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Comprehensive Measurement and Optimization of the Coordinated Development of Ecological Environment and Land Use

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Abstract With the massive use of land, there seems to be an inevitable contradiction between ecosystems service (ES) and land development and utilization. To tackle this problem, we do case studies and empirical analysis on evaluation and prediction of ecosystem service value (ESV) and benefit-cost ratio (BCR) of land use. First, we build a Pressure-State-Response (PSR) framework for the coordinated development of the ecological environment and land use. The framework indexes are composed of the pressures of environmental degradation, the state of land use, and the response of the coordinated development. Then, we construct an ESV comprehensive evaluation indicator system by means of Costanza model. And we establish comprehensive measurement model of environmental cost based on the system. Next, we develop an improved model of BCR of land use. Under different scenarios in varying-size regions, the model takes into account the loss and increase of ESV due to land use. Finally, by using the models, we do case studies on urban construction land use of Shanghai and the project of the Three Gorges Dam in China. The results show that the models are not only suitable for national large-scale land projects, but also for the small-scale ones. Our work may help to optimize the allocation of land resources based on ESV, and promote the understanding of ecological balance and sustainable development.

Keywords Land use development, Ecosystem service, ESV, PSR

1. Introduction

1.1 Statement of the problem

People always ignore the impact of economic development on the ecosystem when we develop the economy vigorously. When we talked about the environment degradation, amount of studies can be mentioned that this catastrophic phenomenon has a tremendous impact on every aspect of society, including economic, culture, and other things.

In the recent years, with the development of productivity, the improvement of production level, the progress of technological and population growth, people used to think environment degradation is a transient problem.

As we all known, human activities play an important role among the factors contributing to environment degradation. As we said, the destruction of the ecosystem is bound to cause the degradation of the environment. By and large, we hold the view that there is no limit to the resources and capacity of the ecosystem, this leads to the ecosystem is carrying far more than it can handle. In some cases, this will be the last straw that can overwhelmed the camel.

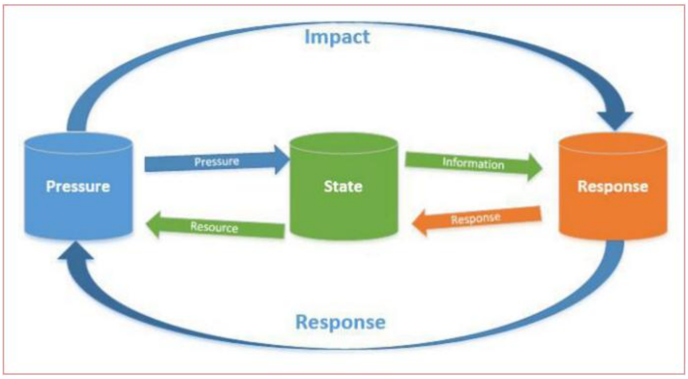


Figure 1: PSR Model [7]

1.2. PSR framework of ecological system and land use

Currently, the PSR [7] structural model is a normal model for assessing resources use, sustainable development, and ecosystems. Here, 'P' represents the pressure dimension, it represents the pressure on the system, and here we assume that environmental degradation is "pressure". In addition, "S" represents the state of the different types of land when investing in land, including before environmental degradation or after environmental degradation. "R" acts as a response to characterize the recommendations and responses to promote sustainable development processes. Based on the PSR model, we have established a similar ecological environment – the PSR framework for coordinated development of land use.

1.3. Our work

In fact, to the Earth, the only planet which are suitable for human survival, the services of ecological system and the original stock that produce them are critical to the functioning of the Earth's life support system. They have a direct contribution to the development of our society, thus indirectly represents a part of the Earth's economic value. According to the published research, we estimated the current economic value of 17 ecosystem in 21 biomes [1].

The value of the whole biosphere, not included in the market, is estimated to be $16-54 trillion per year. Because of the nature of the uncertainties, for instance, due to the deepening of research by biologists and other researchers, so that the value of the biosphere increased continuously. It means that the data just mentioned should be considered a minimum estimate [1].

In order to better match economic development and ecological, here is the economic development of land, we are required to establish an evaluation index model which determines a land assessment model. By selecting the appropriate age to determine the land to obtain the evaluation indicators of the land, give the indicator weights, and combine the different kinds of indicators to achieve some comprehensive indicators, from community small service projects to large-scale national construction projects, through the specific practical projects, testing this model and it is application, and making recommendation for improvement suggestion.

