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**2019**  
**MCM/ICM**  
**Summary Sheet**

## Stable State Needed: a Glimpse of Climate Change Potency in Regional Fragility

### Summary

With the advancement of technology, the world has become less war and violence, and climate change is one of the most pervasive global threats to peace and security in the 21st century. In order to solve these problems, we first propose an evaluation model to measure the fragility of worldwide countries. Then we apply Yemen and Gabon to show their instability. Last but not least, we take human interventions into consideration and modify our model to different regional scale.

Firstly, 55 primary indicators are taken into consideration under the guide of four principles which are Society, Economics, Politics and Climate. And **Principal Component Analysis (PCA)** and **Entropy Weight Method (EWM)** are used to reduce indicator numbers and weight these indicators.

Secondly, **Multiplier Model** is proposed to analyze the indirect impact of climate change on fragility through interacting with indicators. Then we determined the direct impact of climate: Disaster, Arable land, Forest and indirect impact: precipitation, cereal production and extreme temperatures.

And we use **CFSFDP** which is a clustering algorithm considering density peak to identify the tipping point. The conclusion is that a country will reach the tipping point when fragility index increases to 89.5, and it will probably fall into fragile state.

Next, we select Yemen and Gabon as research objects and analyze their fragility situation and reveal the impact of climate change both directly and indirectly. As for Yemen, a fragile country, the fragility decreases from 96.3 to 80.18 without climate change. And for Gabon, a vulnerable country, Forest is the main risk to push it to fragile state. **An optimization model is developed to minimize the total cost to prevent fragility**, and the results show that 22.3% of its GDP which is about 3 billion dollars is needed for Gabon.

At least, **our model is modified to fit the different regional scale**. For smaller and larger states, the factors, data and weights have been reconsidered in order to make the model more comprehensive.

**Keywords:** Climate change; Fragility, EWM, Clustering, Optimization

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# 1 Introduction

## 1.1 Background

In a certain historical period, economic growth has played a huge role in improving people's living standards and national welfare, but economic growth is not without cost, and environmental destruction is one of its main costs. These environmental damages lead to a reduction in the ecosystem services supply, which also leads to a decrease in biodiversity.

For a country, when the marginal cost of economic growth exceeds its marginal benefit, this economic growth is uneconomic [1]. For a land use project, it is also uneconomical when the cost including the environmental costs is greater than the revenue. Therefore it makes great sense to incorporate environmental costs into the economic accounting system.

The economic accounting model for environmental costs of land use project is still in dispute [2]. We, the ICM team, trying to find a solution, faces the problems below:

- Create an ecological services valuation model taking ecosystem services into account to understand the real economic costs of land use projects.
- Perform a cost-benefit analysis of varying size project, from small community-based projects to large national projects.
- Evaluate the effectiveness of our model based on your analyses and model design.
- Consider the implications of land use project planners and managers.
- Explore the possible changes of the model over time.

## 1.2 Literature Review

After realizing the contribution of ecosystem bring to human welfare researchers have estimated the current economic value of ecosystem services non-systematically [3]. The proposal of System of Integrated Environmental and Economic Accounting (SEEA)<sup>1</sup> and The Economics of Ecosystems and Biodiversity (TEEB)<sup>2</sup> is a response to the shortcomings of traditional accounting methods. After that, some people applied those frameworks to various government levels [4] and several scarce resources such as water [5].

We expect to quantify the impact of ecological degradation on computing environmental costs and integrate environmental cost into land-use projects base on the previous wisdom and necessary methodologies.

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<sup>1</sup>The System of Environmental-Economic Accounting 2012 —Central Framework (SEEA Central Framework) is a statistical framework consisting of a comprehensive set of tables and accounts, which guides the compilation of consistent and comparable statistics and indicators for policymaking, analysis and research.

<sup>2</sup>The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative focused on making nature's values visible and its principal objective is to integrate the values of biodiversity and ecosystem services into economic decisions.

