

Research Article

Redefinition of Cost-Benefit Efficiency of Land-Use Projects: Focusing on Environmental Cost

Xu Chen,¹ Qianyi Du,¹ Xueyan Xiong,¹ Deliang Zhong,¹ Na Deng,² Shudong Liu ,¹ and Yipeng Li¹

¹School of Information and Security Engineering, Zhongnan University of Economics and Law, Wuhan 430073, China

²School of Computer, Hubei University of Technology, Wuhan, China

Correspondence should be addressed to Shudong Liu; bupt.mymeng@gmail.com

Received 26 June 2019; Revised 16 October 2019; Accepted 17 October 2019; Published 21 November 2019

Academic Editor: Erik Cuevas

Copyright © 2019 Xu Chen et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The cost-benefit efficiency of projects is often wrongly evaluated due to the neglect of projects' impact on the environment. In this paper, we aim to establish a model to measure such an impact and hence propose a more reasonable approach to evaluating cost-benefit efficiency of projects. We divide the total cost of a certain project into two parts: Business Cost (BC) and Environmental Cost (EC). BC is the explicit cost that can be approached from financial statements, while EC is the implicit cost which we try to quantify. EC is composed of three parts: (1) the Ecosystem Service Value (ESV), (2) the Restoration Cost (RC) to treat the pollution caused by the projects, and (3) the Disaster Cost (DC), potential losses caused by disasters due to launch of new projects. In order to make a cost-benefit efficiency analysis, we introduce profitability index, which is further developed into an adjusted profitability index by taking time value into consideration. Two case studies are conducted to evaluate the effectiveness of the model. A regional case of a coal-mining project proves that RC and DC play a significant role in cost-benefit efficiency analysis, while a nationwide case of high-speed rail shows that project scale matters. Additionally, we put our attention on the intensity of the project, which is a created measurement to characterize the project. Based on the study of intensity, the mechanism of cost-benefit break-even is further explained and some suggestions are proposed to policy makers.

1. Introduction

In developing countries such as China and India, infrastructure construction is in full swing with the acceleration of modernization. To a certain extent, these projects meet the needs of the contemporary era to promote social development. But at the same time, they take a large number of natural land resources, which brings challenges to the sustainable development of society. Therefore, finding a way to quantify environmental cost is crucial to maintain a sustainable society and provide a promising future for the next generations. Over the past decades, a sustainable indicator, which was proposed by Wackernagel and Rees [1], has become one of the most widely used indicators for assessing environmental sustainability, namely, ecological footprint (EF). This indicator refers to the area of a productive land needed to sustain a certain amount of

population within a country or region. More specifically, this concept was designed to quantify the sustainability of a specific land and focused more on the human's influence on environment. Based on this theory, researchers proposed a method called ecosystem service footprint (ESF), which can help us measure various services and products provided by a certain region.

In order to find a balance between current and future needs, decision makers need to calculate the environmental costs of infrastructure projects more accurately. Traditionally, land-use projects do not consider their impact on ecosystem. While individually these activities may seem inconsequential to the total ability of the ecosystem's functioning potential, collectively they are directly accelerating environmental degradation. This kind of degradation is also a cost of the projects that should be included in the total cost. There have been a number of research

studies over calculating environmental costs of land-use projects. For example, Du et al. [2] divided the environmental cost into four classes and evaluated them with proposed methods called activity-based costing method (ABC) and fuzzy comprehensive evaluation method (FCE). Although their study has covered costs of resource consumption, environmental protection, pollution treatment, and environmental loss, they neglected the potential disaster cost caused by the construction project. Moreover, their research focused solely on the construction phase, leaving out the other period of a project which is also important to the calculation of environmental cost. In addition, many related studies concentrated only on one or two aspects of ecosystem service, which induced bias in cost-benefit analysis.

In order to address the issues above, we proposed several methods to adjust our model, so that we can acquire better results for calculating the environmental cost. First of all, we establish a model to help measure the environmental cost of projects and make more comprehensive cost-benefit analysis of projects by including Ecosystem Service Value (ESV), Restoration Cost (RC), and Disaster Cost (DC). Secondly, we apply several methods to improve each submodel according to different situations. For instance, we relate the ESV model to the people's average consumption within a region, reducing the complication of calculation and increasing flexibility of the model. At the same time, taking the entire lifespan of projects into consideration is equally important, so we use different models to estimate costs in terms of different periods of a project. Additionally, we use "intensity" to illustrate the scale of a project, which has a great impact on the measurement of RC. In conclusion, the results of the model can be used not only as the basis for decision-making of infrastructure projects, but also as a simple measuring tool for environmental protection tax, compensation for environmental protection cases, ecological compensation standards, corporate social responsibility measurement, etc. It has good application prospects.

The main objective of this study was to propose and make modifications to models in order to accurately calculate environmental cost of the capital construction project. This paper consists of five parts: Section 1 makes a brief introduction to the calculation of environmental costs, discusses current researches and contributions, and presents issues we will address; Section 2 summarizes related works of environmental cost; Section 3 describes the model we use in detail and presents the results of our case studies; Section 4 conducts modifications to the models and applies the change to the case studies; and Section 5 introduces the advancement of our model. In the end, Section 6 concludes the strengths and weaknesses of our research and proposes our advice to decision makers.

2. Related Work

Recently, some research studies have been conducted to design the calculation method of environmental costs, and

most of the researchers believe that environmental cost consists of Ecosystem Service Value and ecological regulation value. Since the concept of ecosystem services was put forward in the second half of the 19th century, some scholars have continuously perfected and supplemented this theory. There are two main ways to measure the value of ecosystem services, one is that Norgaard et al. [3] systematically analyzed the components of ecosystem services and quantitatively analyzed the value of each part of services. The other is Wackernagel et al. [4] developed the ESF model which gives the corresponding relationship between land area and human demand and is related to the economic development of various regions. After them, researchers basically optimize and empirically analyze the theory in these two directions. It is noteworthy that Norgaard et al. [3] put forward the theory that environmental resources can be exchanged alternately among generations, which reveals the relationship between environmental cost measurement and strategic decision-making of sustainable development.

There are more or less deficiencies in the existing research. The ESV measurement method cannot enumerate ecosystem services in an all-round way and neglects the difference of the land relative value caused by regional development differences, so it cannot measure the accurate value. The ESF method, proposed by Wackernagel et al. [4], only built the corresponding relationship between land area and human needs, but failed to put it into practice. The measurement of the value of ecological regulation is based on machine learning analysis of historical data, which ignores an important impact-government intervention. In China, the data of government's environmental costs have shown the phenomenon of faulty growth, which is difficult to assess through machine learning.

Based on previous studies, this paper proposes that the Environmental Cost (EC) of land consists of three parts: Ecosystem Service Value (ESV), Restoration Cost (RC), and Disaster Cost (DC):

$$EC = ESV + RC + DC. \quad (1)$$

As for the measurement of ESV, we adopt the ESF method as the basis to realize the monetization of the environmental value of land-use projects through the monetization of human needs. RC corresponds to the value of ecological regulation services studied by predecessors. The difference is that we exclude the duplicated human repair costs and only focus on the cost of natural repair. DC is another part of cost proposed by us, representing the economic losses caused by potential disasters resulting from the land-use project. The Ecosystem Service Value (ESV) can be regarded as the internal cost of land, while RC and DC can be regarded as the spillover cost of projects. Two practical cases of the Shanxi coal-mining project and the China high-speed railway project are studied to test the feasibility and robustness of the model.