In order to solve these problems, we will proceed as follows:

- Do imaginary and make a mark. Neglecting some insignificant impacts will narrow the scope of the data and simplify our calculations. Then we will list some symbols to clarify the model and determine their definition is very important.
- Establish an evaluation index model which reflects both the ecosystem service system and land benefits. We will use the entropy weight method to explain this model by screening for factors that are more relevant to the benefit, such as high and low benefits.
- Apply our model to a practice project. Here, we apply our model to China's large national project, The Three Gorges Dam and a small community public service project, and a small community public service project, and study their actual influencing factors. Then we will verify the correctness of the model through the test results of the model to better improve it.

- Sensitivity analysis and model evaluation. Based on the evaluation criteria defined above, we predicted from the results of our model, we evaluated the reliability of the model and performed sensitivity analysis, Later, some modifications were made to apply our model to achieve smaller or larger land use.

2 Assumptions, justification and notations

Table 1: Notations

Notations	
Symbols	Definition
ESV（USD）	Ecosystem Services Values
I	Different kinds of land types
$A_i(ha^2)$	The area of different kinds of land types
E_i （$USD*ha^{-2}*yr^{-1}$）	Ecosystem Services Values of unit area per unit time of different ecological types
$ESV_{loss/increase}$ (USD)	Loss or increase of ESV due to land use
E_0 （$USD*ha^{-2}*yr^{-1}$）	Original ecological type unit area unit time ESV
ESV_s (USD)	Total ESV for n years
B_t(USD)	Benefits of land development and utilization in t years
C_t (USD)	The cost of land development and utilization in t years
n (year)	Assumption of the number of years of development and utilization
R	interest rate
KEV	Benefit cost rate

2.1. Assumptions and Justification

In order to simplify this problem and modify it to a condition which is more suitable for simulating real life, we propose the following basic assumptions, each of which is a property description.

- The exchange rate of RMB against the US dollar remains unchanged and the US dollar does not depreciate or increase its value.
- The ecological structure of the reservoir area is stable after a long time and the structural composition remains unchanged.
- Since then, the government has stopped making additional investments in the dam.
- The annual power generation of the dam and the national average electricity price are stable.

2.2. Notations

We list the symbols and notations used in this paper, see Table 1.

3. Establishment of model

3.1 Comprehensive index system of ESV based on Costanza model

In the Costanza model [1], it presents global annual average ecosystem service value for 21 types and 17 indicators. (Table 2)

Table 2: The ecosystem service of different types [1]

	Marine	Open oce	Coastal	Estuaries	Seagrass/	Coral reef	Shelf	Terrestrial	Forest	Tropical	Temperat	Grass/ran	Wetlands	Tidal mars	Swamps/f	Lakes/rive	Desert	Tundra	Ice/rock	Cropland	Urban
Gas	0	38	0	0	0	0	0	0	0	0	0	7	133	0	265	0	0	0	0	0	0
Climate	0	0	0	0	0	0	0	0	141	223	88	0	0	0	0	0	0	0	0	0	0
Disturbance	0	0	88	567	275	0	0	0	2	5	0	0	4539	1839	724	0	0	0	0	0	0
Water regulation	0	0	0	0	0	0	0	0	2	6	0	3	15	0	3	5445	0	0	0	0	0
Water supply	0	0	0	0	0	0	0	0	3	8	0	0	38	0	76	2117	0	0	0	0	0
Erosion control	0	0	0	0	0	0	0	0	96	245	0	29	0	0	0	0	0	0	0	0	0
Soil	0	5	38	78	0	5	39	0	2	0	4	23	0	0	0	0	0	0	0	24	0
Nutrient cycling	0	118	3677	211	192	0	1431	0	361	922	0	0	0	0	0	0	0	0	0	0	0
Waste	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
Pollination	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	14	0
Biological	0	0	8	131	0	7	0	0	0	0	0	0	34	169	439	0	0	0	0	0	0
Habitat	0	0	0	0	0	58	0	0	87	87	87	87	4177	6696	1659	665	0	0	0	0	0
Food	0	15	93	521	0	22	68	0	43	32	5	67	256	466	47	41	0	0	0	54	0
Raw material	0	0	4	25	2	27	2	0	138	315	25	0	16	162	49	0	0	0	0	0	0
Genetic	0	0	0	0	0	0	0	0	16	41	0	0	0	0	0	0	0	0	0	0	0
Recreation	0	0	82	381	0	38	0	0	66	112	36	2	574	658	491	23	0	0	0	0	0
Cultural	0	76	62	29	0	1	7	0	2	2	2	0	881	0	1761	0	0	0	0	0	0

