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T4 ________	**E**	F4 ________

2017
MCM/ICM
Summary Sheet

(Your team's summary should be included the first page of your electronic submission.)

Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

Modeling Smart Growth Metric Using Entropy Method

Acceleration of urbanization and more constraints on resources and environment urge us to pursue smart growth of our communities, which focuses not only on economic prosperity but also on equitable society and sustainable environment. Our tasks are the following: to construct a mathematical metric capable of measuring the success of smart growth of a city, to use this metric to analyze two mid-sized cities' growth plan, to redesign develop plans for these two cities according to our metric, and to explain how our plan supports the growth of population by 2050.

We approached the problem by selecting a series of indicators based on the three E's principles in order to give a comprehensive description of smart growth. Then, for constructing the basic model, we calculate the weight of each indicator by using Entropy Method and each indicator data is derived from 217 countries in World Bank. Using this basic model as a foundation, we normalized the 18 indicators value so that it is comparable within the indicators. We used this normalized model as our refined model.

After the construction of the basic model and refined model, we applied our refined model to analyze two mid-sized cities (with a population of 100000 to 500000 persons), Honolulu in Hawaii, US and Qionghai in Hainan, China. First, we analyzed the success of their current growth plans by corresponding plans to metric, finding that some of their initiatives are effective but some are not. Then, we redesigned growth plans for these two cities, with geographical location, expected growth rates, and economic opportunities features being considered. In this part, we calculated a ranking indicator by multiplying normalized metric by weight, which can show which indicator should be preferably developed. Aside from that, we ranked the initiatives of the new plans and compared them between the two cities. Finally, we used our metric to analyze and explain how our new plans can support the growth of population by 2050.

Key words: Entropy Method, Normalization, Smart Growth

Modeling Smart Growth Metric Using Entropy Method

Contents

1 Introduction

In today's increasingly global and interconnected world, 54% of the world's population lives in urban areas. The global rural population is now close to 3.4 billion and is expected to decline to 3.2 billion by 2050[1].

Industrialization and urbanization has accelerated, but the resource shortages, environmental pollution and other issues have hampered the future sustainable development. The United Nations World Commission on Environment and Development, for the first time in "Our Common Future", introduced the concept of "sustainable development".

The city is a complex system composed of three basic elements of society, economy and environment, interacting with each other and confronting each other. How to improve the living environment, relieve the pressure of population growth and pay attention to the coordinated development of economy, society and environment in the process of urban development, we need to insist the sustainable development, not only guaranteeing the city's economic efficiency and quality of life, but also minimizing consumption of other resources, so as to meet the current and future urban development needs.

Health, schools, taxes, traffic, the environment, economic growth, fairness, opportunity are all affected by develop decisions[2]. Smart growth initiatives are being implemented in many cities. To measure the success of smart growth of a city. We should construct an index system which can comprehensively reflect the status of various aspects of the urban complex system according to the characteristics of urban type, and then measure the urban sustainable development ability.

2 Basic Model

In this section, We use 18 specific indicators to describe the three E's performance (Economically prosperous, socially Equitable, and Environmentally Sustainable), using the Entropy Method to calculate the weight of each indicator with data comes from 217 countries in the World Bank, in order to obtain the evaluation model of city.

2.1 Indicator Selection and Meaning

We selected data from 217 countries around the world from World Bank based on the three E's principle, economically prosperous, socially equitable and environmentally sustainable .

