of them is the smart management of energy, via a smart infrastructure—the system component that certainly should be considered in a smart city. Improving the quality of life is one of the big aims of smart cities. For this reason, the management of energy is one of the factors that directly and indirectly affect it and public health. The present study is a descriptive-analytical type, and through a meta-synthesis methodology, the analysis explores past studies on decreasing energy consumption and moving toward healthy and smart city initiatives. The conclusion provides actionable recommendations for realizing this vision. Studies indicate that achieving smart, healthier cities requires the integration of smart grids and renewable energy, the implementation of data-driven energy management systems, and the promotion of citizen engagement and behavioral change.

Keywords: smart city; healthy smart city; smart energy management; quality of life

1. Introduction

Urbanization and its challenges of energy for sustainable development in the 21st century, the rapid development of information and communication technology (ICT), gave birth to the new concept of “smart city” and “smart energy” [1]. This is a concept that was introduced in 1990 to incorporate advanced ICT-based hardware and software in urban planning [2]. Providing the city's inhabitants with a better quality of life is considered in these smart cities [3]. Becoming a smarter city is very inviting to a city [4]. Generating smarter cities is very inviting to a city [4]. For these reasons, the city should be equipped with an infrastructure that provides it with data on energy consumption. Since a cleaner urban environment is closely linked to improving the health of citizens, there is no doubt about why it is worth investing in this modern infrastructure [5].

The concept of the Smart Energy City (SEC), its management, and public health are considered in this present study. Since energy management is one of the most challenging issues in these cities [6], it is important to note that the smart city should gradually migrate to a full clean energy scheme, a goal that can be facilitated by renewable energy such as solar energy [7]. Public health can be defined as “The science and art of promoting health, preventing disease, and prolonging life through the organized efforts of society”. In this context, energy management in smart cities can contribute to the organized efforts of society for disease prevention and health promotion [8].

This paper aims to define the term "smart city" and to identify the best infrastructures for optimal energy management in these cities with a positive impact on public health, as well as to inform about the gaps in the current research. This helps to understand "what is"—that which is "actually existing", and what "should be". Because of this aim, the development of the "smart energy city" from disparate perspectives was explored. To begin with, it is necessary to recognize the principles and approaches of a smart city and its energy management with an impact on public health. After that, the approaches must be addressed in the management of energy in the smart city to introduce the best clean energies.

2. Literature review

2.1. Definitions and conceptualization of smart cities

The smart city concept came out in response to the vital problems created when specific regions began to attract a higher number of inhabitants. These migrations resulted in different things, like managing resources [9]. As can be seen in **Table 1**, there are several definitions of a smart city that have come out over time, each differing from the other in terms of the main 'smart' characteristic deemed as the most relevant [10]. As mentioned by [4], most studies point to infrastructure as the central aspect of a smart city concept, while Information and Communication Technology (ICT) is identified as the key driver of the evolution of cities, coupled with social, environmental, and human capital development .

Table 1. Working definitions of the smart city concept.

Author(s)	Year	Smart City Definition
Arroub et al.	2016	"A city can be defined as "smart" when investments in human and social capital and modern transport and communication infrastructure fuel sustainable economic growth and high quality of life, with a wise management of natural resources, through participatory governance" [11].
Mahapatra et al.	2017	"A Smart City is a city which uses information and communication technologies (ICT) such as smart sensors, cognitive learning, and context awareness to make lives more comfortable, efficient, and sustainable" [12].
Abdi and Shahbazitabar	2020	"The place that utilizes the ICT for improving the life quality as well as optimal management of all natural resources, through smart governance" [13].
Radu	2020	"Smart city means providing premises that could generate smarter and more accessible ways to interact, especially between citizens and local government or between suppliers of products and services and consumers".

2.2. Characteristics of the smart cities

According to [14], in the matter of smart cities, there is no specific list of characteristics for it. A city can be smart at a time when investments in human and social capital, traditional infrastructure, and disruptive technologies fuel sustainable economic growth and high quality of life, with a wise management of natural resources, through participatory governance [15]. Eremia et al [16] stated that there is a set of physical and legislative infrastructures that support economic development, ensure social inclusion, and allow environmental protection in the city called smart. Pathak and Pandey [17] state that many things need to be considered in a city as smart including smart society, economy, environment, people, administration, and living. Smart living is important in this study because the aim of it is to achieve a modern lifestyle and reasonable consumption of energy [9,17], Silva et al [18] state that

pervasive attention to sustainability played the main role in the emergence of smart cities. **Figure 1** illustrates the main characteristics, tools, and components of a city, available for both the municipality and citizens, that can transform a city into a smart one.

