Comprehensive Valuation of Environmental Cost Based on Entropy Weight Method

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Abstract. In the past few decades, economic decisions often exert an imperceptible influence on the biosphere. In order to get the real land use valuation of both small community projects and large national projects, environmental costs can be calculated by establishing a comprehensive valuation model. As fluctuations in the main indicators such as land area and biodiversity can affect the value of land use, we calculate the cost-benefit ratio with the comprehensive valuation model which is based on entropy weight method, and take both environmental costs indicators and economic factors into consideration. By using the model, we analyze the cases of Hong Kong Island and find out land indicator has the greatest impact on environmental costs. In general, if all the weights are variable, the deviation between the calculated indicator and the practical indicator will be narrowed. Land use project planners and managers can get recommendations from this model.

Keywords: Environmental costs · Entropy weight method · Comprehensive valuation model

1 Introduction

1.1 Background and Problem Analysis

Throughout the ages, ecosystem services are directly or indirectly beneficial for human life as natural processes, which provide four categories of services for us ——supporting services, provisioning services, regulating services and cultural services. However, people all over the world are potentially limiting or removing ecosystem services by altering it. In order to further illustrate the alteration, we can divide it into two parts ——local small-scale changes and large-scale projects. Although it seems insignificant to the total ability of the biosphere's functioning potential, they can damage the diversity of species and give rise to environmental degradation.

Actually, the impact of, or account for changes to, ecosystem services are not considered by most land use projects. And many negative changes like polluted rivers, poor air quality, hazardous waste sites, poorly treated waste water, climate changes are often not included in the plan. So, we constructed a model with high enough fidelity of the mathematical modelling and analyze to further manifest and elaborate our solutions.

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To work out what is the cost of environmental degradation, we broke it down to 5 tasks to analyze this problem. What we need to do is shown below (Fig. 1) (Table 1):

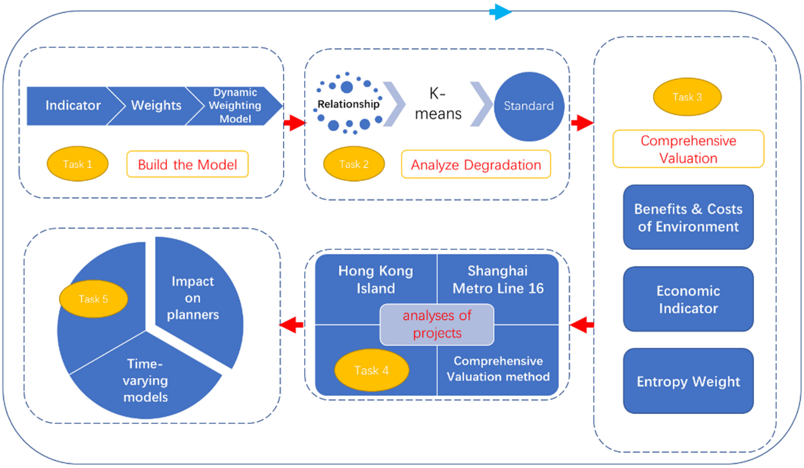

Fig. 1. Flow chart of this paper

2 Symbols and Definitions

Table 1. Symbols and Definitions

Symbols	Definitions
FA	Forest Area (% of land area)
AL	Arable land (% of land area)
TPA	Terrestrial Protected Areas (% of land area)
TPS	Threatened Plant Species
TBS	Threatened Bird Species
CDE	Carbon Dioxide Emissions (metric tons per capita)
AP	PM2.5 Air Pollution (micrograms per cubic meter)
IW	Improved Water (% of total population served with improved water)
IWW	Industrial Water Withdrawal (% of total water withdrawal)
FW	Freshwater Withdrawal
AQI	Air quality Indicator
WI	Water Indicator
LI	Land Indicator

(*continued*)

Table 1. (*continued*)

Symbols	Definitions
BI	Biodiversity Indicator
EWM	Entropy Weight Method
EWI	Entropy Weight Index
SWM	Subjective Weight Method
SWI	Subjective Weight Index
EI	Economic Indicator
EBL	Economic Benefits from Land (one hectare is a unit)
ERWR	Expenditure of the Restoration of Water Resource
ERAE	Expenditure of the Restoration of Atmospheric Environment
EMB	Expenditure of the Maintenance of Biodiversity
CE	Comprehensive Evaluation

3 The Model

3.1 Comprehensive Evaluation

We select the following indicators: environmental costs indicator and economic indicator. For environmental costs indicator, we take the factors of the environment itself and social factors into consideration. Our model includes four overall Indicators —— AQI, LI, BI, WI, which include ten small indicators. The 10 indicators include forest area, arable land, terrestrial protected areas, threatened plant species, threatened bird species, CO2 Emissions, PM2.5 air pollution, improved water, industrial water withdrawal, freshwater withdrawal (Fig 2).