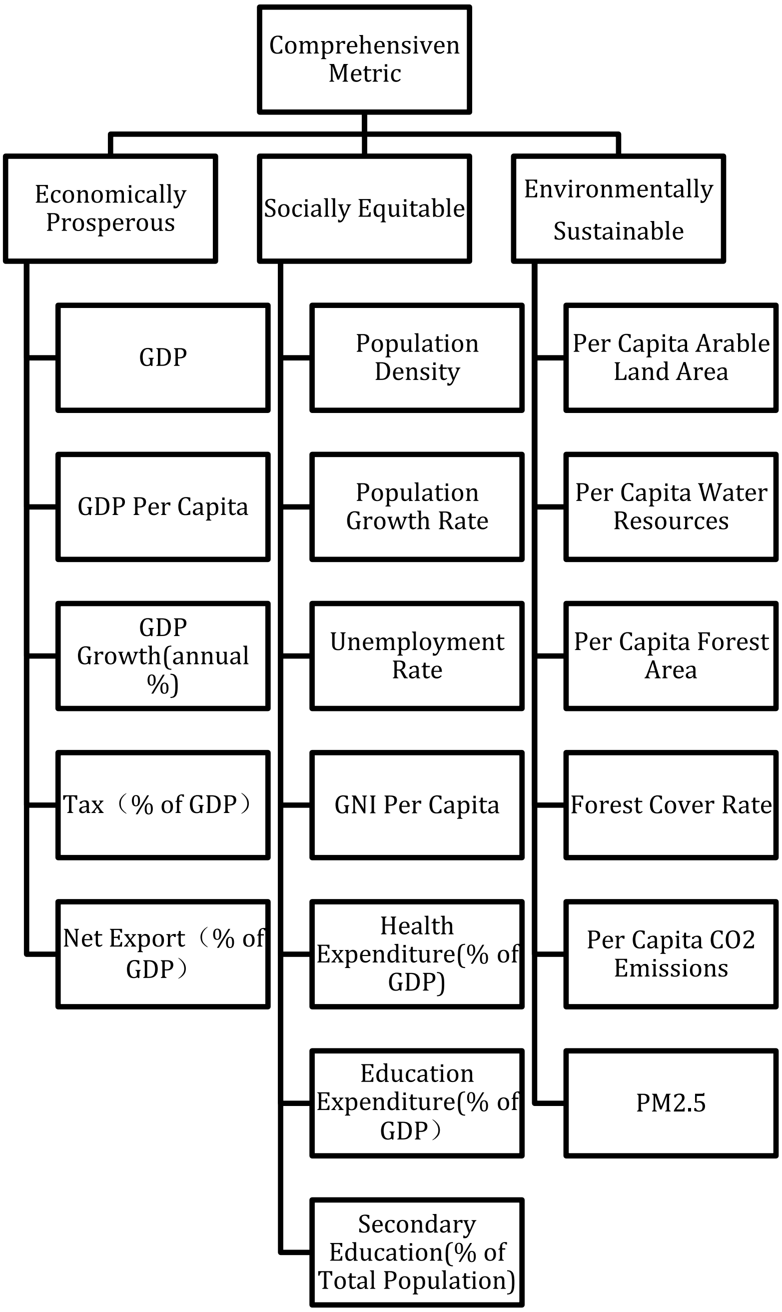

Figure1.Hierarchy chart of indicators

2.1.1 Indicator Construction Principles

1) Comprehensive: the index system can reflect the efficiency of entire functional and the harmony of structural relationship.
2) Representative: Each indicator is representative and typical
3) Practicality: The indicator is operable in the actual data statistics
4) Dynamic: indicators should take into account the dynamic development of the city

2.1.2 Definition

It is necessary to define a comprehensive metric to measure the success of smart growth of a city because smart growth is a complicated problem,. Based on the three E's principles, 18 indexes are chosen in this paper:

2.1.2.1 Economically prosperous

GDP is the sum of gross value added by all resident producers in the economy [8]

GDP per capita is gross domestic product divided by midyear population [9]

Tax revenue (% of GDP) refers to compulsory transfers to the central government for public purposes, expressed as a percentage of GDP [10]

Net export is the difference between the monetary value of a nation's exports and import over a certain period [11]

2.1.2.2 Socially equitable

Population density is midyear population divided by land area in square kilometers [13]

Population growth is the exponential rate of growth of midyear population from year t-1 to t, expressed as a percentage [14]

Unemployment rate refers to the share of the labor force that is without work but available for and seeking employment [15]

GNI per capita is the dollar value of a country's final income in a year, divided by its population [16]

Health expenditure is the sum of public and private health expenditure, expressed as a percentage of GDP [17]

Education expenditure is the General government expenditure on education (current, capital, and transfers), expressed as a percentage of GDP [18]

Secondary education is the total enrollment in secondary education, regardless of age, expressed as a percentage of the population of official secondary education age [19]

2.1.2.3 Environmentally sustainable

Per capita arable land area includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow， which is divided by population [20]

Per capita water resources are calculated using the World Bank's population estimates, which are divided by population [21]

Per capita forest area is land under natural or planted stands of trees of at least 5 meters in situ, which is divided by population [22]

Forest cover rate is land under natural or planted stands of trees of at least 5 meters in situ, expressed as a percentage of the whole land area [23]

Per capita emissions are those stemming from the burning of fossil fuels and population divides the manufacture of cement, which [24]

PM2.5 is defined as the average level of exposure of a nation's population to concentrations of suspended particles measuring less than 2.5 microns in aerodynamic diameter [25]

2.2 Entropy Method

2.2.1 Definition

Entropy is a measure of the number of microscopic configurations Ω that correspond to a thermodynamic system in a state specified by certain macroscopic variables

Information Entropy (more specifically, Shannon entropy) is the expected value (average) of the information contained in each message. 'Messages' can be modeled by any flow of information.

2.2.2 The Principle of Weight Determination by Entropy Method

Entropy can be calculated to determine the degree of randomness and disorder of an event according to its characteristics. Entropy can also be used to determine the degree of dispersion of an indicator in each country. The greater the discrete degree of the indicator, the greater the impact (weight) of the evaluation, the smaller the entropy

2.2.3 Calculation Step

1) Select n countries, m indicators, the value is the j-th indicator of the i-th country (i=1,2…,n; j=1,2,…,m).
2) Normalization of indicators ：

   Because the units of measurement of the indicators are not unified, they must first be normalized in the calculation of comprehensive indicators, that is, the absolute value of the index into relative value, $x_{ij} = |x_{ij}|$, thus addressing the Problem of Homogeneity of Quality Index. And there are positive and negative indicators , the higher the number the better the positive indicators, negative values as low as possible to the index, so negative indicators in the calculation is set to negative number, positive indicators is a positive number. Use the following formula for processing：

$$x'_{ij} = \frac{x_{ij} - min\{x_{1j}, \dots, x_{nj}\}}{max\{x_{1j}, \dots, x_{nj}\} - min\{x_{1j}, \dots, x_{nj}\}}$$

   x'_{ij} is the value of the j-th index of the i-th country after normalization （i=1,2⋯,n; j=1,2,⋯,m）

   For convenience，The normalized data is still denoted by x_{ij}.

3) Calculate the proportion of the i-th country to the indicator under indicator j：

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, \quad i = 1, \dots, n; \quad j = 1, \dots, m$$

4) Calculate the entropy of the j-th indicator：

$$e_j = -k \sum_{i=1}^{n} p_{ij} \ln(p_{ij}), \qquad k = \frac{1}{\ln(n)} > 0, \qquad e_j \geq 0;$$

5) Calculate the redundancy of information entropy：

$$d_j = 1 - e_j$$

6) Calculate the weights of the indicators：

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}$$

2.2.4 Results

We use the corresponding indicators value of 217 countries in the World Bank to calculate the weight of each index by the above steps, as shown in the table below.

