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Application of a hybrid Entropy-McKinsey Matrix method in evaluating sustainable urbanization: A China case

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Abstract:

Urbanization can promote social and economic development but also cause various problems. As the key decision makers of urbanization, local governments should be able to evaluate the performance of urbanization, summarize experiences and find the problems caused by urbanization. This paper introduces a hybrid Entropy-McKinsey Matrix method for evaluating sustainable urbanization. McKinsey Matrix is commonly referred as GE Matrix. The values of a development index (DI) and coordination index (CI) are calculated by employing the Entropy method and used as a basis for constructing a GE Matrix. The Matrix can assist in assessing sustainable urbanization performance through locating the urbanization state point. A case study of Jinan city in China demonstrates the process of using the evaluation method. The case study reveals that the method is an effective tool in helping policy makers understand the performance of urban sustainability and thus formulate suitable strategies for guiding urbanization towards better sustainability.

Key words: sustainable urbanization; performance; Entropy; GE Matrix; China

Introduction

The process of urbanization involves rural people migrating to urban areas. According to a recent report by the United Nations (UN), more than half (52.1%) of the world population were living in urban areas by the end of 2011 (UN, 2012). Developing countries such as China have been engaged in large scale urbanization in recent years and this is expected to continue into the foreseeable future, with the ratio of China's urban population being predicted to reach 65% by 2025 and 77% by 2050 (DESA-UN, 2011). As addressed in the main theme of the 2012 China Central Economic Work Conference, the Chinese government defines urbanization to be the main driving force for boosting future domestic economic and social development (Liu, 2012).

The strategic roles and impacts of urbanization to social and economic development have been well recognized in previous studies. For example, Dyson (2011) opined that urbanization can provide new opportunities to improve social services and promote economic development. Others appreciate that urbanization process helps to upgrade industrial structure and increase per capita income (Spence et al., 2009).

However, it has been increasingly realized that rapid urbanization has also brought with a variety of problems such as the loss of farming land, increase of CO_2 emissions, shortage of water resources, traffic congestion, and rising crime (Huang & Chen, 2001; Wang et al., 2013). Excessive urbanization in many countries worldwide has become a major concern about its detrimental effects on the environment (Jaeger et al., 2010). During the urbanization process in China, about 2.5 to 3.0 million farmers per year lost their farm lands in recent years because of land expropriation, which adds to the problem of social instability as majority of these farmers could not find new jobs in cities (Tao & Cao, 2008).

The recognition of the problems caused by urbanization has led to the promotion of sustainable urbanization practice. Principles and methods for implementing sustainable urbanization have been introduced in various studies. Mobaraki et al. (2012) pointed out that the urban sprawl growth model is one of the reasons of urban unsustainability and suggested that "Smart growth" is the best form of sustainable development for Urmia city in Iran. Amado et al. (2010) pointed out the importance to build public and community participation mechanism for making policies in implementing sustainable urban development. There are other studies presenting various indicators for guiding and measuring the performance of sustainable urbanization, which relate to social, economic, environmental, and governance dimensions (Bossel, 1999; Ronchi et al., 2002; Shen et al., 2011). Meanwhile, governments throughout the world have been devoting great amount of resources and efforts in implementing various sustainable urbanization schemes. For example, Mexico City government launched the Mexico City Green Plan in 2007 to promote the sustainable development of the city in a long-run. Melbourne government adopted the Melbourne's City Plan 2010, which contains strategies, policies and actions to help achieve the vision of becoming a thriving and sustainable city (Shen et al., 2011). The Chinese government has recently decided to devote efforts to implementing sustainable development principles in urbanization process by means of building intelligent, green, ecological and low-carbon cities (Xinhua Website, 2012).

In line with these developments, research works have introduced various models and mechanisms to assess the sustainability performance of urbanization. For example, Hunter and Shaw (2007) introduced the ecological footprint (EF) method to evaluate the sustainable tourism of United Kingdom (UK). EF method is a quantitative tool that helps assess the resource consumption and waste assimilation requirements of a defined economy in terms of a corresponding productive land area (Wackernagel, 1996). This method however oversimplifies the real situation and is not effective for the cities with large population density and small geographical area (Lenzen & Murray, 2001). Another method called data envelopment analysis (DEA) has been adopted by many researchers to evaluate the sustainable development capacity of a specific city based on the input and output of every decision making unit (DMU) (Qiu et al., 2009; Wu & He, 2006; Zeng et al., 2000). The result by using DEA method however, only presents the relevant efficiency of individual indicators (Li & Li, 2009). There are still other methods for evaluating the performance of urbanization based on single aspect such as speed or quality. The assessment results of using mono-parameter based method nevertheless presents difficulty for city decision makers to select suitable development strategy.

In view of the limitations of the previous methodologies in assessing sustainable urbanization performance, this study proposes the application of a hybrid Entropy-GE Matrix method for assessing the sustainable urbanization performance. It is considered that the hybrid method can not only comprehensively assess the performance of urbanization from the perspectives of both speed and quality of urbanization but also provide a method to select development strategies for improving sustainable urbanization. The remainder of the paper is therefore organized as follows. Section 2 introduces the principles of Entropy and GE matrix. Sections 3 present the hybrid Entropy-GE Matrix model and its suitability for assessing sustainable urbanization performance. Section 4 presents the application of the method in a case study. And finally, the results are analyzed and discussed followed in conclusion.