Under the influence of these two famous research studies, there has been a certain amount of research studies on environmental costs of national construction projects. Du et al. [2] studied accounting method of environmental

cost during the construction phase of a project, dividing the cost into four parts and, respectively, calculated the costs of each part. Their study aimed to help governments and construction companies improve their control method of environment cost and arouse the awareness of environmental protection. Khodarahmi et al. [5] used the hydro-power's environmental costs analysis model (HECAM) to assess the environmental cost of Kasilian Dam, focusing on locating the most influential environmental factor of the dam's construction.

To simplify the calculation of environmental cost, some studies focused on estimating the ecosystem service value. Su et al. [6] studied the urbanization impact on several regions in China by combining landscape pattern analysis with ecosystem service value, and the result of their study offered a reference for lands' urbanization planning. Sannigrahi et al. [7] discovered that support vector machine (SVM) and random forest (RF) algorithms had the best performance in different ecosystems' classification, and they conducted experiments on all kinds of ecosystems and compared their sustainability and environmental service capacity. The outcome of their research provided references for policy makers to make a better plan for natural conservation and environment protection. Gao et al. [8] developed a new approach named freshwater ecosystem service (FES) footprint model based on ESF's concept; the whole study revolved about assessing freshwater's sustainability and aimed to improve regional freshwater management for decision makers.

Regulation Cost and Disaster Cost are also important parts of environmental cost. However, in contrast to ecosystem service value, there has been relatively less research on RC or DC. Kim et al. [9] put forward a framework for quantifying the loss of regulating ecosystem service caused by the road construction project, evaluating the monetary value of ecosystem's loss. Although this framework did not consider all kinds of ecosystem service, it provided a direction for sustainable development. On the contrary, Eckhardt et al. [10] summed up the methodologies of assessing disaster cost in the literature and organized the economic cost assessment in a systematic way. Other than the RC and DC, there is research focusing on resource recovery assessment. Millward-Hopkins et al. [11] developed an integrated model for multidimensional assessment, not only allowing them to cover the complex value in assessing sustainability, but also addressing several shortcomings of current assessment methods.

3. Model

3.1. Model Assumptions

- (1) Data source is accurate and reliable.
- (2) People are fully supported by the ecosystem.

All the resources that people live on come from the nature, so the value of the ecosystem can be regarded as equivalent of people's consumption expenditure. That is, people's consumption expenditure is a financial form of ecosystem's value.

- (3) Most land-use projects have much more negative impacts than positive impacts, so we neglect the positive ones.

3.2. *Design of the Model.* The aim of the model is to make a cost-benefit analysis of a certain project, which can be derived from the trade-off between total cost and total benefit. We use a profitability index to measure the cost-benefit efficiency of the project:

$$\text{Profitability index} = \frac{\text{total benefit} - \text{total cost}}{\text{total cost}}. \quad (2)$$

Traditionally, people regard business cost (BC) as the total cost but tend to ignore the negative impact of the project on the environment, which we define as environmental cost (EC) (see Figure 1).

The environmental cost is composed of three parts, namely, Ecosystem Service Value (ESV), Restoration Cost (RC), and Disaster Cost (DC):

$$EC = ESV + RC + DC. \quad (3)$$

The Ecosystem Service Value (ESV) is effectively the opportunity cost of the land to be used. If the land was not used for the project, it could have provided people with natural resources that could be converted into money. The Restoration Cost (RC) represents the money to treat the pollution caused by the project. The Disaster Cost (DC) represents the potential financial losses caused by disasters that may happen due to the project. ESV can be regarded as the internal cost of the land, while RC and DC can be regarded as the spillover cost of the project.

Three submodels are constructed to measure different types of cost.

3.3. Submodel

3.3.1. *ESV Model.* Ecosystem provides people with various kinds of services, and the total value of these services is defined as Ecosystem Service Value (ESV). The services can be classified into three categories, namely, provisioning service, regulating service, and cultural service [3]. Each service is composed of several subservices as shown in Figure 2.

In order to measure the services provided by the ecosystem, a new concept ecosystem service footprint (ESF) is proposed by Zhe et al. [12] ESF calculates the area required to generate the specific ecosystem services demanded by humans in a certain area during a specific period of time. For example, if ESF (hectare/person) of water land equals k , it means that to generate the specific ecosystem services demanded by 1 person in water land during one year needs k hectare of this land.

Zhe et al. [12] divided the whole ecological environment into 5 categories, namely, forests, pastures, croplands, fisheries, and wetlands. Each type of land has a specific ESF which is generated by combining the ESF of different services it can provide (see Figure 3).

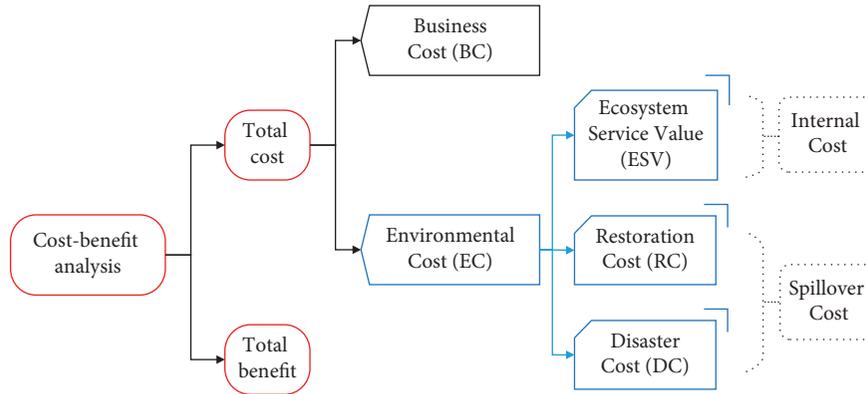


FIGURE 1: The design of the model.

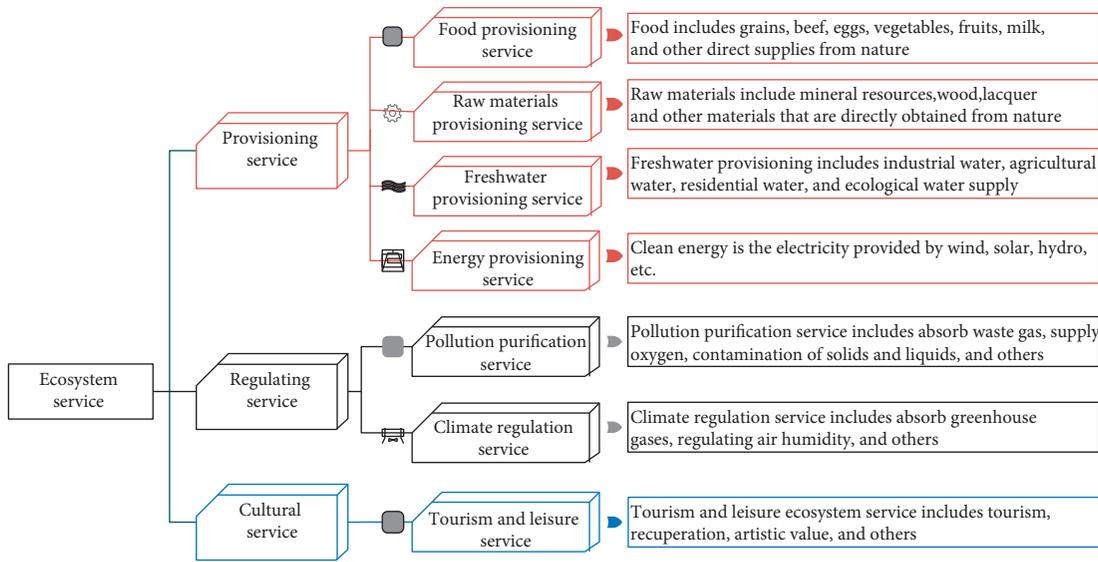


FIGURE 2: Decomposition of ecosystem services.

