smart cities

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Assessing the Progress of Smart Cities in Saudi Arabia

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Abstract: Information and communication technology is changing the manner in which urban policies are designed. Saudi Arabia bases its smart initiative on the use of information and communication technologies in six dimensions, including economy, people, environment, living, mobility, and governance to improve quality of life and sustainable environment. This study draws on four Saudi Arabian cities including Riyadh, Makkah, Jeddah, and Medina, and aims to analyze their progress in the transformation into smart cities. The six identified areas were assessed using 57 indicators based on national and international information and literature. The results show that the four cities are progressing successfully into smart cities, with the highest progress evident for smart economy and the lowest progress for smart mobility in all investigated cities. Study findings show that Riyadh has made the most progress in the six smart city dimensions, concluding that Riyadh has been efficiently executing the smart city initiative with an aim to be a unique model in the world.

Keywords: smart cities; information and communication technology; quality of life; sustainable environment; Saudi Arabia

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1. Introduction

Cities across the world are growing dramatically, with about 55% of the world's population living in urban areas, and this growth is anticipated to outstrip 68% by the year 2050 [1]. Many Middle Eastern countries today have already outstripped this expected universal urbanization level [2]. This rapid urbanization considerably increases pressure on natural and environmental resources and creates concerns about the future of water and energy.

To meet urbanization challenges, a new proposal named "Smart City" emerged in the 1990s [3]. A smart city is considered to use digital information and technological instruments extensively to generate efficiencies for improving economic growth, thus boosting quality of life and enhancing urban sustainability [4]. There is global disagreement about the definition of a smart city, and many definitions exist, highlighting the importance of information and communication technology (ICT) in creating smart cities. Javidroozi et al. [5] described a smart city as a set of complex systems that operate with each other based on inter-communication and inter-operation between sectors. In this vein, cities have become smart not only in terms of automation of urban sectors, but also in manners that help local authorities to follow up, analyze, evaluate, and consequently plan the city to improve quality of life [6].

However, increased reliance on technology has been accompanied by several challenges related to data management, security, and the establishment of digital databases [7]. These challenges can vary from one country to another, and from one region to another. For instance, in the Middle East region, these challenges have imposed more burdens on urban authorities, where most cities suffer from a lack of resources and infrastructures to shift into urban smartness. Thus, a limited number of Middle Eastern cities are highly ranked in international indices for smart cities, such as Dubai, Abu Dhabi, and Riyadh. Nevertheless, the current scenario for Middle Eastern cities requires finding ways to control new urban challenges. Hence, many cities (e.g., Amman, Cairo, and Muscat) have already

begun to look for solutions that enable transportation networks, urban logistics, land uses, and high-quality infrastructures with long-run positive effects on the economy. Many of these solutions are based on the use of ICT, helping to transform them into smart cities. According to Pereira et al. [8], the utilization of ICT in an innovative manner can enhance the performance of infrastructures and services if open data is also incorporated. Various stakeholders are utilizing open data in technology to tackle development challenges through intelligent solutions. Therefore, a smart city should cultivate an open environment that promotes the generation of intelligent ideas while involving residents directly in service processes [9]. By doing so, access to government open data fosters transparency provides new information and contributes to optimizing the delivery of public value in smart city domains [9].

Although the current literature on smart cities has provided important insights into the transformation process from traditional cities into smarter ones [10], the smart city is a relatively new concept in the Middle East; this fact clarifies its late insertion both in the literature and local policies. With the increasing trend towards smart cities, it is important to fill this research gap.

Saudi Arabia is the largest country in the Middle East, with a population of 32.2 million inhabitants; 83% of its population lives in urban areas [11]. Rapid urbanization in Saudi Arabia has created several challenges that require innovative solutions. Therefore, Saudi Vision 2030 has set specific objectives for the implementation process into a smart city. In 2017, in response to Saudi Vision, the Ministry of Municipal and Rural Affairs and Housing (MOMRAH) established the first Smart Cities program. This program seeks to drive a transformation process towards urban smartness, and 17 cities were selected (representing 72% of the overall population) to implement smart urban projects [12]. Hence, smart city projects are implemented in cities such as Riyadh, Yanbu industrial city, Makkah, Jeddah, Medina, Al-Ahsa, and Neom. According to Gaul [13], the financial value of the Saudi smart cities market was calculated at $3500 million in 2019. Hence, it is important to assess the progress these cities have made in the transformation towards urban smartness, contributing to enhancing the decision-making process and enriching knowledge.