Principles of Entropy and GE Matrix for assessing sustainable urbanization performance

The Entropy method

Entropy method appeared first in thermodynamics and was introduced into the information management discipline by Shannon in 1948 for the expression of information or uncertainty. The method is based on the principle that greater uncertainty about the outcomes, the more uniform the probability assigned to the outcomes (Jha & Singh, 2008). Nowadays this method has been widely used in engineering, economy, finance, etc (Zou et al., 2006). The application of the method also has been extended to urban ecosystems such as water management, energy utilization, landscape analysis and the quality of economic growth (Antrop, 1998; Balocco & Grazzini, 2000; Herrmann-Pillath et al., 2002; Larsen & Gujer, 1997). It has been appreciated that this method can be used effectively for performance evaluation based on a group of indicators by determining properly the weightings of evaluation indicators (Shemshadi et al., 2011).

Entropy principle can assess the performance of both development index and coordination index between a set of indicators. In the context of urbanization, these two indexes can be used to reflect the speed and quality of urbanization. The process of using the Entropy theory is as follows (Lei et al., 2012; Qiu, 2002).

Assume that there are *n* indicators, *m* sample cases which apply the indicators. As different indicators have different dimensions, or magnitudes, and or different impact (positive or negative) on performance evaluation, normalization process is needed. For positive indicators, a larger value indicates a better result. Assume that the ideal value of indicator i is x_i^*, and $x_i^* = \max_j\left(x_{ij}\right)$. r_{ij} is defined as the proximity of x_{ij} to x_i^*. Then we can get the equation (1),

$$r_{ij} = \frac{x_{ij}}{max_j(x_{ij})} \tag{1}$$

On the contrary, for negative indicators, a smaller value indicates a better result. Therefore, $x_i^* = \min_j\left(x_{ij}\right)$. Then we can get the equation (2).

$$r_{ij} = \frac{min_j(x_{ij})}{x_{ij}} \tag{2}$$

Let f_{ij} as the standardized value of indicator i for sample j after normalization, which can be written as:

$$f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{m} r_{ij}} \tag{3}$$

In equation (1) to (3), x_{ij} is the original value of the indicator i for the sample case j. (i=1, 2, 3…n; j=1, 2, 3…m). $\max_j\left(x_{ij}\right)$ and $\min_j\left(x_{ij}\right)$ denote for the largest and smallest value among all m samples for the indicator i respectively.

In applying entropy theory, the weighting for each indicator needs to be established. For this, the entropy value for indicator i, H_i needs to be obtained first. When there are n indicators and m samples, the entropy of indicator i is defined as

$$H_i = -k\sum_{j=1}^{m} f_{ij} \cdot \ln f_{ij} \qquad i=1,\ 2,\ 3,\ \cdots n. \tag{4}$$

where, $k = \dfrac{1}{\ln m}$

The weight of indicator i is defined as

$$w_i = \frac{1-H_i}{\sum_{i=1}^{n}\left(1-H_i\right)} \tag{5}$$

According to the Entropy theory, the performance of development index (speed of urbanization) for the sample case j can be obtained through following formula.

$$F_j = \sum_{i=1}^{n} w_i \cdot f_{ij} \tag{6}$$

In the context of urbanization sustainability evaluation, evaluation indicators are classified into three dimensions, namely economic, social and environmental dimensions. The development index for each dimension can be therefore defined as

$$F_{j(e)} = \sum_{i=1}^{n_e} w_{i(e)} \cdot f_{ij(e)} \quad i=1,\ 2,\ 3,\ \cdots n_e \tag{7}$$

$$F_{j(s)} = \sum_{i=1}^{n_s} w_{i(s)} \cdot f_{ij(s)} \quad i=1,\ 2,\ 3,\ \cdots n_s \tag{8}$$

$$F_{j(en)} = \sum_{i=1}^{n_{en}} w_{i(en)} \cdot f_{ij(en)} \quad i=1,\ 2,\ 3,\ \cdots n_{en} \tag{9}$$

In these formulas, $F_{j(e)}$, $F_{j(s)}$ and $F_{j(en)}$ stand for the performance values of development indexes in economic, social, and environmental dimensions respectively.

n_e , n_s and n_{en} denote for the number of indicators in the three dimensions respectively.

The performance value of coordination index (quality of urbanization) between economic, social and environmental dimensions in a sample case *j* is defined as C_j (Zhang, 2004).

$$C_j = 1 - \frac{S_j}{\overline{F}} \quad (10)$$

In which, S_j is the standard deviation of the performance values of development index for economic, social and environmental dimensions, calculated by the following equation: $S_j = \sqrt{\frac{1}{3}\left[\left(F_{j(e)} - \overline{F}\right)^2 + \left(F_{j(s)} - \overline{F}\right)^2 + \left(F_{j(en)} - \overline{F}\right)^2\right]}$

And $\overline{F}$ is the arithmetic mean value of $F_{j(e)}$, $F_{j(s)}$ and $F_{j(en)}$.