Table1. Indicators and Weight

	Indicator	Weight	Total Weight of 3 E'
Economically Prosperous	GDP	11.53%	28.82%
	GDP Per Capita	9.74%	
	GDP Growth（annual%）	1.30%	
	Tax (% of GDP)	4.44%	
	Net Export (% of GDP)	1.81%	
Socially Equitable	Population Density	7.33%	31.18%
	Population Growth Rate	2.95%	
	Unemployment Rate	4.05%	
	GNI Per Capita	8.96%	
	Health Expenditure(% of GDP)	3.18%	
	Education Expenditure(% of GDP)	1.82%	
	Secondary Education(% of Total Population)	2.89%	
Environmentally Sustainable	Per Capita Arable Land Area	5.53%	39.99%
	Per Capita Water Resources	12.42%	
	Per Capita Forest Area	8.39%	
	Forest Cover Rate	2.95%	
	Per Capita CO_2 Emissions	7.39%	
	PM2.5	3.32%	

In order to represent the weight of each indicator more directly, the following figure shows the weight pie chart

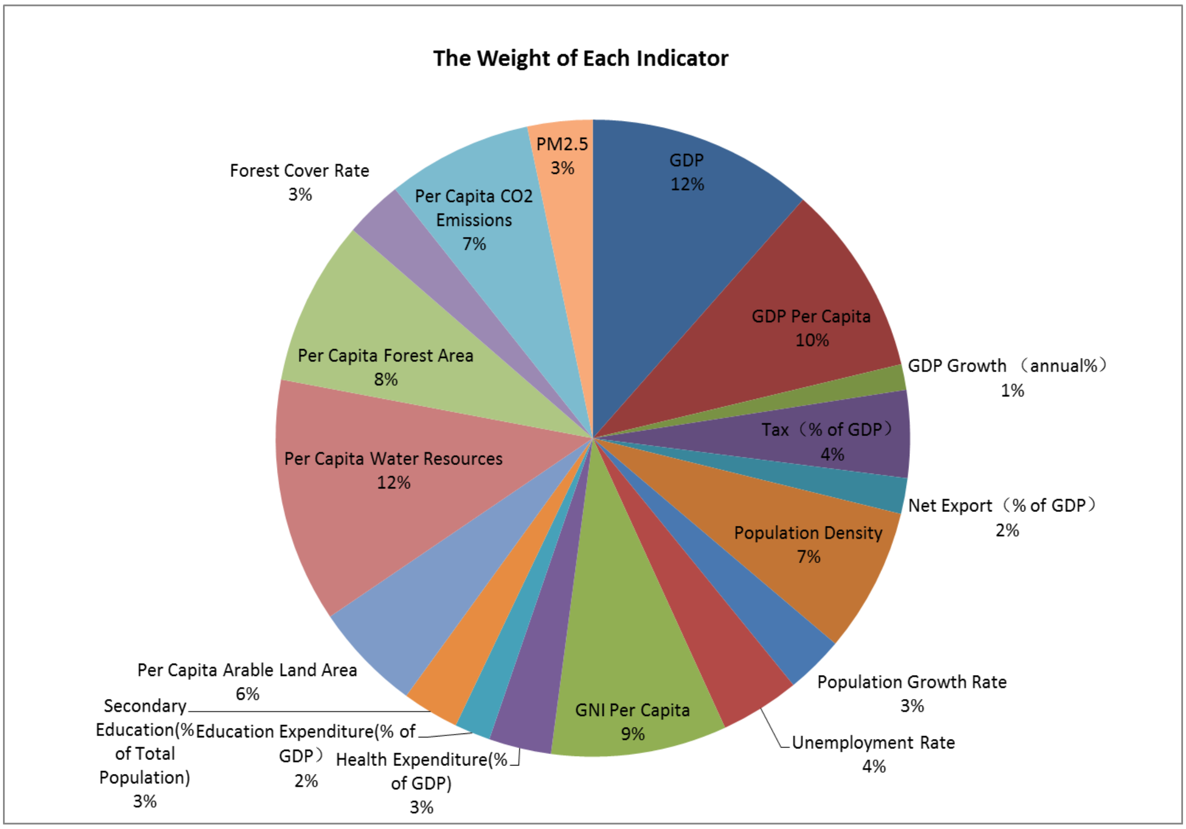

Figure2. Indicators' Weight

2.4.5 Evaluation Model Establishment

We use the following formula to represent the comprehensive indicator:

$$\mathbf{Y = aE_1 + bE_2 + cE_3}$$

Where Y represents a comprehensive indicator reflects the success of a city's smart growth plan; a, b, c, respectively represent the overall weight of economic, social and environmental indicators, $\mathbf{E_1}$, $\mathbf{E_2}$, $\mathbf{E_3}$, respectively represent economic, social and environmental indicator value. If we take the results into account, that is：

$$\mathbf{Y = 0.29E_1 + 0.31E_2 + 0.40E_3}$$

In the following sections, we will use weights and the evaluation function to evaluate two medium-sized cities。

3 Refined Model

In this section, we will improve on the previous model. The main improvement is achieved through the normalization of indicator values to achieve comparability within different indicators of a city.

3.1 Refined Movement

In the basic model, $\mathbf{Y = aE_1 + bE_2 + cE_3}$, $\mathrm{E_1, E_2, E_3}$ respectively represent economic, social and environmental indicator value，which $\mathrm{E_1}$ is subdivided into a number of breakdown indicators can reflect the economic principle, denoted as $e_{11}, e_{12}, \dots e_{1n}$, such as GDP, per capita income, GDP growth, etc. However the measurement standards of these breakdown indicators are different, in order to achieve comparability between indicators, we normalize each index by the following formula：

$$\boldsymbol{e'_{ij} = \frac{e_{ij}}{sum(e_{1j}, e_{2j}, \dots, e_{nj})}}$$

Where $\mathrm{e_{ij}}$ represents the value of the j-th index of the i-th country （$\mathrm{i = 1,2, \dots n; j = 1,2, \dots, m}$）

So refined evaluation model shows as following：

$$\mathbf{Y = aE'_1 + bE'_2 + cE'_3}$$

4 Model Application to Two Cities

4.1 Background

4.1.1 Honolulu

Honolulu is the capital and largest city of Hawaii of the U.S. state. The city is the main gateway to Hawaii and a major portal into the United States. The city is also a major hub for international business, military defense, as well as famously being host to a diverse variety of east-west and Pacific culture, cuisine, and traditions. Honolulu is also one of the world's most popular tourist destinations.