### 1.3 Analysis and Approach Overview

Since climate change is essential to state fragility, it is significant to propose an efficient model to give plans to detect and further predict the climate change poses in this problem. Therefore, index system is needed to evaluate the fragility of a region firstly. Two specific countries are selected to assess their fragility and effect of climate change through the index system. Then we have to propose feasible plans to help the fragile state get rid of the unfortunate situation and help countries that are vulnerable to maintain the status and further stabilise it. Moreover, the cost of human intervention should be considered in this problem. Eventually, We need to make sure the model works well in different regional scale sizes.

This article is about a regional stability issue of in the worldwide, especially the impact of the climate change. We aim to design a measuring system to detect and predict how climate is and will change the regional fragility based on large quantities of data. Through the above analysis, the flow chart of this paper is shown in Figure 3 as follows.

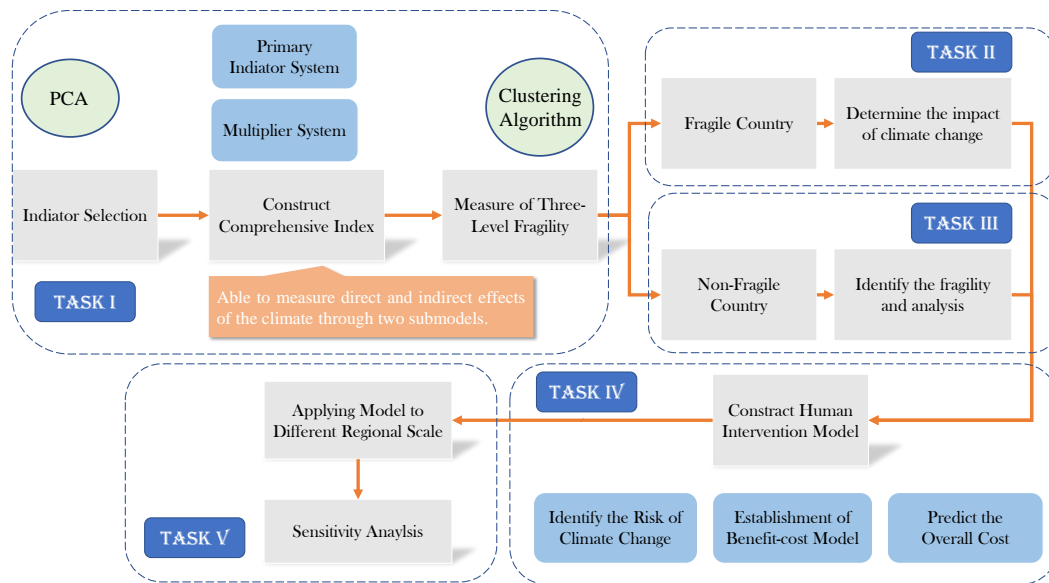


Figure 1: The flow chart in this paper

### 1.4 Main Assumptions

- **There are limits to the demand for earth resources [6].**  
Due to the planet boundaries<sup>3</sup>, the environment is a scarce resource essentially, and it has economic value as well.
- **The value of the environment is not fully reflected in the market.**  
There is a negative externality in the use of ecosystem resources, that is, environmental costs are not truly included in economic costs.

<sup>3</sup>Planetary boundaries define the safe operating space for humanity with respect to the Earth system and if these thresholds are crossed, then important subsystems could shift into a new state, often with deleterious or potentially even disastrous consequences for humans.

- **Ignore inflation and deflation of money.**  
The value of money remains unchanged.

## 2 Preliminaries

### 2.1 Terms and Mathematical Notations

In order to be clear and consistent through the paper, we now settle down some terms and mathematical notations:

Table 1: Symbol Table

Symbol	Definition
AL	Arable land(synthetic action of precipitation and temperature)

### 2.2 Data Pre-processing

#### 2.2.1 Data Collection

Collecting sufficient data is the basis of developing a complete index system. We searched the database and found 88 indicators of about three hundreds countries firstly. Most of the data come from the World Bank <sup>4</sup>, and some data comes from NASA <sup>5</sup> and OWID(Our World In Data) <sup>6</sup>, which is an publication that presents empirical data developed at the University of Oxford.