When combining the ESF_f of different land types, we can generate a comprehensive ESF_f of general land, so does ESF_r , ESF_w , ESF_e , ESF_p , ESF_c , and ESF_l (see Table 1).

Now that we have the general ESF_r , ESF_w , ESF_e , ESF_f , ESF_c , ESF_p , and ESF_l , and the total ESF of a general land within a region can be produced by

$$ESF = ESF_r + ESF_f + ESF_e + ESF_w + ESF_p + ESF_c + ESF_l. \tag{4}$$

The next step is to convert ESF into an economic value, Ecological Service Value (ESV). ESV measures how much money can k hectare of land generate during one year:

$$ESV = \text{Land Area} * \frac{1}{ESF} * PCE, \tag{5}$$

where PCE is the annual consumption expenditure per capital and Land Area represents the hectares of land. $1/ESF$ represents how many people can one hectare of land support during a year. When it is multiplied by annual consumption expenditure per capital (PCE), we can generate a result to measure the economic value of 1 hectare of this land in one year. The assumption lying

behind this is that people are fully supported by nature, and all our resources come from nature, so people's consumption expenditure equals the ecosystem service value.

When $(1/ESF) * PCE$ is multiplied by the land occupation of the project, we can produce the ESV of this project. Figure 4 shows the ESV of one hectare land in different regions of China. Data come from the National Bureau of Statics of China.

As is shown, the lighter color represents a higher ESV per hectare. Southern China enjoys a relatively higher ESV per hectare probably due to mild climate, abundant resources, and beautiful scene, while northern China has a relatively lower ESV per hectare.

3.3.2. RC Model. To help estimate the Restoration Cost (RC) of a certain project, a Pollution Index (PI) is created to measure the level of pollution.

The Pollution Index (PI) is a combination of water index (that represents the water pollution level), soil index (that represents solid waste pollution level), and air index (that represents air pollution level) (see Figure 5).

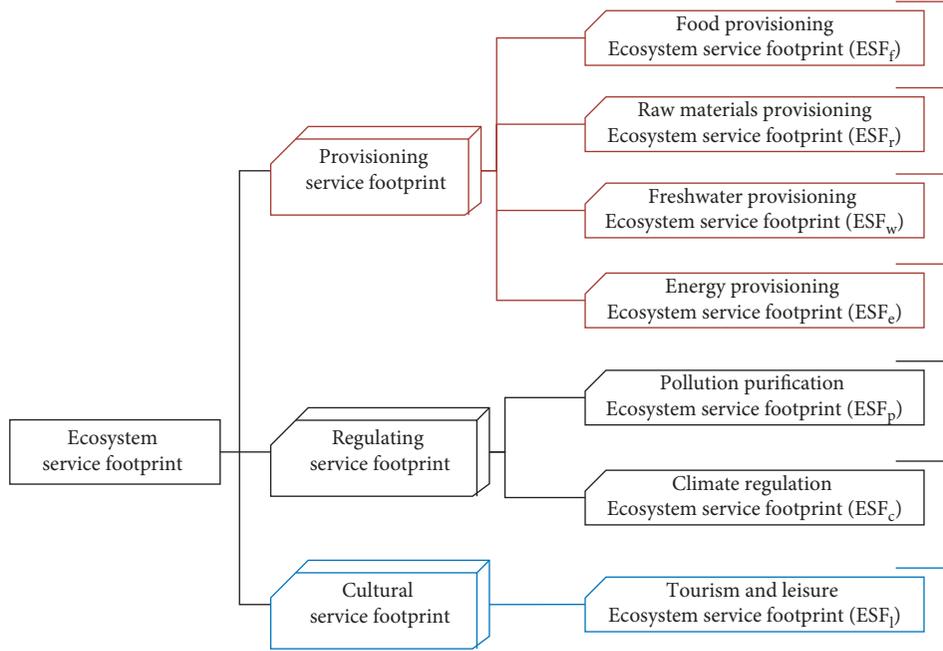


FIGURE 3: Decomposition of ecosystem services footprint (ESF).

TABLE 1: Calculation of ESF of different services proposed by Zhe et al. [12].

Type	Formula	Parameter implication
ESF_r	$ESF_r = \sum_{i=1}^k ESF_{r,k} = \sum_{i=1}^k \sum_{j=1}^5 \beta_{j,k} * c_{j,k} / gP_{j,k}$	$c_{j,k}$ is the consumption amount of food or raw material i in environment j
ESF_f	$ESF_f = \sum_{i=1}^k ESF_{f,k} = \sum_{i=1}^k \sum_{j=1}^5 \beta_{j,k} * c_{j,k} / gP_{j,k}$	$gP_{j,k}$ is the annual provision per unit area of food or raw material i in environment j
ESF_e	$ESF_e = \sum_{i=1}^k ESF_{e,k} = \sum_i U_h / A_h * T_{h,i}$	$ESF_{r,k}$ is the ESF_r of raw materials k , so do $ESF_{f,k}$
ESF_c	$ESF_c = \sum_i U_i / A_i * T_i$	$\beta_{j,k}$ is the proportion of different ecological environment j to total environment
ESF_w	$ESF_w = U_a / (R_a / a_w) * r_w + U_b / (R_b / a_0) * r_0$	U_h is the energy usage of seven categories: coal, gasoline, kerosene, diesel, fuel oil, natural gas, and thermal power
ESF_p	$ESF_p = \sum_{i=1}^5 \beta_{p,i} (\sum_k P_k / A_{i,k})$	A_h is the hectare area of energy supply; $T_{h,i}$ is the ratio of natural energy to clean energy i
ESF_t	$ESF_t = T / V * r_f$	U_a is the surface water usage, U_b is the groundwater usage, R_a is the surface water resources, R_b is the groundwater resources, a_w is the area of a water body, a_0 is the area of another land-use type
		P_k refers to the emissions of different pollutants, $A_{i,k}$ refers to the capability to exhaust pollutants per hectare of environment i .
		T represents the total number of forest park tourists; V is the capacity of forest park tourism; r_f is the equilibrium factor of environment.

Assuming the project is conducted in China, we calculate the Water Index by normalizing the panel data of annual industrial waste water discharge (W_{it}) in different regions of China:

$$\text{Water Index}_{it} = \frac{W_{it} - W_{\min}}{W_{\max} - W_{\min}}, \quad (6)$$

where W_{it} represents the annual waste water discharge in region i in year t , W_{\min} represents the smallest W_{it} among panel data, and W_{\max} represents the largest W_{it} among panel data.

By normalizing the annual industrial solid waste (S_{it}) and industrial waste gas (A_{it}), we produce the Soil Index and Air Index in the same way:

$$\text{Soil Index}_{it} = \frac{S_{it} - S_{\min}}{S_{\max} - S_{\min}}, \quad (7)$$

$$\text{Air Index}_{it} = \frac{A_{it} - A_{\min}}{A_{\max} - A_{\min}}$$

The set of (Water Index_{it} , Soil Index_{it} , and Air Index_{it}) is coordinated that corresponds to a set of points in 3-dimensional

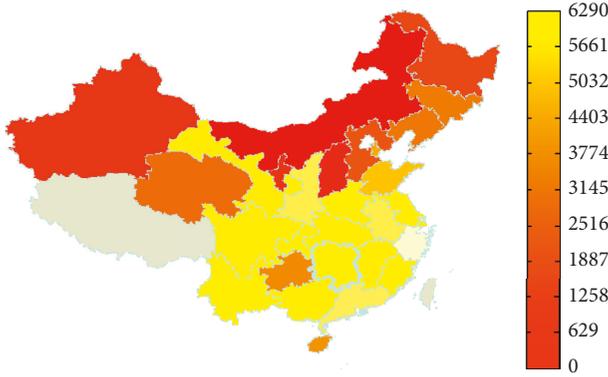


FIGURE 4: ESV of one hectare of land in different regions of China.

