Chapter

Towards a Generic Framework for Smart Cities

Hossny Azizalrahman and Valid Hasyimi

Abstract

Cities are formidable drivers of economic, social and cultural development but face a rising multitude of challenges: urban sprawl, transportation problems and climate change to mention but a few. Evolving concepts such as smart cities, sustainable communities and low carbon cities have been employed to formulate initiatives to tackle these challenges. Smart cities appear to address efficiency in reducing time, cost, and energy in delivering services-smart transportation, intelligent buildings, and green infrastructure with a view to reaching low carbon city development and eventually sustainability. This article attempts to construct a general framework for smart cities. First, the overall smart city system is depicted. Second, the dynamics of urban sector drivers in smart and low carbon cities are elucidated. Third, the performance of smart cities is measured in relation to low carbon development. By applying the smart city framework to the cities of Vienna, London, New York and Tokyo, the model proved robust and flexible. The investigation is concluded with policies to realign city plan and development policies.

Keywords: smart cities, low carbon cities, urban sector drivers, performance indicators, assessment framework

1. Introduction

The rising demand for living in cities is likely to accentuate sustainability challenges, climate change and resource allocation. Cities constantly compete for international investment to generate employment, revenue and funds for development, all leading to elevated energy consumption and CO_2 emissions [1]. Cities also seek innovation and efficiency in reducing time, cost, and energy in delivering services: smart transportation, intelligent buildings, and smart infrastructure that would lead to low carbon city development. In fact, 80% of the world's gross domestic product is created in cities; urban citizens earn on average three times the income of their rural counterparts; and people living in larger cities tend to have smaller energy footprints and require fewer infrastructures, consume less resources, and have higher productivity levels. A city of 8 million has 15% more productivity and 15% less infrastructure needs than two cities of 4 million each [2].

There are several urbanization models that incorporate digital technologies to address some of the urbanization and sustainability challenges. While digital cities attempt to integrate digital technology into city's infrastructure, intelligent cities utilize digital city infrastructure to construct intelligent urban systems featuring intelligent buildings, transportation systems, hospitals, schools, public services.

By the same token, smart cities deploy intelligent urban systems to support socio-economic development and improve urban quality of life [3].

Smart city initiatives seek to overcome the limitations of traditional urban development that manages infrastructure systems in silos and leverage the pervasive character of data and services offered by digital technologies, such as cloud computing, the internet of things, open and big data. As such, different stakeholders, investors and citizens work to enhance existing services and provide new services. Smart city development is highly complex, challenging and context-specific. Challenges arise from discourses of technologies and policies, failure to tackle urban sustainability challenges, and governance framework.

2. Smart city concept

Over the past two decades, the concept of "smart cities" has surfaced to address the economic and social life of first worldwide cities [4]. Put simply, a smart city is a community that uses different data gathering devices to disseminate information that is used to manage services efficiently such as traffic control, power plants, water supply networks, hospitals, and other community services [5]. Within this context, citizens are very important for city's development. To keep them engaged, real quality services have to be offered at reasonable cost.

Associated as it is with technology, the concept of "smart city" has superseded other versions: "information city", "digital city" and the "intelligent city". In fact, the "digital city" originates from an experiment in Amsterdam in 1994, with the aim of democratizing access to the internet. The "digital city" now refers to: a connected community that combines broadband communications infrastructure; flexible, service-oriented computing infrastructure based on open industry standards; and innovative services to meet the needs of governments and their employees, citizens and businesses [6].

Smart city has been widely studied and registered under ISO 37120 sustainable cities and communities. The indicators of smart city services and quality of life are set out in ISO 37122 and resilient city standards are prescribed in ISO 37123 (**Figure 1**).

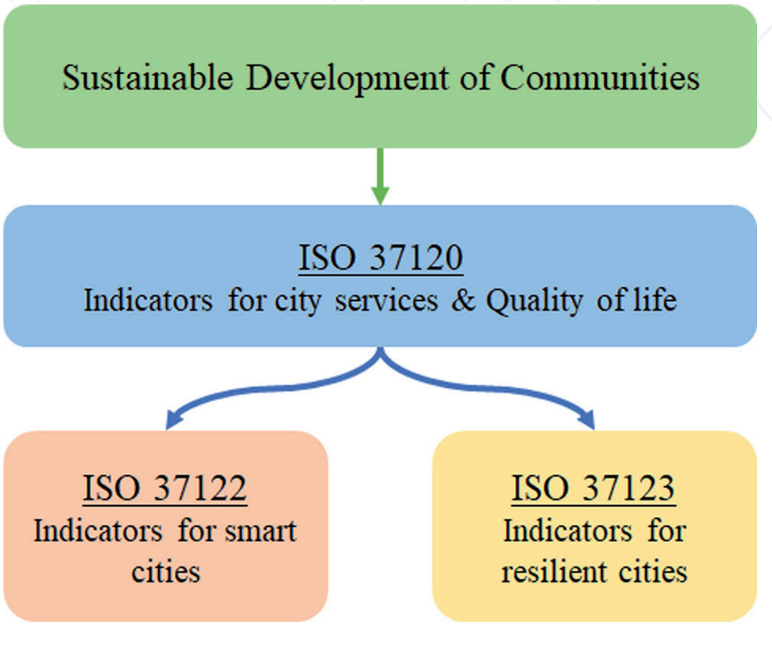

Figure 1.
Smart city indicators and standards of sustainable development.