The GE Matrix for business strategy

The GE Matrix (McKinsey Matrix) is an extension of the Boston Consulting Group matrix (Decuseară, 2013). It is a research tool for product portfolio analysis, which was developed by General Electric Company in 1970s. According to previous research works, this research tool is mainly used in the fields of strategic business analysis for a company, for regional industrial development policy making, strategic selection of products, and resource allocation (Amatulli et al., 2011; Jang et al., 2012; Mokaya et al., 2012; Proctor & Hassard, 1990; Yin & Meng, 2006). The GE Matrix evaluates the performance of two dimensions of a company or product: competitiveness and attractiveness, as shown in Figure 1. Based on the levels of competitiveness and attractiveness (i.e. low, medium and high), the business strategy of the company or product can be grouped into three categories, namely, to grow, to hold, or to harvest.

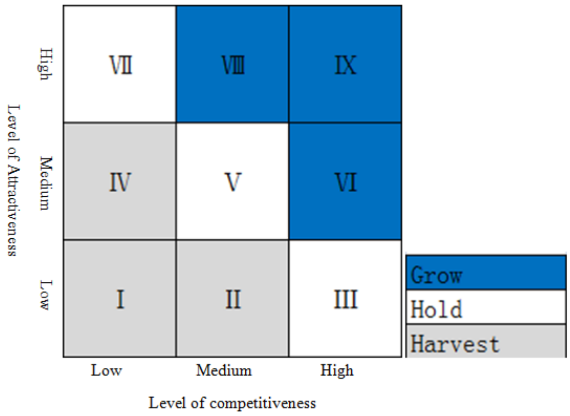

Figure 1 the GE Matrix Model
Source: (Amatulli et al., 2011)

As shown in Figure 1, if a company is located in Grow area (box Ⅵ, Ⅷ, and Ⅸ in Figure 1), it means that the company is strong both in competitiveness and attractiveness, and it should maximize investment. If it is in the Hold area, in particular, in box Ⅲ and Ⅴ, the company should adopt proper strategies to maintain position or to make investment selectively. While in the box Ⅶ (high attractiveness and low competitiveness), the company should seek acquisition (Lin, 2005). If the company is located in the Harvest area (box Ⅰ, Ⅱ, and Ⅳ), it should adopt harvest or divestment strategy to minimize investment in a particular sector (Mokaya et al., 2012).

The hybrid model integrating Entropy theory and GE Matrix for assessing sustainable urbanization

Although differences exist between a city and a company, such as different function, objectives, backgrounds and other aspects, there are similarities in applying management principles and rules in both environments (Wang et al., 2005). For example, a city is also an economic entity. In this way, it is similar to a business organization. Economic benefit is an important goal for a city to enhance and sustain its competitiveness and attractiveness. Furthermore, both a city and a company adopt common management methodologies, such as planning, organizing, coordinating, and controlling (Han & Zhao, 2008). As appreciated in the previous section, the sustainable performance of a company is evaluated from dimensions of market attractiveness and competitiveness. With reference to this, the sustainable performance of urbanization in a city, which is mainly indicated by the speed and quality of urbanization, can be measured collectively by the performance of development index and coordination index.

Market attractiveness of a company is indicated mainly by market size and growth rate, whilst the growth rate reflects the development speed of the company (Cooper, 1988; Tyebjee & Bruno, 1984). On the other hand, market competitiveness of a company is usually indicated by quantitative measures such as costs, prices and profitability, and qualitative measures including particularly the performance of quality (Buckley et al., 1988). Jin (2003) pointed out that a company's competitiveness is a comprehensive performance of the three aspects of product quality, management system and innovation capacity. Higher company competitiveness presents better coordinated development of these three aspects.

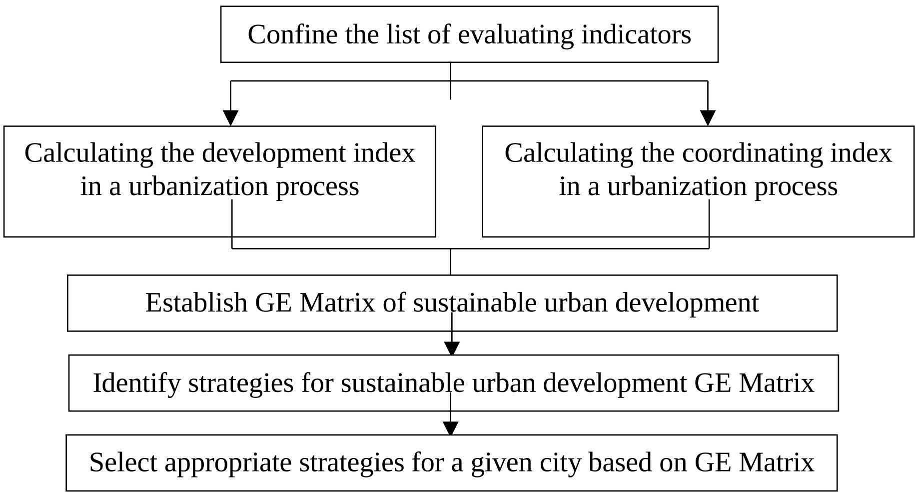

Figure 2 the model for assessing sustainable urbanization performance

By referring the above analogy to the context of urbanization, it is considered possible that the method adopted for analyzing the market attractiveness and competitiveness of company performance can be used for analyzing the development and coordination dimensions of urbanization performance. Therefore, GE Matrix in the context of urbanization can be established based on the two dimensions of