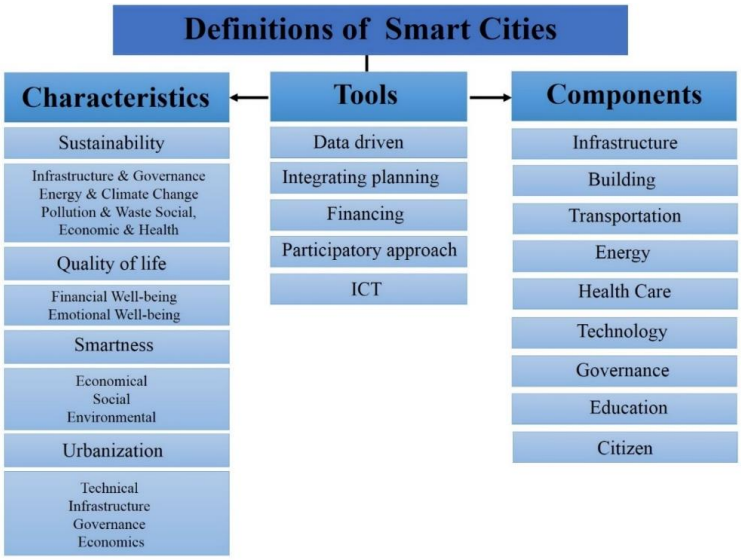

Figure 1. Characteristics, tools, and components used to define the smart city. Sources: [16–18].

2.3. Principles and approaches of smart city

For the smart city concept, there are many approaches and views. In general, the intelligent city is a city that has a good outlook for the future in six characteristics:

- Economy,
- Mobility,
- Environment,
- People, Living and
- Governance [3].

The elements of a smart city, divided into physical and social, are shown in **Figure 2**.

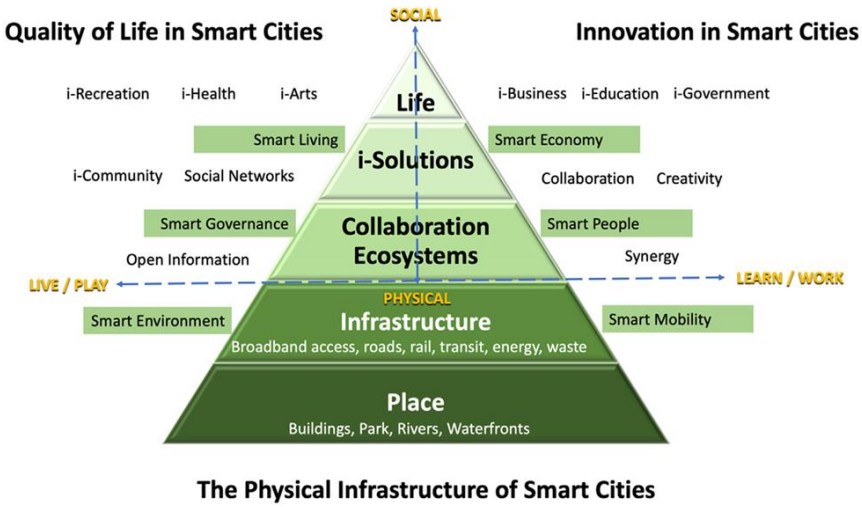

Figure 2. Smart city elements Source: [19].

2.4. Smart energy

Smart energy is described as a smart electrical energy system that interconnects all utilities and end-users via a smart infrastructure [16]. Green energy, sustainable energy, renewable energy, etc., were proposed during the last few decades to address the challenges that arise with increasing energy demand [20]. According [21], the smart energy system is a concept that considers tying in the electricity, heating, industry, and transport sectors. This concept certainly illustrates an extension of the concepts of a "smart city" and its variations. The integration of the smart energy concept from its various components is shown in **Figure 3**.

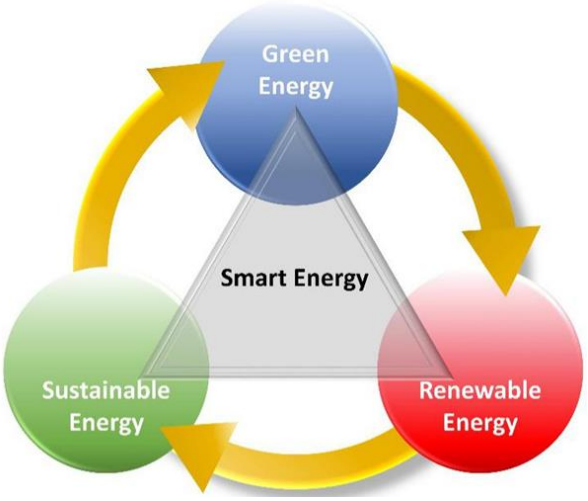

Figure3. Consolidation of smart energy concept Source: [20].