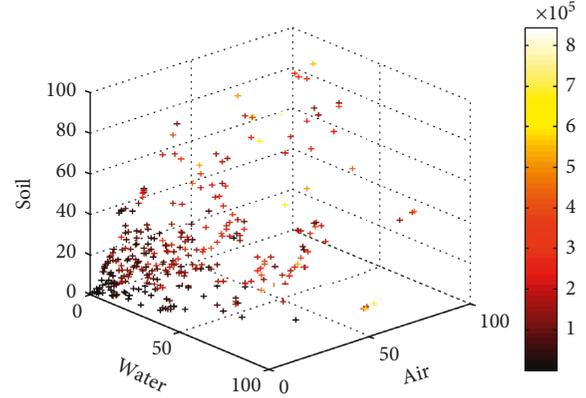


FIGURE 6: Relationship between RC and indices.

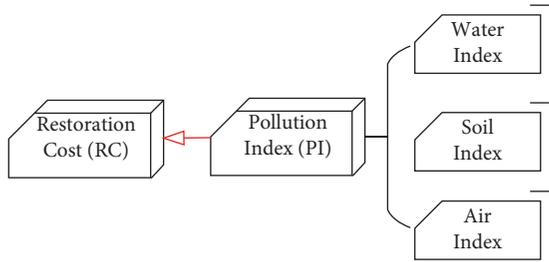


FIGURE 5: Decomposition of PI.

space. The distance from the point to origin measures the comprehensive pollution level, i.e., the Pollution Index $_{it}$:

$$PI_{it} = \sqrt{\text{Water Index}_{it}^2 + \text{Soil Index}_{it}^2 + \text{Air Index}_{it}^2}. \quad (8)$$

When another variable, the annual investment on pollution treatment (RC_{it}), is introduced as the fourth dimension, the relationship between RC and Pollution Index is clearly shown in Figure 6.

As is shown in Figure 6, the color represents the fourth dimension, with the lighter color indicating a higher RC and the darker color indicating a relatively lower RC. The greater the distance from the origin, the greater the Pollution Index, and hence a higher RC.

To further explore the numerical relationship between RC and PI, a liner regression between RC and PI is made (see Figure 7):

$$\begin{aligned} \hat{RC} &= 166.31 + 44.92\hat{PI}, \\ Se &= (103.24) (2.58), \\ t &= (1.61) (17.42), \\ P &= (0.1081) (0.0000). \end{aligned} \quad (9)$$

3.3.3. DC Model. Land-use projects may cause the deterioration of the regional ecosystem around them or even on a larger scale. For example, the construction of the factory may loosen the rocks, making the region more susceptible to the landslides and mudslides. The possibility of these

disasters will cause a potential loss that should be considered as Disaster Cost (DC).

Due to the uncertainty of disasters, we divide the cost measurement of disasters into two parts:

- (1) Simulating the probability of disasters
- (2) Linking the probability of such disasters with their costs based on existing data

Rong et al. [13] believed that a more abstract method can be adopted to study the chain reaction of emergencies and the number of times they occur neglecting the probability the event actually occurs. We revise it to make it more in line with our need to measure DC. The occurrence of a disaster requires two conditions:

- (1) The existence of disaster-pregnant factors
- (2) The trigger condition

Firstly, we need to judge whether there are disaster-pregnant factors within the territorial scope of project construction, and then we should determine whether the impacts of the project are strong enough to trigger the disaster using Monte Carlo simulation.

In general, there are 4 steps to determine DC (see Figure 8).

Step 1. Matching Disaster-Pregnant Environment.

We choose four kinds of geographical disasters and eight kinds of disaster-pregnant factors (see Table 2).

We use an 8-dimensional Landscape Vector to represent the environment conditions that exist in a certain area where the project is located. The i th 1 represents the existence of the i th disaster-pregnant environmental conditions. For example, [1,1,1,1,0,1,0,1] means that the region has (a), (b), (c), (d), (f), and (h) but no (e) and (g).

Four row vectors are used to represent the disaster-pregnant factors required to trigger the four kinds of disasters (see Table 3).

For example, the vector for landslides means that landslides are likely to happen only under the conditions of the existence of slopes, adequate groundwater, and periodic rainstorms.

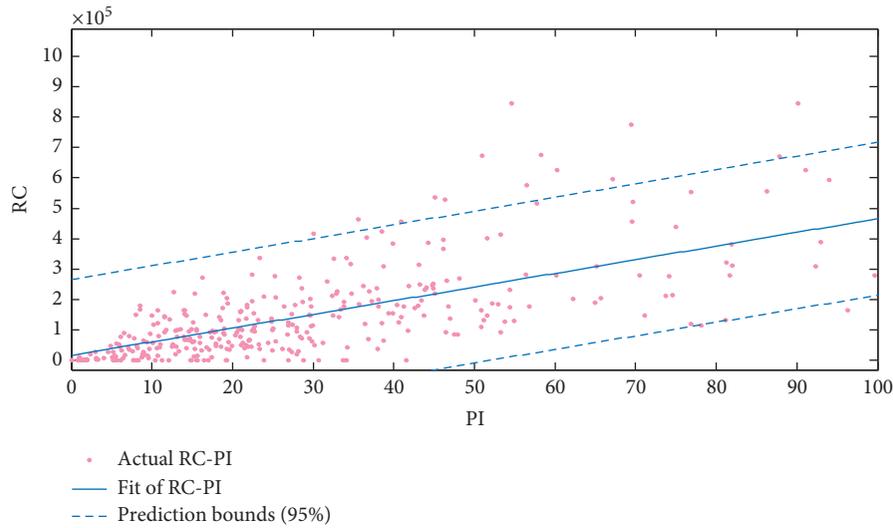


FIGURE 7: Regression of RC and PI.

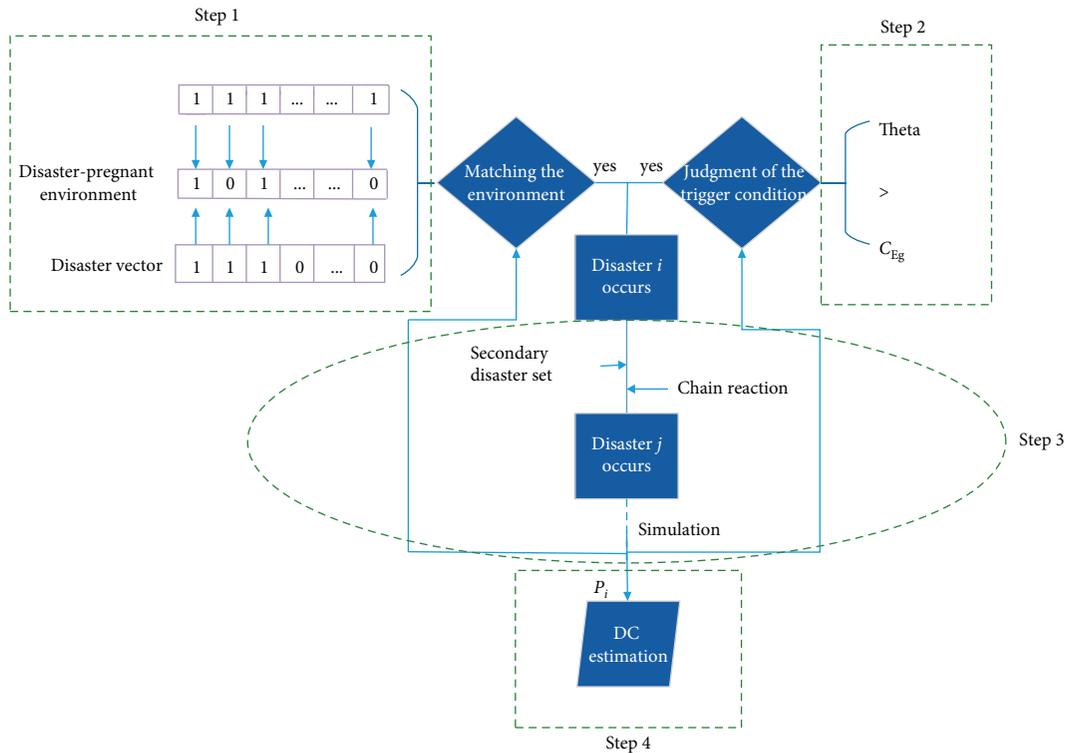


FIGURE 8: Flow chart of DC measurement.