Table 1 indicator system for urban sustainable development

Level 1	Level 2	Level 3
Social (So)	Education(So1)	So1-1 Proportion of educational funds expenditure in GDP
		So1-2 Number of high school and college students per 10,000 population
	Safety(So2)	So2-1 Violent crime rate per 10,000 population
		So2-2 Number of fire related deaths per 10,000 population
		So2-3 Number of production accident death per 10,000 population
		So2-4 Number of traffic death per 10,000 population
	Health(So3)	So3-1 Number of hospital beds per 10,000 population
		So3-2 Number of health workers per 10,000 population
	Livelihood(So4)	So4-1 Average living space per capita
		So4-2 Housing price to income
		So4-3 Per capita disposable income of urban residents
		So4-4 Per capita net income of rural residents
	Transportation(So5)	So5-1 Km of transportation system per 10,000 population
		So5-2 Transportation facilities per 10,000 population
		So5-3 Urban road area per capita
	Entertainment(So6)	So6-1 Number of culture establishments per 10,000 population
		So6-2 number of books per person in public libraries
	Harmony(So7)	So7-1 Social insurance coverage
		So7-2 Income ratio between county and city
		So7-3 Employment- population ratio
		So7-4 Registered urban unemployment ratio
Economic (Ec)	Economic development(Ec1)	Ec1-1 Gross domestic product
		Ec1-2 GDP per capita
	Economic consumption(Ec2)	Ec2-1 Energy consumption of per 10,000 output value
		Ec2-2 Electronic consumption of per 10,000 output value
	Industry structure(Ec3)	Ec3-1 Proportion of GDP accounted for by services
		Ec3-2 Proportion of GDP accounted for by industry
		Ec3-3 Proportion of GDP accounted for by high-tech industry
	Science and Information(Ec4)	Ec4-1 Internet users per 100 population
		Ec4-2 Mobile telephone subscribers per 100 population
		Ec4-3 Gross domestic expenditure on R&D as a percent of GDP
		Ec4-4 Number of authorization of invention patterns per 10,000 population
Environmental (En)	Population(En1)	En1-1 Population growth
		En1-2 Density of population
	Resource(En2)	En2-1 Water resources per capita
		En2-2 Farmland per capita
		En2-3 Forest coverage rate
		En2-4 Green area per capita
	Pollution(En3)	En3-1 Industrial waste gas emissions
		En3-2 Industrial waste water emissions
		En3-3 Industrial solids waste emissions
		En3-4 Sulfur dioxide emissions
		En3-5 Total sewage discharge
		En3-6 Number of days above good air quality
		En3-7 Standards area of environmental noise
	Governance(En4)	En4-1 Attainment rate of water quality
		En4-2 Reusing rate of industrial water
		En4-3 Treatment rate of city life sewage
		En4-4 Attainment rate of industrial soot emissions
		En4-5 Attainment rate of drinking Water Quality
		En4-6Disposal rate of living garbage harmless
		En4-7 Comprehensive treatment rate of industrial solid waste

development index (speed) and coordination index (quality). The decision-makers at city level can select appropriate strategies by using the GE Matrix analysis. And based on the principles of Entropy and GE Matrix, the hybrid Entropy-GE matrix method for assessing sustainable urbanization performance can be established through a flow chart, as shown in Figure 2.

Indicators selection

Indicators were identified from the following sources:

(A) A list of 105 sustainable urbanization indicators developed by Zhou et al. (2013) following their study on the various urbanization indicator systems. These indicators were filtered from eight existing indicator systems proposed by different organizations in China. For the conformity of different indicators, a content analysis was conducted, including redefinition, modification, combination and deletion.

(B) An international list of 115 sustainable urbanization indicators (Shen et al., 2011). They obtained these indicators after examining indicator systems developed by 6 different international organizations such as UN, UN-Habitat, Word Bank and other international organizations.

(C) Indicators from 30 different cities in China such as Harbin (Zhou & Zang, 2009), Qingdao (Zong et al., 2007), and Kunming (Zhu et al., 2006). A list of 259 indicators was obtained after a comprehensive content analysis of redefinition, modification, combination and deletion.

(D) Indicators included in China's 12th Five Year Plan. There are 23 major indicators presented in the Plan for promoting sustainable urbanization and sustainable development.

These four types of research data were presented to a research workshop organized by this research team in Chongqing University. The workshop had the attendance of eleven specialists and researchers from industry, governmental offices and research environments. The discussion in the workshop reached the agreement on the following principles for choosing the indicators:

- Covered in both indicator sources A and B
- Adopted by more than 4 (out of 8) indicator systems in the source A
- Adopted by more than 15 (out of 30) cities in source list C.
- In accordance with the indicators addressed in sources D
- Other indicators which do not fall in the above four sources but have important influence on sustainable urbanization.