#### 2.2.2 Data Filling

It is crucial that all data presented are authentic and easily verifiable. No model can provide stable assessments if based on unreliable or untruthful data. Notwithstanding, we spare no efforts looking for data, there still has some missing data because not all data is provided on the website. To ameliorate this situation, three methods are proposed to complete the data, which are as follows:

- If the timo before and after data is available, the average value can be taken as the missing.
- We fill data using same location data of countries which have similar geographical locations.
- The interpolation method is used in data fitting.

<sup>4</sup><https://data.worldbank.org/indicator>

<sup>5</sup><https://climate.nasa.gov/vital-signs/sea-level/>

<sup>6</sup><https://ourworldindata.org/charts>

### 3 Ecological Cost Evaluation Model

The unconventional characteristic of this report's model comes from its derivation. In the assessment of the environmental cost of a land use project, We classify the environmental cost into two main parts: Cost of ecosystem services loss and Cost of pollution, and we will demonstrate the quantitation analysis of them respectively.

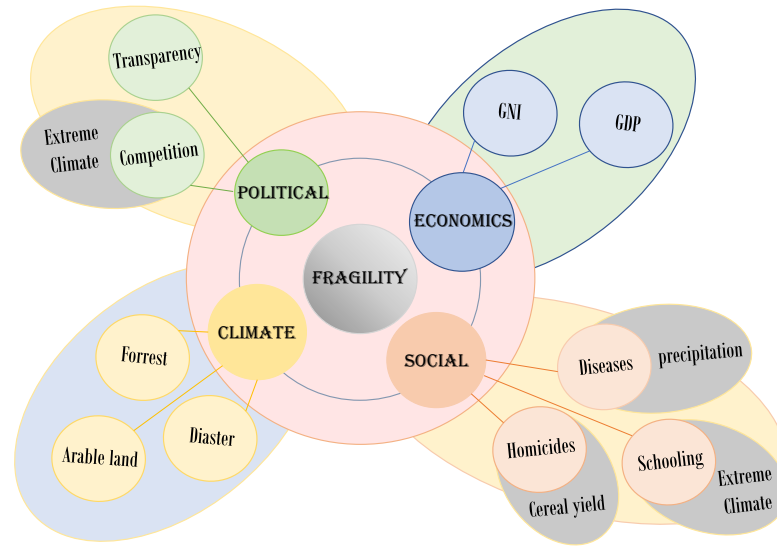


Figure 2: Process flow for the creation of the Fragility Index model. The model incorporated all ten indicators of smart growth and grouped them together into four principles. The sum of these metrics is the overall fragility Index.

#### 3.1 The cost of ecosystem services loss

Under the guide of Ecosystem Services [7] and Environmental Degradation, we classify the factors into four main fields: provisioning services, regulating services, cultural services and environmental degradation caused by biodiversity loss. Factors in separate fields contribute to environment cost in diverse ways. We introduce the quantification of impact from various actors field by field. The quantification of every factor's impact will be presented below.

##### 3.1.1 Provisioning Services

We use four provisioning services indicators in this field. These four indicators measure the decline of the potential material benefits people can obtain from ecosystems.

Product Amount Method (PAM) and Value Amount Method (VAM) are selected to cope with the quantification process. These two methods comprehensively assess the services provided by the ecosystem from the perspective of product amount and the value amount perspective [8].