Smart energy city development is a component of smart city development aiming at a site-specific continuous transition towards sustainability, self-sufficiency, and resilience of energy systems [22].

2.5. Smart city and its energy management

Governments and societies all over the world pay more and more attention to the research and development of smart cities. There is numerous research on energy management of smart cities with an impact on public health, which has been or is being conducted worldwide.

Nowadays, smart energy management has become a key concern in smart cities since it is important and contributes to sustainability. As well, smart energy approaches introduce different energy management strategies to smart environments to improve energy utilization and also reduce energy wastage and cost [20]. Different kinds of approaches are used for energy management, which are mentioned below . This is a model for islanded microgrid energy management by [23].

2.6. Smart city technologies and energy efficiency strategies

This section explores how smart city technologies and data-driven approaches can be effectively leveraged to reduce energy consumption and promote sustainable urban development. It highlights the technological innovations that are crucial for

achieving energy efficiency goals while simultaneously improving public health outcomes. **Table 2** describes the smart grid strategy and renewable energy integration.

Table 2. Smart grids and renewable energy integration.

Strategies	Explanation
Smart grids and renewable energy integration	Smart grids transform urban energy management by integrating renewable sources like solar and wind, reducing reliance on fossil fuels and lowering emissions. They enable real-time monitoring and control, enhancing grid stability and energy security. The incorporation of electric vehicles and vehicle-to-grid technology further supports renewable energy distribution, though challenges in EV adoption and V2G infrastructure development persist [24–26].
data-driven energy management systems	Smart city platforms utilize data analytics and machine learning to optimize urban energy consumption by collecting real-time data from smart meters and sensors. They predict energy demand and enable proactive adjustments, enhancing efficiency in buildings and infrastructure. Examples include smart home management systems and automated street lighting, which help reduce energy use and improve indoor air quality [25,27].
citizen engagement and behavioral change	Smart city initiatives encourage energy conservation by engaging citizens with real-time feedback and incentives for energy-efficient behaviors, enhanced through gamification techniques. These strategies promote community responsibility but face challenges in ensuring equitable access to information and participation across diverse demographic groups [28].

To provide more insight into the existing research on this topic, the table below will review studies aligned with this work and offer a description of their research features. **Table 3** summarizes the key indicators for a "smart energy city" from the perspectives of various experts.

Table 3. Key indicators regarding the "Smart energy city".

Research Title	Author(s)	Year	Dependent Variables	Independent Variables	Methods
Smart energy city development: A story told by urban planners [22]	Mosannenzadeh F et al.	2017	Sustainable city	Smart energy city, smart city	Qualitative (5W+1H/why, what, who, where, when, how)
Smart Energy Systems for Sustainable Smart Cities: Current Developments, Trends, and Future Directions [29]	O'Dwyer E et al.	2018	Sustainable Smart Cities	Smart Energy Systems	Literature Review
AI-Based Physical and Virtual Platforms with 5-Layered Architecture for Sustainable Smart Energy City Development [30]	Park S et al.	2019	a sustainable smart energy city (SSEC)	Independent products and unit technology	Quantitative
A Novel Approach Towards Enhancing the Quality of Life in Smart Cities Using Clouds and IoT-Based Technologies [31]	Mishra KN and Chakraborty C	2020	Quality of Life in Smart Cities	Using Clouds and IoT Based Technologies	Literature Review
From Smart Energy Community to Smart Energy Municipalities: literature review, agendas and pathways [32]	Ceglia F et al.	2020	Sustainable energy systems	Smart Energy Community	Literature Review
Futuristic Sustainable Energy Management in Smart Environments: A Review of Peak Load Shaving and Demand Response Strategies, Challenges, and Opportunities [17]	Silva BN et al.	2020	Futuristic Sustainable Energy Management	Smart environments	Literature Review

Table 3. (*Continued*).