Riyadh, the capital of Saudi Arabia, has been growing and transforming into a smart city. According to the Smart City Index of 2023, Riyadh was ranked 30 out of 141 cities [14]. Recent international indices issued by the Department of Economic and Social Affairs in the United Nations have confirmed the transformation process of Saudi Arabia into urban smartness, where the Local Online Service Index of 2022 ranked Riyadh 34 out of 147 world cities [15] (p. 260); The E-Participation Index of 2022 (EPI) ranked Riyadh 43 out of 193 cities worldwide [16] (p. 257); the E-Government Development Index of 2022 (EGDI) ranked Saudi Arabia 31 out of 193 countries [17]. The Global Cybersecurity Index of 2022 (GCI) ranked Saudi Arabia 2 out of 182 countries [18] (p. 25). The Global Innovation Index (GII) positioned Saudi Arabia as 41 out of 132 countries [19]. Advanced technology and financial capabilities have facilitated Riyadh's transformation into a smart city. It uses ICT as an engine for urban growth to improve sustainability and quality of life and has implemented several reforms in terms of urban governance, community participation, and plans such as Saudi Vision 2023 [20].

Riyadh, similar to numerous other global cities, has faced challenges in transitioning toward becoming a smart urban center. The main hurdles in achieving the smart city paradigm entail modifying regulations, addressing inconsistent guidelines, accurately estimating infrastructure costs, devising intelligent programs based on strategic resources, managing large-scale smart projects, acquiring technical knowledge and proficiency in artificial intelligence, transforming current practices, promoting public engagement in decision-making procedures, fostering human capital development, and establishing collaborative communication channels.

This study aims to assess the progress of transformation towards smart cities in Saudi Arabia while addressing the following research questions: (1) How can the progress of transformation into smarter cities be assessed? (2) What are the indicators that measure the progress of transformation into smart cities? (3) What are the fundamental deviations that meet the transformation process toward smart cities? (4) What are the necessary implications to enhance the transformation process toward smart cities? It is possible to gain a better understanding of smart cities and their evolution by considering these inquiries within a real-life context. In order to effectively implement the smart city model, it is crucial to evaluate the transformation process and identify how new technologies and information can be linked with city elements such as people, infrastructure, etc. This approach can result in sustainable development as well as an improved quality of life for residents.

2. Literature Review

The term "smart city" first appeared in 1994 [21] with a combination between urbanization and information. Since the 2000s, smart city has become a widespread and common label [22]. While this concept is extensively used nowadays, there is still disagreement on its meaning [23–27]. Some of the existing literature highlights the definitions of smart cities (e.g., [28–31]) while other studies emphasize specific sectors, such as green construction, energy, transport, and environment in smart cities (e.g., [29,30]) or the use of ICT in developing smart cities (e.g., [32–35]). Another body of literature has focused on using indicators to assess urban smartness (e.g., [36–39]). Although some studies separate the concept of a smart city from a sustainable city (e.g., [40]), most researchers recognize that these two terms match, as a smart city seeks to achieve sustainability.

Many definitions of smart cities are focused on basic elements, such as sustainability and quality of life. A common understanding, shared by the European Commission, is that the use of technology improves sustainability and quality of life in smart cities [41]. In this way, the transformation of traditional cities into smart cities should not be seen as a goal in itself but rather should be seen as a system coexisting with driving forces and socio-economic and environmental scales. Other definitions of smart cities are focused on a single dimension of smartness. For example, Chen and Silva [42] studied smart transport in the UK. They developed a new framework using 49 indicators, including five new ones, to assess the performance of the transport sector in English cities. Chen and Silva [43] rank Greater London first in smart transport, followed by West Midlands and West of England. Such a new assessment framework is valuable for decision-makers, stakeholders, and researchers in measuring the progress of smart transport in the UK and in other countries.

A smart city is described as a concept in multiple ways, but a general definition consists of three areas: the use of intelligent technology such as the Internet of Things (IoT), sustainability, and quality of life. Alnsour [2] defined a city as a complex mixture of physical and human formations that interrelate with each other, requiring the use of technology and new communication channels to link urban sectors to each other. Bakıcı et al. [44] define a smart city as a high-tech intensive that connects residents, information, and various urban sectors using modern technology to reach sustainable development, a high level of quality of life, and entrepreneurial economics. Giffinger et al. [45] argue that smart city refers to determining intelligent solutions which enable modern cities to improve the quality of the services provided to people. Kourtit and Nijkamp [46] consider smart cities to be a result of knowledge-intensive and innovative strategies aimed at improving the socio-economic, ecological, and competitive performance of urban areas. The progress of smart cities relies upon enhancing human capital (e.g., trained and skilled employees) infrastructural capital (e.g., high-tech communication services) social capital (e.g., open network connections) and entrepreneurial capital (e.g., innovative business activities). Barrionuevo et al. [47] see that smart cities refer to smart use of technology and resources to improve sustainability and quality of life for urban areas. The above different definitions of a smart city show that the

basic objective of the use of new technology is to improve sustainability and quality of life in cities.