4.1.1.1 Demographics

The population of Honolulu was 374701. Of those, 49.3% were male and 50.7% were female. The median age for males was 40.0 and 43.0 for females; the overall median age was 41.3.

4.1.1.2 Geographical Condition

Total area is 68.4 square miles (177.2 km2) 60.5 square miles (156.7 km2) of it (88.44%) is land, and 7.9 square miles (20.5 km2) of it (11.56%) is water. Honolulu experiences a hot semi-arid climate. It’s located at 21°18′32″N 157°49′34″W.

Figure3. Honolulu's Topographic map

4.1.1.3 Economy

Honolulu, the largest city and airport in the Hawaiian Islands, acts as a natural gateway to the islands' large tourism industry, which brings millions of visitors and contributes $10 billion annually to the local economy.

4.1.2 Qionghai

Qionghai City is located in the eastern part of Hainan Province in China and the middle and lower area of Wanquan River, being the location of the world's attention, "Boao Forum for Asia," is a young and attractive regional center of Hainan.

4.1.2.1 Demographics

Qionghai has a total of 458,626 people, male to female ratio is 110.12: 100. Qionghai city has 28 ethnic minorities, the total population of 19,660 people, accounting for 3.9% of the total population of the city, mainly Miao, Li.

4.1.2.2 Geographical Condition

Located in the longitude 110 °7 '5' ~ 40'50 ", latitude 18 °58'50" ~ 19 °28'35 ". The central and northern regions are mesa and hills, covering an area of 714.44 square kilometers, accounting for 42.2%. The southeastern part is plain, covering an area of 567.15 square kilometers, occupying 33.5% of the total area 64.32 square kilometers of water area, accounting for 3.8%.

Figure4. Qionghai Topographic map

4.1.2.3 Economiy

In 2015, Qionghai GDP achieved $ 3.2 billion, of which the first industrial added value increased by 5.4% over 2014; the secondary industry increased by 7.5% over 2014; the tertiary industry increased by 10.2%

4.1.3 Comparison

4.1.3.1 Geographical Features

Hainan is known as the "Oriental Hawaii" , Honolulu and Qionghai are the two major coastal tourist cities for two regions individually, Honolulu is located in 21°18′32″N 157°49′34″W, and Qionghai is located in 110 °7 '5' ~ 40'50 "E, 18 °58'50" ~ 19 °28'35 "N, they are situated in the similar dimensions, both are tropical monsoon climate, taking advantage of unique natural scenery to develop the tourism as their main industry. Therefore, sustainable development is a long-term topic for the two medium-sized cities.

Figure5. Honolulu and Qionghai

4.1.3.2 Three E's

The breakdown indicators of Honolulu and Qionghai under three principles of economy, environment and social equity are given in the following figure.

