

A Review on the research and practice of city sustainable development indicators and indices

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Abstract. City sustainable development indicators and indices have become a hot issue in academic research and practical application, alongside the high-speed worldwide urbanization and driven by the actual managing demand. This article is aimed at a clear understanding of the progress in relevant research and practice. This is done by collecting common indicators and indices for city sustainable development and making comparison of the assessment process and contents, so as to find out main obstacles for the development of this research field and explore the direction for efforts to be made next step. The article divides these indicators and indices into two categories: ① indicators serving as single index which can provide an explicit description on the relationship between economic activities and environmental carrying capacity, but have a narrow scope of assessment and use complicated methods to collect and calculate data; ② indices based on indicator systems which can represent multiple processes, could reflect the view of strong sustainability and are easy to use, but can hardly depict the responding relationship between social, environmental and economic changes for city sustainable development or assure the scientific rigor of weight setting. Practices on indicators and indices for city sustainable development was summarized, and its problems were reviewed with China being representative of transitioning countries. According to the review, great progress has been achieved in the research and practice of indicators and indices for city sustainable development, but consistency of theories, rationality of indicators and scientific rigor of methodology are to be improved significantly.

1. City sustainable indicators and indices as an emerging important issue

1.1. Cities are a key area promoting the sustainable development of humanity

Areas where urban population is concentrated, industry and commerce are developed and residents focus on non-agricultural population are featured by element concentration, systematic development, man-made environment domination and overflow effect. At present, urbanization is advanced rapidly across the world, especially in developing countries. Cities gather more than 50% of world population, and the number is expected to reach 6.3 billion, out of the approximately 9.3 billion world population, by 2050[1], as shown in Figure 1. Along with the trend comes the rapidly increasing impact of cities in



resource and environmental protection and sustained economic growth. Cities take away 75% of the world's natural resources, cover 3% of land, discharge 50% of wastes and 70% of greenhouse gases and produce over 80% of GDP[1-5].

As urbanization proceeds at a high speed, lots of problems in the governance of city sustainable development have started to emerge—economic growth is weakly driven, economic development model is to be transformed urgently; social inclusiveness isn't strong, and equalization of public services is to be improved urgently; resources are used less efficiently, and eco-environment is to be improved; cities are expanded blindly, urban planning and construction and urban governance capacity are to be improved earnestly. Evidently, cities have become a key pushing ahead the sustainable development of human society.

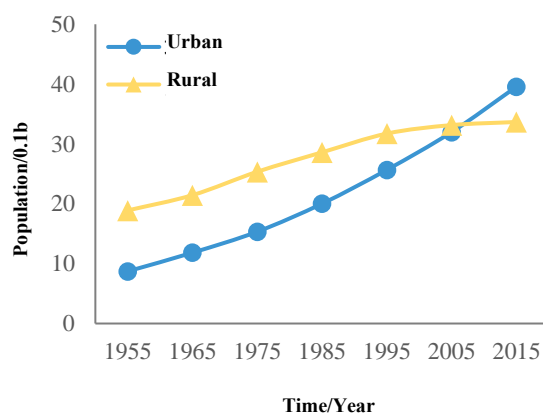


Figure 1. World Population Change, 1955-2015

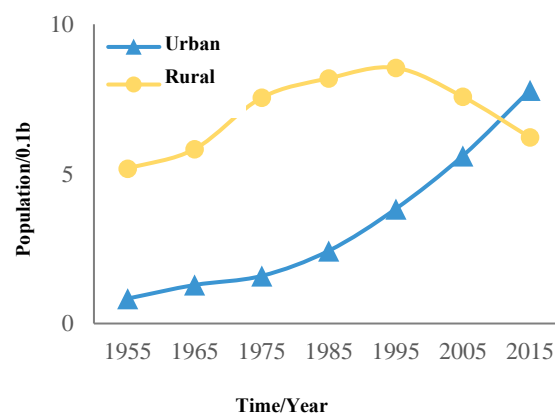


Figure 2. Chinese Population Change, 1955-2015

1.2. City sustainable development indicators and indices are an important instrument supporting urban governance

Intended for city sustainable development, urban activities shouldn't exceed the necessary limit while satisfying the production and living needs of residents. As an important issue worldwide, city sustainable development challenges the management capability and wisdom of all governments. In September, 2015, the United Nations approved 17 sustainable development goals, of which goal No. 11 was to "make cities and human settlements inclusive, safe, resilient and sustainable", targeting urban development.

