# Calculating the True Costs of Land Use Project

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**Keywords:** Environmental costs; Ecological Services Valuation Model; Cost benefit analysis

**Abstract:** In order to measure the environmental costs in land use projects, we establish two types of Ecological Services Valuation Model: The Large-Scale Ecological Service Valuation Model and the Small-and-Medium Scale Ecological Services Valuation Model. Next, we build the Dynamic Measurement Model of Ecological Services Valuation taking time change into account. We obtain environmental costs based on reduction of ecological services value.

## 1. Introduction

Economic theory often ignores the impact of people's decisions on the environment. Many land use projects change the ecosystem, and then leads to the degradation of ecosystem services. They have generated huge environmental cost without taking the cost into account. In order to solve this problem and figure out the real economic cost of a land use project, we are required to establish an ecological services valuation model and conduct cost-benefit analysis on land use projects of different size. At the end of this paper, after evaluating the effectiveness of the model, we reveal the implications of our modeling on land use project planners and managers.

Our tasks are listed as follows:

1) establishing an ecological services valuation model to measure the environmental cost of land use development projects;

2) analyzing the cost and benefit of land use development projects of different scales;

3) revealing our model's implication on the land use project planners and managers based on the obtained model;

4) Evaluating the effectiveness of our model.

## 2. Problem Analysis

Our Ecological Services Valuation Model will be based on the Benefit Transfer Method. To use this model, we will need to make the following assumptions:

1) Since the non-use value of ecological services cannot be measured, we only consider its use value ignoring its non-use value;

2) Unit Value is universal, so there is no deviation;

3) There are no extreme conditions for the land use projects, such as war and waterfalls. Otherwise we cannot use our model to estimate the ecological services valuation.

To use the DEA model, we also assume

4) The land use project will completely eliminate the value of ecosystem services within the scope, that is, the value of local ecosystem services is the environmental cost of the project.

5) All land use projects develop land at a uniform rate during the development period, or we cannot calculate costs and benefits of project;

6) The cost of the land use project only includes the project investment, labor and environmental costs. The income includes only monetary income.

In order to make the results reliable, we also assume

7) Since the South-to-North Water Transfer Project passes many provinces, the land types and proportions of the project equals to that of the overall China.

8) All the data we have obtained about the land use projects are accurate.

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## 3. Ecological services valuation

### 3.1 Land Use Change Model

In order to explore the relationship between land use and ecosystem services valuation, we establish the Land Use Change Model.

● Single Land Use Change Rate $A_S$

Single Land Use Change Rate denotes the change speed and degree of a certain type land use over a period of time, which reflects the impact of human activities [7].

$$A_s = \frac{s_{it_2} - s_{it_1}}{s_{it_1}} \times \frac{1}{t_2 - t_1} \times 100\% ,$$

where $s_{it_1}, s_{it_2}$ are the areas of land $i$ in $t_1$,$t_2$ respectively.

● Comprehensive Land Use Change Rate $A_C$

Comprehensive Land Use Change Rate is an indicator for calculating the changes in all land use types in a certain area, reflecting the comprehensive impact of human activities on land use.

$$A_c = \frac{1}{t_2 - t_1} \sum_{i=1}^{n} (\Delta S_{ij} / S_i) ,$$

where

$\Delta S_{ij}$ is the sum of the conversion areas of land $i$ using in type $j$;

$S_i$ is the sum of the area of the i-type land use;

$n$ is the sum of land types.

### 3.2 Ecological Services Valuation Model

First, we divide the ecosystem service valuation model into two submodels: the large-scale ecological service valuation model and the small- and medium-scale ecosystem service valuation model.

● The Large-Scale Ecological Service Valuation Model

We construct the Large-Scale Ecological Service Valuation Model based on Benefit Transfer Method (BTM). BTM is a secondary assessment method that transfers existing environmental valuation results to other regions with similar demographic, economic, and ecological characteristics [8].

We refer to the Eco-Service Price List (Appendix) and the classification of ecological services (Figure 1 below) in Costanza's paper in 1997 [2].