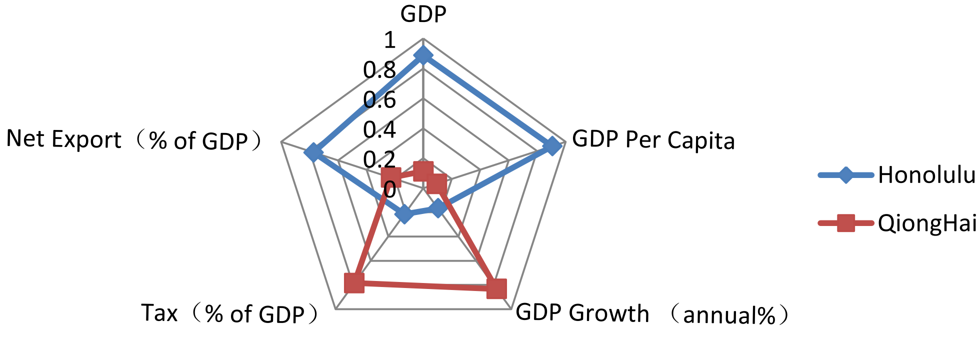

Figure6. Radar Diagram Economic Indicato

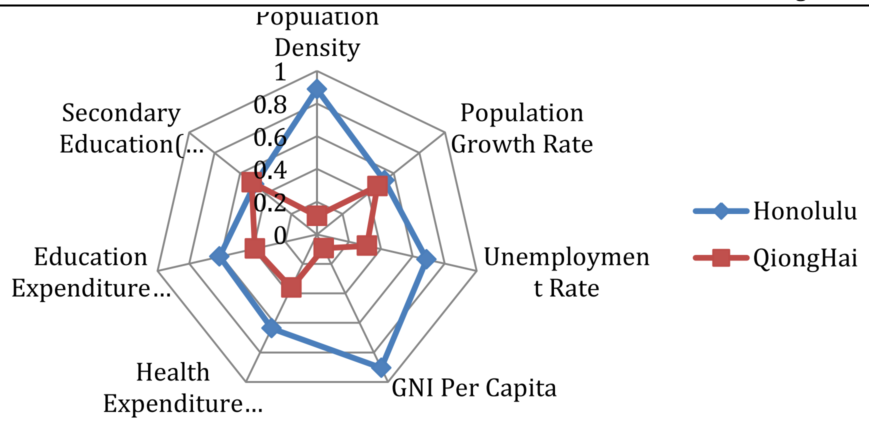

Figure6. Radar Diagram Social Indicator

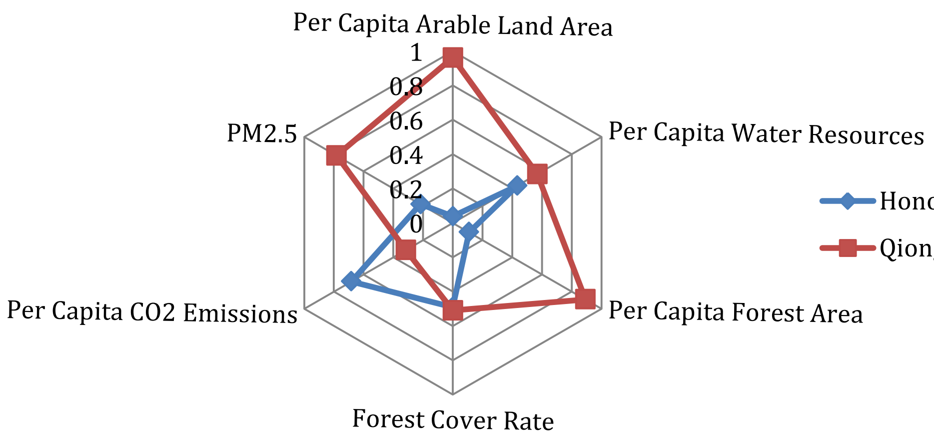

Figure6. Radar Diagram Environmental Indicator

Table2

The Indicators and Stardardized Indicators of the Two Cities

		Indicator		Standardized Indicator	
		Honolulu	QiongHai	Honolulu	QiongHai
Economy	GDP	2057895	260267	0.887727101	0.112272899
	GDP Per Capita	54921	5675	0.906348085	0.093651915
	GDP Growth （annual%）	2.60%	13%	0.166666667	0.833333333
	Tax（% of GDP）	4.70%	17.09%	0.215695571	0.784304429
	Net Export（% of GDP）	5%	1%	0.772525101	0.227474899
social Equity	Population Density	2114.565463	268.2023392	0.887440841	0.112559159
	Population Growth Rate	1.14%	1.02%	0.527533549	0.472466451
	Unemployment Rate	-4.40%	-2.00%	0.6875	0.3125
	GNI Per Capita	33975	3532	0.905831758	0.094168242
	Health Expenditure(% of GDP)	15.50%	9%	0.638239811	0.361760189
	Education Expenditure(% of GDP)	24.80%	16%	0.610777421	0.389222579
	Secondary Education(% of Total Population)	86.60%	90%	0.489542114	0.510457886
Environment	Per Capita Arable Land Area	94.58	2396.07	0.037974023	0.962025977
	Per Capita Water Resources	54.710289	7190%	0.432115663	0.567884337
	Per Capita Forest Area	236.46	1938.09	0.108737823	0.891262177
	Forest Cover Rate	50%	52%	0.490292214	0.509707786
	Per Capita CO2 Emissions	-16.4	-7.6	0.683333333	0.316666667
	PM2.5	-5.83	-21	0.217294074	0.782705926

4.2 Analysis of current plans

In this section, we measure and discuss the current growth plans of the selected cities by corresponding the plan to metric. We found that Honolulu's current growth plan focused on the economic and environmental aspects, while Qionghai focused on the environment, followed by the economy. Specific analysis is as follows:

Table3. Analysis of current plans

	PLAN	METRIC	DISCUSS
Honolulu	First, insist the sustainable development of tourism, and promote the development of economy while protecting the ecological environment;	**Economically prosperous** • GDP • GDP per capita • GDP growth • Net export **Environmentally sustainable** • Forest Cover Rate • Per Capita CO2 Emissions • PM2.5	In the development of the economy, GDP, GDP per capita and GDP growth rate act as a measure of economic growth and condition, net exports act as an indirect indicator of the development of tourism. In addition, per capita carbon dioxide emissions, forest coverage rate and PM2.5 can be used as a measure of ecological sustainability.
	Second, put emphasis on community participation, so that residents can benefit from improving people's livelihood, increase employment and promote the overall development of society;	**Socially equitable** • Unemployment Rate • GNI per capita	Aboriginal people in Honolulu can earn a lot of jobs from the tourism industry and increase per capita income.

<table>
<tr><td rowspan="3">Qionghai</td><td>First, adhere to the development objectives of garden city construction, continue to strengthen the ecological environment protection and construction. Such as afforestation, energy conservation and regional pollution control;</td><td>Environmentally sustainable
• Per Capita Arable Land Area
• Per Capita Water Resources
• Per Capita Forest Area
• Forest Cover Rate
• Per Capita CO2 Emissions
• PM2.5</td><td>Forest area per capita, water resources per capita and per capita arable land, forest coverage can measure the success of Qionghai City in ecological and environmental protection. Besides, ecological indicators, such as the per capita carbon dioxide emissions and pm2.5, can also be measurements of the pollution.</td></tr>
<tr><td>Second, adhere to the quality and efficiency of economic transformation and upgrading, speed up industrial restructuring and plan for the development of tourism;</td><td>Economically prosperous
• GDP
• GDP per capita
• GDP growth
• Net export</td><td>Economic restructuring and transformation can be reflected in GDP, per capita GDP and GDP growth; and net exports as a measure of the development of tourism indicators, reflect the potential of economic development;</td></tr>
<tr><td>Third, make efforts to protect the people's livelihood so that the fruits of development more and more equitably benefit the people of the city, and improve people's happiness index. Give priority to the development of education, accelerate the development of health, family planning career, the implementation of policies to promote employment and entrepreneurship.</td><td>Socially equitable
• Population Density
• Population Growth Rate
• Unemployment Rate
• GNI per capita
• Health Expenditure
• Education Expenditure</td><td>The population density of the city, the population growth rate is a measure of career planning, indicating the city's own historical and cultural properties, while the unemployment rate, per capita income, medical expenses, education spending is able to represent the efforts and results of their implement on protecting livelihood.</td></tr>
</table>

4.3 Develop New Plan

In this section, we will develop two new development plans for the city with the refined model. First of all, we will get the development priority by multiplying the weights and the indicators (after normalization) of the two cities, Ranking Indicator. The weight indicates the impact on the overall smart growth. The indicator value indicates the development advantage of the city. Therefore, the ranking indicator can be used to represent the importance of the index and the characteristics of the city itself. Then we sort the size of the ranking indicator, and the top-ranked indicator is a priority when specifying a plan. The specific process is as follows:

4.3.1 Definition

$$R_{ij}=E_{ij}*w_j$$

Where, E_{ij} represents the j standardized Indicator Value of the i city; w_j represents the j-th weight indicators, (i = 1,2, ..., n; j = 1,2, ..., m).