Indicators are "pointers capable of reflecting or measuring some conditions, which are helpful in translating information in a more intelligible manner and can describe complicated conditions in a concise way". This is taken from reference[6]. A comprehensive evaluation index may be acquired from a mixture of indicators through single index integration. Indicators have the functions of organizing and planning regulation and control, verifying validity and conducting social propaganda [7].

Researching and practicing city sustainable development indicators can guide the formulation of urban development strategies, monitor the implementation effect of public policies and promote through social propaganda information transparency and public supervision. A set of global indicators will be adopted to implement and assess each sustainable development goal and specific targets, according to the *2030 Agenda for Sustainable Development*. In 2012, International Organization for Standardization (ISO) approved to build ISO/ TC 268 Technical Committee for the Sustainable Development of Cities, which has released ISO 37120 Sustainable Development of Communities: Indicators for City Services and Quality of Life and is developing indicators for city resilience and smart cities. It's thus clear that the research and development of indicators for city sustainable

development has drawn universal attention and received vigorous support from international organizations.

To sum up, indicators for city sustainable development are an important instrument supporting city governance and have become a hot issue in academic research and management practice. This paper is designed to explore the research progress of indicators for city sustainable development, learn about their application and review existing problems with the focus on China and thereby, present pertinent directions and suggestions of improvement.

2. Research of indicators and indices for city sustainable development

The establishment of sustainable development indicators was a process of constant evolution. With regard to academic research, the sustainable development evaluation methodology based on environmental impact assessment emerged in the middle of the 20th century; subsequently, multiple integrated environmental and economic assessment techniques sprang up over time, such new methods as lifecycle analysis (LCA) and synthetic environmental and economic accounting (SEEA) system were worked out, the scope of evaluation expanded from environmental damage and resource use to multiple services of ecosystem; theories and indicators relating to city sustainable development, such as ecological city, compact city and low-carbon city were put forward; when it came to the 21st century, apparently more attention was paid to social sustainability. In relation to management practice, developed countries and some developing countries have adopted, since the 1980s, a great mixture of city development policies, such as ecological city, livable city and low-carbon city, which focused on the coordination between society, environment and economy; as a result, they have accumulated application cases and experience of indicators for city sustainable development. In a word, obvious progress has been achieved in the research and application of indicators for city sustainable development in recent years.

The following part contains a summarization of relevant studies starting with the design thought of indicators for city sustainable development. These indicators are divided into two classes, with the first class based on single index and the second class based on indicator system[8]. They have different features in methodology and process: the former are designed to target relatively single objects, whose calculating process is supported by a complete set of conversion coefficient database obtained via long-term experiments and surveys, and the latter target diversified objects, whose reference values are selected in a more subjective manner.

2.1. Indicators serving as single index

These indicators are designed mainly to represent the relationship between economic activities and eco-environmental support levels, based on single, universal computational items, and they can translate, through conversion factor, objects of different categories into computational item values and thereby, sum them to get a single index value. For instance, ecological footprint (EF) takes the area of productive land as the computational item and the genuine progress indicator (GPI) takes the currency as the computational item. Table 1 presents a summarization of ordinary indicators based on single index.

Single-index indicators are advantageous in that the index value has a relatively more intuitional physical significance and thus, can provide a clear description on the relationship between economic activities and natural environment's support levels.

Table 1. City sustainable development evaluation technique based on single index.

Technique Name	Assessment Scope & Computing Method
Ecological Footprint	$EF = P/Y_N \times YF \times EQF$, P is the amount of a product harvested or waste emitted, Y_N is the average yield for P, and YF and EQF are the yield factor and

(EF)[9]	equivalent factor respectively, for the land use type in question.
Genuine Progress Indicator (GPI)[10]	$GPI = C_{adj} + G_{nd} + W - D - E - N$ C_{adj} is personal consumption expenditure adjusted by income unfairness, G_{nd} is government expenditure except defense, W is the non-market contribution of welfare, D is personal expenditure on defense, E is the cost of environmental degradation and N is the depreciation of natural capital stock.
Genuine Saving (GS)	$GS = \text{Gross domestic savings} - \text{fixed capital consumption (depreciation)} + \text{educational spending} - \text{air pollution cost} - \text{water pollution cost} - \text{consumption of non-renewable resources} - \text{CO}_2 \text{ loss cost}$
Life Cycle Assessment (LCA)	<p>Overall load of environmental impact = $\sum (\text{output quantity of the } n^{\text{th}} \text{ type of environmental loads} \times \text{characterization factor of the } m^{\text{th}} \text{ environmental impact type of the } n^{\text{th}} \text{ environmental loads} / \text{reference value of the } m^{\text{th}} \text{ environmental impact type, weighted average})$</p> <p>Environmental impact types include consumption of non-renewable resources, greenhouse effect, acidification effect, forming of photochemical smoke and human health damage.</p>
Material Flow Analysis (MFA)	<p>Total quantity of regional material input = Direct material input + regional hidden flow</p> <p>Total quantity of regional material output = Regional processing output + regional hidden flow</p> <p>Total quantity of regional material consumption = Total material demand - export and its hidden flow</p> <p>Net increase of regional material stock = Total material demand - total material input</p> <p>Measuring unit is fresh weight of materials, and conversion methods include material weight conversion coefficient and the standard coal conversion coefficient of energy materials.</p>