With the above selection principles, the results from the research workshop led to the selection of 52 indicators which are further grouped in three dimensions, namely, economic, social and environmental development, as shown in Table 1.

Calculation for the value of development index and coordination index

By using the Entropy method discussed in section 2.1, the development index F_j and coordination index C_j for a given city in a specific period of time can be calculated.

According to Li et al. (2012b), the degree of urbanization development and coordination can be divided into three levels respectively (i.e. Strong, Medium and

Weak), as shown in Table 2. For example, if the value of development index is between 0.8 and 1, it indicates a strong development level, the value between 0.5 and 0.8 indicates a medium level development, and the value below 0.5 indicates a weak level of development. Similarly, the coordination level is also described in three grades. The classification frame suggested by Li et al. (2012a) provides the tool for producing the research analysis results, which will be presented in the following section.

Table 2 Sustainability classification criteria for urban development(Li, Zhang, Song, & Chen, 2012)

Development index	Development degree	Coordinated index	Coordinated degree
$0.8 \leqslant F \leqslant 1$	Strong sustainability	$0.8 \leqslant C \leqslant 1$	Strong coordination
$0.5 \leqslant F < 0.8$	Medium sustainability	$0.5 \leqslant C < 0.8$	Medium coordination
$0 \leqslant F < 0.5$	Weak sustainability	$0 \leqslant C < 0.5$	Weak coordination

Establishment of Entropy-GE Matrix of sustainable urbanization

By applying the information presented in Table 2 to the GE Matrix Model shown in Figure 1, the Entropy-GE Matrix of sustainable urban development strategies can be established, as shown in Figure 3.

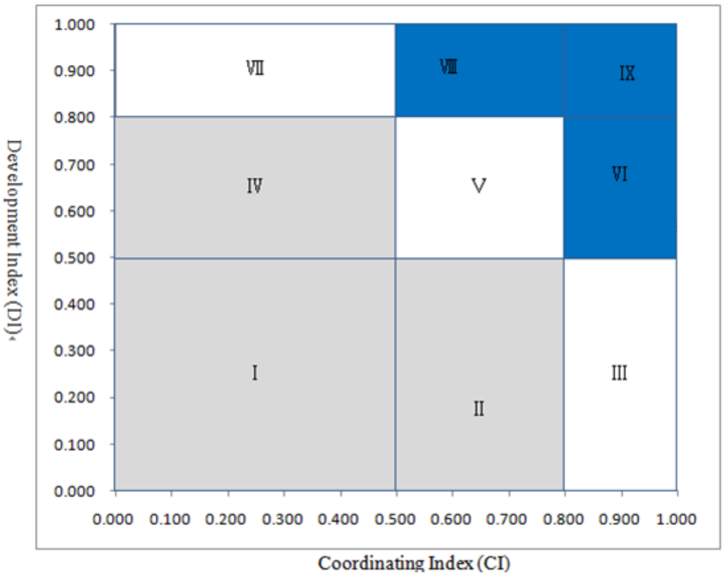

Figure 3 sustainable urban development GE Matrix

In this Matrix, the axis of coordination index presents the degree of coordination between social, economic, and environmental development. And the axis of development index denotes for the development speed of urbanization. The Entropy-GE Matrix can provide valuable references for decision makers to understand the levels of the sustainability of the urbanization (in terms of speed and quality) they are engaging, and select appropriate strategy to improve the practice towards better sustainability performance in the process of urbanization.

Analysis on sustainable urbanization strategies using Entropy-GE Matrix

Urbanization stage is an important factor affecting the selection of urban development strategies. Zheng (2010) argued that cities at different urban development stage face different problems, and local governments should identify and adopt corresponding urbanization strategies accordingly. Zheng and Qin (2009) divided urban development process into four stages, namely element-driven, investment-driven, innovation-driven and wealth-driven. In the early urbanization stage, the urban development is implemented mainly through resources consumption. When more capital is needed for implementing large scale of urbanization activities, local governments will focus on establishing support systems such as various infrastructures to attract investments and therefore promote economic growth. In innovation-driven and wealth-driven urbanization stages, technology and service industries become the key drivers for urban development.

Norton (1979) divided the city life-cycles into youth stage, varied stage, and mature stage. For younger cities, they are more economically vibrant and territorially expanding. These cities are in better positions to explore alternative strategies for fostering the demographic growth and economic resiliency. On the contrary, older cities encounter problems such as deteriorating public infrastructure and the burden of huge public welfare legacies, which make them unable to keep pace with the development of demographic and commercial de-concentration (Kasarda, 1983).