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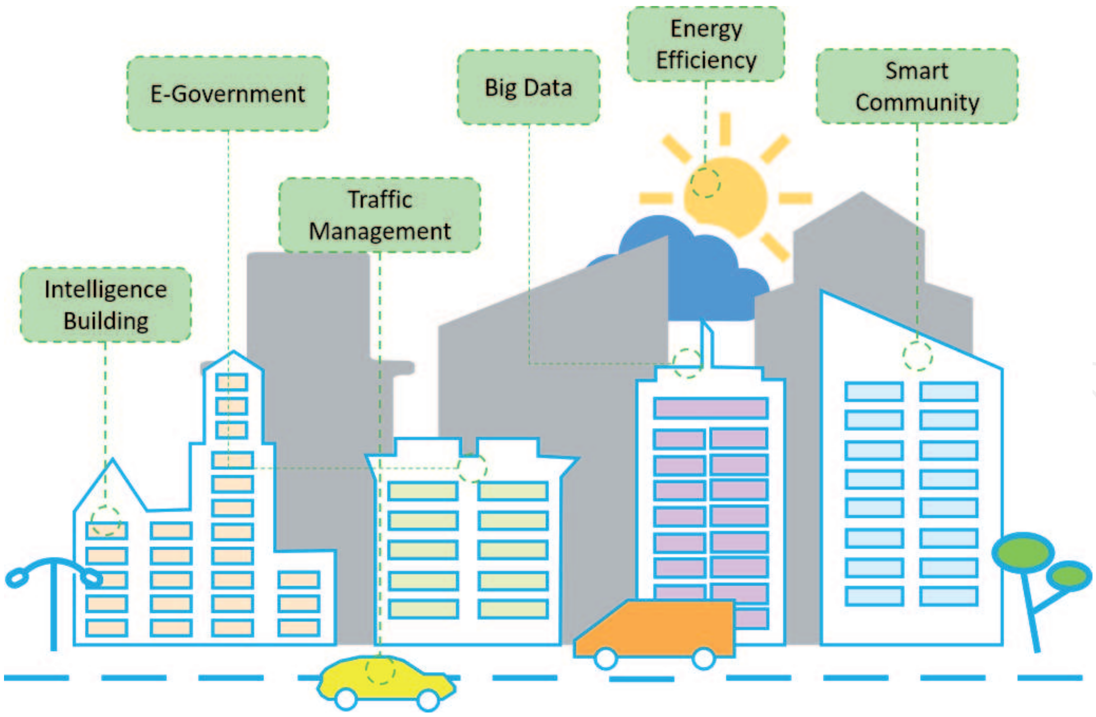

Figure 2.
Basic components of smart city.

Indicators include, inter alia, economy, education, energy, climate change, finance, governance, health, housing, waste water and water quality. In the transportation sector for instance, data mining and sensing are used to obtain real-time data for managing duration of traffic light, traffic jam and accidents. It also potentially encourages mobility sharing through car, motorcycle and bicycle (**Figure 2**).

3. Smart city and carbon emissions

Because energy is central to smart city and low carbon cities, this section investigates the impact of urbanization on carbon emissions focusing on residential, commercial and industrial sectors, the major components of any city's land use.