- **Conservation of water**

Conservation of water measures the value of holding-water and the value of reducing the peak flow, lagging of flood time and supplying water in dry season.

$$V = W \times P = (R - E) \times A \times P \quad (1)$$

where  $V$  represents the economic cost of the annual water-conservation capacity of the area;  $W$  is the water-conservation capacity ( $m^3$ );  $R$  stands for the annual amount of precipitation ( $m^3$ );  $E$  is the average annual evapotranspiration ( $mm$ ) of the area;  $A$  means the wood land area ( $hm^3$ );  $P$  is the water storage cost per unit ( $\$/m^3$ )

- **Reduced waste lands**

Reduced waste lands plays an important role in soil conservation. This indicator measures the cost of ecosystem's loss for reducing waste lands.

$$E_s = \frac{(V \times B)}{(10000 \times L \times D)} \quad (2)$$

$$V = S \times (P - Q)$$

where  $E_s$  represents the value of reduced waste lands ( $\$/year$ );  $V$  is the reduced soil erosion amount ( $t/year$ );  $D$  stands for the average density of soil ( $t/m^3$ );  $L$  is the forest soil thickness ( $t/m^3$ );  $B$  is the average benefits of forestry ( $\$/hm^2$ );  $S$  means forest area ( $hm^2$ );  $P$  is the modulus of potential soil erosion ( $t/(hm^2 \cdot year)$ );  $Q$  is the modulus of realistic soil erosion ( $t/(hm^2 \cdot year)$ )

- **Land fertility**

Nutrients such as N, P and K in soil runoff because of land use. The ability to keep land fertility also plays a significant role in soil conservation. This indicator measure the cost of losing land fertility conservation.

$$E_f = \sum V \times C_i \times \frac{P}{10} \times 1000 (i = N, P, K) \quad (3)$$

where,  $E_f$  is the economic benefits of maintaining soil fertility ( $\$/year$ );  $C_i$  is the net contents of N, P, and K in soil;  $P$  is the price of N, P, K ( $\$$ ).

- **Reduced sediments in rivers.**

According to the law of sediment movement, a lot of erosive soils are deposited in reservoirs, rivers, and lakes. It measures the cost of reducing sediments in rivers.

$$E_n = \frac{P \times V \times U}{10000} \quad (4)$$

Where,  $E_n$  represents the economic benefits of reducing sediments deposit ( $\$/year$ );  $U$  stands for the costs of reservoir project ( $\$$ ).  $P$  is the percent of the erosive soils that are deposited in reservoirs, rivers, and lakes.

The mathematical expression for provisioning services indicators in the environmental cost evaluation model has a form of

$$Provisioning = P_{cons} + P_{wast} + P_{land} + P_{send} \quad (5)$$

### 3.1.2 Regulating services

We use two provisioning services indicators in this field. These two indicators measure the loss of the value of air and soil, providing flood and disease control, or pollinating crops.

- **Carbon fixation and oxygen release**

Carbon fixation and oxygen release refers to the fixation of carbon and release of oxygen. These two indicators represents the cost of losing carbon fixation and oxygen release ability.

$$\begin{aligned} U_c &= A_i \times C_c (63 \times R_c \times B_n + F_c) \\ U_o &= 1.19 \times A_i \times C_c \times B_n \end{aligned} \quad (6)$$

where,  $U_c$  is the annual carbon fixation price of the area;  $U_o$  represents the annual oxygen release price of the area (\$/year);  $C_c$  is the price of fixed carbon, and  $C_o$  is the price of oxygen, yuan/year;  $R_c$  is the carbon content in CO<sub>2</sub> (taking 27.27%);  $B_n$  is the annual net productivity of the area, and  $F_c$  is the annual carbon content per unit area of the area, ( $t/(hm^2 \cdot year)$ ).

- **Purification of the air**

Purification of the air refers to the ability of absorbing sulfur dioxide, fluorine, nitrogen oxides and the ability of reducing noise and detaining dust of the area.

