Environmental cost assessment model based on ecosystem services, environmental pollution indicators and DEA

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Abstract. This paper establishes an environmental cost assessment model and uses the losses of ecosystem services to estimate the environmental degradation. Non-monetary estimates of ecosystem services (ESC) are made to determine ecosystem service indicators. Ecosystem services are integrated into three categories: direct services (DV), indirect services (IV), and existential services (EV). The small indicators of direct services, indirect services and existential services are respectively weighted by entropy weight method. Further the coefficient of variation method is used to weight three services, and finally we can obtain a linear combination of ecosystem services. Environmental pollution indicators (EPI) are used to assess the losses of biodiversity and ecotourism values. The linear function is used to indicate the reduction trend of ecotourism benefits due to environmental pollution. The sigmoid function is used to indicate the decreasing trend of biodiversity due to environmental pollution. Finally, the DEA model is established to evaluate the real benefits of land use projects.

1. Introduction
With the development of urbanization, land use projects are increasing. However, people ignore the pollution problems brought by the project to the environment, which affects the function of ecosystem services. Therefore, it is necessary to use environmental costs as an evaluation factor for land use projects.

According to Liu's article [1], ecosystem services are divided into three areas: direct services, indirect services, and existential services. Direct services are main products/services related to the changes in stock and flows of ecosystems. Indirect services refer to the different environmental matrices: air; Soil. Existence Services include climate regulation, biodiversity maintenance, water and runoff regulation, tourism and recreation value, culture and education value. Research on the trade-offs and synergies between biodiversity and ecosystem services can better assist project managers and land planners in making advisable decision, as well as developing planning and adaptation strategies to reduce the disadvantages of the biodiversity crisis.[2]

2. Symbol Systems:
Table 1. Symbol systems

| Symbol | Symbol Description |
|--------|--------------------|
| DV     | Direct value       |
| IV     | Indirect value     |
| EV     | Existential value  |
| ESV    | Ecosystem services |

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3. Model establishment and solution

3.1. Ecosystem services

First, there is a need to identify the indicator of ecosystem services. According to reference [1], we select the direct services include: net primary productivity [3] and soil mineral content. The benefit of this classification is to eliminate correlations between indicators and avoid double counting of the same value [5]. Indirect services include: harmful gas, dust content, incidence of respiratory disease and heavy metal pollution emissions. Existental services include: greenhouse gases, biodiversity, vegetation coverage and ecotourism benefits. Firstly, the corresponding normalization processing method can be selected according to the different characteristics of each data, and then the 10 small indicators are weighted by the entropy weight method. The coefficient of variation method can be used to weight the three services, and finally, a linear combination of ecosystem services can be identified. The data standardization is:

- Cost-type index:
  \[ y_{ij} = \frac{\max(x_i) - x_{ij}}{\max(x_i) - \min(x_i)} \quad i = 1, 2, \ldots, n; j = 1, 2, \ldots, n \]  

- Benefit-type index:
  \[ y_{ij} = \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)} \quad i = 1, 2, \ldots, n; j = 1, 2, \ldots, n \]  

- Moderate-type index:
  \[ y_{ij} = \frac{|\max(x_i) - x_{op}|}{\max(\max(x_i) - x_{op}, |\min(x_i) - x_{op}|)} \quad i = 1, 2, \ldots, n \]  

Where \( \max(x_i) = \max(x_{i1}, x_{i2}, \ldots, x_{in}) \), \( \min(x_i) = \min(x_{i1}, x_{i2}, \ldots, x_{in}) \), \( x_{op} = 0 \).

The cost-based indexes: greenhouse gas, harmful gas, dust content, incidence of respiratory diseases, and heavy metal pollution. The benefit-type indexes: Vegetation coverage, biodiversity, net initial productivity of vegetation, ecotourism benefits. The moderate-type indexes: the amount of organic matter in the soil.