In addition, according to Costanza's research, unit ecological service value was $54\$ \cdot \mathrm{hm}^{-2}$ in 1997. After taking the time value into account, the present unit ecological service value ($ESV_u$)is:

$$ESV_u = 54 \times (1 + I)^n ,$$

where

$I$ is Federal Reserve benchmark interest rate in 1997 June;

$n$ is the current number of years minus 1997.


Figure 1. The classification of ecological services

Then ecological services value in a large area ($ESV$):

$$ESV = \sum_{i=1}^{m}\sum_{j=1}^{n} S_i \times ESV_u \times ESV_Q,$$

where

$S_i$ is the sum of the area of the i-type land use;

$ESV_Q$ is ecological service value equivalent factor.

● The Small-and-Medium Scale Ecological Services Valuation Model

The Benefit Transfer Method ignores the changes in ecological service functions, which may cause great uncertainty of the results of small and medium-scale ecosystem. Therefore, we should use specific methods on different service types in the small and medium-scale ecological services valuation. The corresponding methods are shown in Table 1.

Table 1. Methods used in the small and medium-scale ecological services valuation

| **Ecological Service Type** | **Valuation Method** | **Value** |
|---|---|---|
| Production of organic matter $N_1$ | Market pricing | *=Organic matter production × Direct use value* |
| Water cycle $N_2$ | Market pricing | *=Annual total water source × water price* |
| Soil production $N_3$ | Opportunity cost | *=Average income from ecosystem production ×(The difference between soil erosion per unit area before and after soil erosion×Total area of ecosystem / average thickness of topsoil)* |
| Biodiversity $N_4$ | Market pricing | *=Fixed assets to protect species inputs in ecosystems+Staff costs+Direct loss of local industries due to the protection of species* |
| Climate regulation $N_5$ | Carbon tax, Alternative cost | *=Fixed carbon in ecosystem×Carbon tax+Oxygen demand of Ecosystem ×Industrial oxygen unit cost* |
| Interference adjustment $N_6$ | Disaster prevention cost | *=The cost per unit area of the ecosystem to prevent biological disasters×Total area of the ecosystem* |
| Scientific research value $N_7$ | Market pricing | *=Annual research costs+Teaching practice value+Publication value+Film and television publicity value* |
| Entertainment value $N_8$ | Expenses | *=Transportation fee+Exceeding the usual food and beverage expenses during entertainment+Accommodation fee+Entrance fee+Other costs+Time value of tourists* |

Then we calculate the value of ecosystem services (*ESV*): $ESV = \sum_{i=1}^{n} N_i$,

where

$N_i$ is the value of the i-th function.

### 3.3 Dynamic Measurement Model of ESV

Since the internal and external structure of the ecosystem are constantly changing with time passing, the ecological services functions and valuation also vary.

According to Xie [5,6], through introducing NPP, precipitation and soil-regulated spatial and temporal dynamic factors, we can construct a Dynamic measurement Model of Ecological Services Valuation. In this model:

● Food production, raw material production, gas regulation, climate regulation, environmental purification, nutrient cycling, biodiversity and aesthetic landscape functions are positively related to biomass; $(n_1)$

● Water supply and hydrological regulation are positively related to precipitation; $(n_2)$

● Soil conservation is positively related to precipitation, topographic slope, soil properties and vegetation cover. $(n_3)$

The ecological service value equivalent factor ($ESV_{Qnij}$):

$$ESV_{Qnij} = \begin{cases} T_{ij} \times F_{n1} or \\ R_{ij} \times F_{n2} or \\ S_{ij} \times F_{n3} \end{cases}$$

The three space-time adjustment factor:

$$\begin{cases} T_{ij} = \dfrac{B_{ij}}{\overline{B}} \\ R_{ij} = \dfrac{W_{ij}}{\overline{W}} \\ S_{ij} = \dfrac{E_{ij}}{\overline{E}} \end{cases}$$

Through the formula above, we can obtain the dynamic $ESV_Q$ table of the ecological service value per unit area, and then study the value of ecosystem services in dynamic processes.