Entropy weight method After getting the relevant data, we chose to use the entropy weight method (EWM) to roughly filter the data:

Because the cost of the service of each type of ecosystem is directly proportional to its economic value, so we use the following formula to standardize the data.

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

Where Xij is the value of the index j under the sample i.

After the data is standardized, we use the following formula to calculate the proportion of the sample i under the index j.

$$P_j = y_{ij} / \sum_{i=1}^{n} y_{ij} \tag{2}$$

Next we calculate the entropy value Li of each evaluation index.

$$L_i = -\ln(n)^{-1} \sum_{j=1}^{n} p_{ij} \ln(p_{ij}) \tag{3}$$

Based on the calculation of the entropy value, we further calculate the weight of each indicator.

$$w_i = \frac{1 - L_i}{k - \sum_{i=1}^{n} L_i} \quad i = 1, 2, \ldots, n \tag{4}$$

We refer to Costanza et al. [1] to divide ecosystem services into 17 types of theories and use The Entropy Method to calculate their own weights. (Table 3)

Table 3: Weights of land

Biome	Weights	Biome	Weights
Marine	0	Grass/rangelands	0.049968
Open ocean	0.066185	Wetlands	0.064824
Coastal	0.097057	Tidal marsh/mangroves	0.074119
Estuaries	0.047937	Swamps/floodplains	0.047993
Seagrass/algae beds	0.088379	Lakes/rivers	0.081032
Coral reefs	0.053303	Desert	0
Shelf	0.101800	Tundra	0
Terrestrial	0	Ice/rock	0
Forest	0.041841	Cropland	0.077853
Tropical	0.049369	Urban	0
Temperate/boreal	0.058341		

And we make the following histogram:

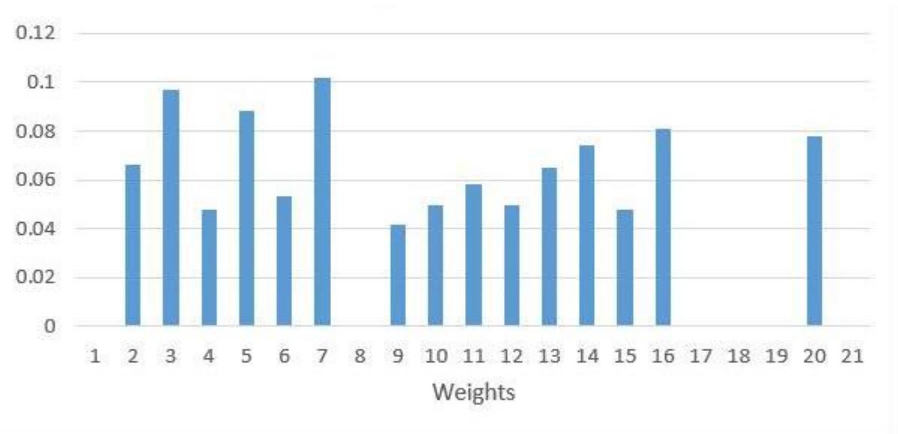


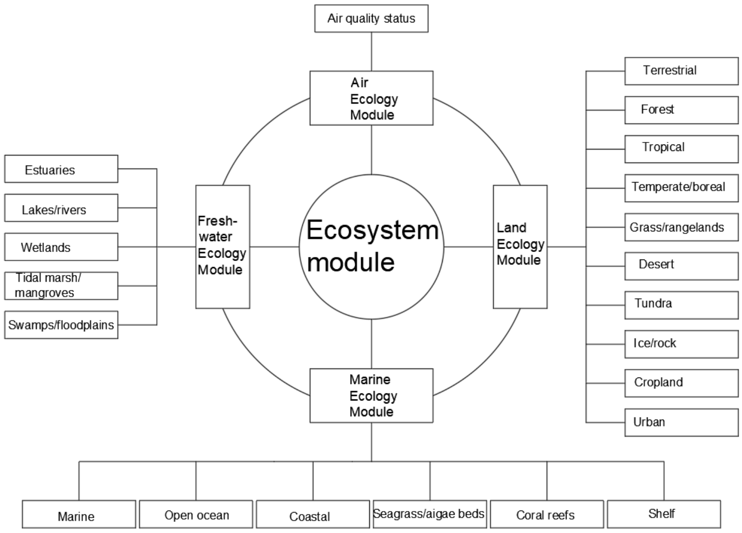
Figure 2: Weights of land

The abscissa of the above histogram is represented from left to right：

Marine, Open ocean, Coastal, Estuaries, Seagrass/algae beds, Coral reefs, Shelf, Terrestrial, Forest, Tropical, Temperate/boreal, Grass/rangelands, Wetland, Tidal marsh/mangroves, Swamps/floodplains, Lakes/rivers, Desert, Tundra, Ice/rock, Cropland, Urban[1].

And we categorized them roughly as Table 4 shows.

Table 4: Classification of ecological biomes [1]



We didn't add all the data to the calculation. First, we excluded the type of data items all 0 out of the data item type that was substituted into the calculation. Secondly, we also removed those that have little effect on the experimental results, including the experiment itself. According to the relevant data, the experimental data items summarized are: Cropland, Forest, Grass, Water, Construction land, and the Unused land.

At last, We get the form as Table 5 shows.

Table 5: Ecosystem service

Ecosystem services (1994 USD ha-1 yr-1)	
	Total value
Cropland	92
Forest land	960
Grass land	244
Water area	8,291
Construction land	0
Unused land	0

3.2. Comprehensive measurement of environmental costs

In 1997, Costanza et al. calculated the average ecosystem service value based on 21 different indicators and 17 different types of areas, and established the Costanza model [1], and quantify the value of ecosystem services according to it. Traditional ecosystem service assessment methods are mainly divided into two categories: value assessment method and substance assessment method. In terms of value assessment, it is mainly to evaluate Ecosystem services values [2] (ESV) from the perspective of value. It expresses the economic attributes of ecosystem services in an intuitive way, that is, the economic value of the evaluation of ecosystem services by monetization. We combined the model proposed by Costanza et al. [1] with the ESV model [2] and improved it to obtain the following ESV calculation formula for different ecological types.

$$ESV_i = n \times E_i \times A_i (E_i = \sum_{j=1} E_{ij}) \quad (5)$$

$$ESV_s = \sum_i A_i \times \mathrm{n} E_i \tag{6}$$

$$ESV_{loss/increase} = n\sum_{i=1}(E_i - E_0)A_i = n\sum_{i=1}(A_i - A_0)E_i \tag{7}$$

3.3 Establishment of cost-benefit ratio improvement model

Benefit-cost analysis is a kind of method to evaluate the feasible options by comparing the present value of all expected and all estimated costs of a project's various schemes for decision makers to make choices.

The formula for calculating the benefit-cost ratio [3] (K) is：

$$K = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+r)^t}} \tag{8}$$

If the benefit-cost ratio is greater than 1, then this option is feasible, and on the contrary it is not feasible. The selection of many programs is based on the level of indicators. The larger the indicator, the more feasible and economical the program is.

However, due to the traditional cost-benefit model doesn't take into account the impact and the changes of the ecosystem services when calculating the land development costs, meanwhile the economic costs of the influence are not included, so wo pass the cost-benefit ratio. The model has been improved and we make the changes in ecological services are quantified and included, and a more realistic and comprehensive estimation formula for the cost-effectiveness of a project is obtained:

$$KEV = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+r)^t} + ESV_{increase}}{\sum_{t=1}^{n} \frac{C_t}{(1+r)^t} + ESV_{loss}} \tag{9}$$

The assessment method is: if the benefit-cost rate is greater than 1, then the scheme is feasible, if less than 1 is not feasible. The selection of many programs is based on the level of indicators. The larger the indicator, the more economical and scientific the program is.

