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Assessing progress towards sustainable development in Shenzhen 2005–2019

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ABSTRACT

Most sustainability assessment systems focus on comparing the sustainable progress across cities, and few concentrate on tracking the sustainability progress of cities over time with the consideration of the 17 United Nations Sustainable Development Goals. Tracking the sustainable progress of cities over time can help unveil the potential obstacles and challenges in city governance and provide references for city policy-makers. Hence, the present study built up a framework to evaluate sustainable development progress in Shenzhen from 2005 to 2019. Shenzhen is a young megacity with only 40 years of history, and it is one of the demonstration zones to represent sustainable development in China. Fifty indicators in the dimensions of innovation vitality, public service, and living environments are chosen to consider the focus of both UN SDGs goals and Shenzhen's sustainable development plans. The potential bottlenecks for city development are identified, and effective policies implemented by Shenzhen policy-makers are highlighted. Results showed that the innovation vitality in Shenzhen had improved continuously since 2005, but public service and living environments both showed a falling trend after a peak in 2014 and 2016. The result revealed that as a megacity, Shenzhen should pay more attention to public service and living environments, especially in the construction of schools at all levels, salvation management centers, and green space, and improve air quality to meet the requirement of higher rank in sustainable urban development. It is suggested that cities build a solid system to monitor their progress towards achieving the 17 Sustainable Development Goals. The experience from Shenzhen can be adapted and implemented by other young megacities worldwide to accelerate their path towards sustainability.

1. Introduction

The concept of sustainable development was first mentioned in the United Nations report named "Our Common Future" in 1987, which defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland et al., 1987). Various economic development modes, strategies, and policies worldwide were then developed by considering economic, social, and environmental factors simultaneously, so-called in a sustainable way (Wu, 2013; Jepson, 2004; Moe et al., 2006; Strong, 2006). In 2015, the United Nations announced the report "Transforming our World: The 2030 Agenda for Sustainable Development" (The, 2030 Agenda), which put forward 17 global sustainable development goals (SDGs) by 2030, which lead the path towards sustainable development to the new page (UN, 2015b).

China actively participates in the 2030 Agenda and raised sustainable development to a higher level of national strategy (Huang, 2022). China released "China's National Plan on Implementation of the 2030 Agenda for Sustainable Development", which defined the guiding ideology, general principles, and implementation path for China to promote the implementation of sustainable development, and elaborated on China's action plan for implementation of 17 SDGs and 169 targets of

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the 2030 Agenda for the upcoming future (Ministry of Foreign Affairs of the People's Republic of China, 2016). Many studies were conducted to discuss the potential strategies for sustainable development at the national level. For instance, a recent study proposed that restructuring the economy to balance the conflict between short-term benefits and long-term benefits, developing a circular economy with specific mechanisms and infrastructure, building up national standards with more accurate indicators, completing market mechanism for green economy and green consumption, and enhancing technology innovations and local incentives, could help China to improve the policy strategies related to climate change and SDGs (Zhang et al., 2020). Another study pointed out that reducing air pollution would not only improve the SDGs that are directly associated with the environment but also benefit SDGs that are indirectly linked to the environment, such as SDG 4 quality education, SDG 9 industrial, innovation and infrastructure, SDG 17 global partnership and so on (Zhao et al., 2020). Multiple studies compare the sustainable development agendas across countries and their potential impact at the regional level. A quantitative study compared the policy agendas for implementing SDGs in China, Japan, and South Korea at the macro level and suggested that China need to strengthen symbolic and advisory mechanisms in sustainable development and also pay more attention to ecological sustainability to improve the follow-up policy design in sustainable development (Xie et al., 2021a). Feng et al. (2019) evaluated the development trend of 17 SDGs between 1990 and 2015 in China and its three neighboring countries along the Belt and Road to understand the current situation of sustainable development in these countries. It proposed a collaborative development plan to realize the SDG across the Belt and Road Countries, including learning from each other's policy practice, cooperating in energy and climate action, constructing a multi-dimensional international collaborative network, and exploring SDGs indicator inspection and precaution system (Feng et al., 2019).

Many studies focused on constructing an evaluation system of sustainable development at different levels to understand SDGs' progress better. Bertelsmann Stiftung and the Sustainable Development Solution Network (SDSN) published an annual report of SDG index and dashboard report to evaluate the progress of sustainable development of UN members since 2016. Zhu et al. (2018) researched constructing an evaluation index system for China's sustainable development under the framework of the UN. They assessed the overall progress of sustainable development in China from 2013 to 2016. Xu et al. (2020) developed systematic methods with 119 indicators under 17 SDG to perform comprehensive spatiotemporal analysis on the progress towards SDGs at the national and subnational levels in China. They concluded that substantial changes in sustainable development occurred across different regions (Wang et al., 2020a), also constructed a sustainable development index system and dashboard evaluation framework under SDGs and presented a quantitative assessment at the subnational level to explore the subnational heterogeneity in China.

Among the sustainability assessment studies at the city level, the focus was on building the evaluation system on three pillars of sustainability (economic, environmental, and social) and ranking different cities based on their performance. For instance, Rama et al. (2020) evaluated and ranked the sustainability of 31 Spanish cities by indicators of economic, environmental, and social. Liu et al. (2021) analyzed the sustainability of Chinese cities based on the big data in city ranking in attributes of economic, environmental, and social. They ranked the top 10 cities with good sustainability. Sustainability assessment at the city level could measure the city's development status and provide references for city decision-makers (Zhou et al., 2021). However, studies on the city-level sustainability assessment benchmark with UN SDGs are rare. Most studies focused on sustainable development index construction under the concept of UN SDGs are at national and subnational levels (Wei et al., 2020; Porfiryev and Bobylev, 2018). As microcosms of sustainable development, cities require a paradigm shift in city governance. The sustainability assessment benchmarking with SDGs could assist in accelerating the progress of SDG implementation. It can also track the progress of sustainability in the city over time, address the common obstacles and challenges in city governance, and adapt better-informed policies at the city level (Chen et al., 2015; Osman et al., 2021).

Shenzhen is one of the cities chosen as the Sustainable Development Demonstration Zones in China and has actively working on sustainable development. Shenzhen released Shenzhen's Sustainable Development Plan (2017–2030) in 2018, which specified Shenzhen's sustainable development plan (Shenzhen Municipal People's Government, 2018). As a new immigrant mega-city with rapid urbanization, Shenzhen has facing an inevitable bottleneck in urban development, including insufficient resource and environment carrying capacity, weak in urban governance, shortage in public service, unbalanced regional development, and inadequate innovative support for sustainable development (Shenzhen Municipal People's Government, 2018; Yu et al., 2019). With the rapid increase in population over the years, it is vital to evaluate the progress of sustainable development in Shenzhen, identify the strengths and weaknesses of Shenzhen's sustainable development, subsequently, form implementable advice for the strategies forward. In addition, constructing the evaluation system at the city level and showcasing Shenzhen's progress can also help other megacities develop their sustainable development strategies.

Our study aims to unveil the progress of sustainable development in Shenzhen over the years, highlight effective policies, identify potential bottlenecks at the city level, and form implementable strategies for megacities worldwide towards realizing sustainable development. An evaluation framework was constructed by combining the focus of both UN SDGs goals and Shenzhen's sustainable development plans. Data from 2005 to 2019 were applied in this study.

The remainder of the article was structured as follows. The following section describes the research methodology of the study. Then, the results of sustainable development in Shenzhen over the years are presented. Subsequently, sustainable growth at city levels was discussed compared to other studies. The potential bottleneck for further improvement in Shenzhen was highlighted in the discussion section, followed by the conclusion section.

2. Methodology

2.1. Study area

Shenzhen is selected for this study due to its spectacular history and outstanding performance in economic aspects, and its commitment to build a sustainable megacity leading by innovation according to Shenzhen Sustainable Development Plan (2017–2030) (Shenzhen Municipal People's Government, 2018). It is also selected as one of the national demonstration zones for sustainable development focusing on innovation-driven megacities (The State Council of China, 2021; Wang et al., 2020b). Shenzhen (113° 43′-114° 38′ E, 22° 24′-22° 52′ N, Fig. 1) is a coastal megacity located in the southeast part of China and is one of the core cities in the Guangdong-Hong Kong-Macao Greater Bay Area. It was established in 1978, and it is the first Special Economic Zone in China that received favorable governmental policy and financial support. Shenzhen is now one of China's most densely populated cities, with a total area of approximately 1997 km^2 with more than 17 million permanent residents (Shenzhen Statistic Bureau & NBS Survey Office in Shenzhen, 2020). Also, the economic growth of Shenzhen is rapid, with GDP increasing from 0.2 billion RMB in 1979 to 2.77 trillion RMB in 2020 (Shenzhen Statistic Bureau & NBS Survey Office in Shenzhen, 2020).