Angelidou [24] argues the factors that form the smart city concept include urban features, knowledge economy, and technology. Dirks and Keeling [48] focus on the integration of a city's different systems (physical infrastructure, energy, transportation, buildings, health care, water, education, food, and public safety) in shaping a smart city. Kanter and Litow [49] argue that linking smartness into each subsystem of a city, one by one, is not enough to make the city smart, as this should be treated as an integrated system. Giffinger and Gudrun [50] define six elements to create a smart city, including a smart economy, smart mobility, smart environment, smart people, smart living, and smart governance. Most researchers argue that all these elements have the goal of improving quality of life [51]. In this context, Lombardi et al. [52] have linked the above six elements with various features of urban development, as presented in Table 1. Such a link demonstrates that a smart city should not be seen as a place of technological innovation only, as other features of urban development are equally significant.

Table 1. Elements of a smart city and related aspects [52].

Elements of a Smart City	Features of Urban Development
Smart economy	Industry
Smart people	Education
Smart governance	E-democracy
Smart mobility	Logistics and infrastructures
Smart environment	Efficiency and sustainability
Smart living	Security and quality

A number of studies in the last two decades have linked the elements of a smart city presented in Table 1 to urban development in a different way. For example, in the context of a smart economy, Grab and Ilie [53] reviewed the role of innovative solutions by business management digitalization in shaping smart cities' economics, while Ardito et al. [54] emphasized the importance of universities as a knowledge provider in building human resources capacity for smart economic projects. Other studies tied the smart economy to innovative industries [55] or tourism [56]. The study conducted by Jiang et al. [35] highlights the significant role of public involvement in a smart city as a primary objective to attain transparency. Transparency, which pertains to the accessibility of information for influencing decision-making, is closely associated with accountability [2]. However, there is always a trade-off between privacy and transparency [2], necessitating legislation to establish an appropriate balance between the two. In the context of a smart city framework, technology can promote transparency through various means such as ensuring online availability of information while preserving privacy and enhancing visibility throughout the decision-making process.

Assessment frameworks of smart cities such as the Smart Cities Wheel (Boyd Cohen) and the European Smart Cities Ranking Giffinger et al. [45] have been designed to facilitate the comparison between cities and to evaluate the extent of a city's progress in the transformation towards urban smartness. The Smart Cities Wheel (Boyd Cohen) is a universal comprehensive framework for considering all key elements that shape a smart city and to enhance smart city benchmarking. The assessment framework includes 6 categories and 26 indicators. The European Smart Cities Ranking was developed by Giffinger et al. [45], with 6 categories and 64 indicators, and was published by the University of Technology, Vienna. Other assessment frameworks also appear in the literature on smart sustainable cities, such as City Protocol, that promote city-centric solutions to increase benefits for people; it has 9 categories and 190 indicators and extends ISO 37120.

Although many studies use elements shown in Table 1 to measure a smart city, an overview of these assessment frameworks illustrates the heterogeneity of the smart city concept; expanding these frameworks and indicators increases the concept's ambiguity [57]. Hence, many models appear to measure urban smartness. For instance, Carli et al. [6] proposed a conceptual framework for smart city performance indicators based on two areas. The first includes two elements: one investigates the physical infrastructure of a city, urban services, and the environment, while the other deals with residents' satisfaction and well-being. The second area consists of three levels which illustrate how data are gathered to assess the elements in the first area. Likewise, Priano and Guerra [58] developed a three-level model to measure the smartness of a city. The first level deals with determining problems, setting solutions, and criteria that a smart city project aims to achieve. The second level highlights the scope of the smart city project (e.g., road and area). The third level is the citizens' evaluation of the city.

As a result, there is no one framework to measure the progress of smart cities in the literature and existing international indices. A common shared point is that a smart city uses various types of ICT in the six dimensions of economy, mobility, environment, people, living, and governance to improve quality of life and the sustainable environment.