Fig. 2. All indicators

Dynamic weighting model consists of entropy weight method (EWM) and subjective weight method (SWM). Then, we get EWI and WEI respectively by using EWM and SWM. Finally, we get ECI, which is the combination of two methods. Through our ECI, we can put a value on the environmental costs of land use development projects.

p_i is the variance ratio of each indicator for every five years. As the great difference of the development of each country or region in different period, we should calculate the weight of each period from 1960 to 2015——5 years is a unit——to get a more scientific ratio every 5 years, and to analyze concretely, we should analyze the actual situation of every country or region. w_i is the weight of each Indicator

$$Land\ Index = \sum_{i=1}^{2} p_{i*}w_i \tag{1}$$

$$Biodiversity\ Index = \sum_{i=3}^{5} p_{i*}w_i \tag{2}$$

$$Air\ Quality\ Index = \sum_{i=6}^{7} p_{i*}w_i \tag{3}$$

$$Water\ Index = \sum_{i=8}^{10} p_{i*}w_i \tag{4}$$

3.1.1 Dynamic Weighting Models

With the evaluation indicators defined above, we further determine the weights of these indicators, resulting in the combination of primary indicators. Recalling on the Entropy Weight Method (EWM), we will carry out the standardized treatment, making the optimal and worst value of each variables after alternation be 1 and 0, respectively. The evaluation indexes are $X_1, X_2, X_3, \ldots, X_\mathrm{k}$, where $X_i = \{x_{i1}, x_{i2}, \ldots, x_{in}\}$. Among there, For the sake of the cost-type indicators, the environmental costs is proportional to the value of the indicator. Nevertheless, in terms of the gain-type indicators, The higher the value, the lower the value of land development in the country. Thus, we have.

$$Y_{ij} = \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)}\ j = 1, 2, \ldots,\ \mathrm{n} \tag{5}$$

where Y_{ij} is the standardized value of each evaluation indicator of each country, $\max(x_i)$ and $\min(x_i)$ are the maximum and minimum value of the evaluation indicator X_i.

$$\max(x_i) = \max\{x_{i1}, x_{i2}, \ldots, x_{in}\},\ \min(x_i) = \min\{x_{i1}, x_{i2}, \ldots, x_{in}\}$$

After standardization, then we introduce.

$$T_{ij} = \frac{Y_{ij}}{\sum_{j=1}^{n} Y_{ij}} \tag{6}$$

According to the concepts of self-information and entropy in the information theory, we can calculate the information entropy.

$$E_i = -\ln(n)^{-1}\sum_{j=1}^{n} T_{ij}\ln T_{ij} \tag{7}$$

On the basis of the information entropy, we will further compute the weight of each evaluation indicator we defined before.

$$w_i = \frac{1 - E_i}{m - \sum_i E_i} \text{i} = 1, 2, \ldots, \text{ m} \tag{8}$$

Subsequently, we can derive the four comprehensive evaluation indicators: air quality index, land index, water index and biodiversity index. Here after this paper will be abbreviated as LI, BI, AQI and WI respectively. On the basis of those calculated weights, we have

$$\begin{aligned} LI &= w_1p_1 + w_2p_2 \\ BI &= w_3p_3 + w_4p_4 + w_5p_5 \\ AQI &= w_6p_6 + w_7p_7 \\ WI &= w_8p_8 + w_9p_9 + w_{10}p_{10} \end{aligned} \tag{9}$$

$p_{nj}(n = 0 \sim 10)$

This is the variation of five years. Hence, we get EWI:

$$EWI = k_1 * LI + k_2 * BI + k_3 * AQI + k_4 * WI \tag{10}$$

According our method and model, it will cause environmental costs if the value of EWI is positive; it will generate environmental costs if the value of EWI is negative.

We assign weights (k_1, k_2, k_3, k_4,) for four indicators (LI, BI, AQI, WI,).