4.3.2 Results

Table 4.

Honolulu Ranking Indicator

Rank	Three E's.	Indicator	R_{ij}
1	Economy	GDP	0.102314264
2	Economy	GDP Per Capita	0.088289444
3	social Equity	GNI Per Capita	0.081148694
4	social Equity	Population Density	0.065080187
5	Environment	Per Capita CO_2 Emissions	0.050482385
6	social Equity	Unemployment Rate	0.027820576
7	social Equity	Health Expenditure(% of GDP)	0.020299809
8	social Equity	Population Growth Rate	0.015567132
9	Environment	Forest Cover Rate	0.014467104
10	social Equity	Secondary Education(% of Total Population)	0.01415528
11	Economy	Net Export（% of GDP）	0.014007852
12	social Equity	Education Expenditure(% of GDP）	0.011133957
13	Economy	Tax（% of GDP）	0.009583727
14	Environment	Per Capita Forest Area	0.009119154
15	Environment	PM2.5	0.007219556
16	Economy	GDP Growth （annual%）	0.002169005
17	Environment	Per Capita Arable Land Area	0.002099123
18	Environment	Per Capita Water Resources	0.000937624

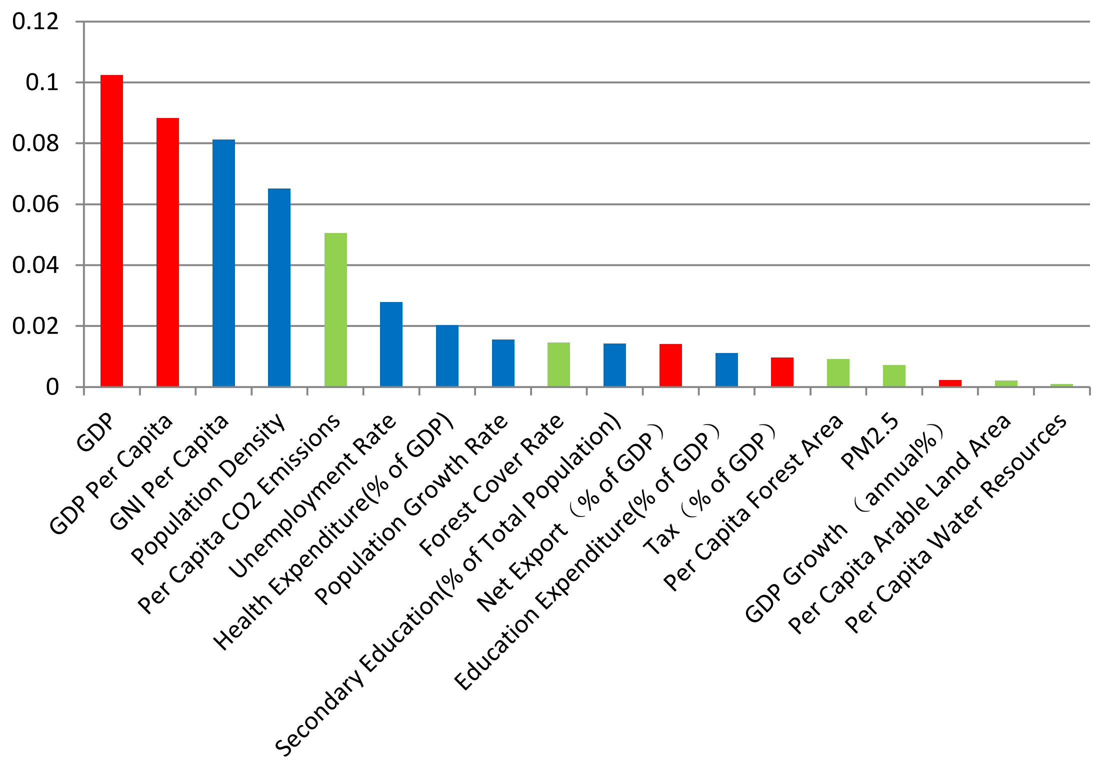

Figure9. Honolulu Ranking Indicators

Table 5.

QiongHai Ranking Indicator

Rank	Three E's.	Indicator	R_{ij}
1	Environment	Per Capita Water Resources	0.123222049
2	Environment	Per Capita Forest Area	0.074744528
3	Environment	Per Capita Arable Land Area	0.053178744
4	Economy	Tax (% of GDP)	0.034848003
5	Environment	PM2.5	0.026005262
6	Environment	Per Capita CO_2 Emissions	0.023394276
7	Environment	Forest Cover Rate	0.015040001
8	social Equity	Secondary Education(% of Total Population)	0.014760066
9	social Equity	Population Growth Rate	0.013942142
10	Economy	GDP	0.012939922
11	social Equity	Unemployment Rate	0.012645717
12	social Equity	Health Expenditure(% of GDP)	0.011506118
13	Economy	GDP Growth （annual%）	0.010845024
14	Economy	GDP Per Capita	0.009122848
15	social Equity	GNI Per Capita	0.008436037
16	social Equity	Population Density	0.008254489
17	social Equity	Education Expenditure(% of GDP)	0.007095199
18	Economy	Net Export (% of GDP)	0.004124701