3. The Smart City Concept in Saudi Arabian Literature

In Saudi Arabia, the concept of a smart city as a set of elements (e.g., smart economy, smart environment, smart governance, smart people, smart governance, and smart living) has appeared in recent decades. The origins of the smart city concept in Saudi literature hark back to studies of e-government. Since 2008, many articles published on e-government are considered the first endeavor for introducing digital instruments of smart approaches in Saudi cities.

In 2014, the concept of a smart city began to appear in Saudi literature in papers focused mainly on smart development (e.g., [59]), highlighting the impotence of urban smartness in enhancing economic aspects such as industry [60], tourism [61], business initiatives [62], and economic contribution to reducing energy consumption [63].

In 2016, the first holistic review of smart cities appeared in Saudi Vision 2030, based on e-government components, causing new studies to focus on the smart cities concept. Several scientific papers discussed the general features of smart cities such as [64,65]. Another body of literature began to discuss smart megaprojects in Saudi cities, analyzing the impact of these projects in the urban context (e.g., [66,67]). The outcomes of these studies have led to an elaborate technical understanding of the smart city concept [68,69], in addition to dealing with smart technology (e.g., [70]), and the transfer of smart practices into different urban areas (e.g., [71]).

After 2016, the above elaboration on the concept of smart cities in the Saudi literature has contributed to emerging research, highlighting challenges and opportunities of the transformation of Saudi cities into smarter ones [72] or systematic approaches assessing infrastructures of smart city elements such as energy (e.g., [73,74]) and mobility [75,76].

Since 2020, the literature has shifted towards the evaluation of smart programs and initiatives at the sectoral level, redeveloping the smart city concept (e.g., [77]). Hence, many studies have dealt with one single element of the smart city in a broader context of urban life, such as a smart environment [78,79], smart mobility [80,81] smart governance [82,83], smart living [84,85], and smart economy [86,87].

Finally, it is worth mentioning that some studies used various labels of smart city elements. For example, Almutairi [88] used the term Intelligent Transportation Systems, Alshammari [89] addressed the intelligent streetscape; Alsheikhy et al. [90] analyzed the intelligent parking system. It must be noted here that the term intelligent city is often used simultaneously with the smart city in some research papers in the Saudi urban context.

4. Data and Method

This study targeted Saudi cities included in the international Smart City Indices, such as IMD, comprising Riyadh, Makkah, Jeddah, and Medina. These cities represent the largest hub for business, technology, international tourism, and innovative industries. Another criterion adopted for these cities is based on Giffinger et al. [45] in which the city population of an examined city should exceed 100,000 inhabitants; this criterion is achieved for all of the sectors above. Table 2 provides demographic information for these cities, which together represent roughly 30% of the overall population in Saudi Arabia.

Table 2. Features of four case studies. Source [11].

City	Population No.	Urban Area km^2
Riyadh	7,070,729	3116
Makkah	2,385,509	1210
Jeddah	3,783,035	3537
Medina	1,411,599	943

To achieve the research objectives, the analytical method is employed. The said approach entails investigating entities, behaviors, and individuals through a range of information that can be measured using precise mathematical formulas. This approach guarantees clarity in the correlation between computed outcomes and initial information. Data were gathered from different sources including the official national statistical reports, international reports, websites of local institutions, ICT stakeholders, and smart city specialized platforms. Collected data covers all smart city dimensions including smart economy, smart mobility, smart environment, smart governance, smart living, and smart people.

In order to evaluate the advancement of four specific cities, Giffinger et al. [45] proposed a set of 73 guidelines for measuring their smart city development. These guidelines have become widely used by both researchers and international organizations when assessing smart cities. However, as data were not available for certain indicators developed by Giffinger et al. [45] and other Smart Cities Indexes such as MID Smart City Index, this study selected only 57 indicators from the total of 73 that were based on obtainable data within the Saudi context. It is important to note that various studies have struggled to assess all of the proposed indicators, including Giffinger et al.'s study which evaluated only 57 out of the original 73 based on available data. Table 3 presents a complete list of selected indicators across all dimensions of smart cities.

Table 3. Smart city indicators. Source: Giffinger et al. [45] and MID Smart City Index [14].