Environmental costs and profit are difficult to be quantized. To avoid the impact of the evaluation of land-use value, we need to define a subjective index to analyze the comprehensive land-use value. A series of human factors can exert impact on the weight of index. For instance, the plans and the thoughts of developers, the time of developing, the emotion of residents, the activities of residents, the interventions of government, etc. Subjective weight are adopted, thus we can get SWI (subjective weight index).

To compensate the deviation of the two methods, we adopt the combined index as the ultimate index. The calculating formula is shown below:

$$ECI = a*EWI + b*SWI(\text{a} + \text{b} = 1) \tag{11}$$

EWI in this equation accounts for main part.

Dynamic weighting model consists of entropy weight method (EWM) and subjective weight method (SWM). Then, we get EWI and WEI respectively by using EWM and SWM. Finally, we get ECI, which is the combination of two methods. Through our ECI, we can put a value on the environmental costs of land use development projects.

3.2 Environmental Degradation in Project Costs

3.2.1 Relationship between Indicators and Environmental Costs

After carefully analyzing the relevant information, we determine the variation tendency between Indicators and environmental costs are shown in the figure below (Table 2):

Table 2. Variation tendency between Indicators and environmental costs

Indicator	Variation Tendency(Index)	Indicator(Environment cost)
FA	↑	↓
AL	↑	↓
TPA	↑	↓
TPS	↑	↑
TBS	↑	↑
CDE	↑	↑
AP	↑	↑
IW	↑	↓
IWW	↑	↑
FW	↑	↑

3.2.2 The Determination of ECI Standard

To scientifically analyze the ECI, we define a set of standard for it. Symbol '−' means the profit of environment. Symbol '+' means the cost of environment. We also divide the degree into low, medium, high.

To determine the standard of environmental costs, we divide all countries into three categories with the K-means clustering algorithm: low environmental costs, medium environmental costs and high environmental costs. Therefore, we randomly selected 36 countries to determine the standard. we calculate its various indices. The K-means clustering algorithm allows us to divide 36 countries into three groups. Then use the index of the country with the lowest and highest indicator as the boundary. It will generate environmental profit if the value of EWI is negative. To scientifically analyze the ECI, we define a set of standard for it. The environmental costs and each standard Indicator are as follows (Fig. 3):

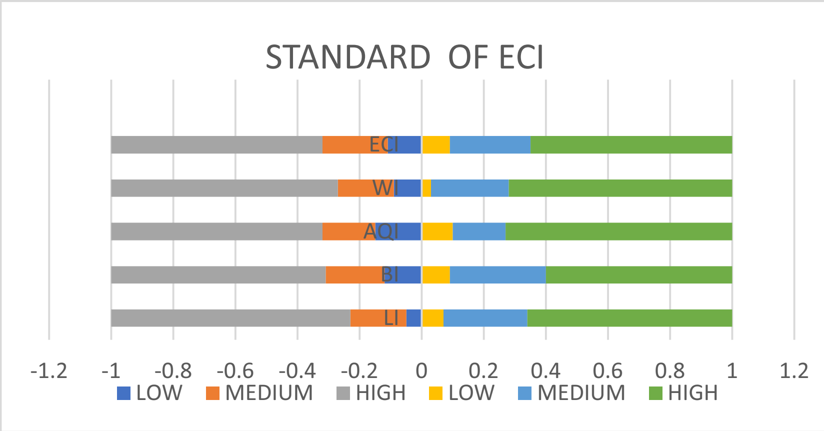

Fig. 3. Standard of ECI

The figure shows that it will generate high environmental profit if the value of ECI is more than −0.40, but less than −0.34. And LI has the most fast growing speed of environmental profit. It begins to generate high environmental profit when the value reaches around −0.23. We regard the overall economic factor as earnings if the economic indicator is positive, and we regard the overall economic factor as economic cost if the economic indicator is negative.

3.3 Comprehensive Valuation of Project

3.3.1 The Determination of Economic Indicator

The way of the selection of economic indicator is similar to ECI. Then, we get four Indicators: Economic benefits from land (one hectare is a unit), Expenditure of the restoration of water resource, Expenditure of the restoration of atmospheric environment, Expenditure of the maintenance of biodiversity.

We define the equation as follows:

$$EI = EBL - (ERWR + ERAE + EMB) \tag{12}$$

Finally, we get the economic Indicator.