2.2. Framework to evaluate the progress of sustainable development in Shenzhen

UNSDGs comprise 17 global sustainable goals classified into three

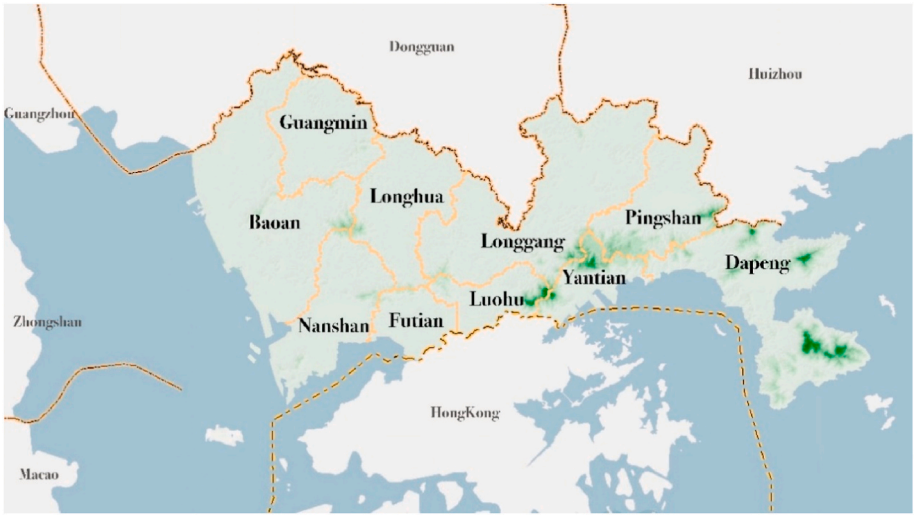

Fig. 1. The geographic location of Shenzhen.

aspects: economic, social, and environmental (Griggs et al., 2013). Shenzhen focuses on developing a sustainable megacity leading by innovation, and its economic development heavily relies on innovative industry (Shenzhen Municipal People's Government, 2018). Thus, the evaluating framework in this study consists of three dimensions, i.e., innovation vitality, public service, and living environment. It aims to combine the focus of both UN SDGs goals and the direction of Shenzhen in planning its sustainable pathway. The framework has three first-level indicators, 15 s-level indicators, and fifty tertiary indicators, respectively. Each dimension covered various indicators regarding data availability, as listed in Table 1.

2.2.1. *Innovation vitality*

Innovation vitality is one of the critical dimensions of evaluating sustainable development progress in Shenzhen, as the demonstration zone was themed as innovation-driven (Wang et al., 2020a). Shenzhen also attached importance to innovation. It established the first science and technology park in Mainland China and launched its first policy to encourage a higher technology industry in the 1980s (Mok et al., 2020). Also, the four pillar industries of Shenzhen are advanced technology, modern logistics, financial service, and cultural industry, which are all closely related to innovation (Greater Bay Area, 2020). From the perspective of UN SDGs, innovation vitality is closely related to SDG 1 No Poverty, SDG 4 Quality Education, SDG 8 Decent Work and Economic Growth, SDG 9 Industry, Innovation and Infrastructure, SDG 16 Peace, Justice and Strong Institutions, and SDG 17 Partnerships for the Goals.

Innovation vitality was evaluated from innovation foundation, innovation input, innovation output, and innovation environment. Innovation foundation is the fundament and guarantee of innovation vitality, reflecting the city's economic development. Our study chose per capita GDP, per capita government income, disposable income per capita, and foreign direct investment as indicators of innovation foundation as these indicators have been frequently used to evaluate the economy of the city (Shenzhen Municipal People's Government, 2018; Wang et al., 2018). Innovation investment is the driver of urban innovation vitality.

Only with necessary innovation investment can guarantee the expected innovation achievement. R&D expenditure of the whole society, the number of R&D personnel per 10,000 people, government R&D fund, and public education expenditure per 10,000 people were selected as indicators of innovation investment. The innovation environment is an essential factor in achieving innovation and development goals. A good innovation environment can effectively gather and optimize the allocation of innovation resources, cultivate innovative subjects with strong competitiveness, and promote steady and sound innovation development. The number of graduates from higher education per 10,000 people, a telephone number per 10,000 people, and a number of innovation carriers to reflect the innovation environment in Shenzhen were selected as the sub-indicators of this area. Innovation output is a direct embodiment of the vitality of urban innovation. The results of innovation output directly reflect the development and implementation of innovation activities and the level of innovation ability. The number of invention patents authorized per 10,000 people, the added value of strategic industries, the output of scientific and technical papers per 10,000 people, the export amount of high-technology products, and labor productivity were selected as the innovation output indicators.

2.2.2. *Public service*

Urban public service is the public goods and services provided by the urban public sector to the public and closely relate to the interests of every urban resident. Referring to UN SDGs, public service is closely related to SDG 3 Good Health and Well-being, SDG 4 Quality Education, SDG 5 Gender Equality, and SDG 11 Sustainable Cities and Communities.

Evaluation on public services of this study contained aspects of transportation facilities, medical and health care, education, cultural resources, support to vulnerable groups, and gender equity. Developing urban public transportation is an effective measure to alleviate traffic congestion, improve the travel efficiency of citizens, and improve the urban living environment. Urban road area in proportion to the metropolitan area, which reflected urban traffic level, bus ownership per 10,000 resident population, which reflected convenience of urban public transportation, the ratio of the rail transit line length to the metropolitan area, which reflected the development of urban rail transit system, were selected as indicators of transportation facilities. Medicine and health care services are closely related to the health of residents. Hospital beds per 10,000 permanent residents, which showed the medical resources ownership per capita, number of supporting health staff per 10,000 permanent residents, which reflected whether the number of health staff meets the needs of residents' healthcare, and hospital beds utilization rate, which reflected the current bed setting has an undersupply or a waste of resources, were selected as indicators of medicine and health care services. Education provides the sustainable impetus for urban economic development. Evaluating education in public service mainly concerned education resources before higher education, as higher education was selected as one of the indicators in evaluation on innovation vitality. Enrollment of secondary schools,

Table 1
Indicators of Sustainable Development Evaluation and its Relevance to SDGs.

Dimensions			Relevance to SDGs
Primary Indicator	Secondary Indicator	Tertiary Indicator	
Innovation Vitality	Innovation Foundation	Per Capita GDP	SDG 8
		Per Capita Government Income	SDG 16
		Disposable Income of Resident per Capita	SDG 8
		Foreign Direct Investment	SDG 17
	Innovation Investment	R&D Expenditure of the Whole Society	SDG 9
		Number of R&D Personnel per 10,000 People	SDG 9
		Government R&D Fund	SDG 9
		Public Education Expenditure per 10,000 People	SDG 1
	Innovation Environments	Graduates from Higher Education per 10,000 People	SDG 4
		Number of Telephone Users per 10,000 People	SDG 9
		Number of Innovation Carrier per 10,000 People	SDG 9
	Innovation Output	Number of Invention Patents Authorized per 10,000 People	SDG 9
		Added Value of Strategic Industries	SDG 9
		The output of Scientific and Technology Papers per 10,000 People	SDG 9
		Export Value of High-technology Products	SDG 17
		Labor Productivity	SDG 8
Public Service	Transportation Facilities	Urban Road Area in Proportion to Urban Area	SDG 11
		Bus Ownership per 10,000 Resident Population	SDG 11
		The ratio of the Rail Transit Line Length to the Urban Area	SDG 11
	Medical and Health Care	Hospital Beds Per 10,000 Permanent Residents	SDG 3
		Number of Supporting Health Staff Per 10,000 Permanent Residents	SDG 3
		Hospital Beds Utilization Rate[b]	SDG 3
	Education	Enrollment of Secondary Schools Corresponds to School-aged Population	SDG 4
		Enrollment of Primary Schools Corresponds to School-aged Population	SDG 4
		Enrollment of Kindergartens Corresponds to School-aged Population	SDG 4
	Cultural Resources	Ownership of Public Libraries per 10,000 Permanent Residents	SDG 4
		Ownership of Art Museums, Cultural Centers, Museums, and Memorial Halls per 10,000 Permanent Residents	SDG 4
	Support to Vulnerable Groups	Number of Beds in Social Nursing Home Per 10,000 Permanent Residents	SDG 11
		Number of Beds in Salvation Management Center Per 10,000 Permanent Residents	SDG 11
	Gender Equity	Female Proportion of Shenzhen Municipal People's Congress	SDG 5
Living Environment	Water Resource Quality	Total Water Resource per 10,000 Permanent Residents	SDG 6
		Water Quality Compliance Rate of Urban Drinking Water Source	SDG 6
		Design Scale of Sewage Treatment Plant Per 10,000 Permanent Residents	SDG 6, SDG 11, SDG 12
		Total Length of Urban Drainage Pipe Per Unit Area	SDG 6 and SDG 11
	Green Space	Green Coverage Rate of Built-up Area	SDG 11 and SDG 15
		Forest Coverage Rate	SDG 11 and SDG 15
		Park Area Per 10,000 Permanent Residents	SDG 11 and SDG 15
		Green Space Area Per Person	SDG 11 and SDG 15
	Air Quality and Noise	Good Air Quality Rate (Ministry of Environment, PR China, 2016)	SDG 11
		Mean Environmental Noise in Urban Areas[a]	SDG 11
		Industrial Exhaust Emission Per 10,000 GDP in RMB[a]	SDG 9 and SDG 12
		Industrial Smoke and Dust Emission Per 10,000 GDP in RMB[a]	SDG 9 and SDG 12
	Waste Disposal	Number of Domestic Garbage Transfer Stations Per 10,000 Permanent Residents	SDG 6 and SDG 11
		Number of Public Toilets Per 10,000 Permanent Residents	SDG 6
		Harmless Disposal Rate of Domestic Waste	SDG 6 and SDG 11
		Industrial Solid Waste Production Per 10,000 GDP in RMB[a]	SDG 6, SDG 9, SDG 12
	Resource Consumption	Energy Consumption Per Unit GDP[a]	SDG 7, SDG 9, SDG 12
		Power Consumption Per Unit GDP[a]	SDG 7, SDG 9, SDG 12
		Water Consumption Per 10,000 GDP in RMB[a]	SDG 6, SDG 7, SDG 9, SDG 12
		Water Consumption of RMB 10,000 Industrial Added Value[a]	SDG 6, SDG 7, SDG 9, SDG 12