Elements of a Smart City	No.	Indicators
Smart economy	8	R&D expenditure in % of GDP, Unemployment rate, Percentage of full time employed, Number of companies per 100 inhabitants, Number of IT companies per number of total companies, Employment rate in knowledge-intensive sectors, local Air transport of passengers, and local New businesses registered.
Smart environment	8	Sunshine hours, Tons CO_2 eq of greenhouse gases emissions per inhabitants, Maximum number of days exceeding the PM10 limit, Residential waste production per inhabitant, Municipal plans in order to promote smart waste management, Percentage of recycled solid waste, Efficient use of water (use per GDP), and Efficient use of electricity (use per GDP).
Smart mobility	8	Public transport network per inhabitant, Satisfaction with access to public transport, Satisfaction with quality of public transport International accessibility, Computers in households, Broadband internet access in households, and Green mobility share. Traffic safety.

Table 3. *Cont.*

Elements of a Smart City	No.	Indicators
Smart governance	11	City representatives per resident, Political activity of inhabitants, Importance of politics for inhabitants, Expenditure of the municipal per resident in PPS, Satisfaction with quality of schools, Satisfaction with transparency of bureaucracy, Satisfaction with the fight against corruption, Drawing up of environmental balances, and Drawing up of acoustic zoning Drawing up of urban traffic plan and Natural disaster prevention policy
Smart people	9	Number of universities, Number research centers, Illiteracy rate, Book loans per residents, Participation ratio in language courses, Foreign language skills, Ratio of people working in creative industries, Ratio of voters in elections, and Participation ratio in voluntary work.
Smart living	13	Museums visits per inhabitant, Life expectancy, Hospital beds per inhabitant, Doctors per inhabitant, Satisfaction with quality of health system, Crime rate, and Death rate by assault Students per inhabitant, Average living area per inhabitant, Satisfaction with personal housing situation, Satisfaction with access to educational system, Satisfaction with quality of educational system, and Poverty rate.
Total	57	

To calculate smart city indicators, a standardization value is suggested by the minimum–maximum approach on a scale of values from zero to ten, assigning zero to the lowest value and ten to the highest value. The value is calculated using Formula (1):

$$I_v = \text{abs}\left((-10 \times p) + ((x_v - x_{min})/(x_{max} - x_{min})) \times 10\right), \quad (1)$$

where:

abs stands for absolute value

I_v is the indicator value

p points out whether the final value is inversely proportional (Yes = 1, No = 0)

x_v is the value obtained for the case study

x_{min} is the minimum value

x_{max} is the maximum value

When it is difficult to calculate ranges from the available database, the use of the average indicator value for the province at which the city is located becomes necessary, with defining deviation percentages to obtain the maximum and minimum values. This percentage was determined through a questionnaire provided to the representatives of the local institutions involved in the smart city strategy. In general, these cases were limited, and maximum and minimum values can be calculated by Formula (2):

$$x_{min} = (x_a - x_a \frac{p_2}{100}), \quad (2)$$

where:

x_{min} is the minimum value

x_a is the average value for the province (e.g., Riyadh, Makkah, Jeddah, and Medina)

p_2 is the percentage of deviation

and Formula (3):

$$x_{max} = (x_a + x_a \frac{p_2}{100}), \quad (3)$$

where:

x_{max} is the maximum value

x_a is the average value for the province (e.g., Riyadh, or Makkah, or Jeddah, or Medina)

p_2 is the percentage of deviation.

Finally, to determine if the goals are achieved for indicators, the value of Yes is set to a score of 10 for an achieved goal, and the value of No is set to a score of 0 for an unachieved goal.

Based on the available database, the maximum and minimum values were analyzed for every specific indicator. Once the calculation of indicators is complete, the second step is to calculate the weight of each indicator in a specific assessment area, as well as the total weight of the entire assessment area, and the overall score for each case study; the maximum score for overall urban smartness is 60.

5. Results and Discussion

Table 4 presents the aggregated indicators of the six dimensions of a smart city for the four cities in the study. The results demonstrate that Riyadh has the highest value, followed by Makkah, Jeddah, and then Medina. It should be noted that the rating values of Riyadh are relatively higher than the other three cities, the rating values for Makkah and Medina are similar, and the rating value for Medina is relatively lower compared to the other three. In fact, after approving Vision 2030, Riyadh designed a set of strategic objectives to facilitate its transformation into a smart city, relying upon its capacities as the largest center for financial–economic operations and the highest population in Saudi Arabia. For instance, in 2019, many smart megaprojects were approved in Riyadh, such as the King Salman Park Project, Riyadh Sports Boulevard, Riyadh Art, and Green Riyadh.

Table 4. Assessment of smart city dimensions.