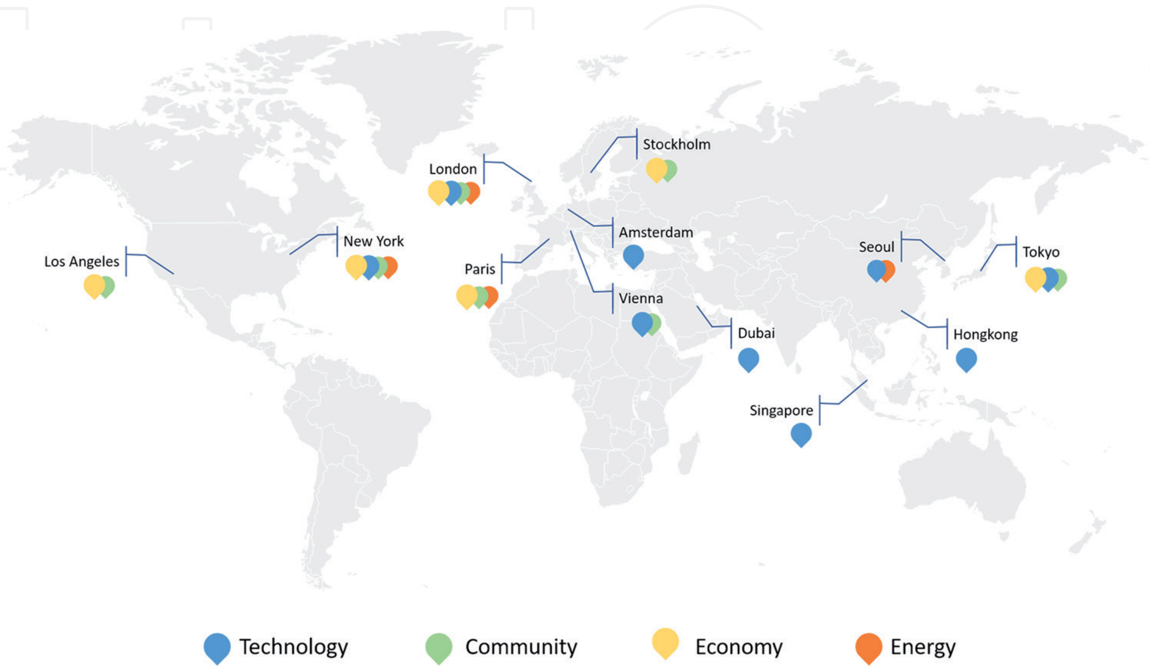

Figure 3.
Significant sectors in selected global cities.

Azizalrahman and Hasyimi [7] have suggested a comparative analysis of low carbon cities in high income, upper-middle income and lower-middle income groups of countries. They have formulated an impact model of urban sector drivers on carbon emissions (USDM) to examine the relationship between urbanization, economic factors and carbon emissions and exposed urban dynamics of variables' interaction at city level. They found that most carbon emissions originating from the residential, commercial and public sectors are strongly influenced by energy consumption. Urbanization displays an inverse function with energy consumption and a positive correlation with economy. Based on IESE Cities in Motion Index 2018 [8], the performance of top global cities are measured and ranked based on dominant sectors which promote to sustainability (**Figure 3**).

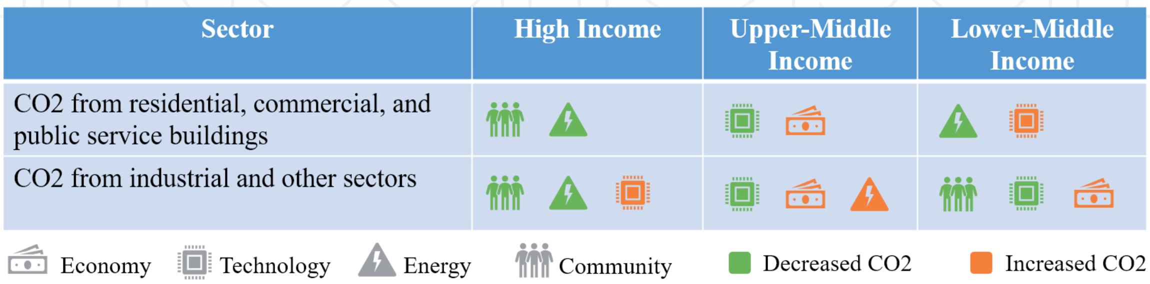

Figure 4.
Effect of carbon emissions in smart cities of high, upper-middle, and lower-middle countries.