[a] Negative indicators, noise/emissions/consumption, and actual scores will be inversed proportional.
[b] Moderate indicator, use the governmental recommended optimal value as the best reference value.

primary schools, and kindergartens corresponding to the school-aged population was chosen as indicators to evaluate whether the education resource meets the need of the school-aged population at each stage. The cultural resource reflects the development degree of the city's cultural soft power, which showed the spiritual and cultural soul of the city. It is a deep driving force for the sustainable development of urban society and the economy. Ownership of public libraries per 10,000 permanent residents and ownership of art museums, cultural centers, museums, and memorial halls per 10,000 permanent residents were selected as our study's indicators of cultural resources. Supporting vulnerable groups can help form an excellent harmonious social atmosphere, promote continuous progress in social civilization, move urban development to fairness and justice, and follow the theme of SDG as no one is left behind. Elderly and homeless personnel were chosen as the representative of vulnerable groups. The number of beds in the social nursing home and vacation management center per 10,000 permanent residents were selected as indicators to reflect whether the support to vulnerable groups satisfies their needs. Gender equity means that both sexes enjoy equal rights in political, economic, cultural, social, and family obligations and is one of the essential goals of UN SDGs. Considering the feasibility of the statistical data, the female proportion of the Shenzhen Municipal People's Congress was chosen as the indicator of gender equity.

2.2.3. *Living environment*

The living environment is one of the critical dimensions of

sustainable urban development and is closely linked to the daily life of urban residents. Urban development shall realize economic development and consider the balance between economic growth and healthy urban environments. Regarding UN SDGs, the living environment is closely related to SDG 6 Clean Water and Sanitation, SDG 7 Affordable and Clean Energy, SDG 9 Industry, Innovation and Infrastructure, SDG 11 Sustainable Cities and Communities, SDG 12 Responsible Consumption and Production, and SDG 15 Life on Land.

In this study, the living environment was evaluated by considering the water resource quality, the area of green space, air quality, the noise level, solid waste produced per unit GDP, and energy consumption per unit GDP. Water is a widely used resource in production and other activities. According to the 13th Five-Year National Construction Plan for Urban Sewage Treatment and Recycling Facilities (2016), total water resources per 10,000 permanent residents, water quality compliance rate of urban drinking water source, design scale of sewage treatment plant per 10,000 permanent residents, and total length of urban drainage pipe per unit area were selected as indicators of water quality, which can reflect the overall tension of urban water resources, drinking water safety, efforts on pollution reduction, and efforts on the urban drainage system. Green space is one of the essential components of urban living environments. The green coverage rate of built-up area, forest coverage rate, and park area per 10,000 permanent residents were selected as indicators to measure coverage of all kinds of urban green space. Good air quality and low noise levels can protect and improve urban living environments, ecology and ensure human health. Several laws in China have set a stringent standard for air quality and noise control (Guangdong Provincial Development; Reform Commission, 2021, The Central People's Government of the People's Republic of China, 2021a, The Central People's Government of the People's Republic of China, 2021b, The National People's Congress of the People's Republic of China, 2021; Ministry of Ecology and Environment of the People's Republic of China, 2021). Reasonable air quality rate, mean environmental noise in the urban area, industrial exhaust emission per 10,000 GDP in RMB, and industrial smoke and dust emission per 10,000 GDP in RMB were selected as indicators of air quality to reflect urban air quality, mean environmental noise in the metropolitan area, and cleaner production in the industry. Solid waste is an inevitable by-product of urban development. Improper waste treatment hinders the city's appearance and harms the ecological environment. The number of domestic garbage transfer stations per 10,000 permanent residents, number of public toilets per 10,000 permanent residents, the harmless disposal rate of household waste, and industrial solid waste production per 10,000 GDP in RMB were selected as indicators of solid waste to reflect the carrying capacity of urban collection and transfer of domestic garbage, necessary sanitation infrastructure, level of municipal management, and cleaner production in the industry. Energy conservation is still a significant task for further development in China. The Chinese government issued several policies and plans, such as the Comprehensive Work Plan for Energy Conservation and Emission Reduction During the 13th Five-year Plan (The National People's Congress of the People's Republic of China, 2016), to promote work in energy conservation effectively. The Changes in energy consumption per unit GDP, power consumption per unit GDP, water consumption per 10,000 GDP in RMB, and water consumption of RMB 10,000 industrial added values were selected as indicators to reflect energy consumption of all kinds.

2.3. Data process

Most of the data were obtained from open public sources, including the Shenzhen Statistical Yearbook, Shenzhen Municipal Health Statistics Yearbook, the official website of Shenzhen Municipal People's Congress, and other governmental resources (the data sources of each indicator are listed in Appendix Table S1). If no public data was available from the public open source in the early analysis year, the study took 0 as the alternative data. The missing data among the analysis year was estimated using linear regression.

2.3.1. Normalization

It is essential to define maximum and minimum values for each indicator as to the value range of each indicator varied. If the indicator does not have a govern recommended optimal value, the maximum and minimum values of the data in the analysis year were defined as that indicator's range. If the governmental recommended optimal value is available, the recommended optimal value was applied either as the maximum or the minimum in the normalization analysis, depending on the situation. Under such circumstances, the indicator's corresponding minimum or maximum value is the minimum or maximum value among the analysis year.

After establishing each indicator's lower and upper boundary, the following equations adopted the extreme value normalization.

$$Positive\ \ indicator: \ \ y_i = \frac{x_i - x_{min}}{x_{\max} - x_{min}} \quad (1)$$

It should be noted that some of the indicators, such as noise, emissions, production, and resource consumption, are negative indicators. The value increases of these indicators represent the decrease of the environmental conditions. Therefore, a negative indicator measurement method is hereby introduced by considering the peculiarities of these indicators, as shown in Eq. (2). If there is an optimal value for the indicator, for instance, the hospital beds utilization rate, the calculation is carried out using Eq. (3), Eq. (4), and Eq. (5). The negative indicators and the indicator with optimal value are marked in Table 1.

$$Negative\ \ indicator: y_i = 1 - \frac{x_i - x_{min}}{x_{\max} - x_{min}} \quad (2)$$

Indicator with optimal value

$$y_i = 1 - \frac{x_i - x_{opt}}{max(x_i - x_{opt}) - min(x_i - x_{opt})} \ (x_{opt} < x_i) \quad (3)$$

$$y_i = 1 - \frac{x_{opt} - x_i}{max(x_i - x_{opt}) - min(x_i - x_{opt})} \ (x_{opt} > x_i) \quad (4)$$

$$y_i = 1 \ (x_{opt} = x_i) \quad (5)$$

Where y_i is the normalized value of indicator i, x_{opt} is the optimal value of the indicator i, x_i is the ideal value for moderate indicator i, x_{max} and x_{min} are the maximum and minimum bounds for the indicator i.