## 4. Cost-benefit analysis of different projects

### 4.1 DEA-Malmquist Index Model

Data Envelopment Analysis (DEA) is an effective method for comparing the relative efficiency and effectiveness of several similar types of decision units with multiple inputs and multiple outputs [9]. Based on the actual decision-making unit in a production system, DEA is built on the “Pareto optimal” concept of the decision-making unit. By using the linear programming technique to find the leading-edge production function of the production system, we can obtain the relative efficiency and scale benefits of each decision unit. [10]

● Model establishment

In order to quantitatively analyze the costs and benefits of land use development projects when considering environmental costs, we introduce the concept of green cost-benefit ratio (*GCBR*). The larger the *GCBR*, the higher the cost-benefit efficiency of the land use project, and vice versa. This paper evaluates the costs and benefits of projects by establishing the *DEA Model* to calculate *GCBR*.

We assume that there are $n$ decision units $DMU_i, i = 1,2,\cdots n$ . $DMU_i$ inputs are $x_i = (x_{1i}, x_{2i}, \cdots\ x_{mi})^T$, outputs are $y_i = (y_{1i}, y_{2i}, \cdots\ y_{si})^T$. $m$ is the number of inputs,$s$ is the number of outputs,$x_i$, $y_i \geq 0$,$i = 1,2,\cdots n$, which means the components of $x_i$,$y_i$ are non-negative and at least one is positive. $D_i^t(x^t, y^t)$ is input distance function。According to the DEA -Malmquist method [11], We calculate the *Malmquist Index* from t to t+1 period:

$$M_i^t = \frac{D_i^t(x^t, y^t)}{D_i^t(x^{t+1}, y^{t+1})}$$

Similarly, the Malmquist index of the *GCBR* change from period *t* to *t*+1 can be defined under the technical conditions of period *t*+1:

$$M_i^{t+1} = \frac{D_i^{t+1}(x^t, y^t)}{D_i^{t+1}(x^{t+1}, y^{t+1})}$$

In order to avoid the randomness of the period selection, we take the two Malmquist indexes as geometric mean, finally obtain the *GCBR* changes from period *t* to *t*+1:

$$GCBR_{i,t+1} = M_i(x^{t+1}, y^{t+1}; x^t, y^t) = [\frac{D_i^t(x^t, y^t)}{D_i^t(x^{t+1}, y^{t+1})} \cdot \frac{D_i^{t+1}(x^t, y^t)}{D_i^{t+1}(x^{t+1}, y^{t+1})}]^{1/2}$$

If $GCBR_{i,t+1}$>1, it indicates that *GCBR* increases from period *t* to *t*+1; If $GCBR_{i,t+1}$<1, it indicates that *GCBR* declines from period *t* to *t*+1; If $GCBR_{i,t+1}$=1, it indicates that *GCBR* is stable from period *t* to *t*+1

The Malmquist index can be further divided into three decomposition indexes: green technology level change (*GTC)*, green technology efficiency change (*GPE*) and green scale efficiency change (*GSE*):

$$GCBR_{i,t+1} = GTC_{i,t+1} \times GPE_{i,t+1} \times GSE_{i,t+1},$$

$$GTC_{i,t+1} = [\frac{D_i^t(x^t, y^t)_{CRS}}{D_i^{t+1}(x^t, y^t)_{CRS}} \cdot \frac{D_i^t(x^{t+1}, y^{t+1})_{CRS}}{D_i^{t+1}(x^{t+1}, y^{t+1})_{CRS}}]^{1/2},$$

$$GPE_{i,t+1} = \frac{D_i^t(x^t, y^t)_{VRS}}{D_i^{t+1}(x^t, y^t)_{CRS}} \cdot \frac{D_i^t(x^{t+1}, y^{t+1})_{CRS}}{D_i^{t+1}(x^{t+1}, y^{t+1})_{VRS}},$$

$$GSE_{i,t+1} = \frac{D_i^{t+1}(x^{t+1}, y^{t+1})_{VRS}}{D_i^t(x^t, y^t)_{VRS}},$$

where

*CRS*, which is a subscript, indicates that the scale returns are unchanged;

*VRS* indicates that the scale returns are variable;

*GTC* reflects the translation of the frontier of the technology in consideration of environmental costs;

*GPE* is the ratio of the actual factor input of the i-th decision unit to the minimum input of the same output level. It reflects the efficiency of economic resource use under consideration of environmental costs when the level of green technology remains unchanged.