Single-index indicators are disadvantageous in that ① the scope of evaluation is small, and processes that can be taken into consideration are fewer than the indicators based on index system. In particular, it's more difficult to reflect social sustainability and the equity principle. For instance, EF can measure environmental sustainability alone; ② The view of strong sustainability isn't adopted. For instance, SEEA converts natural and social costs into currency amount and sums it with total income, total expenditure or total savings and thus, doesn't reflect fully natural environment's significance in limiting city development; ③ The scientificity of conversion factor is in dispute. For instance, converting natural and social costs into currency amount using SEEA must be on the premise of several assumptions; and ④ High requirements are raised for data collection and computing methods are complicated, which together increase the cost of evaluation and make it hard to generalize.

2.2. Indices based on indicator systems

Indicators based on index system can obtain single-dimensional index or comprehensive index through combining and integrating multiple indicators that represent different objects or processes, and relatively more influential indexes include Green City Index (GCI), City Development Index (CDI) and Human Development Index (HDI); see Table 2 for more details. The generalized flow for building an indicator system is to establish a conceptual model of city sustainable development, set an assessment framework and select indicators. Ordinary assessment frameworks are the three-pillar framework, city sector constitution, city metabolism model, life cycle theory and city sustainable development policies and goals.

These indicators are advantageous because they can give consideration to all dimensions or processes of city sustainable development at the same time, and make it convenient for conducting the horizontal comparison of single indicators and experience reference. Theoretically, these indicators can express from the perspective of strong sustainability. In addition, they are easy to generalize because they can be increased and modified according to local characteristics and data availability, and their data collection and computing methodology are relatively easier.

Their disadvantages are: ① variable selection and indicator weight are more random than the indicators serving as single index discussed in subsection 2.1; ② composite index value has a non-intuitional physical significance; ③ limited to people's knowledge level, the indicator system evaluation technique can hardly capture the complex nature of the city system and is difficult to give an accurate description on the responding relationship in changes of social situation, natural environment and economic activities; and ④ when indicators are converted into indices, the weighted mean method is adopted generally, in which environmental quality isn't taken as the fundamental limiting condition and the view of strong sustainability isn't reflected.

Table 2. City sustainable development evaluation technique based on the indicator systems.

Technique Name	Assessment Scope & Computing Method
Green City Index (GCI)[11]	GCI= CO ₂ emissions+ energy+ building+ land utilization+ transport+ water+ health+ waste management+ air quality+ environmental governance
City Development Index (CDI) [11]	GCI= (Infrastructure index+ waste index+ well-being index+ education index+ product index)/5; Here, infrastructure= 25× water supply+ 25× sewage discharge+ 25× electricity supply+ 25× communication; Waste= Wastewater treatment× 50+ regular solid waste disposal× 50; Well-being= (Life expectancy- 25) × 50/60+ (32-child mortality) × 50/31.92; Education= Literacy rate× 25+ comprehensive enrollment rate× 25; Product= (log city product-4.61)×100/5.99
Environmental Performance Index (EPI) [11]	EPI=f (Environmental health, ecological vitality), where 21 indicators represent 9 themes, and the weighted mean method is used for weighting
Human Development Index (HDI) [11]	HDI (1990-2009)= 1/3(life expectancy)+ 1/3(education index)+ 1/3(parity purchase power-adjusted per capita GDP); here, educational index is the integration of adult literacy rate and enrollment rate; HDI (2010-)= (Life expectancy) ^{1/3} + (educational index) ^{1/3} + (parity purchase power-adjusted per capita GDP) ^{1/3} ; here, educational index is the integration of the upper limit of average schooling years and the schooling year expectancy.
Happy Planet Index (HPI) [11]	HPI= Happy life expectancy/ ecological footprint, Here, happy life expectancy is a product of life expectancy and happy experience obtained from questionnaire form
Well-being Index (WI) [11]	WI= (Ecosystem well-being index+ human well-being index)/2; Here, Ecosystem well-being index= (Land+ water+ air+ species and gene+ natural resources)/5; Human well-being index= (Health and population+ wealth+ knowledge