4. Case study of the models

4.1. Case 1: Shanghai

Table 6: The changes of land use in Shanghai [5]

Land use change in Shanghai										
Land use type	In 1995		In 2000		In 2005		In 2010		In 2015	
	Area/ha	Proportion/%	Area/ha	Proportion/%	Area/ha	Proportion/%	Area/ha	Proportion/%	Area/ha	Proportion/%
Crop land	539800	67.5	509880	63.8	469740	58.7	411080	51.4	400390	50.2
Forest land	21270	2.7	20480	2.6	35100	4.4	48960	6.1	49280	6.2
Grass land	3600	0.4	950	0.1	1150	0.1	750	0.1	590	0.1
Water area	163560	20.5	172000	21.5	164290	20.5	159480	19.9	158260	19.8
Construction land	71410	8.9	96300	12	129290	16.2	179340	22.4	189280	23.7
Unused land	0	0	0	0	0	0	0	0	0	0

Next, we intend to use our established model to quantify the ecosystem services of Shanghai from 1995 to 2015.We reviewed the relevant information and obtained the changes in land use in Shanghai in 1995, 2000, 2005, 2010 and 2015. (Table 6） The table based on Table 5 Ecosystem service.

With the above data and the quantitative evaluation form of the ecosystem service of Shanghai land use type, we can use the formula (7) to calculate the following thing:

$$ESV_{loss/increase} = -61{,}225{,}720 \text{ USD}$$

But if we assume that the type of land use does not change during the year, then we can use the formula (6) to calculate the ESV of all types of land use in Shanghai over the past 20 years and the change in the total value of ecological services ESVs asFigure 3 shows.

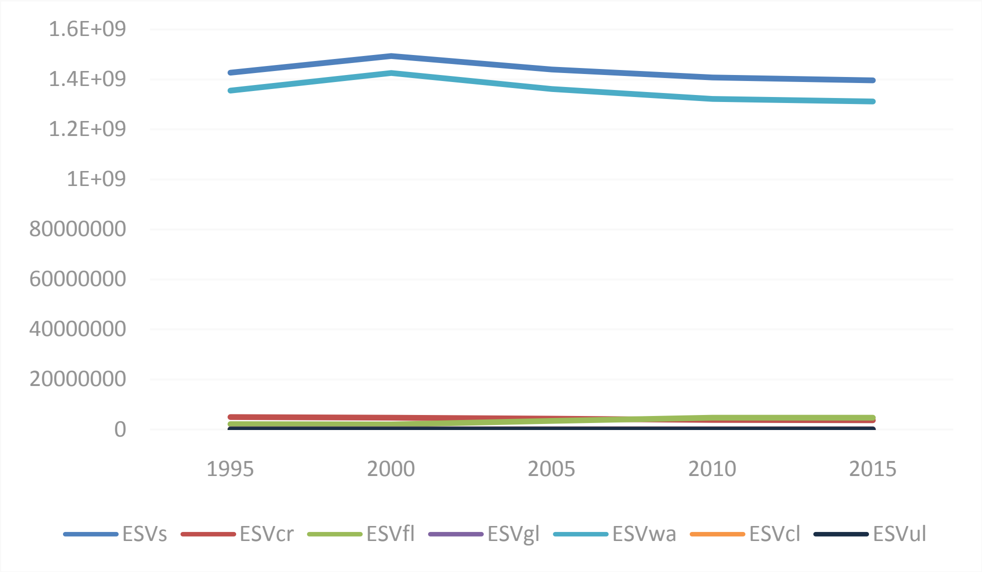


Figure 3: The changes of land ESV

4.2. Case 2: The Three Gorges Dam Reservoir Area

By consulting relevant information, we obtained relevant data from the Three Gorges Dam Reservoir Area:

- At that time, the total investment of the project was 59.75 billion US dollars (including static investment of 39.64 billion US dollars and dynamic investment of 20.11 billion US dollars) [6].
- Installed capacity is 22.4 million kilowatts [6]
- Assume that the operating time of the Three Gorges Dam is 150 days per year.
- It can be calculated that the annual power generation of the Three Gorges Dam is 80.64 billion kWh.
- Assume that the average electricity price in recent years is $0.1/kWh, and the net profit is 60% of annual income.
- It can be calculated that the annual net profit of the Three Gorges Dam is 4.84 billion US dollars, and the annual cost is 3.23 billion US dollars.
- Land use change in the Three Gorges Dam area from 2000, 2007 and 2014 can be obtained through satellite remote sensing technology and reference papers.

