A Comprehensive Evaluation Approach to Measure Sustainable Development of Countries

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Abstract—**Based on the quantitative definition of sustainable development, comprehensive evaluation method is used to estimate the level of a country's sustainable development. The indices chosen under four principles are divided into positive and negative indices after deliberate consideration. AHP is implied to determine the weights of indices. Two types of aggregated index are formed through two evaluation methods, and results show that the two methods prefer different types of countries. According to the difference, three types of sustainable development are defined: Backward, Unstable and Stable Sustainable Development. The aggregated index from the first method can help sort out the first two kinds of countries and regions, and that from the other method is able to help pick out the last two kinds.**

Keywords-sustainable development; analytic hierarchy process; comprehensive evaluation method

I. INTRODUCTION

In 1987, a concept named "sustainable development" which soon became widely accepted, was defined on the Brundtland Commission as the "ability to ensure that the development meets the needs of the present without compromising the ability of future generations to meet their own needs. The 'environment' is where we live; and 'development' is what we all do in attempting to improve our lot within that abode. The two are inseparable." [1] Thus the description of sustainable development was interpreted as sustaining nature, life support and community while developing people, economy and society.

Sustainable development was measured by some indicators based on country or regional data, though determining the indicators and quantifying their influence is a laborious task which "needs to translate the uncertainties and arbitrariness of an infinitely complex world into a definite and preferably small set of quantitative indicators, or simply, numbers. As one might suspect, this is not easy to do." [2]

Many noble efforts have been made in the approaches, and their result reflects in the creation of various indicator initiatives. For instance, the UN established Commission on Sustainable Development (CSD) considering 58 different indicators [3]; the Genuine Progress Indicator (GPI) was created on the basis of consideration of 26 indicators by C. Cobb et al [4]; and Ecological Footprint included discussion of 6 indicators traced annually from 1961 to 1999 [5].

II. INDEX SELECTION AND STANDARDIZATION

A. Choosing Indices

There are hundreds of indices available on various aspects of nations all over the globe. However, some data is not complete, and some indices are unrelated to sustainable development, so several principles are considered when choosing indices. (i) Only indices with data available on the internet will be chosen. (ii) Only indices which have strong relations with sustainable development will be taken into consideration. (iii) Only indices which have a certain level of diversity among nations will be taken into consideration. (iv) There are both positive indices and negative indices, and they are chosen separately.

Different from many models established by pioneers [1], some indicators of development evaluating consequences of human activity, though lead to degradation of environment, are considered as positive indices. The reason is that some kinds of human activities are unavoidable, for instance, mining. However as the advances of those activities have been made, they tend to lead to a higher efficiency on production, which means more output with same cost of environment. Moreover, effect on environment has been displayed on other indices of environment. To be rigorous, both negative and positive effects are taken into consideration determining weights of each of the indices.

Based on the principles above, 26 positive indices $(p_1, p_2, \cdots, p_{26})$ and 14 negative indices $(n_1, n_2, \cdots, n_{14})$ are selected. They belong to 6 groups $(C_1, C_2, \cdots, C_6)$: Health, Environment, Workforce, Education, Urban and Finance. For full details of all 40 indices, see appendix.

B. Index Standardization and Elimination

For each index, $x_i(x_i \geq 0)$ stands for the value of such index of the ith nation, and $x = (x_1, x_2, \cdots, x_n)^T \in \mathbb{R}^n$ denotes the value vector of such index, where n refers to the number of nations taken into consideration.

The linear method is one common way to do the standardization: $\hat{x} = (x - x_{min})/(x_{max} - x_{min})$, where $x_{min} = \min_{1 \leq i \leq n} x_i$, $x_{max} = \max_{1 \leq i \leq n} x_i$. The linear method is selected since it ensures all the data being mapped into interval $[0, 1]$.

Indices selected share importance to some extent, but when an index is similar in all the countries (regions), it is no more decisive in evaluating sustainable development. So these indices can be ignored to avoid large-scaled worthless

modeling and calculation. Expectations of elimination in this model is that 20 positive indices and 12 negative indices are left at last, which can be modified if necessary.