Research Title	Author(s)	Year	Dependent Variables	Independent Variables	Methods
Smart energy cities in a 100% renewable energy context [33]	Thellufsen JZ et al.	2020	Smart Energy Cities within the context of 100% renewable energy	Flexible operation of power to heat in terms of heat pumps in combination with thermal storage and district heating/smart charging of electricity	Quantitative
Smart Energy in a Smart City: Utopia or Reality? Evidence from Poland [34]	Lewandowska A et al.	2020	Smart Energy in a Smart City	Renewable energy sources (RES)	Quantitative/survey
A systematic review of the smart energy conservation system: From smart homes to sustainable smart cities [35]	Kim H et al.	2021	Managing energy in smart cities	Energy conservation systems	Quantitative
Smart energy cities: The evolution of the city-energy-sustainability nexus [18]	Thornbush M and Golubchikov O	2021	Smart energy cities	Low carbon	Literature Review

2.7. Smart and healthy city

Smart cities include important ingredients for a healthier environment and for improved quality of life and well-being of city dwellers [36]. A healthy city must prioritize basic infrastructure for all. Many smart-city discussions focus on high technology, overlooking more basic, yet innovative, equitable solutions that are emerging [37]. The World Health Organization (WHO) defines a healthy city as a city that constantly creates and improves its physical and social environments while expanding the community resources that empower the people to mutually support one another in the performance of functions of life altogether as well as their development to their full potentials [38].

3. Methodology

The method of the research is “meta-synthesis”. Qualitative meta-synthesis is an intentional and coherent approach to analyzing data across qualitative studies [39]. Since this is an interpretive approach suitable for higher-level analyses and the formation of new interpretations beyond the discoveries of individual qualitative research, it is suitable for this study [40]. It means that theoretical foundations in this field and the results of studies and researches are combined to give a more comprehensive view of the management of energy in the smart city and buildings with the aim of good, improved public health.

4. Analyzing previous research

Kamel Boulos and Al-Shorbaji [36] undertook. “On the Internet of Things, Smart Cities and the WHO Healthy Cities”. The authors argue that IoT-powered smart cities stand a better chance of becoming healthier cities. The World Health Organization (WHO) Healthy Cities Network and associated national networks have hundreds of member cities around the world that could benefit from, and harness the power of, IoT to improve the health and well-being of their local populations.

Ryser [41], in his review paper entitled “Planning Smart Cities, Sustainable, Healthy, Liveable, Creative Cities or Just Planning Cities? discusses “Smart City”

confined to ICT support systems. He mentioned that “smart city” has close connections with the “sustainable city”, the “resilient city”, the “liveable”, “playable healthy”, “sensible”, “green city”, and more directly the “eco-city”. In this sense, a “smart city” is a platform for innovation, where converging technologies transform government” (or governance). Sectorally, this translates into “smart water”, “smart energy”, “smart transportation”, the key fields in which ICT is being put to use, most frequently at the level of buildings, to control their utilization and more specifically that of their appliances, as well as to measure their technical performance. Cisco postulates that the Internet has become the fourth “essential utility”.

A research entitled “Linking future energy systems with heritage requalification in Smart Cities. Ongoing research and experimentation in the city of Trento (IT)” by Andreucci [42], stated that Trento was selected in 2014 as an IEEE Core Smart City in consideration of its specific research and experimentation focusing on six significant areas: Big Data/Open Data, Fostering Smart Mobility for Mid-sized Cities, Innovative Tourism Services, Smart Citizens for Healthy Cities, Energy Systems, and e-Government.

Bisello and Vettorato [43], in their research entitled “The latest generation of EU Smart City projects: turning “Clean Energy for All” into “Clean Benefits for All”, stated that the European Union is in the process of updating its energy policy and legislative framework under the motto “Clean Energy for All Europeans”. Besides expected climate-energy benefits, the EU narrative is introducing new elements to persuade citizens and stakeholders to change their perspective, shifting the general perception from mitigation costs to development opportunities. They introduced and explained the positive energy district. Positive energy districts consist of several buildings (new, retrofitted, or a combination of both) that actively manage their energy consumption and the energy flow between them and the wider energy system, having an annual positive energy balance. The positive balance is achieved thanks to the exploitation of local renewable energy sources (RES), local storage, smart energy grids, demand-response systems, integrated energy management (electricity, heating, and cooling), co-design, and user interaction.

Su et al [44] did research entitled “The Experience and Enlightenment of Asian Smart City Development—A Comparative Study of China and Japan” They first expound on the development process of low-carbon cities, eco-cities, and smart cities in Japan and China. Then, they analyze the coordinated development of intelligent environmental protection measures in government policies, transportation, energy utilization, resource recovery, and community management. Finally, they compare Japan's and China’s smart city development characteristics. They discuss the improvement measures for energy utilization, urban transportation, and urban operation, including developing renewable energy systems, efficient energy use, and citizen participation policy. These experiences can provide feasible measures for constructing smarter and healthier cities. **Table 4** summarizes the achievements and results of previous research.

Table 4. Results of reviewing the previous research.