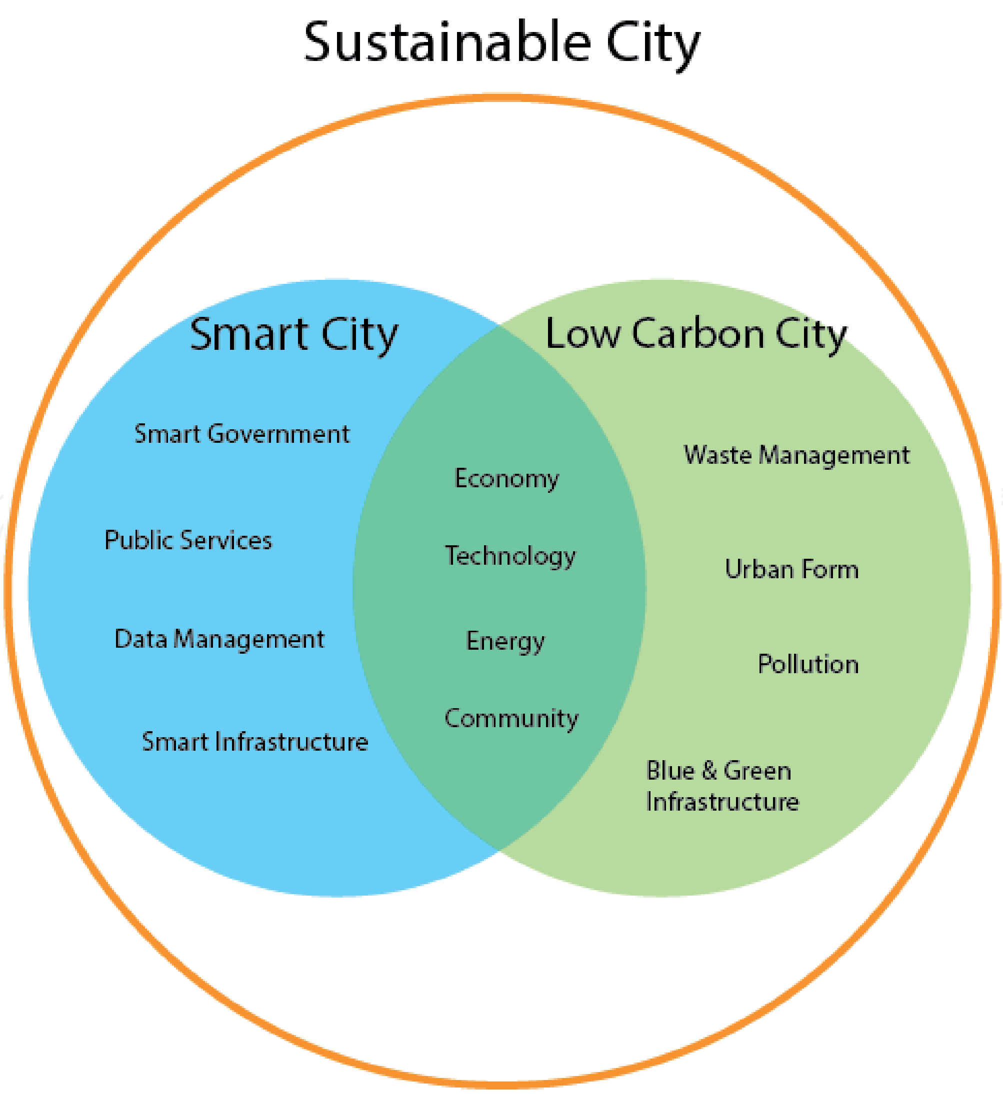

Figure 5.
Commonalities between smart city and low carbon city in sustainability framework.

Based on their dominant characteristic, cities in lower middle-income countries have typical market towns that struggle on rapid urbanization. By contrast, cities in upper middle-income countries have typical production centres which focus on productivity. Cities in high income countries have become centres of finance and creative industries which face challenges of migrating firms to other regions (**Figure 4**).

Low carbon city and smart city are two forms of city development frameworks that purse sustainability. Low carbon city was established earlier than smart city in response to global warming and climate change. On the other hand, smart city has surfaced in the past decade to disseminate information and deploy technology solutions to improve efficiencies of city systems. Whereas low carbon city is mitigation purpose oriented, smart city is an adoption or adaptation targeted. Smart city has potentials to disseminate real data and record big data simultaneously thereby, enabling decision maker to track city system changes [9], see **Figure 5**.

Low carbon city framework has robust and clear targets, e.g., sulphur, nitrogen, and carbon emission levels. On the contrary, smart city has general; less specific targets that render measurement of smartness more difficult. Further, there is a widespread body of literature on low carbon city as opposed to relatively scant literature on smart cities. Some institutions have tried to develop evaluation models using sets of indicators to rank smart city performance such as smart cities ranking for Europe, world smart city government ranking, and the IESE Cities in Motion Index (CIMI) [8, 10–12].

4. Smart city framework

A smart city can be viewed within the wider perspective of sustainable city. The basic sectors include, amongst other things, technology, community, economy and energy which facilitate the development of a real concept of smart city. As such it gets closer to the definition of [11] who maintain that a city is smart when governance drives investment in human capital and IT infrastructure to achieve sustainable development. The authors have constructed a fourfold framework for a typical smart city comprising technology, community, economy and energy to clearly distinguish between smart city and low carbon and sustainable cities (**Figure 6**).

a. Technology framework: ostensibly, smart cities are heavily dependent on the use of technology that is supported by technological infrastructure. These varied technologies are applied to diverse urban domains (e.g., economy, transportation, energy, environment, water management, waste disposal, education and healthcare, governance and public participation) to achieve efficiency and better management [9]. Within a Smart city context, information technology is not considered independently, but rather within wider physical and social systems that seek to deliver efficient service to people, business and government. It has become popular not only to smart cities, but also to engineering firms seeking innovation and investment opportunities for physical urban and infrastructure development.

b. Community framework: communities are central to city's intelligence as exemplified by human activities, innovation and knowledge. Human and social capital drives city's economy and technology deployment. Their power lies in effective creation of economic, cultural, social environment and formation of public opinion. Through participatory function, communities can influence policy formulation and decision making, such as redistribution of public finance and increasing the transparency of public expenditure. Representatives