2.3.2. Index weighting

Based on the 2030 Agenda, economic, social, and environmental are integral and of the same importance. In addition, a previous study showed that equal weight could be applied when it is difficult to judge the significance of the single index (Sachs et al., 2020; Xu et al., 2020). Thus, the same weight was given to the three dimensions. The second-level indicators were equally weighted under the primary and tertiary indices.

2.4. Result presentation

The overall state of Shenzhen's sustainable development since 2005 was firstly evaluated. Then, innovation vitality, public services, and living environments were assessed. Following the results session, the discussion focused on benchmarking the index system of our study with UN SDGs and discussed the subsystems of each dimension. Finally, some suggestions on future development were put forward.

3. Result

3.1. Evaluating the progress of sustainable development in Shenzhen

The progress of Shenzhen's sustainable development since 2005 was

evaluated, as shown in Fig. 2. According to our framework, Shenzhen significantly improved its sustainable development in recent years. The highest score was 72.81 in 2018, and the lowest score was 16.83 in 2005. Progress was significant before 2013, as the growth rate was higher than 10%, the progress was relatively slow in 2013 and 2014. After that, the state was relatively stable.

Taking a closer look at the progress on the three dimensions, improvement in environment and public service had a relatively significant contribution to the overall progress before 2010. Improvement in the environment contributed the most to the overall progress between 2010 and 2016. After 2016, innovation vitality contributed most to the overall progress, indicating the focus on sustainable development was different at different stages. The result also showed that all dimensions improved before 2012. However, public service improvement after 2012 was much slower than before 2012. Living environments improved before 2016, yet regressed after then. Innovation vitality was the only dimension that was improved steadily after 2005.

3.2. Innovation vitality in Shenzhen

Innovation is the soul of Shenzhen, and the local government paid enormous effort to improve its innovation vitality. As shown in Fig. 3, innovation vitality was improved rapidly since 2005, with the highest score as 89.31 in 2019 and the lowest score as 0 in 2005. The growth rate of innovation vitality was higher before 2010 than after 2010, with the highest growth rate as 89.97% in 2007 and the lowest growth rate was 5.8% in 2019.

All secondary indicators under innovation vitality, i.e., the innovation foundation, innovation investment, innovation output, and innovation environment, were continuously improved over the years. The growth rate of all secondary indicators of innovation vitality was rapid before 2010. This might result from the missing data in the indicators of the beginning year were counted as 0. It can be found that the innovation environment regressed since 2014.

The pattern of tertiary indicators unveiled factors affecting the overall performance of innovation vitality. The highest score of innovation foundation was in 2019, while the lowest score was 0 in 2005 (Fig. 4(a)). Per capita GDP and per capita government income improved overtimes, while the disposable income of residents per capita decreased since 2014. Overall, the innovation foundation in Shenzhen showed a rapid growth trend and promoted economic development.

Innovation investment is one of the main factors contributing to the improvement in innovation vitality. Overall, innovation investment improved gradually, especially after 2015, the growth rate accelerated, the highest score of innovation investment was in 2019 (Fig. 4(b)). The R&D expenditure of the whole society and government R&D fund increased over time. Public education expenditure also showed an increasing trend over the years. The number of R&D personnel per 10,000 people increased rapidly in 2008–2012 and decreased slightly in 2013–2014.

The innovation environment improved significantly from 2005 to 2014 yet declined after 2015 (Fig. 4(c)). Graduates from higher education per 10,000 people and the number of innovation carriers per 10,000 people increased. In comparison, the telephone number per 10,000 people decreased, mainly due to the growth rate of the resident population accelerated after 2014. China implemented the policy that new landline telephone and mobile phone users must register with accurate identity information (The Central People's Government of the People's Republic of China, 2013a).

Innovation output in Shenzhen was increased over the years. The added value of strategic industries, the output of scientific and technical papers per 10,000 people, and labor productivity improved gradually. The export value of high-technology products increased before 2013 yet showed a declining trend after 2013 (Fig. 4(d)). The reason for the decline might relate to slow global economic recovery, the general decline in commodity prices, and trade protectionism. According to the Ministry of Commerce, China encountered 97 foreign trade relief investigations involving USD 10.49 billion in 2014 (Shenzhen Municipal Bureau of Statistics, 2018). Moreover, China's export also suffered 337 investigations from the US, one anti-avoidance survey, and one anti-absorption survey from the EU (Shenzhen Municipal Bureau of Statistics, 2018). The number of innovation patents authorized per 10,000 people declined since 2013. The main reason for that was China had taken a series of measures to improve the quality of invention patents, such as Several Opinions on Further Improving the Quality of Patent Application issued by the China National Intellectual Property Administration (The Central People's Government of the People's Republic of China, 2013b). Overall, innovation output showed a growing trend.

3.3. Public services in Shenzhen

The core of public services in Shenzhen fluctuated since 2005, as shown in Fig. 5. Overall trend improved before 2014 and worsened afterward. The highest score of public service was only 65.9 in 2014, much lower than that of innovation vitality. This might be because the performance of different secondary indicators varied over the years. The score of cultural resources increased progressively over the years. Scores of transportation facilities, medical and health care, and gender equity

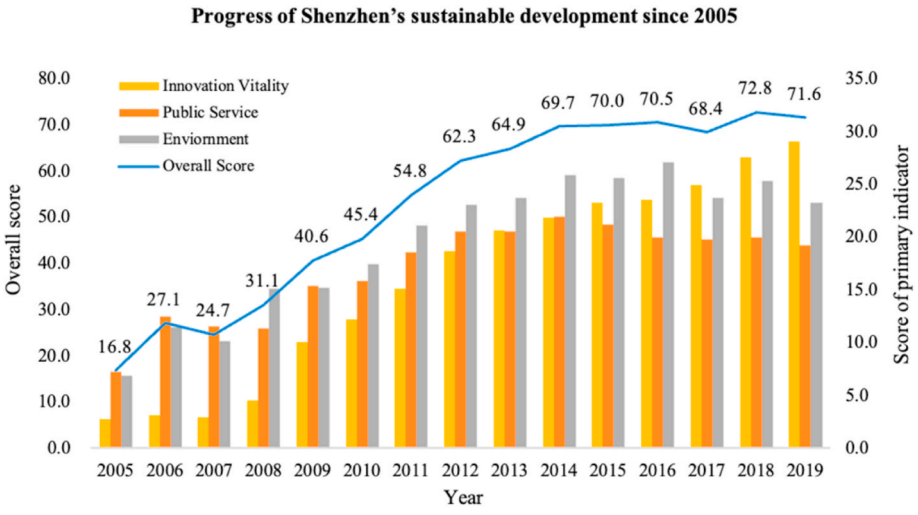

Fig. 2. Progress of Shenzhen's sustainable development since 2005. This figure presented both the overall score (in line) and the score of each primary indicator (in column). The total score was 100%, and the entire score of each dimension was equally weighted as 33.3%.

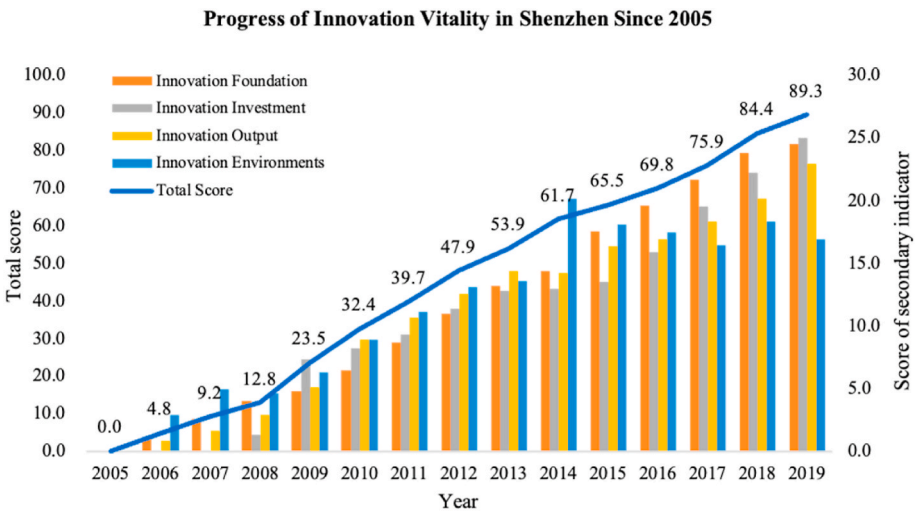

Fig. 3. Progress of innovation vitality in Shenzhen since 2005. This figure shows the score of innovation vitality (in line) and the score of each secondary indicator (in column) under the dimension of innovation vitality. The total score of innovation vitality in this section was 100%, and the total score of each secondary indicator was equally weighted as 25%.