Then we bring the standardized results into the entropy method:

- \( p_{ij} \) Calculation:
  \[ p_{ij} = \frac{y_{ij}}{\sum_{j=1}^{n} y_{ij}} \]  

- Information entropy calculation:
  \[ E = - \ln(n)^{-1} \sum_{j=1}^{n} p_{ij} \ln(p_{ij}) \]  

- The corresponding weight \( w_i \):
  \[ w_i = \frac{1 - E_i}{k \sum_{i=1}^{k} E_i}, i = 1, 2, \ldots, k \]  

The larger the information entropy \( E \), the smaller the corresponding weight.

The results of the various components obtained are:

- Direct value indicator: \( DV = 0.5085y_{11} + 0.4915y_{12} \)
  
  Where \( y_{11} \) is the content of organic matter in the soil and \( y_{12} \) is the net primary productivity of vegetation. From the data in the table, it can be seen that the net primary productivity of vegetation and the organic matter content in the soil has almost the same contribution to the direct value.

- Indirect value indicator: \( IV = 0.2535y_{21} + 0.2510y_{22} + 0.2428y_{23} + 0.2528y_{24} \)
Where $y_{21}$ is the dust content, $y_{22}$ is the amount of harmful gas emissions, $y_{23}$ is the incidence of respiratory diseases, and $y_{24}$ is the amount of heavy metal pollution.

Existential value indicator: \[ EV = 0.2627y_{31} + 0.2259y_{32} + 0.2621y_{33} + 0.2494y_{34} \]

Where $y_{31}$ represents vegetation coverage and $y_{32}$ represents biodiversity, $y_{33}$ represents eco-tourism benefits, and $y_{34}$ represents greenhouse gas emissions. It can be seen that vegetation coverage and ecotourism income contribute more to the value of existence.

Then we use the entropy weight method to calculate the weight between the three types of indicators:

The coefficient of variation $V_i$:
\[ V_i = \frac{\theta_i z_i}{z_i}, i = 1, 2, 3 \]  

where $V_i$ is the coefficient of variation of the index $i$, which can also be called as standard deviation coefficient, and $i$ means the standard deviation of the index $i$. And the $z_1, z_2, z_3$ separately means DV, IV, and EV. Then the weight of each index comes to us:
\[ W_i = \frac{V_i}{\sum V_i}, i = 1, 2, 3 \]  

The answer is: \[ ESV = 0.3035DV + 0.4629IV + 0.2336EV \]

As can be seen from the data, indirect value contributes more to ecosystem services, which is more consistent with common sense. Indirect services are co-products or even by-products of the ecological processes. Second is the direct value generated by ecosystems, these benefits can be direct, as in the production of provisions, such as food and water.

3.2. Biodiversity and ecotourism benefits

The increase in environmental pollution will lead to a decline in local ecotourism benefits. We can use linear functions to indicate the trend of ecotourism benefits reduction due to environmental pollution. The emissions of greenhouse gases, harmful gases, dust and heavy metal pollution are selected to represent environmental pollution indicators. Then the four data were normalized by using the logistic normalization method:
\[ P_i = \frac{1}{1 + e^{-b(p_i - \min(p_i))}} \]  

Where $y_i$ is standardized data and $p_i$ represents emissions of greenhouse gases, harmful gases, dust, and heavy metals. Logistic standardization is used to ensure that new data is added to the standardized results and still fall within [0,1].

We use the entropy weight method to calculate the weights and get: \[ EPI = 0.2417P_1 + 0.2513P_2 + 0.2538P_3 + 0.2532P_4 \]

When there is no environmental pollution, it will not cause loss of ecotourism benefits in the area. When the environment is completely polluted, the ecotourism benefits will become 0, and a linear function can be used to express the process:
\[ y = 1 - EPI \]  

For biodiversity, due to the self-regulating function of ecosystems, the impact of environmental pollution on biodiversity is not obvious at first. When environmental pollution reaches a certain level and threatens species survival, it will trigger a series of species extinction. Therefore, the sigmoid function can be used to indicate the trend of biodiversity loss due to environmental pollution. Since the range of the environmental index is [0, 1], the parameter a is set to 10 to limit the span of the function to [0, 1]. It is assumed that when the degree of environmental pollution reaches 50%, the change in biodiversity is the most severe. From this it can be estimated that the value of the parameter b is 5. Therefore, the function expression is:
\[ y = \frac{1}{1 + e^{-5(EPI - 0.5)}} \]
3.3. DEA evaluation model

DEA is an efficient method for evaluating metrics multiple inputs and multiple outputs, and compares inputs with outputs. DEA is to make a linear plan for the input index and the output index, and transform them, then according to the dual problem of its linear programming, the maximum value of the dual problem is θ, generally the bigger the θ value,[4] the better the effect.[6]

Prior to this, land use projects only considered accounting costs, while ignoring environmental costs. Therefore, we will add the environmental cost in the evaluation model to estimate the true economic costs of land use projects.