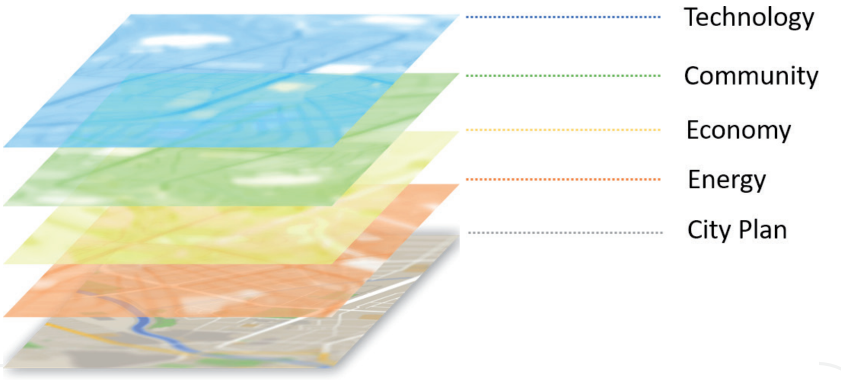

Figure 6.
Basic smart city's sectors.

of cities, policy and decision makers should aim to reach consensus with the community on smart urban development [13].

c. Economy framework: knowledge and digital economy are essential drivers of the smart city discourse. The terms "knowledge-based economy" refer to an economy where more knowledge-intensive than labour-intensive activities take place. It played a significant role in the emergence of the idea of smart cities; it is one of the two strands of thinking that formed the current ideas about what a smart city is, how it works, and what it can do. Moreover, smart city changes people's behaviour in purchasing from traditional to online transaction. It increases e-money usage, encourages store owners to react to this condition with some changes in their business models, etc.

d. Energy framework: smart cities seek to develop smart energy infrastructure, disseminate data to create efficiencies, leverage economic development, and enhance quality of life. A smart city features, inter alia, smart street lighting, intelligent buildings, smart mobility and power grid. The common thread is energy, economics and impact on cities. However, smart cities seem to have shifted attention away from environmental problems, climate change and carbon emissions to infrastructure and information usage and sharing.

4.1 Proposed smart city framework

A generic framework for smart cities is proposed comprising: (1) goal, (2) conceptualization, (3) assessment, and (4) implication. This model is useful to address smart city transformation that leads to sustainability. It affords a summary of complex transformation processes that are needed for cities seeking to be smart (**Figure 7**).

4.2 Smart city criteria and indicators

Common performance measurement methods use scoring methods which assess the current city condition. Here, the authors have used quantitative indicators used in the proposed model to create a generic framework to increase objectivity and realism. The indicators were obtained from several sources: ISO 337122, smart city in Europe, and generic model for low-carbon city [10]. The authors have initiated gathering of data for the basic sectors of the smart city: technology, community, economy and energy for which 20 key performance indicators (KPIs) were selected. For modelling purpose, the KPIs were then categorized under six urban

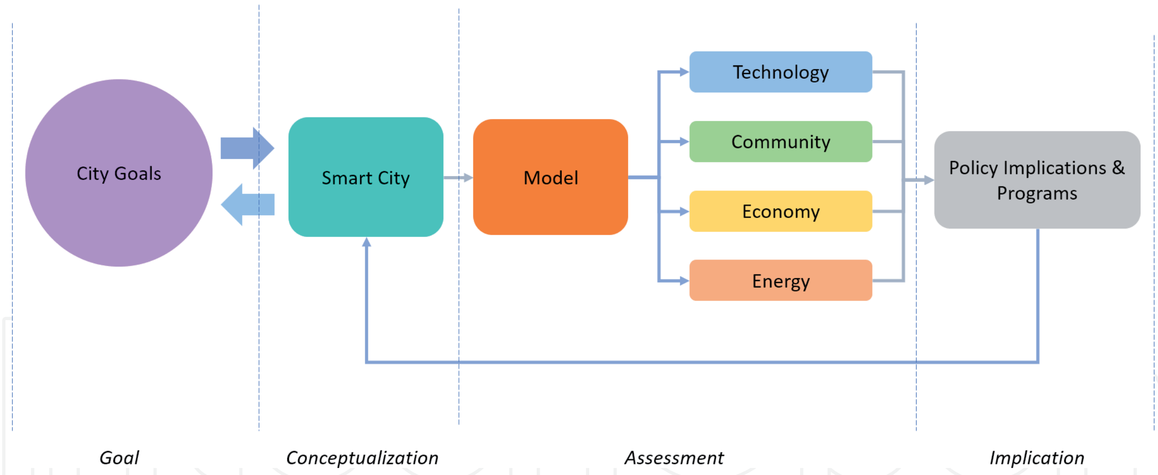

Figure 7.
Proposed smart city framework.

development sectors: competitiveness, energy, mobility, urban management, urban living and waste management. The selected indicators can be seen in **Figure 8**.