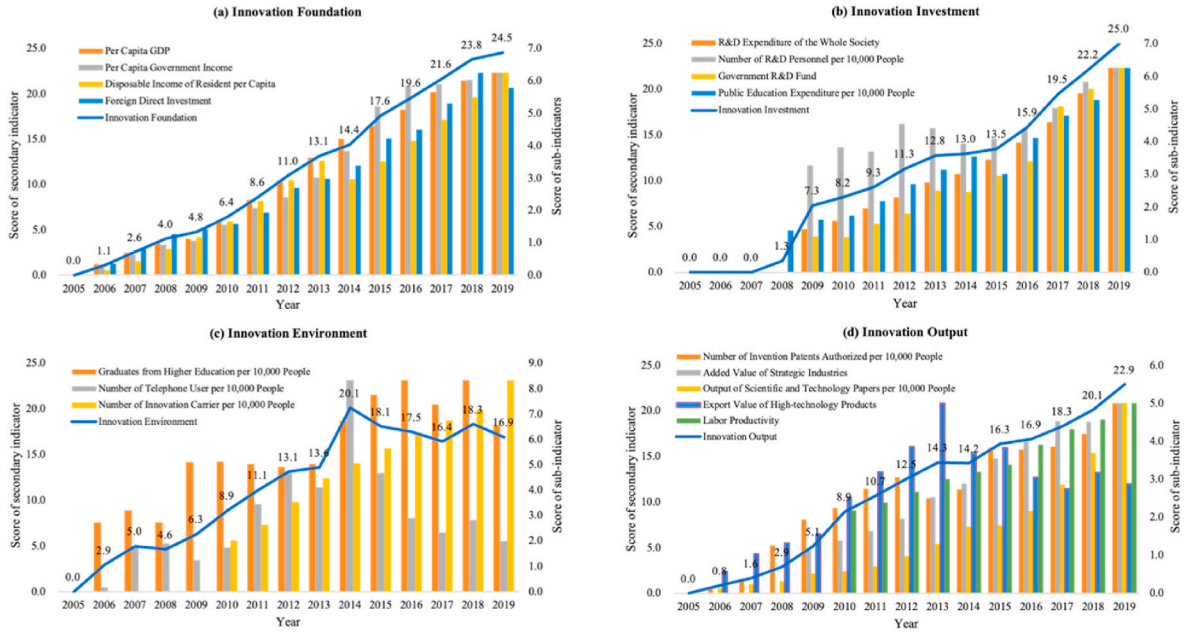

Fig. 4. Progress of tertiary indicators of innovation vitality in Shenzhen since 2005. (a) Scores of innovation foundation (in line) and its sub-indicators (in columns). (b) Scores of innovation investment (in line) and sub-indicators (in columns). (c) Scores of innovation environment (in line) and its sub-indicators (in columns). (d) Scores of innovation output (in line) and sub-indicators (in columns).

in recent years were higher than that in 2005, but they all showed a decreasing trend in recent years. A score of support to vulnerable groups increased before 2015, a sudden decrease in 2016, followed by an increase afterwar. Education scores declined continuously after the rise before 2010 and reached the lowest in 2019.

The secondary indicators in public services include transportation facilities, medical and health care, education, cultural resources, support to a vulnerable group, and gender equity. Their performance in the past 15 years varied. The overall trend in transportation facilities grew from 2005, but the tendency of tertiary indicators varied (Fig. 6(a)). The score of the rail transit line increased continuously. Other tertiary indicators' scores peaked some years before 2019 and then decreased.

For the tertiary indicators in the medical and health care category, both scores of hospital beds and supporting health staff showed a growing trend. In contrast, the score of the utilization rate of hospital beds peaked in 2012. It decreased afterward, which indicated that the utilization rate was not in the suggested range after 2012 (Fig. 6(b)). The increasing trend in the number of health staff and hospital beds was that Shenzhen promoted the construction of hospitals and explored medical reform mode in recent years. A decrease in the utilization of hospital beds might be due to the increasing number of non-public hospitals (See Appendix Table S2).

The overall trend in education worsened in recent years (Fig. 6(c)), as scores of enrolments of secondary schools, primary schools, and kindergarten corresponding to the school-aged population all reached the lowest point in recent years. The main reason for this may be that the increase in the number of enrolments approved by schools at different stages cannot meet the increasing school-aged population.

The tertiary indicators of supporting vulnerable groups showed a different trend. The score of the social nursing home increased rapidly

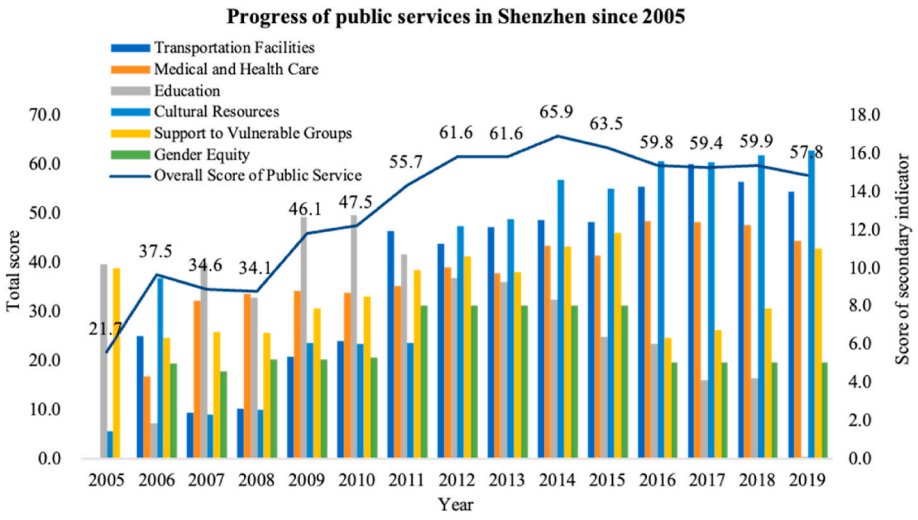

Fig. 5. Progress of public services in Shenzhen since 2005. This figure shows the score of public services (in line) and the score of each secondary indicator (in column) under the dimension of public services. The total score of public services in this section was 100%, and the total score of each secondary indicator was equally weighted as 16.7%.

since 2007. The score of the salvation management center fluctuated during the analysis years. The rapid increase in the social nursing home was that Shenzhen carried out pension reform in various ways over the years, including the construction of public nursing homes and community nursing systems (Zhao et al., 2020). The reason for the worsening score of the salvation management center might be because the increase