Dimensions	Riyadh	Makkah	Jeddah	Medina
Smart economy	4.24	3.88	4.06	3.68
Smart environment	3.78	3.11	3.02	3.01
Smart mobility	3.26	2.74	2.25	2.21
Smart governance	4.11	3.29	3.25	3.18
Smart people	4.00	3.46	3.21	3.10
Smart living	4.16	3.85	4.02	3.38
Total	23.55	20.33	19.81	18.56

Findings from Table 4 reveal that the smart economy has the highest value compared to the other smart dimensions for all four case studies. Results imply that the transformation process into a smart city has provided diverse economic opportunities for these cities, with the economy operating at all levels (i.e., international, national, regional, and local) for all. Recently, concepts such as innovation, knowledge economy, and partnerships have been embodied in smart city strategies. Innovation is supported by universities in many aspects of urban life, such as knowledge communities, industries, infrastructures, cultural heritage, tourism, planning, and development. In addition, one of the key factors that have contributed to creating a smart economy in the four case studies is that Saudi Arabia is dependent on its strategic assets in establishing smart megaprojects. Reliance on available strategic assets requires welcoming new ideas and high creativity values to achieve balanced and sustainable economic growth. Such an orientation has created high flexibility in the labor market and increased investment opportunities.

In all four cities, many smart practices have been instigated to transform into a smart economy. Riyadh has executed several smart initiatives, such as the King Abdullah Financial District, Konoz Box of Treasures, New Murabba Development Company, the City of Communication, and Information Technology, and the first and second industrial cities. Likewise, King Abdullah Economic City (KAEC), that lies between Jeddah and Medina, is the biggest single investment. Constructed as a free zone, KAEC is designed to accelerate the national economy by considering innovative investments, international trade and taxation, sophisticated smart logistics, and a regulatory environment.

Findings reveal that smart mobility has the lowest value for the four cities. In Saudi, public transportation is lacking. Thus, individuals use their private vehicles to commute for work and other urban activities. The high income per capita and low fuel prices further reinforce this trend. Based on these situations, it appears that the existing master plans and urban policies fail to offer an effective smart mobility model that incentivizes people

to use public transportation. Consequently, the overall focus of transport infrastructure, information infrastructure, mobility methods and vehicles used, and legislation remain restricted to a single mode of transportation. Smart mobility should be accompanied by improving smart services such as parking information, roadside message panels, mobile applications, and web portals; these services are considered in Vision 2030 but are still in the implementation phase. Smart services improve accessibility, reduce travel delays, raise the efficiency of transit operations, and make public transport more effective. In addition, smart practices, such as forecasting, healing, and prevention, are still being established. Thus, the use of artificial intelligence in forecasting real-time demands to offer a responsive supply may be seen as one of the best smart practices. Although Saudi plans are based on ITS, a general platform for the execution of the smart mobility system has effectively not been established.

The findings in Table 4 illustrate that Riyadh has the highest rating value for smart mobility compared to other cities. As infrastructure is one of the most important elements which create smart mobility, Riyadh has already preceded other cities in upgrading transport infrastructure to be more intelligent. Further, several megaprojects were approved to reach smart mobility, contributing to Riyadh's high score. For example, the Riyadh Metro project is one of the most important urban infrastructure initiatives to improve smart mobility. The metro includes six lines with an overall length of 176 km and aims to achieve low energy consumption, low maintenance costs, a high safety system, and high standards of facilities such as Wi-Fi.

Table 4 demonstrates that the second most important dimension for all four case studies is smart living; Riyadh scored the highest value and Medina the lowest. Furthermore, all of the other five dimensions are aimed at improving smart living; that is, targeting quality of life. In the case studies described above, quality of life was considered to be the fundamental component in terms of the smart living dimension for smart urban strategies. The Saudi Arabian strategies prioritized advanced technologies in order to achieve efficient integration into public infrastructure and facilities. These were frequently provided by means of e-services and wireless communication technologies such as 5G, WiMAX, Wi-Fi, PHS, and Zigbee, all of which provide digital information to the general population. These applications were also used to measure citizens' satisfaction with their daily life. The prioritization of these applications confirms that the Saudi government was seeking to engage citizens in the decision-making process while emphasizing that smart living, smart governance, and smart people are all interrelated. In Makkah, for example, many endeavors have been approved to achieve smart living, such as Sumuw, a new residential area in the western part of Makkah which has been designed to provide smart facilities and smart housing for its roughly 690,000 inhabitants. Another smart initiative is the Rua Al Madinah project, one of the most important smart megaprojects in KSA; as a mixed-use real estate development, it provides high-quality added value to comply with the overall dimensions of a smart city, mainly smart living. Finally, innovative technological equipment such as face recognition, computerized locks, and sensors are routinely used throughout construction in residential, mixed-use, and industrial areas for all four case studies.