		and culture+ community+ fairness)/5
Sustainable Society (SSI) [11]	Index	SSI= Human health+ environmental health+ economic health, or SSI= (Basic needs+ health+ personal and social development+ natural resources+ climate and energy+ transport+ economy)/7
Sustainable Chinese Cities [12]		R=(Average life expectancy+ ratio of educational spending to GDP under municipal administration+ per capita GDP under municipal administration+ urbanization rate+ ratio of added value of non-agricultural industries+ centralized treatment rate of domestic sewage+ harmless treatment rate of domestic garbage+ integrated utilization rate of industrial solid wastes+ standard attainment rate of industrial wastewater emission+ SO ₂ emissions per unit of industrial output value+ smoke emissions per unit of industrial output value+ green coverage ratio of built-up areas)/ 12
Development Satisfaction[13]		Development satisfaction= f(development sustainability, development coordination, development level); Here, development sustainability is represented by 3 themes and 13 indicators, development coordination by 4 themes and 16 indicators and development level by 3 themes and 17 indicators. The analytic hierarchy process is used to determine the weight, and weighted mean is adopted.
City Development Level Index [14]		Development level index= f(environmental sustainability index, economic sustainability index, social sustainability index); Here, environmental sustainability index= f(air quality, water environment quality, acoustic environment quality, environmental control, eco-environment); Economic sustainability index= f(gross economic strength, economic structure, economic effectiveness, economic extroversion, economic prosperity, economic intensiveness); Social sustainability index= f(population index, dwelling level, infrastructure level, educational level, cultural life conditions, medical conditions, social security status, living level, technological level); Weighted mean

3. Practice of indicators for city sustainable development: taking China as example

Many international organizations and city management agencies have designed and practiced indicators for city sustainable development. These indicators are applied largely in three circumstances: action plans of international organizations designed to promote city sustainable development, local sustainable development strategies made by Chinese and foreign cities based on *The 21st Century Agenda* and city development plans relating to sustainable development. In the course of the formulation and implementation of these plans and strategies, assessment of city sustainable development serves as important basis and reference for identifying problems, setting goals, making strategies, conducting supervision and checking results. At present, no indicator has been universally accepted in practice and these indicators have poor political influence. Parris et al. concluded there are

three reasons[15]: fuzziness of concept, multiple goals of sustainable development measurement and confusions in the terminology, data and methodology of measurement.

Over more than 30 years of rapid economic development, China has highly representative problems in city development. Figure 2 shows the changes in urban and rural distribution of Chinese population between 1955 and 2015; over the 60 years alone, China's urbanization rate soared from 10% to 50%, and its urban population accounted for as much as 54.77% in 2014. By 2030, China will have had another 310 million urban residents, adding its urban population to over 1 billion and urbanization rate to 70%. Apparently, China needs urgently to intensify city sustainability so as to cope with the social, environmental and economic challenges arising in the high-speed urbanization process.

The Chinese government attaches great importance to city sustainable development. In 2015, the Central Urban Work Conference was held again, after 36 years, presenting overall requirements of "building harmonious, livable and viable modernized cities with their respective characteristics, and opening up a characteristic path for city development". Starting from the problems they concern respectively, departments of the central government have released multiple development plans and policies relating to sustainable development and applicable to the urban scale, and have formulated indicators serving as a technical instrument for policy implementation. Seen from Table 3, the great quantity of urban development plans have different themes and goals, involving a huge number of indicators with different themes and levels. Based on the feasibility research conducted by competent departments, such city assessment indicators have a foundation in the effectiveness, usability, feasibility and replicability for reflecting specific problems. Nevertheless, their relationship with city sustainable development assessment isn't clear enough, with great differences in the structure of indicator system and involving redundant, overlapping indicators. Due to the fragmented urban assessment activities, indicators are more expensive to use and more difficult to generalize, basic-level departments receive a bigger pressure and many government resources are consumed internally.

Table 3. Examples of city sustainable development plans & policies of China's central government.