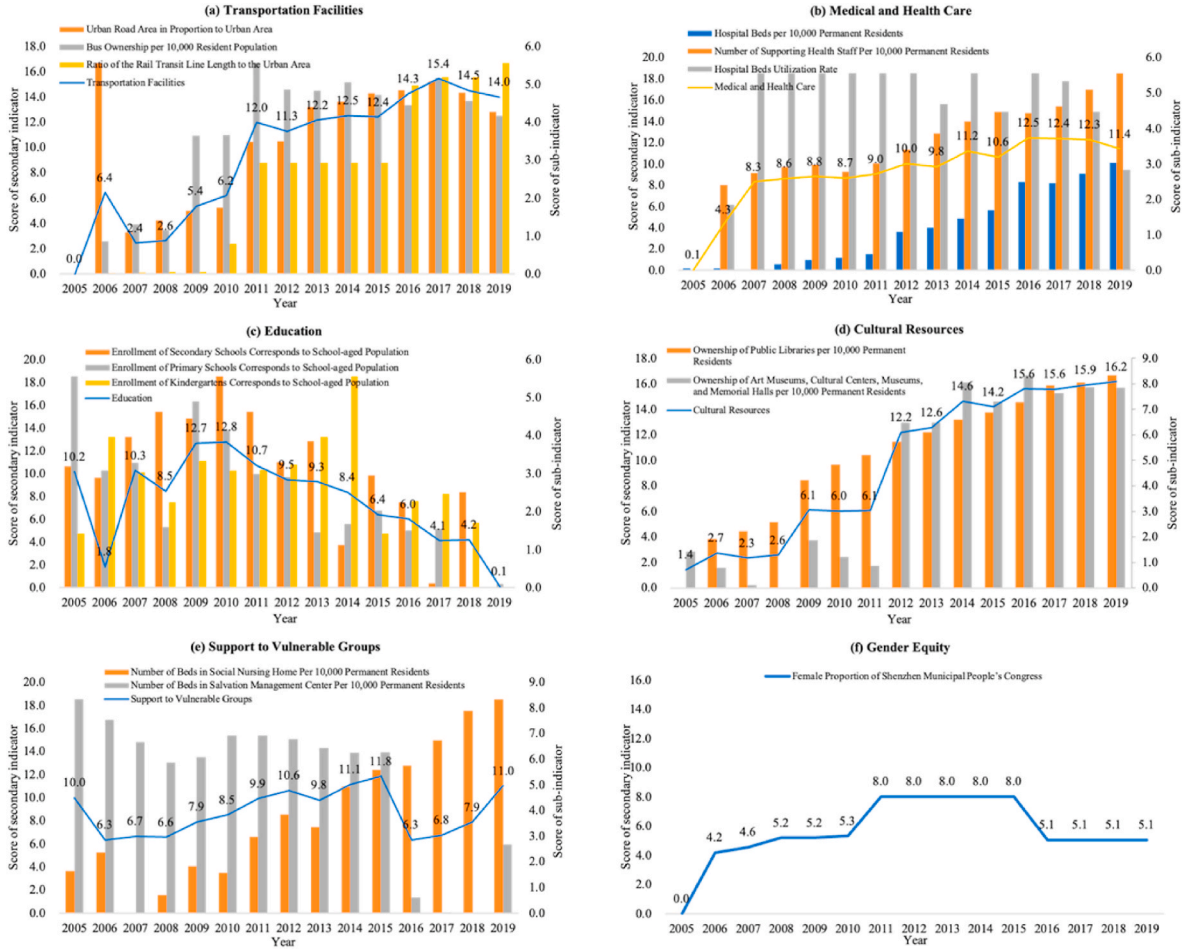

Fig. 6. Progress of tertiary indicators of public services in Shenzhen since 2005. (a) Scores of transportation facilities (in line) and sub-indicators (in columns). (b) Scores of medical and healthcare (in line) and its sub-indicators (in columns). (c) Scores of education (in line) and sub-indicators (in columns). (d) Scores of cultural resources (in line) and sub-indicators (in columns). (e) Scores of support to vulnerable groups (in line) and sub-indicators (in columns). (f) Scores of gender equity (in line) and sub-indicators (in columns).

in the number of beds in the salvation management center was slow. In contrast, the rise in the permanent resident population was rapid, which led to the downward trend in the indicator of the number of beds in the salvation management center.

Shenzhen attached great importance to soft power construction, built libraries at different levels, and constructed art centers, museums, and memorial halls (General Office of the People's Government of Shenzhen Municipality, 2010). Therefore, the tertiary indicators under the category of cultural resources showed an increasing trend (Fig. 6 (d)), although the increase was relatively mild after 2014.

Female proportion in Shenzhen Municipal People's Congress closely related the gender equity. Its score increased from 2005-to 2010, then stayed relatively high from 2011 to 2015, followed by a decreasing trend. However, the female proportion has not reached the recommended value in recent years, which shows that gender equity is still lacking.

3.4. Living environment in Shenzhen

The living environment kept increasing until 2016 and decreased afterward (Fig. 7). The implementation of the new development concept of innovation, coordination, green, openness, sharing, and implementation of sustainable development strategy since 2005 contributed significantly to improving the living environment over the years (Yang, 2017). However, with the considerable increase in population, the score of the live environment deteriorated in recent years.

Scope of the study in living environment included elements of water resource quality, green space, air quality and noise, waste disposal, and resource consumption. The performance of secondary indicators varied (Fig. 7). The water resource quality increased over the years, with the highest score appearing in 2016 (Fig. 8(a)). The score of total water resources per 10,000 permanent residents fluctuated in recent years. The compliance rate of water resource quality from urban drinking sources increased rapidly before 2009, then stayed stable since 2009. Scores of both design scale of the sewage treatment plant and the total length of urban drainage pipe showed a growing trend since 2005, which might closely relate to the implementation of several laws on wastewater management (The State Council of China, 2015; She et al., 2019). The total score of green space increased from 2005 to 2012, then stayed stable from 2012 to 2015, then rapidly decreased afterward (Fig. 8(b)). The score of the green coverage rate remained stable before 2018, then suddenly reduced in 2019. Scores of forest coverage rate and park area fluctuated in these years. The score of green space increased before 2015, then declined rapidly from 2015 to 2019, with the lowest score in 2019.

Air quality and noise stayed relatively stable in recent years (Fig. 8 (c)). The excellent air quality score was steady at a relatively high level before 2012, suddenly decreased in 2013, then fluctuated afterward. A score of mean environmental noise in the urban area showed a decreasing trend. The score of industrial exhaust emission increased from 2005 to 2015, then stayed stable afterward. The industrial smoke and dust emission score rose before 2012, then remained steady at the highest level since then. It should be noted that all noise, emissions, production, and resource consumption (including those below) indicators are negative indicators. Therefore, the higher the actual score, the lower the actual noise, emissions, production, and resource consumption, and the better the actual environmental situation.

The overall waste disposal score increased rapidly from 2005 to 2011, then stayed stable at a relatively high level since 2011 (Fig. 8(d)). Scores of domestic garbage transfer stations and public toilets showed a similar trend to waste. The harmless disposal rate of household waste was stable from 2005 to 2012, then increased from 2012 to 2014; after that, it stayed steady at a relatively high level. The score of industrial solid waste production increased continuously from 2005 to 2013, then remained at a relatively high level afterward.

Resource consumption in Shenzhen continuously increased since 2005 (Fig. 8(e)). Scores of all sub-indicators of this category showed an increasing trend in recent years, which reflected the effort and successful implementation of green development in Shenzhen (Liu et al., 2016).

4. Discussion

4.1. Alignments with UN SDGs

Indicators of this study mainly came from the commonly used indicators from the Shenzhen Statistical Yearbook, Shenzhen Municipal Health Statistics Yearbook, the website of Shenzhen Municipal People's Congress, and other governmental reports, and they were all relevant to at least one UN SDG in our study. However, these indicators did not cover all UN SDGs due to invalid data in some areas. The index system set by this study included 13 of the 17 UN SDGs. Goal 2 Zero Hunger, Goal 10 Reduced Inequality, Goal 13 Climate Action, and Goal 14 Life Below Water were not covered in the assessment., which agreed with Zhou et al. (2019) opinion that it is expected that the statistical data are inadequate to meet the needs of measuring 2030 Agenda. It is suggested that government could improve their indicator systems by adding indicators in Goal 2, Zero Hunger, Goal 10, Reduced Inequality, Goal 13 Climate Action, and Goal 14 Life Below Water, so that progress of

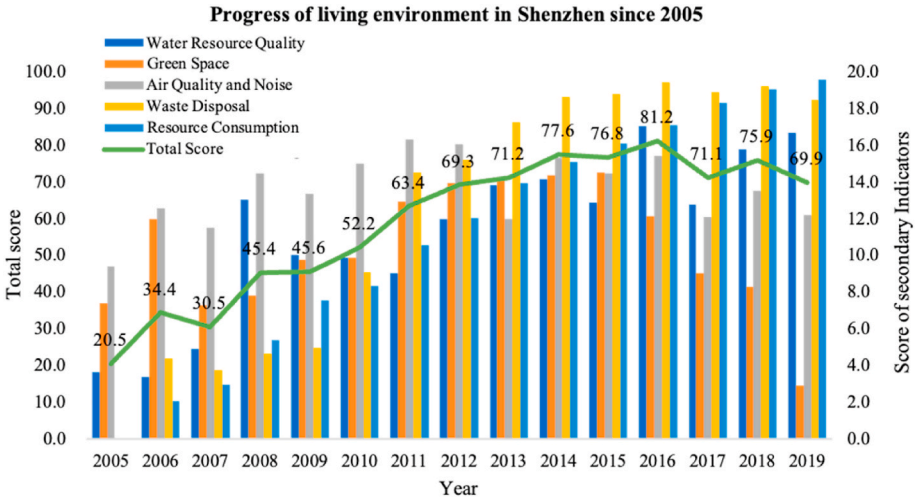

Fig. 7. Progress of living environment in Shenzhen since 2005. This figure presented both the total score (in line) and the score of each dimension (in column). The total score was 100%, and the total score of each dimension was equally weighted as 20%.