Quantifiable indicators under each criterion are then selected to measure smart city performance and compare it with the benchmarks [14]. Benchmark setting is important because it aims to sufficiently differentiate between cities of various performance. Benchmarks were derived from multiple sources: (1) World Bank and WHO; (2) top city performances, such as green city index; (3) International targets for developed countries set out by EU (**Table 1**).

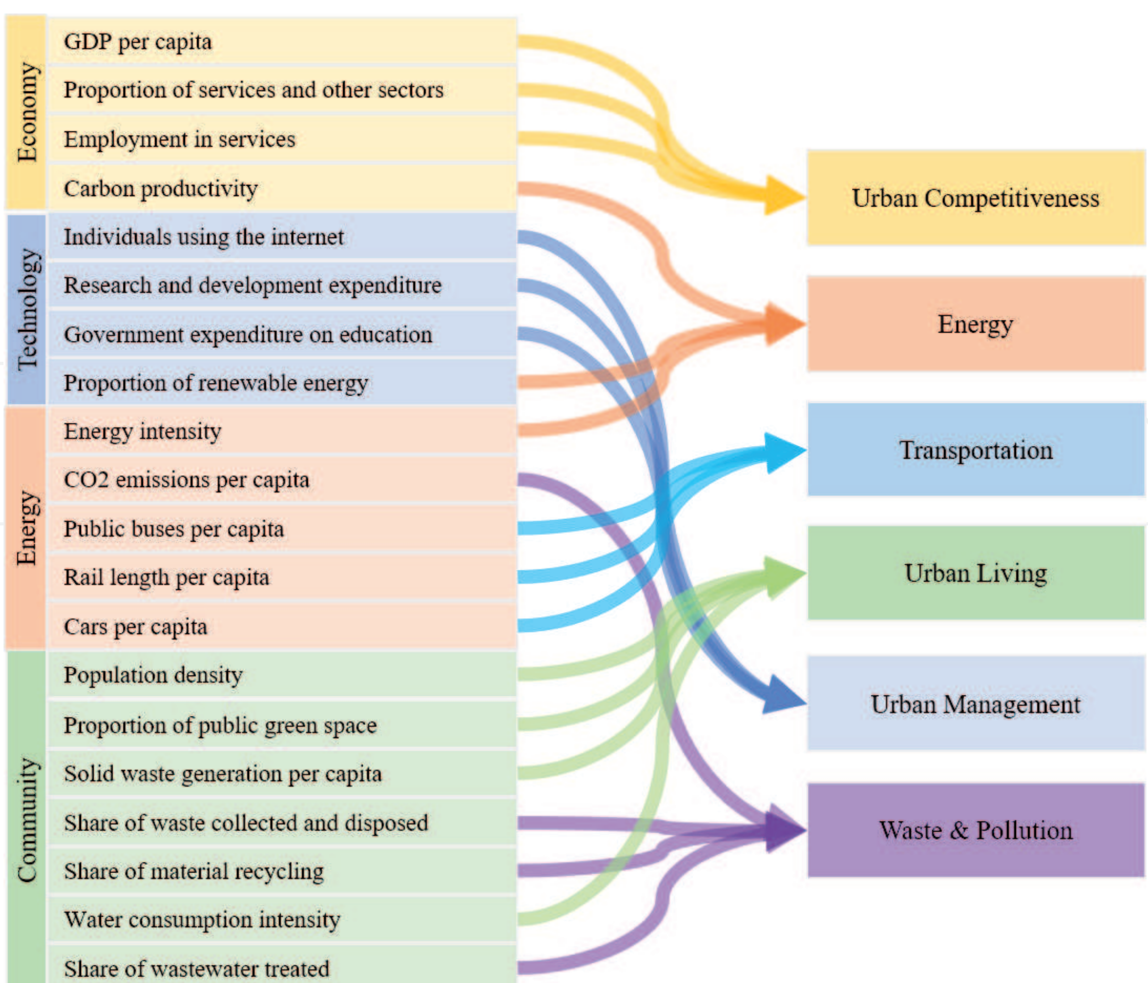

Figure 8.
Smart city indicators and categorization.

Category	Indicator	Effect	Unit of measurement	Benchmark value	Source
Competitiveness	GDP per capita	+	$/capita	25,616	[15]
	Economy: services and other activity	+	% of gross value added	60	[16]
	Employment in services	+	% employed	60	[16]
Energy	Carbon productivity	+	USD/ton	8244	[17]
	Proportion of renewable energy	+	%	10	[17]
	Energy intensity	–	MJ/USD	4	[17]
Transportation	Public buses per capita	+	buses/million persons	694	[17]
	Rail length per capita	+	km/million persons	40	[17]
	Cars per capita	–	Private cars / persons	0.39	[17]
Urban Living	Proportion of public green space	+	%	35	[18]
	Population density	+	People/km^2	4236.1	[19]
	Solid waste generation per capita	–	Kg/capita/day	0.8	[20]
	Water consumption intensity	–	L/capita/day	102	[21]
Management	Education: government expenditure	+	% of GDP	3	[16]
	Individuals using the internet	+	per 100 inhabitants	70	[16]
	Research and development expenditure	+	% of GDP	1.5	[16]
Waste and pollution	CO_2 emission per capita	+	Ton/person	2.19	[21]
	Share of waste collected and adequately disposed	+	%	80	[20]
	Share of material recycling	+	%	30	[22]
	Share of wastewater treated	+	%	75	[21]

Table 1.
Smart city indicators and benchmarks.