TABLE 2: Geographical disasters and disaster-pregnant factors.

4 geographical disasters	8 disaster-pregnant factors
(A) Landslides	(a) Existence of slopes
(B) Collapses	(b) Adequate groundwater
(C) Debris flows	(c) Periodic rainstorms
(D) Ground sink	(d) Seepage of the surface water
	(e) Unstable rock structure
	(f) Massive vegetation-free lands
	(g) Loose sediment structure
	(h) Existence of soluble rock

In Step 1, we judge the scale of the project and the environmental conditions it contains and then choose the random disaster set representing the possible disasters happening within this scale.

Step 2. Identification of Trigger Conditions.

To decide whether a possible disaster is triggered or not, we introduce two parameters:

TABLE 3: Required disaster-pregnant factors of 4 disasters.

	Landslides	Collapses	Debris flows	Ground sink
Vector	[1,1,1,0,0,0,0]	[1,0,0,1,0,0,0]	[0,0,1,0,1,1,0]	[0,0,0,1,0,0,1,1]

θ , a variable indicating the status of the environment of the project, and we use normal distribution to describe possible values of θ . The bigger the parameter, the worse the environment. We classify the environment into seven categories: A, B, C, D, E, F, and G (see Table 4).

C_{Eg} , which is used to quantify the trigger threshold of a natural disaster. It represents the attributes of the disaster itself. It is also a comprehensive quantification of the factors that can induce the disaster. This property is not constant, but may change slightly around a mean. Normal distribution is adopted to describe it. Despite the variability of the threshold of a disaster, its variation is less than that of θ , so it is designated a smaller variance. ($C_{Eg} \sim N(\mu C_{Eg}, 0.1)$). If $\theta > C_{Eg}$, the disaster is triggered.

In Figure 9, two shorter curves are the possible distributions of θ . The one on the left is the distribution of θ when $\mu\theta = 0.3$, $\sigma\theta = 1$, and the one on the right is the distribution of θ when $\mu\theta = 0.6$, $\sigma\theta = 1$. The higher curve denotes the distribution of the threshold C_{Eg} , whose average is greater than θ and variance is smaller than θ . For one specific disaster, the larger the $\mu\theta$, the larger the overlapped area of the distribution of θ and C_{Eg} , and the more likely the disaster happens.

Step 3. Disaster Occurrence Simulation.

Inspired by the ideas from Rong et al. [13], we take into account the possible chain reaction effects of disasters. When a disaster occurs, it may create disaster-pregnant environments and lead to other disasters. We compare the value of θ and the value of C_{Eg} generated by normal distribution to judge whether secondary disasters occur or not. If secondary disaster occurs, we will repeat this process until there are no other possible secondary disasters reaching triggering conditions. We calculate the probability of each disaster through 1000 simulations.

Step 4. Disaster Cost Estimation.

According to the movement of the Earth, the geographical structure of a region changes at daily intervals, so it is reasonable to calculate the probability on a daily basis. We can get the disaster cost of the land-use project using the following formula:

$$DC = \sum_i (P_{i1} - P_{i0}) * T * \frac{TL_i}{N_i}, \quad (10)$$

where P_{i1} denotes the probability of the i th disaster after the project has been built, P_{i0} denotes the probability before the project is built, T denotes the number of days in

a year, TL_i denotes the total loss of the i th disaster in one country or other geographical unit whose data are accessible, and N_i denotes the number of occurrences of the disaster in the same geographical unit. That is, TL_i/N_i measures the loss of the i th disaster happening once. Summing up the loss of all the disasters gives the total DC of the land-use project.

Note that we just apply a rough measurement of the occurrence probability of some certain disasters, and it is likely that the real possibility is not consistent with our calculation; but when we do the abstraction, we only care about the incremental occurrence probability caused by the project and the error is far less than the original possibility. This method provides us with an approach to measure the probability without accounting for various complex natural factors but from a more comprehensive perspective.

4. Case Study

In these two case studies, all data are collected from the National Bureau of Statistics of China [14] and the Choice database [15] by East Money Co. For the Shanxi coal mining project, we use the ESV per hectare in Shanxi, land area of mining factories, three types of annual pollution, and times and losses of natural disasters in the past 10 years to fit the three submodels. For the high-speed rail project, we use ESV per hectare in China, covered area of rail to calculate ESV of this project, and use the average revenue of the railway company to make a cost-benefit efficiency analysis.

4.1. Coal Mining Project in Shanxi, China. Shanxi, China, is famous for its abundant coal reserves. There are more than 1000 coal mining factories in Shanxi province. We regard all these factories as a large coal mining project and now evaluate the cost-benefit efficiency of the project.

4.1.1. ESV Model Fit. The ESV of Shanxi province is 2328.06 yuan per hectare. The land occupation of all mining factories is about 189840 hectare. So

$$\begin{aligned} \text{ESV}_{\text{Shanxi Mining Project}} &= 2328.06 * 189840 \\ &= 441958910.4 \text{ yuan} \\ &= 441.96 \text{ million yuan.} \end{aligned} \quad (11)$$

4.1.2. RC Model Fit. In the last 10 years, the average annual industrial waste water $W = 67380.58$, the average annual industrial solid waste $S = 18423.86$, and the average annual

TABLE 4: Seven categories of θ .

A	B	C	D	E	F	G
$\mu\theta = 0.3$	$\mu\theta = 0.4$	$\mu\theta = 0.5$	$\mu\theta = 0.6$	$\mu\theta = 0.7$	$\mu\theta = 0.8$	$\mu\theta = 0.9$

$\mu\theta = 0.3$ denotes $\theta \sim N(0.3, 1)$.

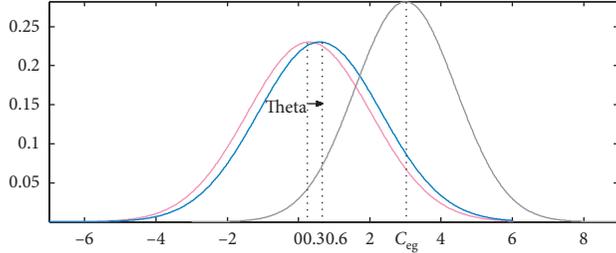


FIGURE 9: Distribution chart.

industrial waste gas $A = 26116.02$. So the Pollution Index in Shanxi 2019 can be estimated as follows:

$$\begin{aligned} \text{Water Index} &= \frac{67380.58 - W_{\min}}{W_{\max} - W_{\min}} = 11.15, \\ \text{Soil Index} &= \frac{18423.86 - S_{\min}}{S_{\max} - S_{\min}} = 40.42, \\ \text{Air Index} &= \frac{26116.02 - A_{\min}}{A_{\max} - A_{\min}} = 33.82, \\ \text{PI}_{\text{Shanxi 2019}} &= \sqrt{11.15^2 + 40.42^2 + 33.82^2} = 53.87. \end{aligned} \tag{12}$$

Because coal mining is a dominant business in Shanxi province and is the major cause of all the pollution, we assume that the $\text{PI}_{\text{Shanxi 2019}}$ equals the incremental PI caused by the coal mining project in Shanxi province. RC of this project can be calculated as

$$\text{RC}_{\text{Shanxi Mining Project}} = 44.92 \times 53.87 = 241.98 \text{ million yuan.} \tag{13}$$

4.1.3. DC Model Fit. Shanxi is a typical mountainous plateau covered by loess, which is high in the northeast and low in the southwest. It belongs to temperate continental monsoon climate. This geography has unstable rock structure and is prone to suffer many other geographical problems.