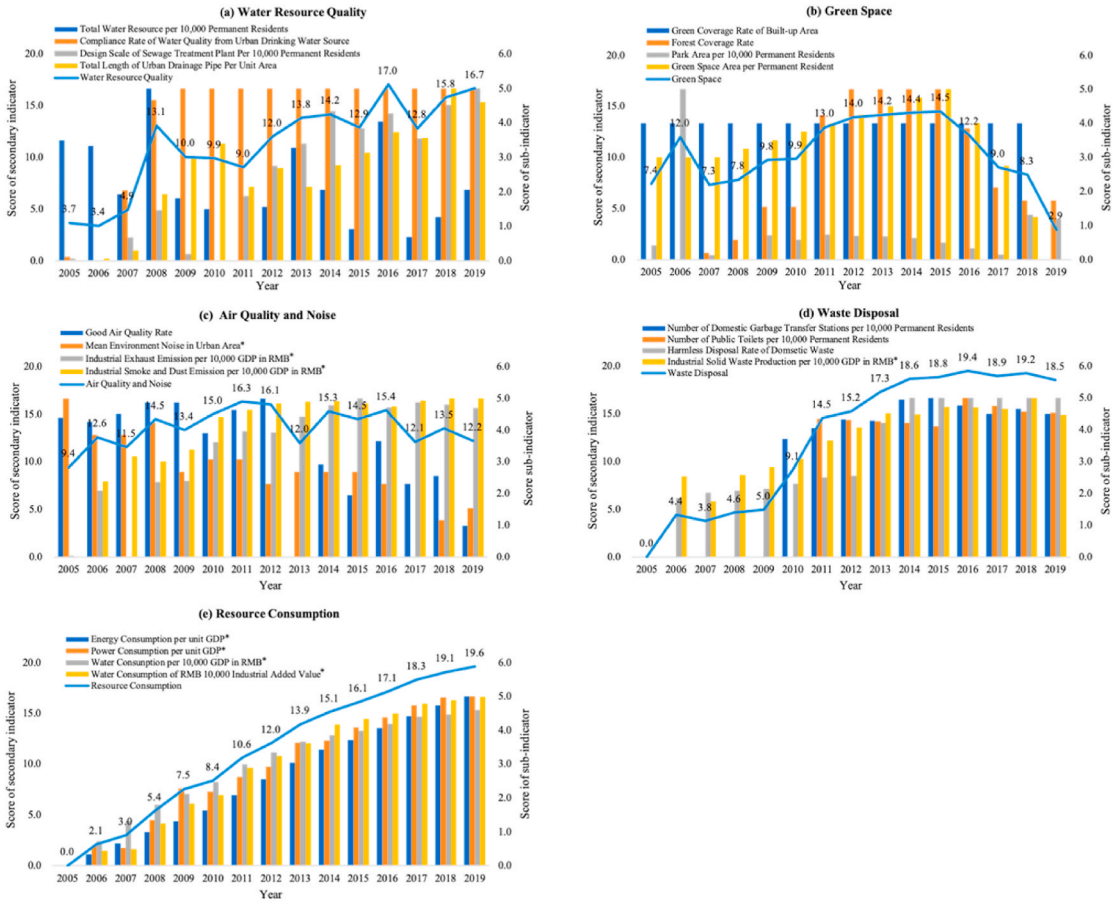

Fig. 8. Progress of tertiary indicators of living environments in Shenzhen since 2005. (a) Scores of water resource quality (in line) and sub-indicators (in columns). (b) Scores of greenspaces (in line) and sub-indicators (in columns). (c) Scores of air quality and noise (in line) and sub-indicators (in columns). (d) Scores of waste disposal (in line) and sub-indicators (in columns). (e) Scores of resource consumption (in line) and sub-indicators (in columns).
*: Negative indicators, noise/emissions/consumption, and their actual scores will be inversed proportional.

sustainable development could be better assessed.

4.2. Sustainable development in Shenzhen

It is well recognized that it might be difficult for a country or city to fully optimize all goals simultaneously as the progress towards each goal is significantly different, and a complex correlation exists between them (Xie et al., 2021b; Wang et al., 2020b). Shenzhen government could thus prioritize goals that lag other goals by different management strategies. Overall performance of innovation vitality, public service, and living environment will be discussed in the following part.

4.2.1. The performance of innovation vitality gained remarkable achievements

Shenzhen's innovation vitality showed rapid growth from 2005 to 2019, with remarkable achievements in innovation output. The municipal patent authorization in Shenzhen was the highest among large and medium-sized cities in China. The number of PCT international patents in Shenzhen was also the highest in China in 2019 (Shenzhen Administration for Market Regulation, 2020). Shenzhen was also the top city in the 2020 National Innovation City Top 20 published by the Ministry of Science and Technology and Institute of Scientific and Technical Information of China (2021). There were the following factors for Shenzhen to gain these achievements. Firstly, as the first national innovation city and the first city-scale National Innovation Demonstration Area, Shenzhen enhanced its innovation capacity and adopted several policies to promote innovation these years. Moreover, as the economic foundation is an essential guarantee for sustainable development in innovation, the sound financial foundation with 2692.7 billion GDP in Shenzhen, which ranked third place in China, provided vital support to innovation and sustainable development (Wang et al., 2020c). Thirdly, the R&D capital investment of Shenzhen was at a top level. In 2019, Shenzhen invested 132.8 billion RMB in R&D, which accounted for 4.93% of GDP. Fourthly, the enterprises in Shenzhen had a prominent position in innovation. R&D institutions in Shenzhen were mainly enterprises, and invention patents were mostly from enterprises. The R&D expenditure of Shenzhen's enterprises accounted for 95.4% of society's R&D expenditure (Shenzhen Municipal People's Government, 2020). The high-tech industry became a well-known symbol for Shenzhen. Shenzhen owns more than 17,000 national high-tech enterprises, ranking second among cities with the most innovative companies (Shenzhen Municipal People's Government, 2020).

4.2.2. The performance of public services showed a downward trend after 2014

The performance of public services improved from 2005 to 2014 but worsened afterward. The main reason was that the growth in the number of enrolments approved by schools at different stages could not meet the rapidly growing school-aged population. The growing trend was shown in the rail transit length, hospital beds, supporting health staff, social nursing homes, ownership of public libraries, and other cultural services; indicators that declined in recent years after peak value were urban road area, bus ownership, the utilization rate of hospital beds, and female proportion of Shenzhen Municipal People's Congress. Downward

trends were shown in the education of all school-aged and the number of beds in salvation management. The Shenzhen government should pay more attention to road construction, women's right to participate in politics, and schools at all levels.

4.2.3. The performance of the living environment showed a growing trend

The overall trend of living environment showed a growing trend from 2005 to 2019. Water and air quality reached a high level, and waste was treated safely. This may be because the Shenzhen government attached great importance to improving the living environment, adhered to the concept of sustainable development, and constantly updated new environmental indicators in planning. The Shenzhen government was also promoted environmental legislation (Standard Committee of the Sixth Shenzhen Municipal People's Congress, 2019).

4.3. Comparing sustainable development of Shenzhen with other cities

4.3.1. Innovation vitality

Although innovation vitality in Shenzhen progressed significantly, there were still gaps with other top cities. According to the 2019 Evaluation of Science and Technology Innovation Ability, Shenzhen ranked sixth in comprehensive innovation ability among metropolises worldwide (Gu, 2019). The Global Innovation Cities Index released by Australian Think Tank 2thinkhow ranked according to cultural assets, infrastructures, and networked markets. According to their ranking in 2019, Shenzhen was ranked No.55 (2 thinknow, 2019).

The main reason for the low competitiveness might be as follows. Firstly, the number of higher education institutions was insufficient, as there were only 13 institutions in 2019. This number was far smaller than that in Beijing and Shanghai, 93 and 64. Guangzhou, which owned a resident population of 10 million as Shenzhen but slightly lower GDP, also held 81 higher education institutions. Shenzhen's higher education institutions did not match its economy and population. Secondly, the innovation of Shenzhen relied heavily on enterprise, as 95.4% of the whole society's R&D expenditure was from enterprise. It is relatively appropriate if enterprises occupy 70% of society's R&D expenditure (Li, 2019). The gap in the source of R&D expenditure may lead to significant economic pressure on local enterprises. Thirdly, primary research and original innovation were still weak. Although the investment in basic research increased substantially after 2015, the proportion of basic research to R&D investment in Shenzhen was 2.59% in 2019, which was lower than the national average level of 5.5% and far lower than the intermediate level in developed countries as 15–20% (Li, 2019).