A multi-criteria evaluation model has been proposed by modifying the framework of Azizalrahman and Hasyimi [23].

The equation of data normalization is set out in Eqs. (1) and (2).

$$y_i = \frac{x_i - x_b}{x_b} \tag{1}$$

$$y_i = \frac{x_b - x_i}{x_b} \tag{2}$$

where y_i is normalized data of assessed object on i indicator, x_i is original value of the object on ith indicator, x_b is benchmark value of ith indicator. While Eq. (1) is used for indicators with positive effects, Eq. (2) is used for indicators with negative effects. This calculation will produce the score from minimum (−1) to maximum 1 (**Table 2**).

For better performance presentation, the standardization by score conversion to 0–100 could be seen in Eq. (3).

$$S_c = 50\ (y_i + 1) \tag{3}$$

Where S_c denotes the average score per category. S_T defines the average total score as shown in Eq. (4).

$$S_T = \left(\sum_{c=1}^{n} S_c\right)/6 \tag{4}$$

To obtain an average score S_T, an equal weight is assigned to 6 categories, the result of which features a smart city scale 0–100, from: unsustainable (0–9); high carbon (10–29); neutral (30–49); low carbon (50–69); smart (70–89) and sustainable (90–100) as illustrated in **Figure 9**.

Indicator	Unit of measurement	Formula	y_{ic}	S_c
GDP Per capita	\$/capita	$y_i = \frac{\dots-25616}{25616}$		
Economy: services and other activity	% of gross value added	$y_i = \frac{\dots-60}{60}$		
Employment in services	% employed	$y_i = \frac{\dots-60}{60}$		
Carbon productivity	USD/ton	$y_i = \frac{\dots-8244}{8244}$		
Proportion of renewable energy	%	$y_i = \frac{\dots-10}{10}$		
Energy intensity	MJ/USD	$y_i = \frac{4-\dots}{4}$		
Public buses per capita	buses/million persons	$y_i = \frac{\dots-694}{694}$		
Rail length per capita	km/million persons	$y_i = \frac{\dots40}{40}$		
Cars per capita	Private cars/persons	$y_i = \frac{0.39-\dots}{0.39}$		
Proportion of public green space	%	$y_i = \frac{\dots-35}{35}$		…
Population density	People/km^2	$y_i = \frac{\dots-4236.1}{4236.1}$		
Solid waste generation per capita	Kg/capita/day	$y_i = \frac{0.8-\dots}{0.8}$		
Water consumption intensity	L/capita/day	$y_i = \frac{102-\dots}{102}$		
Education: government expenditure	% of GDP	$y_i = \frac{\dots-3}{3}$		
Individuals using the internet	per 100 inhabitants	$y_i = \frac{\dots-70}{70}$		
Research and development expenditure	% of GDP	$y_i = \frac{\dots-1.5}{1.5}$		
CO_2 emission per capita	Ton/person	$y_i = \frac{2.19-\dots}{2.19}$		
Share of waste collected and adequately disposed	%	$y_i = \frac{\dots-80}{80}$		
Share of material recycling	%	$y_i = \frac{\dots-30}{30}$		
Share of wastewater treated	%	$y_i = \frac{\dots-75}{75}$		
Average (S_T)				…

Table 2.
Proposed multi-criteria evaluation model for smart city.