We summarize the geological environment of Shanxi as slopes, periodic rainstorm, seepage of the surface water, unstable rock structure, loose sediment structure, and soluble rock. The Landscape Vector of Shanxi is $[1,0,1,1,1,0,1,1]$. The possible disasters are collapse and ground sink, which can be denoted by two vectors: $[1,1,1,0,0,0,0,0]$ and $[0,0,0,1,0,0,1,1]$.

Because Shanxi is located in North China, the environment is relatively bad compared with that of South China. Before the construction of mining projects, we designate level D ($\mu\theta = 0.6$) to Shanxi's environmental quality. After the development of the mining industry, combined with the regional environmental quality ranking

TABLE 5: Values of parameters.

	$\mu\theta_1$	$\sigma\theta_1$	$\mu\theta_2$	$\sigma\theta_2$	μC_{Eg1}	σC_{Eg1}	μC_{Eg2}	σC_{Eg2}
Before	0.6	1	0.6	1	3	0.1	3.2	0.1
Later	0.8	1	0.8	1	3	0.1	3.2	0.1

published by China, we assume that the environmental level of Shanxi has been degraded to level F ($\mu\theta = 0.8$) (see Table 5).

The parameters involved in the model are stated as follows.

Based on the trigger condition and the chain reaction rules, we simulate 1000 times and the result is as in Table 6.

$$\text{DC} = \sum_i \text{DC}_i = 519.46 + 714.26 = 1233.74 \text{ million yuan.} \tag{14}$$

4.1.4. Cost-Benefit Analysis. The coal mining business in Shanxi province made a total revenue of about 1000 billion in 2018. The average gross profit margin in this line of business is 23.18%, so the total cost is about 768.2 billion.

Assuming this market situation remains in 2019, we have a project investment of 768.2 billion and a total revenue of 1000 billion:

$$\begin{aligned} \text{Total Cost} &= \text{BC} + \text{EC} = 768,200 + 1917.68 \\ &= 770,117.68 \text{ million,} \end{aligned}$$

$$\text{Total Benefit} = 1,000,000 \text{ million,}$$

$$\begin{aligned} \text{Profitability Index} &= \frac{\text{Total Benefit} - \text{Total Cost}}{\text{Total Cost}} \\ &= \frac{1,000,000 - 770,117.68}{770,117.68} = 29.85\%. \end{aligned} \tag{15}$$

4.2. Case Study of High-Speed Rail Project in China. High-speed rail is a typical nationwide project in China. We make a cost-benefit analysis of this project.

4.2.1. ESV Model Fit. The ESV of China is 4,570.91 yuan per hectare, and the covered area of all railway facilities amounts to about 294,576 hectares. So ESV can be calculated by

$$\begin{aligned} \text{ESV} &= 294,576 * 4,570.91 = 1,346,439,245 \text{ yuan} \\ &= 1,346.44 \text{ million yuan.} \end{aligned} \tag{16}$$

TABLE 6: Results with various parameters.

	f_{i0}	P_{i0}	f_{i1}	P_{i1}	$\Delta P = P_{i1} - P_{i0}$	TL_i/N_i (million yuan)	DC_i (million yuan)
Collapse	7	0.7%	9	1.8%	1.1%	177.9	714.26
Ground sink	3	0.3%	4	1.1%	0.8%	177.9	519.46

4.2.2. *RC and DC Model Fit.* Since high-speed rail is driven by clean energy like electricity, it produces very little waste. The RC is so small that we can neglect it.

Furthermore, in the process of high-speed railway construction, a large amount of funds are used to reinforce mountains and build canals and bridges to prevent geological disasters. Therefore, we believe the probability of high-speed railway inducing geological disasters is pretty small. Thus, DC is also neglected here.

4.2.3. *Cost-Benefit Analysis.* For the benefits of high-speed rail projects, we believe they are composed of two parts:

- (1) The transportation capacity of high-speed rail that directly converts into revenue
- (2) The pulling effect of high-speed rail on the economy, we measure it with reference to the research of the literature [16]

$$F_{\text{direct-revenue}} = 28404 \text{ million yuan.} \quad (17)$$

According to the annual reports of China Railway Co., the average business cost in the last ten years is 9,219.98 million yuan. The high-speed rail takes 1/5 of the whole corporation's business, so the business cost of high-speed railway is roughly 18440.00 million yuan (9,219.98/5).

$$\text{Total Cost} = \text{BC} + \text{ESV} = 18440.00 + 1346.44$$

$$= 19,786.44 \text{ million,}$$

$$\text{Profitability Index} = \frac{\text{Total Benefit} - \text{Total Cost}}{\text{Total Cost}} = 43.55\%. \quad (18)$$

5. Advancement of Our Model Compared with Existing ESF and ESV Model

There are many ways to evaluate the pressure of human activity on the environment, the one popular among them is known as EF theory. This approach focuses on the pressure generated during the production and consumption of crops and food and buildup and emission of carbon. In order to incorporate all these resources and develop a more general as well as consistent model in quantifying diverse pressures, Zhe et al. [12] presented the ESF model which converts all kinds of services nature provides for us into hectares of land. It includes provisioning ESF, regulating ESF, and cultural ESF in which food supply, water, air cleaning, and other services are all taken into account. But the major demerit of the ESF model is that the area of land a person needs to make a living is not connected with monetary value, so the

accurate cost on a cash-basis cannot be derived which hinders the cost-benefit analysis of a land-use project.

Another relevant model is the ESV model. Compared with the ESF model, this one monetizes each hectare of land and once the area of occupied land is multiplied by ESV, the opportunity cost of the land-use project is presented.

However, one common flaw shared by these two models is that only the implicit cost of a project is measured and the explicit costs involving pollution as well disaster treatment are omitted. So our model incorporates the latter two explicit costs while still uses the original ESF model for reference in order to better evaluate the environment cost caused by the land-use project.

Some concepts similar to ESV are ESF and ESF over GDP, which we will illustrate here to compare with ESV. ESF calculates the area required to generate the specific ecosystem goods and services demanded by humans in a certain area at a certain time. It can show the ecological value of lands but not in an economic value. ESF over GDP is ESF divided by the GDP in a certain area, which reveals the trends of use efficiency of the ecosystem services. In order to monetize the ecological value of the lands, we propose an ESV model which is basically the reverse of ESF over GDP multiplied by land area. Therefore, the results of ESV are in clear contrast to those of ESF over GDP, which also testifies the stability of our model results (see Figure 10).

6. Model Modification

6.1. *Timing Problem.* In the previous model, we focused on the annual Profitability Index, while the project is already on the run but ignored the initial investment when the project is being constructed. If we take into consideration the entire lifespan of the project, we can develop our model into a more reasonable one.