In the future, we can collect more information about projects and improve the evaluation model of large, medium and small land use projects. And the economic theory can be used to make a reasonable prediction of the long-term variable cost of the project, thus the accuracy of the model can be improved.

In addition, since the environmental impact of land use projects is an ongoing process, time variables need to be considered. We evaluate the true economic costs of land use projects in the short-term (10 years) and long-term (50 years). The cost of the project includes: fixed cost (construction cost), variable cost (cost incurred during operation) and environmental cost. Assuming that the variable costs and benefits of the project are fixed each year, then we can calculate the cumulative costs and benefits of the project for 10 and 50 years. Seven representative medium and large projects were selected for analysis. Large-scale projects include: Walt Disney World (WDW), Denver International Airport (DIA), California north south water (NSW), medium-scale projects: Golden Gate Bridge (GGB), Hoover Dam (HD), Grand Coulee Hydroelectric Power Station (GCH), Boston Grand Tunnel (BGT).

Large projects are typically large national projects or some large-scale commercial projects. It may cause large losses to ecosystem services and affect the local ecological environment, which results a significant decline in the ecological diversity and ecotourism of the region. Therefore, the environmental factor as a criterion for considering the benefits is very necessary.

![Figure 1. Accounting and environmental costs for large projects](image)

The left side of the picture represents the short-term status of the project and the right side represents the long-term status of the project. Each project has two column indicators, the columnar indicator on the left represents the accounting cost of the project, and the columnar indicator on the right represents the environmental cost of the project. The polyline represents the total revenue of the project during the operation period. It can be seen from the figure that the input cost of the project is positively correlated with the environmental cost of the project, and the environmental cost is gradually increasing as the time goes.
Table 2. DEA analysis model for large projects

| Projects | Technical efficiency | Scale efficiency |
|----------|----------------------|------------------|
| 1        | 1.000                | 1.000            |
| 2        | 1.000                | 1.000            |
| 3        | 1.000                | 0.110            |

Large-scale project (10 years)

In the short term, the cost of Walt Disney World and Denver International Airport is already at the best value without adjustment. In addition, for California north south water should continue to increase investment, because when it continuously operates, people can get good returns.

In the long term, all three projects are in the best mix of cost investment. However, Denver International Airport should reduce its current total investment. Although it can generate a lot of profits when it operates, it will generate large environmental costs in long-term operation.

Table 3. DEA analysis model for medium-sized projects

| Projects | Technical efficiency | Scale efficiency |
|----------|----------------------|------------------|
| 1        | 1.000                | 0.099            |
| 2        | 1.000                | 0.699            |
| 3        | 1.000                | 1.000            |
| 4        | 1.000                | 1.000            |

Medium-scale project (10 years)

In the long term, the Golden Gate Bridge and Hoover Dam are in economies of scale. In the short-term and long-term, managers of the Golden Gate Bridge and Hoover Dam are advised to increase investment. It can be seen in the model that this is a very correct choice.

Figure 2. Accounting costs and environmental costs for medium projects

4. Conclusion
The article provides a non-monetary estimate of ecosystem services, further we defined the environmental degradation cost and the environmental cost. The environmental costs are added to the land use project assessment model. The DEA evaluation model is used to compare and analyze each project. Reasonable suggestions are made to land planners and project managers.

In the future, we can collect more information about projects and improve the evaluation model of land use projects. And the economic theory can be used to make a reasonable prediction of the long-term variable cost of the project, thus the accuracy of the model can be improved.
We can use this assessment model to assess the benefits of environmental protection programs for ecosystem services, which only needs to convert the environmental cost index into the environmental benefit index.

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