Then the Least Mean Square Deviation method (LMSD) is utilized in elimination: For each index, calculate the mean square deviation of such index, then eliminate 6 positive indices which have least mean square deviations among all positive indices, and eliminate 2 negative indices by similar method. The eliminated indices are: $p_7, p_{15}, p_{17}, p_{20}, p_{25}, p_{26}, n_3, n_4$. Then rename the remaining indices as $(p'_1, p'_2, \cdots, p'_{20})$ and $(n'_1, n'_2, \cdots, n'_{12})$ according to the original order.

III. Quantify Sustainable Development

A. Finding Weights

Analytic Hierarchy Process (AHP) [7] is the method to find the weights of each index. Below is the hierarchy structure of positive indices and similar for negative indices.
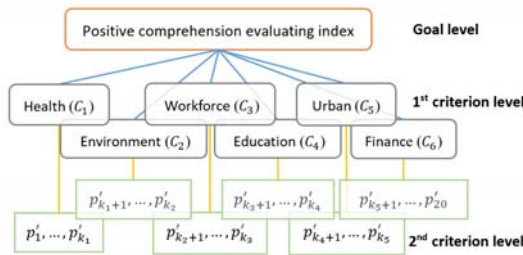

FIGURE I. HIERARCHY STRUCTURE OF POSITIVE INDICES

The next thing to do is to establish the judgment matrices. There are totally 13 judgment matrices: one (A) refers to the judgment matrix of the first criterion level to the goal, six $(A_1, A_2, \cdots, A_6)$ refer to 2 judgment matrices of the second criterion level to the first criterion level of positive indices and another six $(B_1, B_2, \cdots, B_6)$ refer to that of negative indices. According to the second principle introduced above, the difference among weights of the indices should not be too big. So the scale used in AHP is 1.0~1.9 . Following is the value of judgment matrix A:

$$A = \begin{pmatrix} 1 & 1/1.2 & 1.4 & 1 & 1.3 & 1.2 \\ 1.2 & 1 & 1.6 & 1.2 & 1.5 & 1.4 \\ 1/1.4 & 1/1.6 & 1 & 1/1.3 & 1 & 1/1.2 \\ 1 & 1/1.2 & 1.3 & 1 & 1.3 & 1.2 \\ 1/1.3 & 1/1.5 & 1 & 1/1.3 & 1 & 1 \\ 1/1.2 & 1/1.4 & 1.2 & 1/1.2 & 1 & 1 \end{pmatrix}$$

The consistency proportion CR of judgment matrix A is $0.0004 < 0.1$, which shows that A is proper. For values and consistency proportions of other 12 judgment matrices, see appendix.

Then the weight vector of positive (negative) indices to the positive (negative) evaluation function can be directly acquired as $w_p \in \mathbb{R}^{20}$ ($w_n \in \mathbb{R}^{12}$) through the 13 judgment matrices by using the standard AHP method [7]. Values of w_p and w_n are (index in sequence):
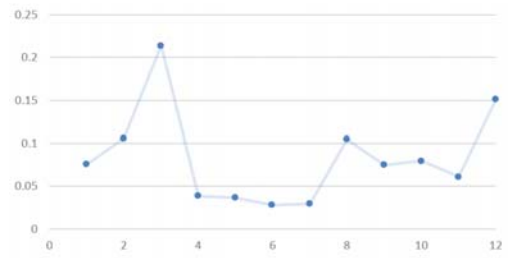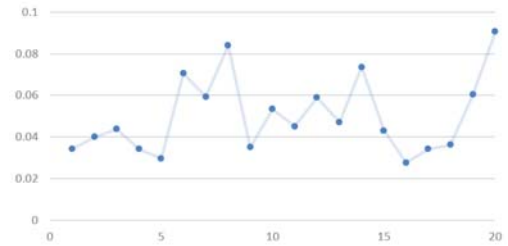

FIGURE II. VALUES OF w_p

FIGURE III. VALUES OF w_n

B. Index Aggregation

Two methods: LWCA (Linear Weighted Comprehensive Assessment method) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), are used separately to get aggregated index, resulting in acknowledgment of two different values I_i and I'_i . Suppose country i has complete values on the 20 positive indices ($p^i \in \mathbb{R}^{20}$) and 12 negative indices ($n^i \in \mathbb{R}^{12}$), then the two methods are shown below:

- LWCA: It directly contrasts the positive side and the negative side:

$$I_i = \frac{w_p^T p^i}{w_n^T n^i} = \frac{\sum_{j=1}^{20} w_p(j) p^i(j)}{\sum_{j=1}^{12} w_n(j) n^i(j)}$$

- TOPSIS: It measures the distance between the current condition of the country and the ideal state, where values of all positive indices are 1 and those of negative indices are 0:

$$I'_i = \left(\sum_{j=1}^{20} w_p(j) \left(p^i(j) - 1\right)^2 + \sum_{j=1}^{12} w_n(j) \left(n^i(j) - 1\right)^2 \right)^{-1}$$

In 2013, developed countries makes a percentage of 25.13% of all countries (regions) participating statistics [8], so assume that the sustainable countries (regions) also make 25.13% of all. Sorting countries (regions) by their Is and I's, the last among sustainable ones is determined as the threshold.

Top rankings including 20 countries (regions) and bottom rankings including 10 countries (regions) are listed in Table 1. Then the threshold countries and indices value are found, shown in Table 2. Details of these two tables are in Appendix.

IV. ANALYSIS

Table 1 illustrates that countries (regions) in top rankings of I got through LWCA appear to be those with no or little heavy industry and low consumption of resources and those in the Middle East. Additionally, most of them have poor territory. This is a reasonable outcome of LWCA, for the aggregated index is calculated through positive comprehensive evaluation index divided by negative comprehensive evaluation index, and the latter is made up with pollution from heavy industries, consumption of natural resources and per-capita indices (especially advantageous for small countries in territories). Therefore 4those countries, together with countries heavily rely on the income of resources export, have very small denominator in the evaluating function and eventually get higher evaluation than many developed countries. The development status of former countries is called Backward Sustainable Development (BSD) - slow-paced development with hardly any damage to the environment, which is undoubtedly sustainable. (Features see in the table below) As for the latter countries which heavily rely on resources export, e.g. Kuwait and UAE, their development status is called Unstable Sustainable Development (USD) - "illusion" of sustainable development (e.g. constant oil production every year) with high risk of rapid collapse (e.g. oil production of dried field). For Kuwait and UAE, what if the resources dry up? They should immediately launch transformation, in order to avoid the possible impacts on resource problems. In a word, the aggregated index calculated through LWCA place emphasis on sustainability.

From Table 1, countries (regions) in top rankings of I0 aggregated index calculated through TOPSIS are mostly developed countries in Europe. The reason to get a different outcome compared with the former method is that the negative indices are not treated as denominator anymore, instead, they are summed up. As a result, this evaluation index place emphasis on degree of development, because positive indices are 67% more than negative indices in amount and calculating Euclidean distance enlarges the deviation in influence of final result between positive and negative indices. In this case, developed countries (regions) with high-leveled industries and technologies have dominating advantages, such as a high value in the indicator "GDP per unit of energy use"(value of this indicator in Hong Kong of China is 4.86 times the value in China mainland [9]) which enables them produce enormous wealth while consuming not much. Their development status is called Stable Sustainable Development (SSD). (Features see table above).

Table 1 also illustrates that the countries (regions) with USD status are the only ones that have high rankings under different evaluation emphasis. It is implied from this phenomenon that the USD status is the transitional status from BSD to SSD.

FIGURE IV. RELATIONSHIP OF THREE STATUS OF SUSTAINABLE DEVELOPMENT

ACKNOWLEDGMENT

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APPENDIX

Below is Table of countries or regions with the highest and lowest value of aggregated indices.

TABLE I. COUNTRIES (REGIONS) WITH THE HIGHEST AND LOWEST VALUE OF AGGREGATED INDEX

Ranking	LWCA		TOPSIS	
	Countries (Regions)	I	Countries (Regions)	I'
1	San Marino	2634.235	Sweden	4.281314
2	Monaco	2371.222	Norway	3.898829
3	Andorra	925.5979	Finland	3.764083
4	American Samoa	610.3015	Kuwait	3.369426
5	Cayman Islands	373.8311	Iceland	3.142231
6	Palau	153.5057	Costa Rica	2.998307