Author(s)	Year	Becoming a smart and healthier city
Kamel Boulos and Al-Shorbaji	2014	IoT-powered smart cities stand better chances of becoming healthier cities.
Ryser	2014	ICT support systems
Andreucci	2018	Big Data/Open Data, Fostering Smart Mobility for Mid-sized Cities, Innovative Tourism Services, Smart Citizens for Healthy Cities, Energy Systems, and Government.
Bisello and Vettorato	2019	Positive energy district [43]
Su et al.	2022	Developing renewable energy systems, efficient energy use, and citizen participation policy.
Mosannenzadeh et al.	2017	Genuine smart energy cities integrate new technologies, stakeholders, and energy domains within clear targets, thriving when combined with broader sustainability efforts.
Ceglia et al.	2020	The intelligent energy community relies on a coherent, intersectoral approach to optimize energy control strategies. It fosters sustainable renewable systems, enhances storage synergies through energy sharing, and maximizes economic efficiency in energy use.
Lewandowska et al.	2020	Renewable energy installations play a key role in the development strategies of Polish cities, particularly those aiming to become "smart cities". Notably, solar energy facilities dominate among renewable energy sources.

5. Conclusion

This study has explored the critical intersection of smart energy management, public health, and quality of life in the context of smart cities. The findings underscore that the integration of advanced information and communication technologies (ICT) and innovative energy solutions plays a pivotal role in shaping sustainable urban environments. By leveraging tools such as smart sensors and data analytics, cities can optimize resource management, reduce carbon footprints, and create healthier living conditions for their residents.

A key highlight of the research is the dual impact of energy management on public health—both directly and indirectly. Directly, efficient energy systems contribute to reducing pollution and enhancing air quality, which are vital for minimizing respiratory and cardiovascular diseases. Indirectly, the availability of reliable and clean energy supports broader aspects of well-being, such as access to healthcare, education, and economic opportunities. The impact of energy management in a healthy smart city is shown schematically in **Figure 4**.

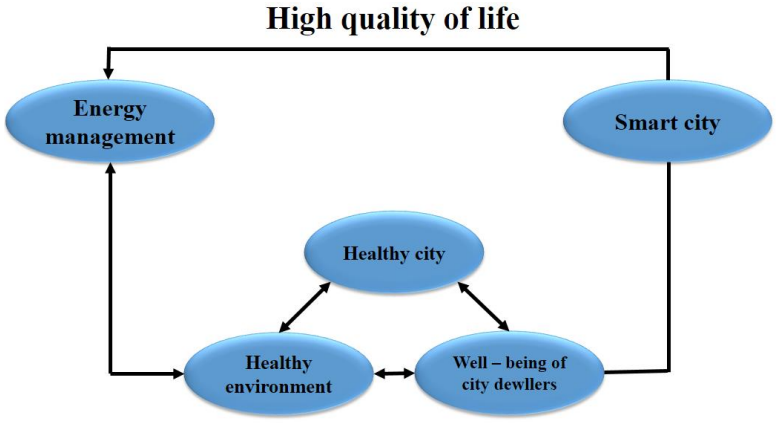

Figure 4. The impact of energy management in the smart healthy city.

The study also emphasizes the importance of transitioning to renewable energy sources, particularly solar energy, as a cornerstone of sustainable urban development. This transition not only addresses environmental challenges but also aligns with public health objectives by promoting cleaner and safer energy alternatives. However, the research acknowledges that achieving these goals requires overcoming significant challenges, including smart grids and renewable energy integration, data-driven energy management systems, and citizen engagement and behavioral change.

Looking ahead, the findings call for a more holistic approach to energy management in smart cities, one that prioritizes both sustainability and public health. Future research should focus on identifying gaps in current practices, exploring innovative solutions, and assessing the long-term impacts of energy systems on urban populations. By doing so, cities can ensure that their energy strategies not only meet technical and environmental criteria but also contribute to the overall well-being and quality of life of their residents. Ultimately, this study serves as a reminder that the pursuit of smart cities is not just about technological advancements but also about creating environments that are livable, healthy, and equitable for all.

As a final point, some of the impacts of energy consumption management in the effort to achieve healthier smart cities have been discussed, as shown in **Table 5**.

Table 5. The impact of energy management on becoming a smart healthy city.

Energy management	Becoming a smart healthy city
Islanded microgrid	This has considerable renewable sources, which cause less or zero pollution, minimize depletion of ozone layers, and ensure sustainability.
Future Sustainable Smart Energy City (SSEC)	Five components are required for a future smart energy city: intelligent energy, smart energy data analytics, energy prosumer, energy security for the city, and renewable energy.

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