3.3.2 Comprehensive Valuation Method

To compensate the deviation of the two methods, we adopt the combined Indicator as the ultimate Indicator. The calculating formula is shown below:

$$CE = c * EI - d * ECI\,(\mathrm{c} + \mathrm{d} = 1) \tag{13}$$

Reiteration: the plus-minus of ECI and EI is the same as above.

3.4 Comprehensive Valuation of Hong Kong Island

According to our analysis in Sect. 3.1.1, we get the weights of all the indicators. The weights of all the indicators is shown as below (Table 3):

Table 3. The weights of all the indicators

Indicator	Weights	Indicator	Weights
Land	0.3632	FA	0.8067
		AL	0.1933
Biodiversity	0.2199	TPA	0.2609
		TPS	0.4081
		TBS	0.3310
Air Quality	0.2873	CO2 Emissions	0.2437
		AP	0.7563
Water	0.1296	IW	0.6873
		IWW	0.1319
		FW	0.1806

And we also calculate the percentage of each indicator. The percentages of LI, BI, AQI and WI are 36%, 22%, 29% and 13%, respectively. As the weights of LI is greater than other three Indicators, we select LI to test and verify the weights we calculated before.

We divide the development period of Hong Kong into two 20-years-long period —— 1997 is the time node —— before 1997 and after 1997. The reason is that Hong Kong became British colony in 1842 and returned to China in 1997 (Fig. 4).

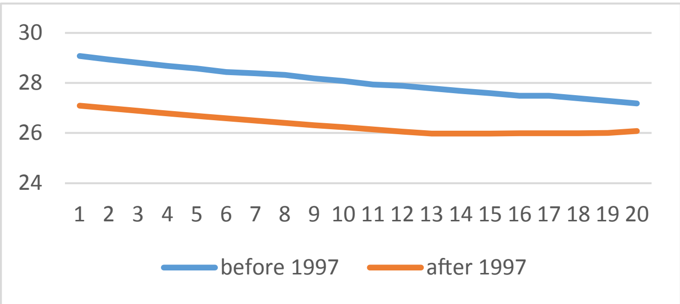

Fig. 4. The change rate of forest area

The line chart shows the change rate of forest area in Hong Kong. The blue curve represents the change rate of forest area before 1997; the orange curve represents the change rate of forest area after 1997. It is obvious that the change rate did not stop decreasing until 2010. (the white circle is 2010) Then, the line chart became smooth from 2010 to 2017 (Fig. 5).

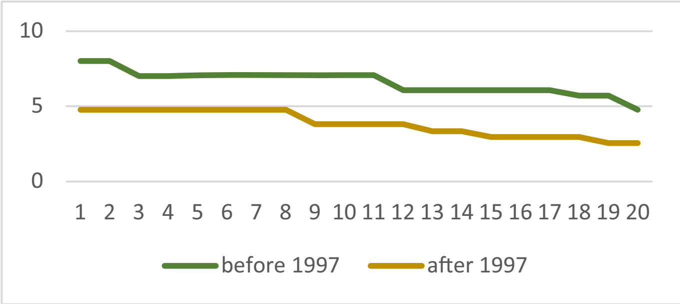

Fig. 5. The change rate of arable land

The line chart manifests the change rate of arable land in Hong Kong. The green curve represents the change rate of arable land before 1997; the brown curve represents the change rate of arable land after 1997. The change rate was keep decreasing all this time (Fig. 6).