$$\begin{aligned} U_f &= \frac{5.256 \times 10^{15} \times A_i H K_f (Q_f - 600)}{L} \\ U_c &= A_i K_c Q_c + A_j K_{fo} Q_{fo} + A_i K_{ro} Q_{no} + A_i K_{rn} Q_{no} + K_z A_z + A_1 K_{sc} Q_{xc} \end{aligned} \quad (7)$$

where  $U_f$  is the anion value provided by the area, and  $U_c$  represent the annual absorption of sulfur dioxide, fluorine, nitrogen oxides by the area, the annual value of reducing noise and detaining dust of the area, (\$/year);  $H$  is the height of the area ( $m$ );  $K_f$  is the cost generated by an anion (\$/one);  $Q_f$  is the anion concentration of the area ( $one/cm^3$ );  $L$  is the lifetime of an anion ( $min$ );  $K_e$ ,  $K_{fo}$ ,  $K_{no}$ , and  $K_{zc}$  stand for the costs of pollution governance and dust fall cleaning of sulfur, fluoride and nitrogen oxides (\$/kg);  $A_z$  is the mile of sound-proofing walls converted from the area ( $km$ );  $Q_e$ ,  $Q_f$ ,  $Q_{no}$ , and  $Q_{zc}$  are amounts of sulfur dioxide, fluoride, nitrogen oxides and dust retention absorbed by the area per unit area [ $kg/(hm^2 \cdot a)$ ].

The mathematical expression for regulating services indicators in the environmental cost evaluation model has a form of

$$Regulating = R_{carb} + R_{puri} \quad (8)$$

### 3.1.3 Cultural services

Cultural services measure the loss of the the non-material benefits people obtain from ecosystems. It will be measured in terms of willingness to pay and ability to pay. Conditional valuation method (CVM) is widely used in valuing environmental goods and services in terms of willingness to pay [9].



Average willingness to pay is calculated as follow:

$$\begin{aligned} E(WTP) &= \sum_{i=1}^n P_i A_i \\ V_{WTP} &= E(WTP) \times N \end{aligned} \quad (9)$$

Where  $A_i$  is the bidding value that the respondent will pay.  $P_i$  is the probability that the respondent chooses this tender value.  $n$  is the number of bids;  $N$  is population. According to econometric theory, we adopt extended linear expenditure system (ELES) model to measure people's ability to pay.

$$\begin{aligned} p_i q_i &= p_i r_i + \beta \left( I - \sum_{j=1}^n p_j r_j \right) \\ V_{ATP} &= \sum_{i=1}^n p_i q_i \end{aligned} \quad (10)$$

Where,  $i$  is the category of consumer expenditure;  $n$  is the total number of categories;  $q_i$ ,  $r_i$  and  $i$  are the actual demand, basic demand and marginal propensity to consume of consumers for the  $i$ th commodity or service.  $p_i$  is the price of the  $i$ th commodity or service;  $I$  is consumer income.

No one can pay more for a product than they can afford, and no one are willing to pay more for a product than their willingness. So the value of ecosystem services' cultural services is determined by the minimum value of  $V_{WTP}$  and  $V_{ATP}$ . It's show as follow:

$$V_{cs} = \min(V_{WTP}, V_{ATP}) \quad (11)$$

## 3.2 Environmental Degradation

### 3.2.1 Environmental degradation caused by biodiversity loss

There is a positive relationship between biodiversity and most ecosystem services. Biodiversity has multiple roles in the delivery of ecosystem services, as a regulator of ecosystem processes, as the service and good [10].

表 1 生物多样性与生态系统服务的多重关系

Table 1 Multiple relationships between biodiversity and ecosystem services

生态系统过程的调节者 Regulator of ecosystem processes	最终生态系统服务 Final ecosystem services	商品 Goods
土壤动物和微生物:有机质分解与土壤养分循环; 初级生产者(陆地和水中的植物):生物量生产和碳储存、空气质量调节、水质净化; 捕食者:种群调节、食物网调节、减少害虫爆发; 传粉动物:非农业生态系统的稳定性。	野生作物和牲畜亲缘植物(动物):确保遗传多样性,提供食品生产系统的弹性以应对未来气候变化/疾病等; 具有次级化合物的生物体:具有商业开发潜力,例如新型药物; 传粉动物:许多粮食作物的安全。	大型脊椎动物,尤其是鸟类、哺乳动物和供人观赏的开花植物:因其魅力和审美情趣而被认可; 旗舰树种或伞护种:为更广阔的群落和动物栖息地提供保护; 系统发育不同的物种:维持进化多样性; 濒危物种:保持分类学多样性