Table 3 Different strategies selection for every box in sustainable urbanization GE Matrix

The number of box	Performance of sustainability	Strategies to be selected
Ⅰ	Weak sustainability/Weak coordination	Speed up the urbanization process to improve the function of urban areas; perfect infrastructure construction; make full use of land resources in return for capital.
Ⅱ	Weak sustainability/Medium coordination	
Ⅲ	Weak sustainability/Strong coordination	
Ⅳ	Medium sustainability/Weak coordination	Improve population urbanization; take measures to protect environment; promote social harmony and stability
Ⅴ	Medium sustainability/Medium coordination	Continue to increase the level of urbanization; develop high-tech industry
Ⅵ	Medium sustainability/Strong coordination	establish modern industrial system and promote comprehensive development
Ⅶ	Strong sustainability/Weak coordination	Structural adjustment, promote urbanization of rural areas; improve the social security system
Ⅷ	Strong sustainability/Medium coordination	Promote urbanization of rural areas and realize transition from spillover-echo model to leap-type model
Ⅸ	Strong sustainability/Strong coordination	Strengthen innovation development and realize leap-type urbanization model for urban and rural integrity

Considering urban spatial expansion, urbanization is an orderly and gradual process from low to high level (Luo, 2002). The early stage of urban development is characterized by urban self-development. In this stage, the traditional spillover-echo model which advocates that all functions of city expand outward in the original scope, is suitable for urban development (Zhao, 2001). After the migrations of rural population to urban area, the connection between urban and rural areas is strengthened, but the migration also causes the unbalanced development between cities and rural villages, the shortage of land supply for the growth of urban area, and excessive rise in land price in original city area (Liu, 2011). Therefore, when urbanization is in the stage of rapid development, the leap-type development is to replace the spillover-echo pattern for better sustainability performance of urbanization (Zhang et al., 2009). An alternative to this situation is to construct new towns outside the old city in order to accommodate new urban functions. Then, the development focus would turn from single to multiple (Yang, 2001). In the counter-urbanization stage, however, when rural areas have made greater development, the local government shall promote the construction of small towns to integrate urban and rural areas (Luo, 2002).

Based on the urban development theories mentioned above, the strategies for each area in the Entropy-GE Matrix (Figure 3) were proposed, as listed in Table 3. For the area Ⅰ, Ⅱ and Ⅲ in Figure 3 , due to the low development level, local government should contribute efforts to improve the level of urbanization and to provide more infrastructures. For areas which have high development speed but low coordination level (e.g. Ⅶ), local government should adjust industrial structure and improve the rate of urbanization in rural areas. For areas which have high development speed and strong coordination (e.g. Ⅷ, Ⅸ in Figure 3), the leap-type model is considered the best choice. When in the stage of medium development speed (e.g. Ⅳ, Ⅴ and Ⅵ), local government should develop new technology industries and continue to push forward the scheme of coordinated development between rural areas and urban areas.

It is considered that the hybrid Entropy-GE Matrix can avoid the limitations of Entropy method and GE Matrix method. The Entropy method cannot help identify strategies for improving the performance of sustainable urbanization, although it can assist in evaluating the sustainability of urban development. On the other hand, GE-Matrix is only a tool to present the status of organizational competitiveness and attractiveness. GE-Matrix method must be adopted in association with Entropy method, namely a hybrid approach, in order to find out strategies for sustainable urbanization.

The application of Entropy-GE Matrix: A case study

A chosen case study of Jinan, the provincial capital of Shandong province of China, is used to illustrate the application of Entropy-GE Matrix model for analyzing the performance of city’s urbanization. Jinan is one of the cities that the Central Government has endorsed to promote sustainable urbanization. The data needed for analysis in this research is accessible. Therefore, choosing Jinan as the case study can ensure the effectiveness of conducting this research.

Data collection

The data for all indicators listed in Table 1 are collected for the period of 2000 to 2011 from Statistical Yearbook of Jinan, Statistical Yearbook of Shandong Province, China City Statistical Yearbook, Statistical Bulletin of Jinan, and official website of Jinan government.

Data analysis

The values of development index (F_j) and coordination index (C_j) can be calculated by using the Entropy method addressed in section 2.1, and the relevant calculations are obtained, as shown in Table 4. Based on the results in Table 4, the Entropy-GE Matrix can be obtained by allocating F_j and C_j respectively, as shown in Figure 4.

Table 4 Results of urban sustainable development index and coordinated index

Years	So		Ec		En		F_j	S_j	$\overline{F}$	C_j
	$F_{j(s)}$	w_i	$F_{j(e)}$	w_i	$F_{j(en)}$	w_i				
2000	0.121	0.465	0.059	0.312	0.092	0.223	0.273	0.031	0.091	0.658
2001	0.113		0.057		0.100		0.270	0.030	0.090	0.671
2002	0.127		0.086		0.102		0.314	0.021	0.105	0.802
2003	0.142		0.103		0.116		0.361	0.019	0.120	0.839
2004	0.165		0.118		0.110		0.394	0.030	0.131	0.772
2005	0.224		0.124		0.140		0.488	0.054	0.163	0.669
2006	0.365		0.149		0.149		0.663	0.125	0.221	0.436
2007	0.228		0.174		0.157		0.559	0.037	0.186	0.800
2008	0.203		0.194		0.173		0.570	0.015	0.190	0.919
2009	0.222		0.230		0.192		0.643	0.020	0.214	0.906
2010	0.203		0.297		0.198		0.699	0.056	0.233	0.760
2011	0.394		0.299		0.195		0.888	0.100	0.296	0.663