At the beginning of the project, a big lump sum of money is needed for initial investment (II). This is a one-time cost that will not happen again during the operation of the project. Additionally, there will also be ESV, RC, and DC, the amount of which depends on the construction period. To put it in another way, ESV, RC, and DC are variable costs while II is the fixed cost. The net cash flow of this construction period is

$$\text{NCF}_0 = -(\text{II} + \text{ESV}_0 + \text{RC}_0 + \text{DC}_0). \quad (19)$$

During the operation of this project, the annual total cost of the project will be the sum of OC_t , ESV_t , RC_t , and DC_t during this year. When the total revenue (R_t) of this year is taken into consideration, the net cash flow of the project in year t equals

$$\text{NCF}_t = R_t - \text{OC}_t - \text{ESV}_t - \text{RC}_t - \text{DC}_t. \quad (20)$$

At the end of the project, there will usually be some machines, factories, or other assets left, the residual value

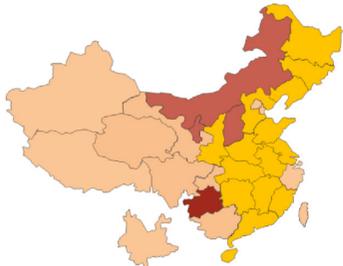
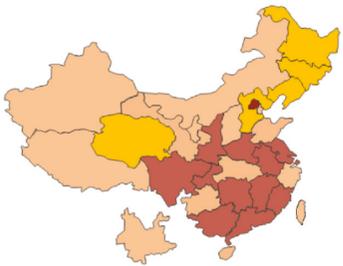
	ESF	ESF over GDP	ESV
Definition	ESF calculates the area required to generate the specific ecosystem goods and services demanded by humans in a certain area at a certain time	ESF over GDP = 1/GDP * ESF ESF over GDP reveals the trends of use efficiency of the ecosystem services	ESV = LandArea * 1/ESF * GDP ESV measures how much money can k hectare of land generate during one year
Result			

FIGURE 10: The comparisons of different models.

(RV) of which can be turned into cash. So, the net cash flow at the end is

$$NCF_{end} = RV. \tag{21}$$

All cash flows happen in different time points so they cannot be summed up directly. With time value of money taken into consideration, the present value of all cash flow should be

$$NPV = NCF_0 + \sum_{t=1}^N \frac{NCF_t}{(1+r)^t} + \frac{RV}{(1+r)^N}, \tag{22}$$

where N is the duration of the project and r is the risk-free discount rate, usually being the interest rate of treasury bonds.

If NPV of a certain project exceeds zero, this project is worth being invested, and vice versa. Furthermore, Adjusted Profitability Index can also be used to evaluate the cost-benefit efficiency of the project. The higher the profitability index, the more worthwhile to invest in the project.

$$\text{Adjusted Profitability Index} = \frac{NPV}{II}. \tag{23}$$

6.2. *Scale Problem.* By “scale” we mean how intense the project is. The “intensity” of the project can be measured by

$$\text{Intensity} = \frac{\text{Exploited Area}}{\text{Total Area}}. \tag{24}$$

If the project is a regional one, the Total Area is the area of the region, and Exploited Area is the project’s occupation of land. If the project is a national one, the Total Area is the covered area of this nation. If the project is an international one, the Total Area would be the area of Earth (Figure 11).

The more intense the project, the more pollution can the project produce. If the project is small enough (less intense), there will be no external Restoration Cost (RC) because the ecosystem has enough self-cleaning capacity to absorb the

pollution. If the project is too intense, pollution exceeds the ecosystem’s self-cleaning capacity and additional RC is needed. The relation is shown in Figure 12.

The red line in Figure 12 is the Ecosystem Service Value (ESV) of available land that has not been exploited. As the intensity (Exploited Area/Total Area) grows, the amount of available land shrinks and its total ESV decreases accordingly. Additionally, ESV decreases at a diminishing rate because ESV per unit of land tends to be smaller when intensity is greater.

As the intensity grows, more lands are used and more pollution is produced. Assuming there is no external pollution treatment by humans, the ecosystem has to retain some unexploited land whose self-cleaning capacity is big enough to deal with the pollution caused by the utilized land. This kind of division of available land is represented by gray arrows in Figure 12. We can generate a yellow line by joining all the division points from different intensities. The yellow line represents the ESV in equilibrium situation, where the pollution caused by the utilized land is just absorbed by the unexploited land with no human interruption.

When intensity exceeds threshold K^* , the ecosystem will never be able to absorb the pollution from the utilized land and people have to treat the extra pollution. Hence, the Restoration Cost (RC) occurs.

In Figure 13, the yellow line is RC. When intensity grows beyond threshold K^* , a positive RC occurs and increases at a growing speed. The blue line represents the total revenue of the project. The benefit grows at a diminishing rate because of decreasing profit margin. By subtracting the RC from the initial revenue, a lower line is generated representing the adjusted benefit when RC is taken into consideration.

In conclusion, only when the intensity of the project goes beyond the threshold K^* , the restoration cost can occur.

6.3. *Adjusted Case Studies.* We reevaluate the two case studies with the modified model, and the results are shown in Table 7.

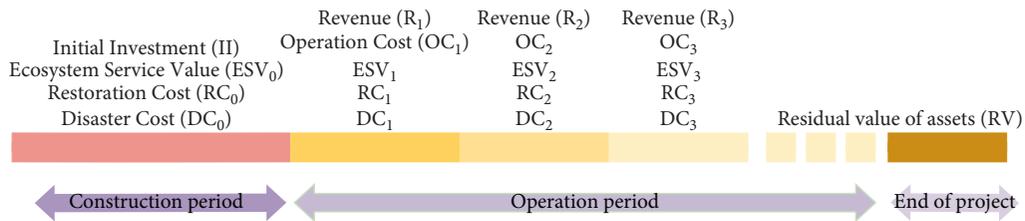


FIGURE 11: Cash flow during the life of the project (with red letters indicating cash inflow and black ones indicating cash outflow).

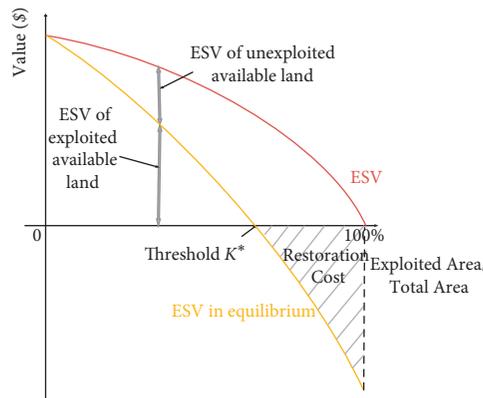


FIGURE 12: Scale problem.

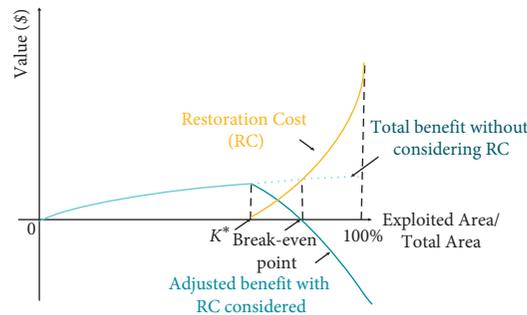


FIGURE 13: Scale problem.

TABLE 7: Results of basic model and modified model.

Case	Initial profitability index (%)	Adjusted profitability index (%)
Coal mining project in Shanxi province	29.85	11.76
High-speed rail project in China	43.55	12.08

When the initial investment is taken into consideration, the adjusted profitability index for the high-speed rail project is much smaller due to its heroic initial investment. Both the Profitability Indices of the coal mining project are much smaller than those of the high-speed rail because of the considerable DC and RC of the coal mining project.