Figure 3: The flow chart in this paper

### 3.2.2 Biodiversity Regulator

The extent of human impact on an ecosystem is a key factor in assessing the provision of different categories of ecosystem services [11]. In this paper, we mainly talk about the land use projects' impact on ecosystem, and they cause change on ecosystem services by impacting the biodiversity directly.[12] Biodiversity plays an important role in regulating ecosystem services, which means that it can buffer environmental changes and maintain ecosystem services in the face of disturbance. The prevailing view is that when biodiversity is lost, ecosystems become less resilient, so the sum provision of different categories of ecosystem services is impacted by the varying degrees of biodiversity.

According to a simplified set of relationships between the sum provision of different categories of ecosystem services and the degree of loss of biodiversity, we consider biodiversity as a multiplier. When biodiversity change from high to low, this multiplier increase first, then decrease. The formula is as follow:

### 3.2.3 Biodiversity service and good

We make a reasonable assumption that individuals in aggregate would be willing to incur these costs if the natural services were no longer available.

When biodiversity plays as goods or plays as a kind of ecosystem services, it's a direct component of ecosystem service cost when running a land use project. To measure this direct cost, replacement/restoration cost technique is our best choice. The restoration cost (RC) approach assesses the value of an ecosystem service by how much it costs to replace/restore it after it has been damaged [13].

$$U_s = S_s \times A_i \quad (12)$$

where,  $U_s$  represents the value of protecting species of area (\$/year);  $S_s$  is the annual opportunity cost of lost forest species per unit area ((yuan)/(hm<sup>2</sup> · a)).

### 3.2.4 Environmental degradation caused by Pollution

If all pollutants are treated, environmental degradation will not occur so badly. The economic value of environmental degradation already occurring should be the cost of treating all pollutants. To measure the economic more accurately, we divide pollution into **water pollution**, **air pollution** and **solid waste pollution** to calculate each economic value of them.

- **Cost of water pollution**

The cost of pollutant treatment for industry and urban life are both taken into account. The pollutants in industrial wastewater include COD, ammonia nitrogen, hydride, petroleum and heavy metals. Domestic wastewater includes tertiary industry wastewater and residential wastewater, and the treatment cost of each part is composed of COD treatment cost and ammonia nitrogen treatment cost.

The formula for calculating the cost of treating water pollution is as follows

$$V_{iw} = \sum_{i=1}^7 (A_i \times C_i \times r_i) \quad (13)$$

where  $A_i$ ,  $C_i$  and  $r_i$  represent each pollutants' emissions, unit governance cost and removal.

- **Cost of air pollution**

We consider air pollution comes from industry and urban life. The pollutants in industrial gas include  $SO_2$ , dust,  $NO_x$ . The formula for calculating the cost of treating industrial is as follows

$$V_{ig} = \sum_{i=1}^3 (A_i \times C_i \times r_i) \quad (14)$$

where  $A_i$ ,  $C_i$  and  $r_i$  represent each pollutants' emissions, unit governance cost and removal.

Urban life air pollution comes from the fuel gas including Natural gas, gas and liquefied petroleum gas, the formula for calculating the cost of treating industrial is as follows

$$V_{ug} = \sum_{i=1}^3 (N \times p_i \times C_i) + C_h \quad (15)$$

where  $N$  is the city' s population,  $p_i$  is gas usage ratio,  $C_i$  is Per capita gas use cost,  $C_h$  is Heating costs,  $I$  represents three kinds of gas.

- **Cost of solid waste pollution**

Solid waste includes industrial solid waste and municipal solid waste. Industrial solid waste consists of two parts, a waste of storage and discharge. Their treatment cost can be calculated in the same way; the formula is shown as follow:

$$V_s = A \times C \quad (16)$$

where  $A$  represents discharge or storage capacity,  $C$  stands unit processing costs.