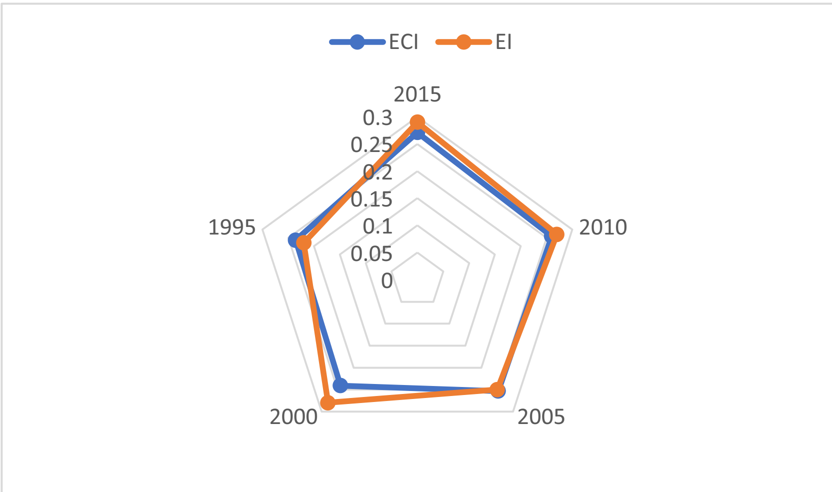

Fig. 6. The comparation of ECI and EI

According to our calculation, both ECI and EI were increasing from 1995 to 2015. Besides, the date of ECI was close to EI. Our comprehensive valuation also shows that the environmental problems are taken more seriously in the process of developing land for HKI projects. During this process, FA and AL were declining in a sharp way. The developers exchanged environmental costs for short-term economic profit. In the long run, economic profit cannot offset environmental cost when the weight of ECI is increasing in our comprehensive valuation. As the data in 1995, EI was less than ECI. Through our comprehensive valuation, EI should be greater than ECI in the next decade if we want to assure the sustainable development of land.

4 Impact of Modeling on Land-Use Project Planners and Managers

As many factors could lead to environmental costs, land-use project planners should consider the indicators we proposed in the process of land development and focus on the indicators with great weights. These great indicators occupy a dominant position in the environmental costs of land development. At the same time, the influence of social factors cannot be ignored. For example, the damage of environment can cause dissatisfaction among residents and terrible reputational cost of developers. In general, people will feel relaxed if we live in protected environment. The satisfied residents can promote the stability of society (Table 4).

Table 4. The Weights of all the indicators in China

Indicator	Weights	Indicator	Weights
Land	0.2338	FA	0.4682
		AL	0.5318
Biodiversity	0.3522	TPA	0.3022
		TPS	0.2979
		TBS	0.3999
Air Quality	0.2732	CO2 Emissions	0.5837
		AP	0.4163
Water	0.1408	IW	0.2545
		IWW	0.4223
		FW	0.3232

According to Fig. 10, BI tend to have the greatest weight for large-scale national land development projects in China. Therefore, In the process of land development for large national projects, the environmental costs brought by biodiversity is the most important part. We should avoid developing land in terrestrial protected areas, some areas with threatened plant species, and the other areas with endangered birds.

AQI also occupies a great weight. It will cause more environmental costs if air quality is not up to the standard in some areas. For example, the great carbon dioxide emissions with terrible PM2.5 in a specific small area can lead to more environmental costs.

In the process of land development for small national projects, forest area Indicator and arable land Indicator play the most indispensable roles through all the Indicators. It would cause huge environmental costs if we develop land in this area. Besides, it would accelerate the trend of environmental degradation.

Once thinking about these Indicators, especially the Indicators with great weights, we should take effective measures to reduce environmental costs and to increase revenue. In the long run, it can reduce the environmental damage caused by land development and mitigate the adverse effects of environmental degradation.

From what we have discussed above, the economic cost, the impact of environmental costs, the environment itself, and social factors should be taken into account when we are assessing the value of land development and utilization.

5 Time-Varying Models

As time goes by, all indicators will change with the land policy and development strategy of the country. Besides, some social factors such as population, living condition, and social stability also be taken into account. As the factors we discussed above, the weights of each Indicator should be variable. For instance, social factors have significant impact on the weights of ECI and EI in our comprehensive valuation. So, the developers will pay more attention to ECI when social factors are changing greatly. For example, on the case of HKI, the developers improved the weight of ECI in the comprehensive valuation of land development after 1997. After that, environmental degradation was alleviated by the improvement of EI. Actually, the weights of LI, BI, WI and AQI can be changed with social factors. In general, the deviation between calculated Indicators and practical Indicators would be narrowed if all the weights are variable.

6 Sensitivity Analysis

All Indicators will change with many factors such as the scale of project, social stability, natural disasters, etc. Based on our analysis and outcome above, we can determine some of Indicators which have high weights and get accurate value through the combination of EWM and SWM. The indicators with low weights cannot exert huge impact on our final comprehensive valuation of environmental costs even if there are some inevitable errors in it. For instance, on the case of HKI, FW changed 0.09 while the final ECI changed 0.002, which means some Indicators with low weights play slight roles in our model. Therefore, our model is stable because it is not easily affected by errors.

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