7	Turks and Caicos Islands	137.6472	Seychelles	2.963683
8	Sint Maarten (Dutch part)	98.79866	France	2.950987
9	Northern Mariana Islands	59.42375	Oman	2.888266
10	Tuvalu	29.4201	Bahamas, The	2.860301
11	Pacific island small states	25.28996	Switzerland	2.849595
12	Kuwait	21.75739	Guyana	2.828708
13	Marshall Islands	21.7335	Denmark	2.794578
14	United Arab Emirates(UAE)	21.25511	Suriname	2.777231
15	Greenland	20.4204	Cabo Verde	2.758934
16	Antigua and Barbuda	15.27164	UAE	2.740371
17	Micronesia, Fed. Sts.	15.00409	Slovenia	2.693649
18	Dominica	12.69345	Belgium	2.640722
19	Grenada	10.07641	Belize	2.614173
20	Solomon Islands	9.684683	Bhutan	2.60677
⋮	⋮	⋮	⋮	⋮
239	Bosnia and Herzegovina	0.947587	Somalia	1.101075
240	Somalia	0.939788	Faeroe Islands	1.086949
241	Yemen, Rep.	0.904898	Turks and Caicos Islands	1.076444
242	South Africa	0.89214	Libya	1.072777
243	Haiti	0.853117	St. Martin (French part)	1.030178
244	Iraq	0.79115	Isle of Man	1.029617
245	Libya	0.781795	Sint Maarten (Dutch part)	1.028382
246	Channel Islands	0.533914	Channel Islands	1.002103
247	Curacao	0.417934	Curacao	0.99506
248	Kosovo	0.297477	Kosovo	0.93076

Below is Table of threshold countries and indices values.

TABLE II. THRESHOLD COUNTRIES AND INDICES VALUE

Method	Ranking	Country (Region)	Threshold
LWCA	62	Finland	$I = 3.064507$
TOPSIS	62	Bolivia	$I' = 2.067360$

Below is Table of three sustainable status with their features and typical countries.

TABLE III. HREE SUSTAINABLE DEVELOPMENT STATUS WITH THEIR FEATURES AND EXAMPLE COUNTRIES

Status	Features	Examples
Backward Sustainable Development (BSD)	Low-leveled industries and techs, agriculture-dominated economy	San Marino Andorra
Unstable Sustainable Development (USD)	Low-leveled industries and techs, resources-depended economy	Kuwait UAE
Stable Sustainable Development (SSD)	High-leveled industries and techs	Sweden Norway

Full details of all 40 indices (26 positive and 14 negative ones) are in Tables 4 and 5, where red rows refer to eliminated indices.

TABLE IV. POSITIVE INDICES

Group	Group Name	ID	Name
C_1	Health	p_1	Health expenditure, total (% of GDP)
C_1	Health	p_2	Immunization, measles (% of children ages 12-23 months)
C_1	Health	p_3	Improved sanitation facilities, urban (% of urban population with access)
C_1	Health	p_4	Health expenditure, public (% of total health expenditure)
C_1	Health	p_5	Life expectancy at birth, total (years)
C_2	Environment	p_6	Forest area (% of land area)
C_2	Environment	p_7	Energy use (kg of oil equivalent per capita)
C_2	Environment	p_8	Total natural resources rents (% of GDP)

C_2	Environment	p_9	Improved water source, rural (% of rural population with access)
C_3	Workforce	p_{10}	Proportion of seats held by women in national parliaments (%)
C_3	Workforce	p_{11}	GDP per person employed (constant 1990 PPP $)
C_3	Workforce	p_{12}	Employment to population ratio, 15+, total (%) (modeled ILO estimate)
C_4	Education	p_{13}	Public spending on education, total (% of GDP)
C_4	Education	p_{14}	School enrollment, secondary (% gross)
C_4	Education	p_{15}	Technicians in R&D (per million people)
C_4	Education	p_{16}	School enrollment, primary (% net)
C_4	Education	p_{17}	High-technology exports (% of manufactured exports)
C_5	Urban	p_{18}	Improved water source, urban (% of urban population with access)
C_5	Urban	p_{19}	Urban population (% of total)
C_5	Urban	p_{20}	Mobile cellular subscriptions (per 100 people)
C_5	Urban	p_{21}	Internet users (per 100 people)
C_5	Urban	p_{22}	Motor vehicles (per 1,000 people)
C_6	Finance	p_{23}	GDP per capita (current US$)
C_6	Finance	p_{24}	Services, etc., value added (% of GDP)
C_6	Finance	p_{25}	Cash surplus/deficit (% of GDP)
C_6	Finance	p_{26}	Gross savings (% of GDP)