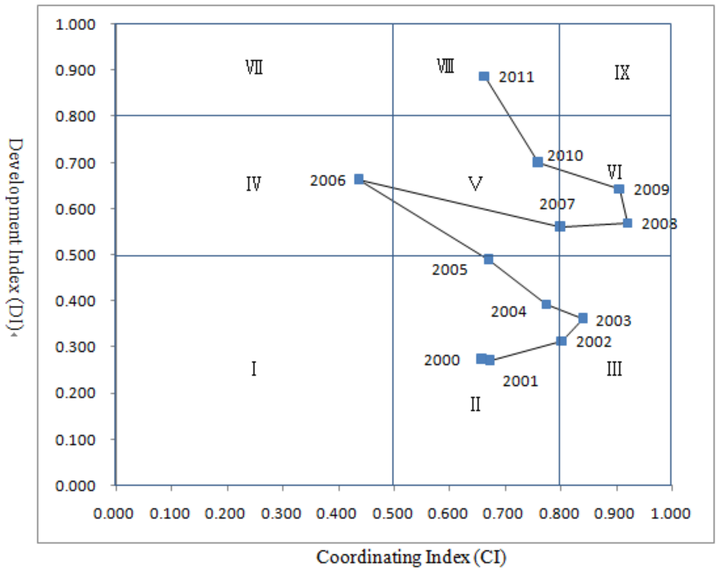

Figure 4 the GE Matrix of urban sustainability of Jinan city from 2000-2011

Strategy analysis based on Entropy-GE Matrix

Jinan is an inland city in a relatively developed area in China. Its urbanization rate increased from 30.69% in 1990 to 62.95% in 2011 (Zhu et al., 2012). As can be seen from Figure 4, Jinan city had entered in the stage of rapid development in 2011 with the development index located in Ⅷ area. Meanwhile, the coordination degree between economic, social and environmental dimensions was, between a medium and strong level.

In 2011, the performance of urbanization sustainability located in area Ⅷ in Entropy-GE Matrix. It represents a strong development speed but a medium quality performance (coordination). In fact, the focal role of urbanization for economic growth and modernization program was further emphasized by Chinese government in the Central Working Conference of Urbanization held in 2014. It is suggested that local governments of Jinan city shall continue to expand the space for further development and drive the transition from spillover-echo model to leap-type model. More importantly, the local government should take measures to improve rural-urban integration and the coordination performance between economic, social and environmental interests, with particular efforts given to environment protection.

In view of the relationship between coordination index and development index that incorporates social, economic, and environmental aspects, a further analysis on these three dimensions is conducted. From Table 4, it can be found that the values of the development index for social, economic and environmental dimension, denoted by $F_{j(s)}$, $F_{j(e)}$ and $F_{j(en)}$ respectively, have been calculated by using equation (7), (8), and (9) addressed in section 2.1. Based on the three sets of data as shown in Table 4, the changing trends of development index for each dimension during the period from 2000 to 2011 are simulated, as shown in Figure 5.

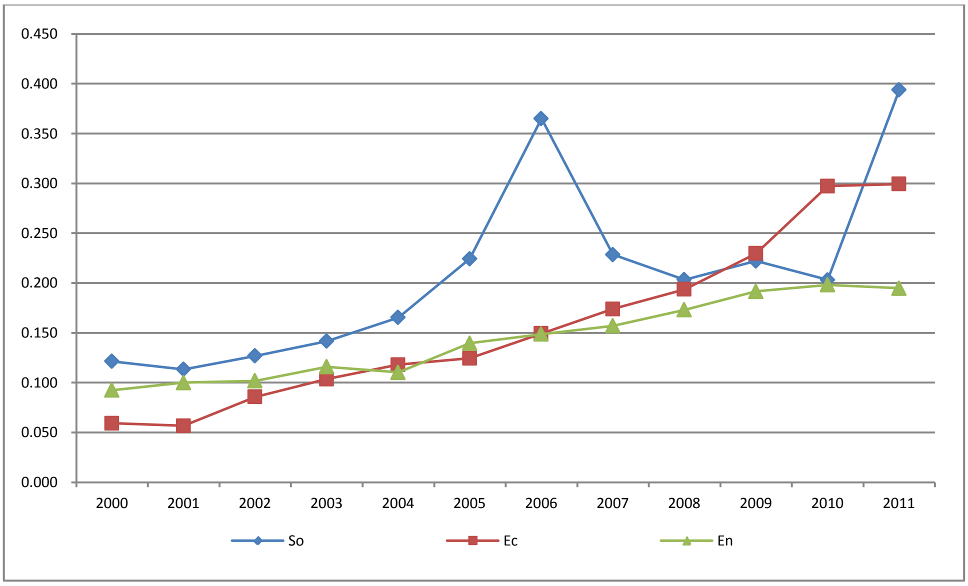

Figure 5 the variation trend of DI in social, economic, and environmental dimensions

The changing trends of development index in Figure 5 illustrate that the improvement of environment performance is comparatively small in the past 12 years in Jinan On the contrary, the development of economic and social dimensions has improved greatly. As a result, the coordination index experienced a downward trend in recent years. Therefore, Jinan government should strive to improve the performance of environmental dimension in the process of urbanization. This issue can be examined in more details in referring to the 20 environmental indicators identified in the section "Indicators selection", which are divided into four categories, as seen in Table 1. These four categories are named as population (en_1), resource (en_2), pollution (en_3), and governance (en_4) based on the attribution of indicators. By using the method for calculating development index, which has been addressed in section 2.1, the values of development index for each environmental category ($F_{j(en1)}$, $F_{j(en2)}$, $F_{j(en3)}$, and $F_{j(en4)}$) from 2000 to 2011 are calculated (see Table 5). Based on the results in Table 5, the changing trends of development index for these four environmental categories are shown in Figure 6.