Figure 1 (below) establishes that the dimensions of smart people, smart governance, and smart environment are similar for all four case studies, while rating values indicate that progress is continuing in the transformation toward smart cities. In this context, several initiatives have taken place to improve smart people. In Riyadh, King Saud University (KSU) is one of the knowledge hubs in Saudi Arabia and has adopted innovative and entrepreneurial initiatives. Moreover, KSU has played an important role in transforming Riyadh into a smart city via two distinguished projects: Riyadh Techno Valley (RTV) and Riyadh Knowledge Corridor (RKC). The RTV is a science and technology park project which can be considered a type of public–private partnership that aims to enhance information and knowledge flows targeting a smart economy by smart people. RTV seeks to improve research and development to maximize economic capabilities. Both the RTV and RKC projects represent a knowledge-based economy in which knowledge becomes an economic

value. In line with the smart people dimension, King Abdullah University of Science and Technology (KAUST) and King Abdulaziz University (KAU) in Jeddah are both considered global hubs for knowledge. For instance, in 2022, KAUST announced they had earned a LEED Platinum rating for Leadership in Energy and Environmental Design. These practices have improved the learning process, provided knowledge to the community, and promoted quality of life and sustainable development. In Medina, it is expected that the Al-Madinah Knowledge Economic City (KEC) will be finished in 2025. KEC is designed to be a smart city which will incorporate knowledge-based industries such as the IT industry and business entrepreneurs, contributing to learning technology and building skills.

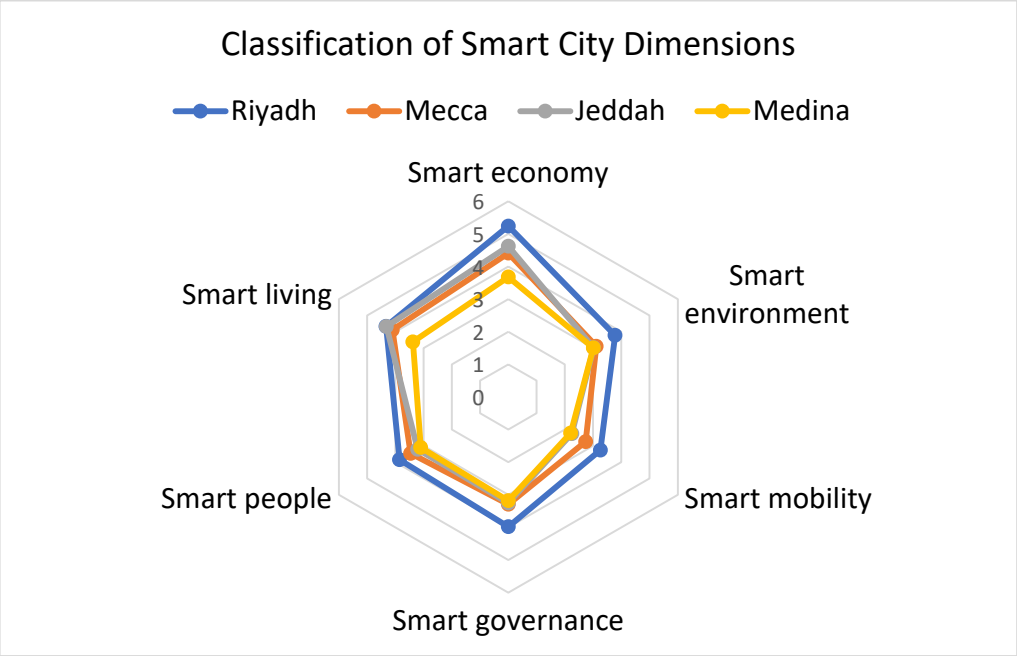

Figure 1. Classification of Smart City Dimensions.

In order to promote the development of advanced smart cities, it is recommended that governments prioritize the establishment of an educational environment for citizens through the provision of Information and Communication Technology (ICT) services and knowledge centers. Such measures would serve to foster innovation and creative culture that can positively impact economic performance. Furthermore, education and training programs should emphasize the acquisition of IT skills and technical knowledge to facilitate social learning, bolster organizational capacities, and enhance industrial performance.