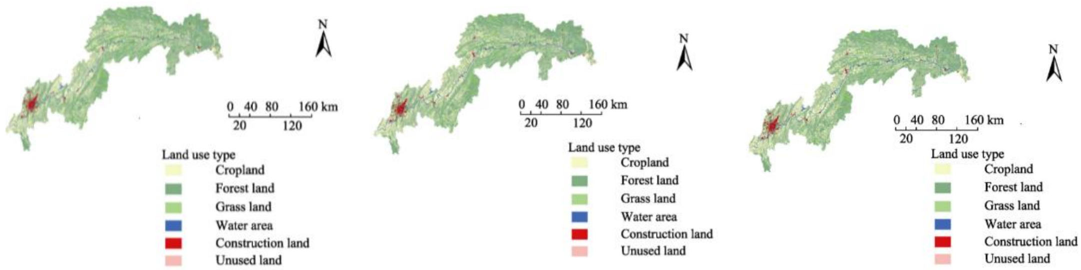


Figure 4: The land use status in 2000, 2007, 2014 [4]

The Table 7 based on Table 5 Ecosystem service, we can use the formula (7) to calculate the following thing:

$$ESV_{loss/increase} = 135{,}641{,}715{,}000 \text{ USD}$$

Then bring the above existing data into the cost-effective improvement mode (9)
and then calculate the true benefit of this project cost-rate KEV=1.62.

Table 7: The changes of land use in the Three Gorges Reservoir Area[4]

Land use change in Three Gorges Reservoir Area						
Land use type	In 2000		In 2007		In 2014	
	Area/ha	Proportion/%	Area/ha	Proportion/%	Area/ha	Proportion/%
Cropland	2,186,842	38.11	2,172,699	37.86	2,146,048	37.39
Forest land	3,149,358	54.88	3,143,052	54.77	3,129,655	54.53
Grass land	140,974	2.46	140,656	2.45	139,790	2.44
Water area	132,497	2.31	143,454	2.50	151,626	2.64
Construction land	127,671	2.22	137,556	2.40	170,259	2.97
Unused land	1,730	0.03	1,656	0.03	1,695	0.03

5. The validity analysis of the model

The model that we propose can only roughly estimate the true cost-benefit ration of a project. Because we use the 17 indicators of the Costanza model [1] and the ESV quantification table [1] to discuss the weight of the ecological types proposed, and remove the most of types that we can't calculate we can't refer to, and finally we get a simplified ESV quantification table and apply it to the application. Through the quantitative assessment of ecological services in the Three Gorges Dam reservoir area from 2000 to 2014, the estimation of cost-benefit ratio and the evaluation of ESV during the construction of Shanghai from 1995 to 2015, rough results were obtained. At the same time, based on the preliminary fitting of the results and the actual situation, we found that is basically met the expected goals.

6. Conclusion

Strengths of our model We based on the Costanza model [1] to improve the EVS formula [2] and optimize the cost-benefit ration formula [3] to enable a rough estimate of the ESV of a project and the true cost-benefit ratio after considering the impact on the ecosystem service, According to the simplified ESV quantification table [1], it is more suitable for quantitative evaluation of ecological services changes due to changes in the land uses types, which is convenient to use.

We improve the cost-benefit ratio [3] formula so that it can calculate the cost-benefit ratio of changes in ecological services more realistically and accurately, It will make land planners and managers to plan and utilize land for project projects more intuitively and conveniently, improve land use patterns, make land utilization higher, promote ecological balance and sustainable development, promote indirectly social development and human history and promote ecological balance and sustainable development.

Weakness of our model But our model still has a lot of shortcomings, for example, if the evaluation parameters are so small that the results may cause large deviations or the project data is not enough so we must use so many assumptions, and the results can only be quantified and analyzed, but the change process cannot be simulated and predicted and so on.

Further Exploration In the future, the model needs to be improved, for example, adding more time evaluation parameters to the model enables it to speculate on unknown data based on existing data and even predict and analyze the impact on the environment after a project finished. In this way, it is possible to more accurately estimate and predict the ESV change of a project and the cost-benefit ratio.

Acknowledgments

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