Table 5 the result of DI of four categories in environmental dimension

Years	Development Index			
	$F_{j(en1)}$	$F_{j(en2)}$	$F_{j(en3)}$	$F_{j(en4)}$
2000	0.004	0.022	0.054	0.011
2001	0.005	0.023	0.061	0.012
2002	0.005	0.024	0.058	0.015
2003	0.008	0.029	0.057	0.021
2004	0.005	0.031	0.056	0.019
2005	0.005	0.055	0.059	0.021
2006	0.006	0.057	0.065	0.021
2007	0.006	0.060	0.073	0.019
2008	0.005	0.058	0.090	0.020
2009	0.007	0.070	0.094	0.021
2010	0.006	0.073	0.097	0.023
2011	0.004	0.071	0.097	0.023

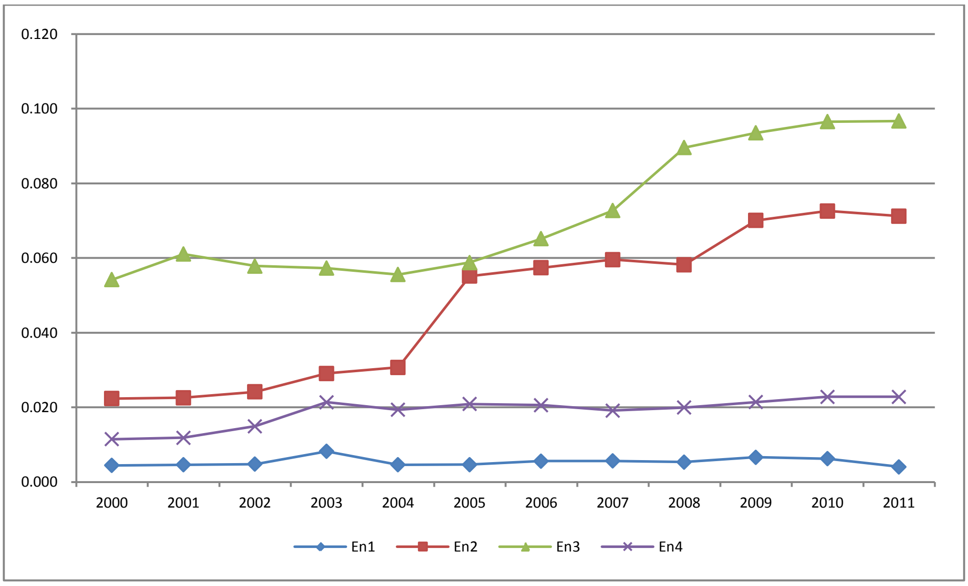

Figure 6 the variation trend of DI of the four environmental categories

As seen from Figure 6, the trends of $F_{j(en1)}$ and $F_{j(en4)}$ are very flat, indicating that the performance of population density and environmental management has little improvement in the past 12 years. This is considered main reason hindering Jinan's sustainable urbanization process. For example, the performance of environmental governance or management, measured by "Attainment rate of water quality" and other six indicators (see Table 1), has no significant change. In fact, the problems such as Sulfur dioxide emissions and Industrial waste gas emissions have little improvement through measures such as dismantling some out-dated furnaces and other pollution sources have been taken. It is considered that the local government should contribute more resources and management efforts to improve the effect of environmental governance. For example, local government should contribute resources to to enhance water quality, to improve the treatment rate of industrial fumes and solid waste, and to raise the reuse rate of industrial water.

Conclusions

To evaluate the performance of urbanization sustainability, a comprehensive indicator system and an effective method are needed, and this research proposes a hybrid Entropy-GE Matrix for this purpose. The case study presented in this study shows that the entropy-GE Matrix is an effective tool to evaluate changes and performance of urbanization sustainability in a concerned city or urban area. The hybrid method has a number of advantages. Firstly, it assists in determining the weights of indictors using the observed values, which can avoid the influence of subjectivity. Secondly, the method examines both development and coordination dimensions collectively when evaluating urbanization sustainability, which provides a balanced view on the sustainable urbanization. Thirdly, the combination of Entropy and GE Matrix can display the overall status of a city's urbanization sustainability based on both Development and coordination Index, which enable city managers to realize the level of urban development from corresponding areas in Entropy-GE Matrix, and develop suitable strategies for improving the performance of sustainable urbanization. The research outcomes add value to the development of the methodology for further studying the sustainability of urbanization.

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