*GSE* refers to the distance between the actual economic scale of the i-th decision unit and the optimal scale with the current technology under the condition of variable scale returns. It reflects the extent to which green economies of scale are achieved.

- Index selection

(1)Input index $x$

- Capital Investment ($x_1$):Funds invested in the land use project;
- Environmental Cost ($x_2$):The reduction of *ESV* (based on Assumption 4)
- Labor ($x_3$): Number of participants in the project.

(2)Output index $y$

- Income of the project ($y_1$)

- Model application

Using the DEA model, we can calculate the *GCBR* for each land use project at different times. On the one hand, we can evaluate the trend of *GCBR* of the project itself, and then find a balance point between environmental protection and economic benefits. we can also analyze the cause based on the three decomposition indexes. On the other hand, we can compare the cost benefits of different land use projects based on *GCBR.*

## 5. Implication on project planners and managers

### 5.1 Selection of optimal land use plan

In order to help project planners and manager select the optimal land use plan considering the cost of ecosystem degradation, we introduced the DEA-$C^2R$ Model in the DEA method:

$$\max \frac{u^T Y_j}{v^T X_j},$$
$$s.t.\begin{cases} \frac{u^T Y_j}{v^T X_j} \le 1,\ j = 1,2,\ldots,n \\ u, v \ge 0 \quad and \quad u, v \ne 0 \end{cases}$$

where

$X_j, Y_j$ $(j = 1,2,\cdots n)$ are the cost and benefit vector of the plan $j$ respectively;

$V$, $U$ is the corresponding weight vector.

Using Charnes-Cooper transformation, we converse the above model into an linear programming problem:

$$\max V_j = \mu^T Y_j,$$
$$s.t.\begin{cases} \omega^T X_j - \mu^T Y_j \ge 0,\ j = 1,2,\ldots,n \\ \omega^T X_j = 1 \\ \omega \ge 0, \mu \ge 0 \end{cases}$$

where

$$\omega = tv, \mu = tu, t = \frac{1}{v^T X_j}.$$

Then through the dual processing of the above model, we get

$$\min \theta$$
$$s.t.\begin{cases} \sum_{j=1}^{n} \lambda_j X_j \le \theta X_j \\ \sum_{j=1}^{n} \lambda_j Y_j \le Y_j, \lambda_j \ge 0,\ j = 1,2,\ldots,n \end{cases}$$

where

$\theta$ is the decision coefficient (when $\theta = 1$, we say DEA is effective and land use project is optimal).

## 6. Case study

### 6.1 Qixinghe Nature Reserve Project

We select Qixinghe Nature Reserve project as a case study for our model. Qixinghe Nature Reserve is a national nature reserve in China, located in the Heilongjiang Province. It was listed in the International Important Wetlands List in 2011. Here is the topographic map of the Qixinghe Nature Reserve by GIS remote sensing technology (Figure 2):

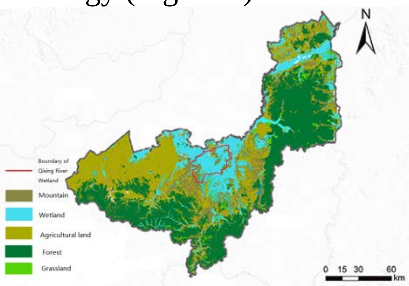


Figure 2. The topographic map of the Qixinghe Nature Reserve

We calculated the Environmental Cost ($x_2$) by entering the parameters of the Qixinghe Nature Reserve (Appendix) into the Small-and-Medium Scale Ecological Services Valuation Model . Then according to Assumption 5 (the project exploits land at a uniform rate during the development period), we can estimate the annual cost and benefit of the project. Finally, we get the input and output parameters in the DEA-Malmquist Model of the Qixinghe Nature Reserve.

## 6.2 South-to-North Water Transfer Project

The South-to-North Water Transfer Project is one of China's greatest projects aiming at alleviating water shortage problem in northern China.