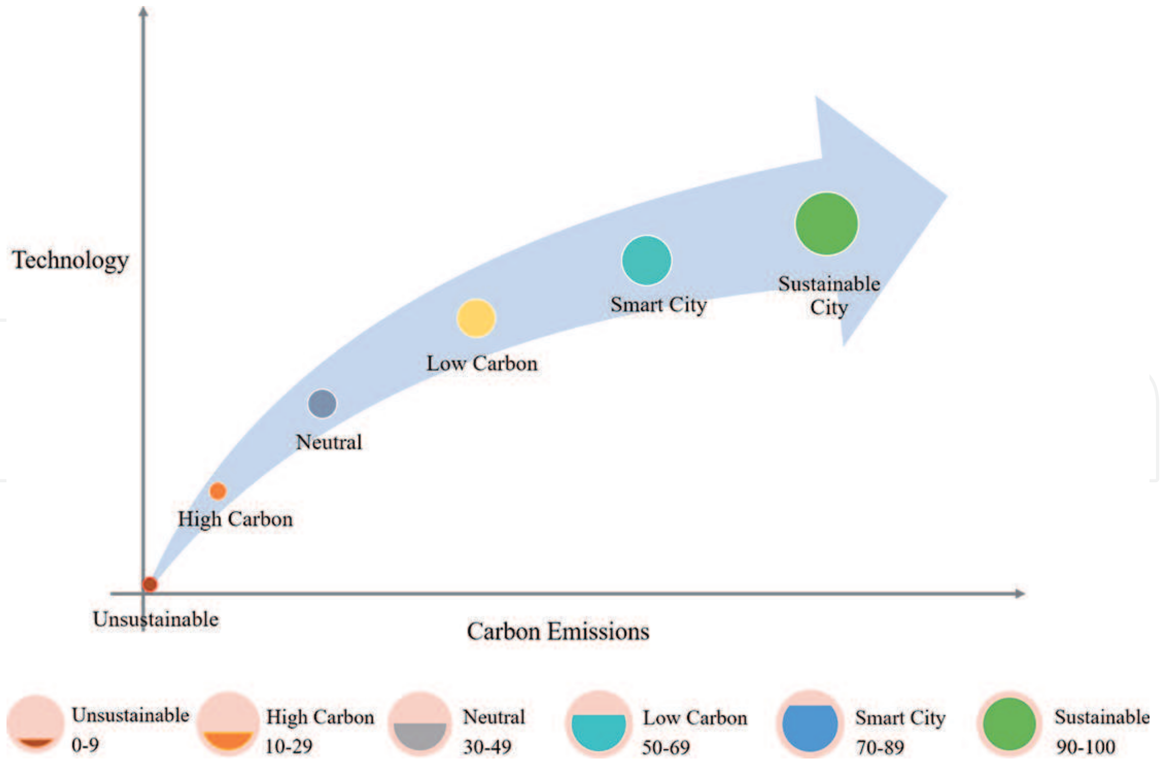

Figure 9.
Smart city pathway to sustainability.

5. Smart city model and testing

The proposed model is tested on four cities: Vienna, London, New York, and Tokyo, the result of which can be seen in **Table 3**. The pilot cities are selected based on the good performance in technology sector based on IESE Cities in Motion Index 2018.

From the figure above, we can see that from four pilot cities, Vienna, London and New York are categorized as smart city. On the other side, Tokyo is low carbon city. The above scores were transformed into smart city metrics (**Figure 10**).

Smart city metrics help us summarize a detailed analysis for city's performance by sector. Through this presentation, the strength and weakness of each sector can be easily identified and promoted to achieve the desired targets. Vienna, a global tourism destination, has a very good performance in transportation and city management. Vienna has become a city of high mobility systems such as smart buses, smart ride, smart sharing, smart public transport, and eMorail to mention but a few. Moreover, Vienna has a peaceful balance between the city and green areas which account for half of the city's total area [24]. Therefore, the city is a leading smart city.

London and New York are examples of global cities with multiple central functions and populous agglomerations. Both have a strong performance in urban competitiveness and management. As centres of global trade and economy, London and New York have focused on, amongst other things, technology, human resource development, quality of urban living, and waste management.

London proved how smart the city could be by establishing London Datastore and innovation in transportation known as Heathrow pods; building up intelligent road network; facilitating trade with digital money; and making use of new technology in reusing waste heat from underground chambers and sub-ways. London also executed the innovative program named as "Innovate18" which attempted to rejuvenate the old railway network [25].

By the same token, New York attempted to be a smart city by canvassing the concept of equitable city—a city where anyone and everyone has access to facilities

	Vienna	London	New York	Tokyo
Competitiveness	68	78	78	66
Energy	83	68	62	68
Transportation	83	84	79	75
Urban living	58	60	67	63
Management	62	66	60	63
Waste	69	73	72	70
Average score	71	71	70	68
Category	Smart city	Smart city	Smart city	Low carbon

Table 3.
Result of smart city model on the pilot cities.

Figure 10.
Smart city metrics.

justly. Being the economic hub of the world, the city is continuously engaged in delivering smart innovations. Current initiatives include reduction of greenhouse gases, fair management of water and energy, smart protection of public health increasing mortality rate and tech-based plans to make the city safer. Further, New York aims to set up strategies and policies to successfully actualise the connected devices and internet of things (IoT) [26].

Tokyo on the other hand, is categorized as a low carbon city and is being transformed to a smart city. In the last few years, Tokyo has unveiled a chain of environment friendly initiatives which include: solid waste reduction through technology, encouragement of large-scale recycling plants and rain water harvesting, rooftop planting of trees and herbs which helps in absorbing carbon dioxide, adoption of energy efficient photovoltaic solar panels, and launch of Tokyo Super Eco Town [27].

Author details

Hossny Azizalrahman* and Valid Hasyimi
King Abdulaziz University, Jeddah, Saudi Arabia

*Address all correspondence to: hazizalrahman@kau.edu.sa

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