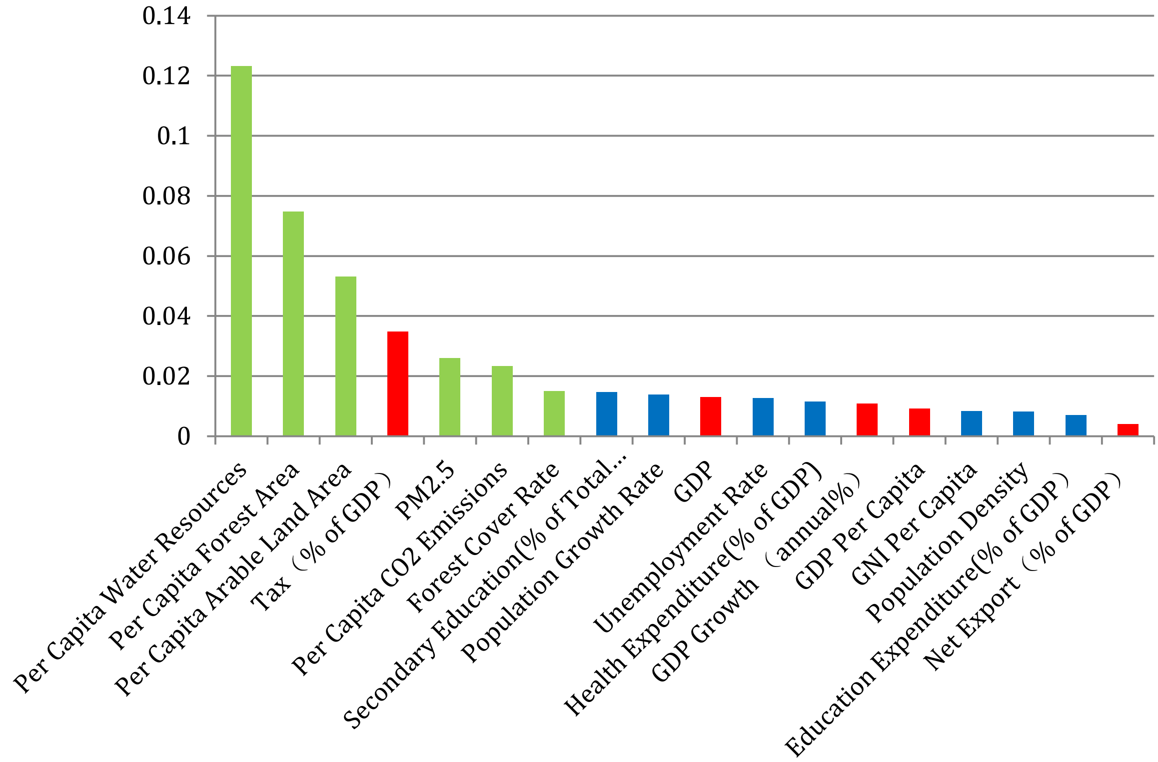

Figure10. Qionghai Ranking Indicators 1

4.3.3 Plan and Analysis

4.3.3.1 Honolulu

1. Give priority to economic development, and focus on the development of pillar industries， which is tourism.

   Analysis: GDP and GDP per capita rank first and second, indicating that economic growth has the largest impact on the smart growth of Honolulu.

2. Promote GNI per capita, reduce unemployment and increase health care spending.

   Analysis: As GNI Per Capita, the unemployment rate and other 5 indicators of social equality rank the top, Honolulu needs to give priority to economic development at the same time take social equality into account. Focus on community participation so that the local people can benefit from local economy, thereby increasing per capita income and reducing unemployment.

3. Protect the ecology, develop energy-saving environmental protection industry, and reduce CO_2 emissions.

   Analysis: CO_2 emissions per capita ranks relatively top, reducing the CO_2 emissions of smart growth also has a role in promoting smart growth.

4.3.3.2 Qionghai

1. Strengthen the protection of ecological environment, protect water resources, forests and

arable land, reduce CO2 emissions and control air pollution.

Analysis: As can be seen from the table, Qionghai six of the first seven indicators are belong to environment, indicating that strengthening the ecological environment construction is the most important.

2. Regulate the fiscal and taxation system and appropriately increase the tax revenue.

   Analysis: Tax Revenue ranks fourth in the table, indicating that the increase in fiscal revenue plays a catalytic role.

3. Develop education, improve the quality of people and relax the family planning policy.

   Analysis: Secondary Education Population(% of Total Population) in the table ranked No. 8, so developing education, improving the quality of the people and increasing human capital investment can promote long-term economic growth. Population growth rate ranks ninth, so government needs to relax the family planning policy, to increase the supply of labor and adjust the population structure.

4.4 Compare and Contrast

In this section, first, we redesign smart growth plans for the two cities by using the three E's principles involving 18 indicators. Then, we compare and contrast the initiatives and their ranking between the two cities.

Table 6.

The Ranking of the Indicators for Two Cities

		Ranking	
		Honolulu	QiongHai
Economy	GDP	1	10
	GDP Per Capita	2	14
	GDP Growth （annual%）	16	13
	Tax（% of GDP）	13	4
	Net Export（% of GDP）	11	18
social Equity	Population Density	4	16
	Population Growth Rate	8	9
	Unemployment Rate	6	11
	GNI Per Capita	3	15
	Health Expenditure(% of GDP)	7	12
	Education Expenditure(% of GDP）	12	17
	Secondary Education(% of Total Population)	10	8
Environment	Per Capita Arable Land Area	17	3
	Per Capita Water Resources	18	1
	Per Capita Forest Area	14	2
	Forest Cover Rate	9	7
	Per Capita CO_2 Emissions	5	6
	PM2.5	15	5

For example, the GDP ranking indicator ranked first in Honolulu, but the tenth in Qionghai suggests that the contribution of GDP growth to Honolulu is greater than in Qionghai. GNI Per Capita ranks third in Honolulu and fifteenth in Qionghai, indicating that GNI Per Capita in Honolulu has a greater impact on the success of smart growth than Qionghai from the social equality perspective.

4.5 How to support population growth by 2050

4.5.1 Assumptions

1. The annual population growth rate is equal .
2. The GDP increases by an additional 50%, with the GDP per capita fixed.
3. The population density will increase by an addition 50%.
4. The Per Capita Arable Land Area, Per Capita Water Resources and Per Capita Forest Area will decrease to their 2/3 as a result of the increasing of population.
5. The other indicators remain stable.