7. Conclusion

In this paper, we establish a model to measure projects' impact on the environment and hence propose a more reasonable approach to evaluating cost-benefit efficiency of projects. We divide the total cost of a certain project into two parts: BC and

EC. BC is the explicit cost that can be approached from financial statements, while EC is the implicit cost which we try to quantify. EC is composed of three parts: ESV, RC, and DC. We use three cases to demonstrate the feasibility and reliability of our model.

7.1. Strengths and Weaknesses

7.1.1. *Strengths.* We take into account both the internal environmental cost, namely, the ecosystem service cost of a piece of land and the spillover cost due to the long-term intersection of the project and the environment. These two dimensions give an overall measurement of the environmental cost of a land-use project.

In the ESV model, nearly all kinds of ecosystem services are taken in consideration, and we link the value of the land to the area of the project and the average consumption of each person in that region. This conversion simplifies the calculation and improves the adaptability of our model.

In the RC model, we first quantify the environment condition of a region using a Pollution Index (PI). All the data required to obtain the index are easy to get. Besides, the coefficient in the regression is highly significant, indicating the robustness of our model.

In the DC model, we adopt an abstract approach to estimate the probability of disasters, which creatively take the chain reaction effects into consideration. These characteristics make our model easy to use without dealing with complicated prediction process for disasters.

7.1.2. Weaknesses. Some values of the parameters are subjectively designated due the lack of referable criteria. Also, some unavailable data may bring about errors in evaluation.

7.2. Future Plan. In the DC model, we subjectively determine classification of θ and C_{Eg} only based on analysis of some qualitative data and did not develop a quantitative assessment system to judge the environment condition of a region. In the future, such an assessment system can be developed to classify the environment condition more objectively and precisely.

7.3. Implications to Policy Makers. Whether a project will be accepted is determined by the NPV and the profitability index of the project. If the Environmental Cost (EC) is left out, the NPV and profitability index would be unreasonably high and wrong projects can be accepted. From the perspective of the whole planet, we take more land for projects than we should.

When mistakenly taking more land, it is very likely that we wrongly measured the sustainability of the society. Norgaard et al. [3] thought that ESV can be exchanged between generations.

In Figure 14, the wrong frontier (leaving out EC) is higher than the real one (considering EC), so when we choose the allocation of the resources between the current generation and the future generation, we may choose to consume x_1 , believing it is the best point to satisfy our needs to the greatest extent without burdening the next generation. But the truth is that this point actually does not meet the sustainability criteria, and we can consume at most x_0 units of resources, and the severity of the mistake is denoted by the shadow.

In conclusion, our suggestions for the policy makers are as follows:

- (1) Do not ignore the changes of environment caused by the project, or the spillover cost will burden the current as well as future generations

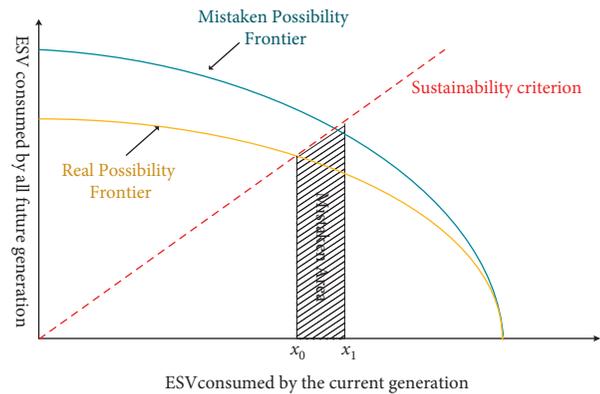


FIGURE 14: Exchange of ESV between generations.

- (2) Bring in advanced pollution purification techniques, which are once-for-all cost and will bring scope effects
- (3) Encourage the application of the cutting-edge technology to reduce the Restoration Cost in the long-term
- (4) Improve the disaster prevention measures to reduce potential losses caused by changes in the geographical environment due to the construction of land-use projects

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

This study was financially supported by the National Natural Science Foundation of China (nos. 61602518 and 71872180) and the Fundamental Research Funds for the Central Universities, Zhongnan University of Economics and Law, (nos. 2722019JCG074 and 2722019JCT035).

References

- [1] M. Wackernagel and W. E. Rees, "Perceptual and structural barriers to investing in natural capital: economics from an ecological footprint perspective," *Ecological Economics*, vol. 20, no. 1, pp. 3–24, 1997.
- [2] H. Du, M. Ge, W. Zhang, and Y. Chen, "The analysis on the accounting methods system of environmental costs focused on the construction phase of construction projects," in *Proceedings of the 20th International Symposium on Advancement of Construction Management and Real Estate*, pp. 425–435, Singapore, May 2016.
- [3] R. B. Norgaard, "Ecosystem services: from eye-opening metaphor to complexity blinder," *Ecological Economics*, vol. 69, no. 6, pp. 1219–1227, 2010.
- [4] M. Wackernagel, L. Onisto, A. C. Linares et al., "Ecological Footprints of Nations: how much nature do they use? How

- much nature do they have?," *Commissioned by the Earth Council for the Rio+5 Forum*, pp. 4–12, International Council for local Environmental Initiatives, Toronto, Canada, 1997.
- [5] M. Khodarahmi, M. J. Amiri, A. Karbassi, S. Tajziehchi, and H. Darabi, "Assessment and estimation of environmental costs of Kasilian dam," *Asian Journal of Water, Environment and Pollution*, vol. 15, no. 2, pp. 107–114, 2018.
- [6] S. Su, R. Xiao, Z. Jiang, and Y. Zhang, "Characterizing landscape pattern and ecosystem service value changes for urbanization impacts at an eco-regional scale," *Applied Geography*, vol. 34, pp. 295–305, 2012.
- [7] S. Sannigrahi, S. Chakraborti, P. K. Joshi et al., "Ecosystem service value assessment of a natural reserve region for strengthening protection and conservation," *Journal of Environmental Management*, vol. 244, pp. 208–227, 2019.
- [8] Y. Gao, Z. Feng, Y. Li, and S. Li, "Freshwater ecosystem service footprint model: a model to evaluate regional freshwater sustainable development—a case study in Beijing-Tianjin-Hebei, China," *Ecological Indicators*, vol. 39, pp. 1–9, 2014.
- [9] B. Kim, H. Kim, and H. Kim, "A framework for pricing the loss of regulating ecosystem services caused by road construction," *KSCE Journal of Civil Engineering*, vol. 20, no. 7, pp. 2624–2631, 2016.
- [10] D. Eckhardt, A. Leiras, and A. M. T. Thomé, "Systematic literature review of methodologies for assessing the costs of disasters," *International Journal of Disaster Risk Reduction*, vol. 33, pp. 398–416, 2019.
- [11] J. Millward-Hopkins, J. Busch, P. Purnell et al., "Fully integrated Modelling for sustainability assessment of resource recovery from waste," *Science of The Total Environment*, vol. 612, pp. 613–624, 2018.
- [12] F. Zhe, Y. Cui, H. Zhang, and Y. Gao, "Assessment of human consumption of ecosystem services in China from 2000 to 2014 based on an ecosystem service footprint model," *Ecological Indicators*, vol. 94, no. 1, pp. 468–481, 2018.
- [13] L. Rong and H. Tan, "Chain reaction model of emergencies based on disaster-pregnant environment," *System Engineering*, vol. 30, no. 7, pp. 40–47, 2012, in Chinese.
- [14] National Bureau of Statics of China.
- [15] Choice database by East Money Co.
- [16] X. Li, j. Li, Q. Sun et al., "Expectation analysis of high-speed railway operation on economic and social promotion," *Journal of Beijing Union University (Humanities and Social Sciences)*, vol. 16, no. 4, pp. 1–10, 2018.



Hindawi

Submit your manuscripts at
www.hindawi.com