TABLE V. NEGATIVE INDICES

Group	Group Name	ID	Name
C_1	Health	n_1	Incidence of tuberculosis (per 100,000 people)
C_1	Health	n_2	Population ages 65 and above (% of total)
C_2	Environment	n_3	CO_2 emissions (kt)
C_2	Environment	n_4	GDP per unit of energy use (constant 2011 PPP $ per kg of oil equivalent)
C_2	Environment	n_5	Fossil fuel energy consumption (% of total)
C_3	Workforce	n_6	Unemployment, female (% of female labor force) (modeled ILO estimate)
C_3	Workforce	n_7	Unemployment, male (% of male labor force) (modeled ILO estimate)
C_3	Workforce	n_8	Vulnerable employment, female (% of female employment)
C_3	Workforce	n_9	Vulnerable employment, male (% of male employment)
C_4	Education	n_{10}	Unemployment, total (% of total labor force) (modeled ILO estimate)
C_4	Education	n_{11}	Prevalence of HIV, total (% of population ages 15-49)
C_5	Urban	n_{12}	CO_2 emissions from residential buildings and commercial and public services (million metric tons)
C_5	Urban	n_{13}	Urban poverty headcount ratio at national poverty lines (% of urban population)
C_6	Finance	n_{14}	Total debt service (% of exports of goods, services and primary income)

Values of other 12 judgment matrices are shown below, and the consistency proportions are shown in Table 6.

$$A_1 = \begin{pmatrix} 1 & 1/1.3 & 1/1.2 & 1 & 1.2 \\ 1.3 & 1 & 1/1.2 & 1.2 & 1.3 \\ 1.2 & 1.2 & 1 & 1.3 & 1.4 \\ 1 & 1/1.2 & 1/1.3 & 1 & 1.2 \\ 1/1.2 & 1/1.3 & 1/1.4 & 1/1.2 & 1 \end{pmatrix}, A_2 = \begin{pmatrix} 1 & 1.2 & 1/1.2 \\ 1/1.2 & 1 & 1/1.4 \\ 1.2 & 1.4 & 1 \end{pmatrix}, A_3 = \begin{pmatrix} 1 & 1/1.5 & 1/1.3 \\ 1.5 & 1 & 1.2 \\ 1.3 & 1/1.2 & 1 \end{pmatrix}$$

$$A_4 = \begin{pmatrix} 1 & 1.3 & 1/1.3 \\ 1/1.3 & 1 & 1/1.5 \\ 1.3 & 1.5 & 1 \end{pmatrix}, A_5 = \begin{pmatrix} 1 & 1.5 & 1.3 & 1.2 \\ 1/1.5 & 1 & 1/1.2 & 1/1.4 \\ 1/1.3 & 1.2 & 1 & 1 \\ 1/1.2 & 1.4 & 1 & 1 \end{pmatrix}, A_6 = \begin{pmatrix} 1 & 1/1.5 \\ 1.5 & 1 \end{pmatrix}$$

$$B_1 = B_4^T = \begin{pmatrix} 1 & 1/1.4 \\ 1.4 & 1 \end{pmatrix}, B_2 = B_6 = (1), B_3 = \begin{pmatrix} 1 & 1.1 & 1.3 & 1.3 \\ 1/1.1 & 1 & 1.3 & 1.3 \\ 1/1.3 & 1/1.3 & 1 & 1/1.1 \\ 1/1.3 & 1/1.3 & 1.1 & 1 \end{pmatrix}, B_5 = \begin{pmatrix} 1 & 1.3 \\ 1/1.3 & 1 \end{pmatrix}$$

TABLE VI. TABLE 6: CONSISTENCY PROPORTIONS OF 12 JUDGMENT MATRICES

Matrix	A_1	A_2	A_3	A_4	A_5	A_6	B_1	B_2	B_3	B_4	B_5	B_6
CR	0.0014	0	0.0002	0.0015	0.0010	0	0	0	0.0008	0	0	0