4.3.2. Public service

Overall performance in public service dramatically improved since 2005, but there were still deficiencies compared to other cities. According to the Report on China's Implementation of 2030 Sustainable Development Agenda Goal 11, which evaluated public transportation by indicators of bus ownership per 10,000 people, bus travel ratio, the coverage rate of the bus stop in the built-up area, and road network density, Shenzhen was classified as medium level (China National Engineering Research Center for Human Settlement, 2020). Moreover, according to Huang and Jin (2017)'s assessment of medical services of Shenzhen, Beijing, Shanghai, Guangzhou, Hangzhou, and five other cities in China, Shenzhen was ranked the lowest among these cities. Also, according to the City of Opportunity 2021 Report (PwC and China Development Center, 2021), Shenzhen was ranked 29th in the category of medical and health resources, which was far lower than other megacities in China, such as Beijing, Shanghai, Guangzhou, Chongqing, and Tianjin. Deficiencies also showed in the support to vulnerable groups, especially in constructing a salvation management center. Shenzhen only owned three salvation management centers, while Beijing owned 20 salvation management centers with precise classification. Guangzhou also held seven salvation management centers at municipal and district levels. The salvation management centers were closely linked with local infectious disease hospitals, general hospitals, and psychiatric hospitals. In terms of public cultural resources, Shenzhen had deficient in quantity and scale compared with other advanced cities. Shenzhen only owned one national-level museum, while Beijing had 14 first-level national museums and three key art museums, and Shanghai owned five first-level national museums. Overall, public service in Shenzhen still needs to be improved in all aspects.

4.3.3. Living environment

The living environment in Shenzhen is premier in China. For example, air quality is higher than that in other megacities in China, and the greening and forest coverage rate is at the international garden cities level (Zhou, 2011). However, this city still faces typical living environment problems as a fast-developing megacity, such as the conflict between lack of resources and rapid population growth (The City and Competitiveness Research Center of Chinese Academy of Social Sciences, 2020). As our study showed, with the city's fast development, the most directly affected indicators were total water resource per 10,000 population, forest coverage rate, per capita green space area of the park, reasonable air quality rate, and urban regional environmental noise. In terms of energy consumption, there was a gap between Shenzhen and other megacities in China. For instance, although Shenzhen performed well in water consumption per capita GDP (water consumption per capita GDP in Shenzhen was 7.82-L meter per million GDP while that of Beijing was 11.78-L meter per million GDP), the energy consumption of Shenzhen was high (energy consumption per capita GDP in Shenzhen was 0.35 ton equivalent of coal per million GDP while that of Beijing was 0.23 ton equivalent of coal per million GDP), which indicated that Shenzhen can still improve its energy consumption to reach a higher level of energy-saving.

4.4. Policy implications

4.4.1. Improving SDGs indicator system

By constructing the city-level sustainability assessment system in our study, it is found that indicators of Goal 2 Zero Hunger, Goal 10 Reduced Inequality, Goal 13 Climate Action, and Goal 14 Life Below Water are lacking. Compared to the inadequate SDGs progress monitoring system, Eurostat, the statistical office of the European Union, constructs a robust SDGs index system to regularly monitor the progress towards SDGs (Eurostat, 2021). It is suggested to incorporate indicators, such as government support to agricultural research and development, the income share of the bottom 40% of the population, greenhouse gas emissions, and bathing sites with excellent water quality, as reference indicators to Goal 2, 13, and 14.

4.4.2. Innovation vitality

According to our assessment, innovation vitality in Shenzhen improved significantly with proper financial and policy support. However, compared to the top megacities, the construction of higher education institutions and the support for basic scientific research are insufficient. Shenzhen could accelerate the construction of higher education institutions by cooperating with top universities worldwide. It is recommended to expedite the construction of research institutes with financial and policy support. Also, innovation in Shenzhen relies highly on innovation from enterprises. Shenzhen could explore the possibilities to attract the top 500 companies, especially those with their own sustainable development strategies (Song et al., 2022). The burden of innovation investment in companies may be relieved by providing funds, technical training programs, and promoting alliances and networking among firms, research institutes, universities, and investment agencies (Doh and Kim, 2014).

4.4.3. Public services

The greatest obstacle to sustainable development in Shenzhen is the insufficient public services. Our study shows that the public service

cannot meet the need for rapid growth in Shenzhen. It is suggested that the government should pay particular focus on accelerating the construction of the road network, medical services, and salvation management center. Urban renewal is a strategy to improve public services and life quality. It will keep bringing positive changes in urban areas as old neighborhoods are constantly struggling with poor living quality and lack of public services (Wang et al., 2021; Zhuang et al., 2017). Also, it is suggested to further investigate the obstacles in public services by establishing more pertinent surveys, such as analyzing how many elderly need nursing houses and how many homeless people need salvation centers.

4.4.4. Living environment

A good living environment is one of the strengths of sustainable development in Shenzhen. The challenges in this area mainly come from an insufficient carrying capacity of resources under the fast growth of the city, especially water resources. It is recommended the government work on constructing a resource-saving society by conducting water-saving projects (Du et al., 2021), harvesting and utilization of rainwater (Zheng et al., 2010), construction of green buildings (MacNaughton et al., 2018), introducing environmental tax(Bashir et al., 2020), and other related strategies.

4.5. Limitations of the study

Indicators in this study were selected from the open public source to ensure the authenticity and continuity of data. However, data were still limited in some years. The study then assumed the missing data as 0 or an estimated value using linear regression. This might then lead to bias in the evaluation. Also, the lack of indices for certain SDGs or targets may result in an uncompleted picture of Shenzhen's sustainable development progress. It is suggested that the government consider adding more SDGs related indicators in their annual statistical report. This framework could also be used to understand other cities' progress to evaluate the strength and deficiencies in their sustainable development.

Another limitation is the weights of each indicator are equally weighted in this study. Weight is one of the most critical steps during constructing composite indicators. However, there are no statistical or empirical results for choosing the different weights for different indicators in this study. The equal weight applied to all indicators in this study presents the recognition of equal status for all indicators (European Commissions, 2022; OECD, 2008). Future research could consider collecting public or expert opinions to optimize weighting methods better. Different weight settings could be considered to evaluate how the weight settings would affect the whole system.

5. Conclusion

The research focused on evaluating sustainable development progress in the megacity Shenzhen from 2005 to 2019 by constructing an index system covering three dimensions of innovation vitality, public service, and living environment with 15 s-level and 50 tertiary indicators. According to the assessment, overall sustainable development in Shenzhen was much better in recent years. The growth rate of sustainable development score was rapid before 2013 but slower afterward. In terms of the three dimensions of Shenzhen's sustainable development, innovation vitality kept improving since 2005. Public service improved before 2014 but regressed after that. The living environment improved before 2016 but showed a falling trend afterward. The evaluation indicates that Shenzhen paid great attention to the construction of innovation vitality.

In terms of future development, it is suggested that the local government build a more solid sustainable assessment system with indicators covering all 17 SDGs to monitor the progress to sustainability. Shenzhen could accelerate the construction of higher education institutions and research institutes by cooperating with top universities and financial and policy support for sustainable urban development. The burden of innovation investment may be relieved by training programs or networking organized by the government. The obstacle of public services is suggested to be taken seriously and could be reduced by urban renewal. The living environment is one of the strengths of sustainable development in Shenzhen and could be maintained by constructing a resource-saving society.

The sustainability assessment system in our study serves as an SDGs progression monitoring system in Shenzhen. It could also be used as a reference to construct the SDGs progression monitoring system for other cities by slightly changing some localized indicators. With this assessment system, the government could evaluate the strengths, obstacles, and challenges during the development and use it as a reference for policy-making.

CRediT authorship contribution statement

Shujie Xu: Data curation, Data collection, Methodology, Investigation, Formal analysis, Visualization, Writing – original draft. **Shuyang Zheng:** Data curation, Data collection, Methodology, Investigation, Formal analysis, Visualization. **Zhiqiu Huang:** Methodology, Investigation, Formal analysis. **Lan Song:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration. **Ying Long:** Formal analysis, Visualization. **Xiaojiao Zhan:** Data curation, Data collection, Methodology, Investigation. **Lianjie Jiang:** Data curation, Data collection, Methodology. **Yimin Wang:** Data curation, Data collection. **Yaqing Shu:** Writing – review & editing, Supervision. **Chunmiao Zheng:** Supervision, Resources, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.131496.

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