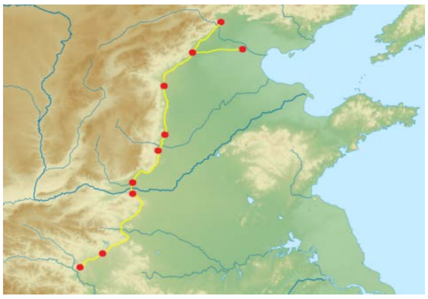

Figure 3. The middle route of South-to-North Water Transfer Project

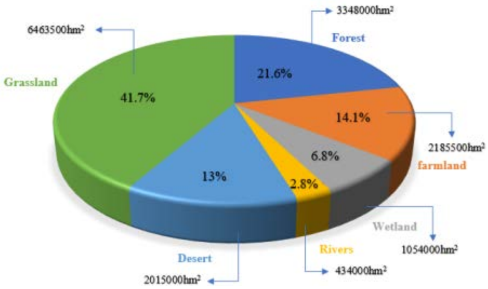


Figure 4. The proportion of land types in the South-to-North Water Transfer Project

We calculated the Environmental Cost ($x_2$) by entering the parameters of the South-to-North Water Transfer Project (Appendix) into the Large-Scale Ecological Service Valuation Model(based on Assumption 7). Similarly, we get the input and output parameters in the DEA-Malmquist Model of the South-to-North Water Transfer Project.

## 6.3 Cost-benefit analysis

Using the data , we use the DEA-Malmquist Model to analyze the cost-benefit situation of these two projects when considering environmental costs.

We calculate the green cost-benefit ratio (*GCBR*) of the two projects from 2005 to 2013 with DEAP2.1.

Table 2. GCBR of the two projects from 2005 to 2013

| year | Qixinghe Nature Reserve | | | | South-to-North Water Transfer Project | | | |
|---|---|---|---|---|---|---|---|---|
| | ***GCBR*** | ***GTC*** | ***GPE*** | ***GSE*** | ***GCBR*** | ***GTC*** | ***GPE*** | ***GSE*** |
| 2005 | 1.463 | 1.555 | 1 | 0.941 | 1.154 | 1.154 | 1 | 1 |
| 2006 | 1.354 | 1.83 | 1 | 0.74 | 1.697 | 1.697 | 1 | 1 |
| 2007 | 0.806 | 1.201 | 1 | 0.671 | 1.171 | 1.171 | 1 | 1 |
| 2008 | 0.785 | 1.098 | 1 | 0.715 | 1.188 | 1.188 | 1 | 1 |
| 2009 | 0.833 | 1.042 | 1 | 0.8 | 0.911 | 0.911 | 1 | 1 |
| 2010 | 2.286 | 0.8 | 1 | 2.855 | 0.772 | 0.772 | 1 | 1 |
| 2011 | 2.025 | 0.931 | 1 | 2.175 | 0.818 | 0.818 | 1 | 1 |
| 2012 | 0.576 | 1.105 | 1 | 0.521 | 0.855 | 0.855 | 1 | 1 |
| 2013 | 0.857 | 1.159 | 1 | 0.74 | 0.942 | 0.942 | 1 | 1 |
| Mean | 1.221 | 1.191 | 1 | 1.129 | 1.056 | 1.056 | 1 | 1 |

According to the results of Table 2, the average *GCBR* of Qixinghe Nature Reserve from 2005 to 2013 was 1.221, which shows the overall cost-benefit condition of it has improved during this period of time. Moreover, *GCBR* is boosted by *GTC* and *GSE*. In 2010, *GCBR* (=2.286) reached its maximum, so the cost-benefit condition was optimal when considering environmental costs. In addition, by observing the three decomposition indexes in 2010, we know that the growth of *GCBR* is only derived from the increase of *GSE*, which reflects that the economic effect of scale expansion of land use projects can promote cost-benefit situation. In 2012, *GCBR* (=0.576) was the lowest. Although *GTC* improved significantly in 2012, *GSE* was low, resulting in *GCBR* of the whole project was not high.

Compared with the Qixing Nature Reserve Project, the South-to-North Water Transfer Project is a state-scale land use development project, so the cost-benefit situation of the project differs greatly from the former. As can be seen from Figure 5, the average *GCBR* of the South-to-North Water Transfer Project was 1.056 from 2005 to 2013, so the overall cost-benefit situation of the project optimized during the development period. The increase of GCBR is totally due to the increase of *GTC*, while *GPE* and *GSE* remain unchanged.