4.5.2 Analysis

Table 7.

Comprehensive Index

	Honolulu	change	QiongHai	change
2050	364417.6892	↑	46095.37991	↑
2013	31188.43144		245760.2437	

4.5.2.1 Honolulu

According to previous assumptions, when the population growth is 50% by 2050, GDP will increase by 50%, while other economic indicators remain unchanged. According to basic model, comprehensive index will be a corresponding increase of 118,591. From social equity’s perspective, population density increased by 50%, comprehensive index will be a corresponding increase of 78. On the other hand, the area of per capita arable land, per capita water resources and per capita forest area are reduced by 2/3, and the comprehensive index will be reduced by 11. Priority to develop economic and social equity can increase comprehensive index, which make up for the negative effect of the environment, causing the comprehensive index in 2050 increased by 118,657 comparing with 2013. According to the above new plan, Honolulu's initiative is to develop the economy first, followed by social equity, and finally the environment. As a result, the development plan can support population growth.

4.5.2.2 Qionghai

When the population growth increased by 50%, economic GDP growth increased by 50%, comprehensive index will be a corresponding increase of 14,998. From social equity aspect, population density increased by 50%, comprehensive index will be a corresponding increase of 10. In terms of the environment, the per capita arable land area, per capita water resources and per capita forest area are reduced by 2/3, and the comprehensive index will be reduced by 101. And the difference is that environmental factors’ negative pull is greater than the social equity index’s positive pulling effect. The impact of social equity caused by population growth is secondary, so it is primary to protect the ecology and develop the economy. According to the above new plan, Qionghai's initiative is to protect the ecological environment first, followed by the economy, and finally social equity, which is in line with the results in the table. Calculated 2050 comprehensive index increased 14,906 over 2013. The development plan can support the population of the growth.

Table 8.

The Population of Each City Increases by an Additional 50% by 2050

		Change rate	Indicator2050		Weight	Indicator2050*Weight		Change*Weight	
			Honolulu	QiongHai		Honolulu	QiongHai	Honolulu	QiongHai
Economy	GDP	1.50	3086843.043	390400.1781	11.53%	355771.5812	44995.25461	118591	14998
	GDP Per Capita	1.00	54921	5674.924347	9.74%	5349.980496	552.8073883	0	0
	GDP Growth (annual%)	1.00	0.026	0.13	1.30%	0.000338365	0.001691824	0	0
	Tax (% of GDP)	1.00	0.047	0.170899699	4.44%	0.002088291	0.007593369	0	0
	Net Export (% of GDP)	1.00	0.05	0.014722816	1.81%	0.000906628	0.000266962	0	0
social Equity	Population Density	1.50	3171.848194	402.3035088	7.33%	232.6064608	29.50279761	78	10
	Population Growth Rate	1.00	0.0114	0.01021	2.95%	0.000336406	0.00030129	0	0
	Unemployment Rate	1.00	-0.044	-0.02	4.05%	-0.001780517	-0.000809326	0	0
	GNI Per Capita	1.00	33975	3531.964959	8.96%	3043.641225	316.4101296	0	0
	Health Expenditure(% of GDP)	1.00	0.155	0.087855424	3.18%	0.004929919	0.002794323	0	0
	Education Expenditure(% of GDP)	1.00	0.248	0.158039895	1.82%	0.004520831	0.002880934	0	0
	Secondary Education(% of Total Population)	1.00	0.866	0.903	2.89%	0.02504069	0.026110557	0	0
Environment	Per Capita Arable Land Area	0.67	63.05333333	1597.38	5.53%	3.485453773	88.29975916	-2	-44
	Per Capita Water Resources	0.67	36.473526	47.93333333	12.42%	4.52854105	5.951386977	-2	-3
	Per Capita Forest Area	0.67	157.6368002	1292.059325	8.39%	13.22000258	108.3568531	-7	-54
	Forest Cover Rate	1.00	0.5	0.5198	2.95%	0.014753552	0.015337793	0	0
	Per Capita CO_2 Emissions	1.00	-16.4	-7.6	7.39%	-1.211577237	-0.561462622	0	0
	PM2.5	1.00	-5.83	-21	3.32%	-0.193700687	-0.697721169	0	0
	Comprehensive Index					364417.6892	46095.37991	118657.4456	14906.94847

5 Evaluation of model

5.1 Strength:

The entropy method is based on objective data, which can avoid the bias caused by human factors and make our analysis more credible and accurate. Besides, the entropy method is much simpler and more efficient.

At present, in the evaluation method of regional sustainable development ability, the analytic hierarchy process (AHP) often cannot meet the reasonable assignment of relatively perfect index weight because of the difference of the level. Gray correlation analysis method also has certain problems, known as the perfect degree is not high ". The ecological footprint model also has some obvious flaws: 1).the model results overestimate the regional ecological status; 2).emphasis only on human development on the environment, do not care about the economic, social, technical and other aspects of sustainability; 3).a static index-based analysis; 4).ignore the regional differences in fine.

Entropy method can solve many of the above problems, but in the face of some extreme values and negative cases when it is inadequate, so the need for the index data transformation and standardization of the method to make certain improvements is necessary, for example, our refined model.

5.2 Weakness:

The entropy method did not consider the indicator's own importance, only calculate the weight by the degree of dispersion of the data, sometimes leading to errors. Besides, the calculated weight by entropy method varies from different data, which demand us to use large numbers of data to ensure its applicability.

6 Conclusion

Our team set out to come up with a simple but efficient model to evaluate two different cities' growth plan based on entropy method and three E's principles. Our process of model construction is based on large numbers of objective data, not involving subjective judgment, which results in more straight and accurate analysis. We have also improved the model to increase the applicability by normalizing indicator value.

We found some of the initiatives of the two cities meet with smart growth needs through analyzing current growth plans with the refined model, but others are not. So, we redesigned the growth plans for the two cities based on the refined model.

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