Urban governance is a key to success in transitioning towards smart cities. Urban governance in Saudi Arabia is characterized by community participation and public–private partnership and involves multiple stakeholders. To successfully transfer into smart governance, the KSA government designed the Smart Government Strategy (2020–2024) which integrates a number of governmental institutions into one leading smart government, including Robotics and Automation, Big Data, Blockchain, Internet of Things (IoT), and Artificial Intelligence (AI). The government has already initiated the strategy, establishing a service system based on a shared digital system. The strategy takes resident perceptions, needs, priorities, and expectations into consideration as a guideline for the decision-making process. The system has elaborate communication channels between citizens and the government, leading to more accountability and transparency. Further, several projects have been approved to facilitate the transformation into smart governance, such as Data Insights CoE, Hackathons, Digital Academy, and Vendor Communities. Another example of transformation into smart governance is the Riyadh Wiki Information and Complaining System, which is a free open-source smart tool that encourages local people to participate. It has

been developed as a web-based system, which allows both learned people and unlearned people to provide proposals and information. The system has elaborate communication channels between the people and the government, leading to enhanced community participation, transparency, and accountability. Another example of smart governance is that the municipalities of Riyadh, Jeddah, Mecca, and Medina have already transferred their work environment into an e-service system, using high-tech infrastructure, which has created an active network linking all municipal branches to each other. The implementation of modern technologies enables smart cities to improve their governance by incorporating open data platforms to promote transparency and accountability. Additionally, the integration of artificial intelligence can enhance governmental services, effectively reducing routine and bureaucratic processes.

Achieving a smart environment is an important dimension of a sustainable environment, and the Saudi government has already instituted a series of initiatives that have accomplished this. In Riyadh, the Natural Resources and Environmental Research Institute at King Abdulaziz City for Science and Technology (KACST) has established five stations for monitoring air quality. In addition, the Smart Water Meters system has contributed to the gathering and assessing of data and has developed databases and water strategies to increase water efficiency. In Medina, the Pollution Measurement Laboratory was established as a holistic smart center which monitors air quality and other pollutants; as a result, successful strategies have been initiated, based on international indicators in the context of a smart environment. In Makkah, the smart environment is targeted successfully by the design and operation of a smart system that enables systematic monitoring for cleanliness and maintenance work.

Intelligent technologies that rely on a wireless sensor network (WSN), IoT, and ICT are frequently utilized in smart cities to address environmental issues. Applications for managing the environment, including water distribution management and wastewater management, can be provided through intelligent environmentally friendly solutions. These solutions establish monitoring systems such as intelligent water and sewage grids by leveraging wireless sensor networks.

6. Conclusions and Recommendations

The analysis undertaken in this study indicates that Riyadh has achieved more progress in the transformation toward a smart city than the other cities in the study. If we look more widely at the progress Saudi Arabian cities have made in terms of the transformation towards urban smartness, Riyadh has succeeded despite all the difficulties it has encountered, such as designing smart initiatives based on strategic assets, management of smart megaprojects, providing necessary infrastructure, and establishing collaborative channels. In addition, local inhabitants and both the public and private sectors have benefited from this transformation, in terms of improved quality of life and a sustainable environment. Hence, smart city practices in Riyadh should be seen as a paradigm for other cities in Saudi Arabia and the wider Middle East region.

The analysis demonstrated that all four cities need to adopt an inclusive strategy, standardization, and policy instruments to improve smart mobility. To achieve success, they should base smart mobility strategies on three key elements; infrastructure, technology, and information, while the smart mobility strategies should be a composition of several local authorities and private organizations. Further, the use of artificial intelligence for forecasting real-time demands to provide a responsive supply may be seen as one of the best smart options to improve smart mobility.

The smart city concept in Saudi Arabia is used as a strategic instrument to include urban economics in an analytical framework and diversify the economy. Smart city dimensions in Saudi Arabia are performing efficiently to improve quality of life and sustainable environment. Riyadh's smart city model has proved that the performance of local authorities can be effective, which is a requirement for improving the smart city. To continue increasing the effectiveness of local authorities' performance, smart network technologies

are required to hasten the transformation of other cities into smart cities. It can be concluded that the overall transformation of Riyadh into a smart city is progressing successfully, while the other three case studies still require more effort and initiatives. As a result, smart city practices, in Riyadh specifically, can be considered useful and could be generalized to other cities in Saudi Arabia, the Arabian Gulf, and the wider Middle East region.

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