Comparing the two projects, we find that the average *GCBR* of the Qixinghe Nature Reserve Project is significantly higher than that of the South-to-North Water Transfer Project when considering the environmental cost. And this result is consistent with reality. The South-to-North Water Transfer Project changed the ecological environment of its passing provinces during the development process, increasing the risk of geological disasters and destroying biodiversity [12]. Therefore, although it brings high benefits to the residents of northern China, the environmental cost is extremely high, which reduces the *GCBR*.

Based on the analysis of the above cases, we can extend the conclusions to other land use projects. For large-scale land use projects, although the high economic effect of scale, due to their strong destructiveness to the environment, development strategies based on environmental protection should be adopted to minimize reduction of the ecosystem services value. For small-and-medium land use projects, their environmental damage is small. So, it is only necessary to appropriately invest in environmental protection.

### 6.4 Implication on project planners and managers

We simulate ten development plans of Qixinghe Nature Reserve Project (Figure 5). Then, we enter the data in Figure 5 into the selection model for the optimal land use plan in 5.1. Using MATLAB, we calculate the $\theta$ for each phase of the project, as shown in Table 3 below.

| Plan | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Capital Investment ($x_1$) | 12.20 | 25.20 | 39.85 | 56.60 | 76.21 | 96.45 | 118.90 | 142.57 | 162.85 | 179.94 |
| Environmental Cost ($x_2$) | 2.08 | 4.48 | 6.61 | 9.11 | 10.58 | 14.79 | 19.47 | 28.11 | 40.26 | 51.35 |
| Labor ($x_3$) | 2780 | 5558 | 8338 | 11117 | 13896 | 16671 | 19453 | 22227 | 25000 | 27773 |
| Income of the project ($x_4$) | 16.03 | 43.15 | 99.07 | 175.90 | 274.64 | 380.89 | 375.18 | 367.74 | 255.43 | 241.01 |

Figure 5 Plans of Qixinghe Nature Reserve land use development Project plans

Table 3. θ for each phase of the project

| **Plan** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Degree of development** | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |
| $\boldsymbol{\theta}$ | 0.3327 | 0.4336 | 0.6295 | 0.787 | 1 | 1 | 0.8442 | 0.7241 | 0.4472 | 0.3798 |

It can be seen from the above table 3 that $\theta$=1 in the 5th and 6th phases, which means at this time the DEA is valid. We can conclude that the land use achieves optimum situation at 50% and 60%, which balance the environmental protection and project profitability. Although both are the best decision points, the environmental protection and profitability of the two plans are not the same. The former achieves optimum situation under the relatively minimal degradation of ecological services, while the latter seeks to minimize the degradation of ecological services and maximize returns. In other words, the environmental protection of Plan 5 is relatively greater than the profitability, while the profitability of Plan 6 is relatively greater than the environmental protection.

Hence, we recommend planners and managers select the land development plan taking the local economic conditions and natural environment into consideration.

## 7. Conclusion

In this paper, we solve the problem of environmental cost measurement and cost- benefit analysis of land use projects by establishing mathematical models.

First, we establish the Ecological Services Valuation Model based on the Benefit Transfer Method, market pricing method and so on. Then we further extend the model to dynamic measurement.

Second, we analyze the cost-benefit situation of land use projects using the DEA-Malmquist Index Model. Through the model calculation, we get the green cost-benefit ratio (GCBR) and three decomposition indexes. Among them, GTC can be used to assess the green technology efficiency of land use projects; GPE can be used to judge the green resource allocation efficiency of the project; GSE refers to the green scale efficiency of the project.

Third, we conduct the model using two land use projects in China. We find:

- For large-scale land use projects, due to their high environmental damage power and economic benefits from economies of scale, they should develop a development plan based on environmental protection and try their best to reduce the degradation of ecosystem services;
- For small-and-medium-sized land use projects, because their income is unstable and the damage to the environment is usually small, development plan can pay more attention to revenue.

Finally, our model passes the sensitivity test and accuracy test to prove that the model is stable and accurate.

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