No.	Theme	Competent Authorities	Relevant Document	Type & Quantity of Indicators
1	Sponge City	MOHURD ^a ; MWR ^b ; MOF ^c	Guiding Opinions of the General Office of the State Council on Advancing the Construction of Sponge Cities (GBF [2015] No. 75)	18 norms
2	Eco-city	MEP ^d	Notice on Issuing the Work Appraisal Plan for the Establishment of National Eco-counties and Eco-cities (HB [2005] No. 137)	34 indicators, inc. 6 qualitative
3	Circular Economy Demonstration City	NDRC ^e	Interpretation of the Evaluation Content for the Construction of National Circular Economy Demonstration Cities (2013)	67 core indicators, inc. 14 qualitative and 8 characteristic
4	Water Saving City	MOHURD ^a ; NDRC ^e	Measures for the Declaration and Assessment of National Water Saving Cities (JC [2012] No. 57)	24 indicators, inc. 10 qualitative
5	Health City	National Patriotic Health Campaign Committee	Health City Standard (2014 Version)	40 norms

6	National Forest City	SFA ^f	Indicators for the Assessment of National Forest Cities (LY/T 2004-2012)	40 indicators, inc. 21 qualitative
7	Garden City/ Ecological Garden City	MOHURD ^a	Measures for the Declaration and Assessment of National Garden Cities, Standard for National Garden Cities (JC [2010] No. 125)	62 core indicators, inc. 11 qualitative and 4 negative; 68 improvement indicators, incl. 15 qualitative and 7 negative
8	“China Human Settlement Prize”	MOHURD ^a ;	Assessment Indicator System of China Human Settlement Prize (for Trial Implementation) (JC [2010] No. 120)	64 indicators, inc. 22 qualitative and 1 comprehensively negative
9	Environmental Protection Model City	MEP ^d	Assessment Indicators for National Environmental Model Cities and Detailed Rules of Implementation (Stage VI) (HB [2011] No.3)	26 norms

^a MOHURD is short for the Ministry of Housing and Urban-Rural Construction of P.R. China.

^b MWR is short for the Ministry of Water Resources of P.R. China.

^c MOF is short for the Ministry of Finance of P.R. China.

^d MEF is short for the Ministry of Environmental Protection of P.R. China.

^e NDRC is short for the National Development and Reform Commission of P.R. China.

^f SFA is short for the State Forestry Administration of P.R. China.

4. Brief summary

Cities have become an important focal point advancing the sustainable development of human society. For the purpose of city sustainable development, the three pillars of society, environment and economy must be sustainable at the same time and the view of strong sustainability should be adopted[8]. Indicators are an important instrument supporting the governance of city sustainable development.

These indicators can be divided into two classes. On the one hand, indicators serving as single index can provide a clear description on the relationship between economic activities and the environment, but are applicable to a small scope and request complicated methods for collecting and calculating data. On the other hand, indicators based on the indicator system can represent multiple processes, reflect the view of strong sustainability and adopt simple methods to collect and calculate data, but they present a responding relationship, not clear enough, among changes in social situation, natural environment and economic activities and the scientificity of weight setting can be hardly assured. These indicators are practiced in the city development strategies and policies relating to sustainable development by international organizations, central governments and municipal governments. However, there is no such indicator commonly accepted by academia or in practice. For instance, many government organs of China have had management practice based on city sustainable development assessment, but with great differences in the selection of assessment themes and indicators and the methodology of calculation. When selecting indicators, they always highlight excessively local advantages and stress departmental benefits, which is more random and less comprehensive.

To sum up, great progress has been achieved in the research and application of indicators for city sustainable development in terms of theory presentation, indicator establishment, assessment methodology and empirical verification. Nevertheless, theoretical consistence, indicator rationality,

methodology scientificity are still to be improved significantly. On the whole, the assessment contents about assessment indicators and indices for city sustainable development are decentralized, and the assessment methods are diversified. The lack of a unified theoretical paradigm and a method system is a key technology obstacle for relevant practice.

In future work regarding city sustainable development indicators and indices, the focal point is to build a consensus on the concepts as well as the construction method of indicators and indices. On the one hand, standardized and process-based institutional arrangements and management tools could be used to strengthen communication between interested parties at all levels to reach a consensus on the concept of city sustainable development and gradually form city sustainable development indicators with stronger universality. On the other hand, research on city classification needs to be strengthened to find out similarities and differences of challenges in sustainability facing various cities and enhance pertinence of indicators and indices for city sustainable development, so as to work out appropriate city development goals and strategies according to local conditions.

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