### 3.3 Calculation

## 4 Cost-benefit Analysis Model

Cost analysis method is mainly used to calculate the net present value(NPV) and benefit-cost ratio, then select the best project by comparing all of the options.

Objectively, land use projects can produce two different kinds of effects. One kind is internal effect, point to the expenditure that belongs to development land itself to go up economically and accrual, expression is internal cost and internal benefit. The other is the external effect, which refers to the positive and negative effects of land development

and utilization on surrounding resources and environment. Traditionally, most land use projects only consider internal costs and benefits, but ignore the external costs. Then it causes a lot of ecological problems, and destroyed the overall development of agriculture and the virtuous cycle of ecological and economic system, results in great external costs. That's why we should take external costs into cost-benefit analysis (CBA).

## 4.1 Costs and Benefits Analysis

### 4.1.1 Costs

The costs of land use projects can be classified as internal costs and external costs.

- **The external costs.**

The external costs are not directly shown as expenditures on land use but as a monetary estimate of the loss of its other environment arising from the development of the land. Based on our ecological services valuation model, we can calculate the specific external costs of this project.

- **The internal costs.**

The internal cost is the direct expense incurred by the land use project. It includes the investment in land use, operating expenses for land use and so on. These costs can be obtained from statistics.

### 4.1.2 Benefits

The benefits of land use projects can be classified as internal benefits and external benefits. Usually land use projects do not produce external benefits, so we don't take external benefits into consideration. internal benefits are the benefits resulting from land use that can be estimated directly from market prices. They're the direct results of the land use projects.

## 4.2 Calculation

We use two indicators for cost-benefit analysis: Net Present Value(NPV) and Benefit-cost Ratio(BCR). The two indicators have both goodness and shortcoming. When analysing projects of the same size, they have the same function. But when considering projects of different scales at the same time, the NPV method is more inclined to choose large-scale projects, while the rate is more willing to select small-scale projects.

- **NPV**

$$NPV = \frac{B}{1+r} - C_i - C_e \quad (17)$$

where  $B$  is benefits,  $C_i$  is internal costs,  $C_e$  is external costs,  $r$  is the discount rate.

- **BCR**

$$K = \frac{\frac{B}{1+r}}{C_i + C_e} \quad (18)$$

where  $B$  is benefits,  $C_i$  is internal costs,  $C_e$  is external costs,  $r$  is the discount rate.

## 5 Analysis for Two Project

## 6 Implication on Planners and Managers

### 6.1 Assumptions

In order to better understand the application of the model in real life and its implication on land use project managers and planning, we made the following assumptions for further in-depth discussion.

- **The planner and manager are the rational economic man.**  
Economic man refers to an idealized human being who acts rationally and self-interested, who seeks to maximize personal utility or satisfaction.
- **The planner of a land-use project consider economic net present value.**  
The planner of a land use project whose primary purpose is to maximize economic benefits, that is to say, will not consider environmental costs, and the secondary purpose is to choose a plan with less environmental costs.
- **Managers take environmental cost into account.**  
Managers of the city are responsible for choosing planners' projects to implement in cities, so, in the long run, they consider environmental costs as same as accounting cost when selecting projects.
- **The market for land use project is a completely competitive market.**  
This means that the market will choose projects with high NPV or high BCR.

### 6.2 Data Processes

### 6.3 Help planners to site selection

For a project, there are many possible locations, and the different site does not just mean different economic costs, but the various ecological and environmental costs.

A good choice should take care of economic cost and the cost of environmental degradation. Our model can comprehensively evaluate each option, helping planners choose the most appropriate one by comparing the financial costs, ecological costs and overall costs.

## 6.4 Implication on managers

## 7 Sensitivity Analysis

## 8 Strengths and Weaknesses

### 8.1 Strengths

- **Wide application**

Our model is based on most countries' data so that it can be applied to most countries.

### 8.2 Weaknesses

- **Lack of ability to deal with special problems**

Lack of ability to deal with particular problems There might be some errors when our model is applied to some specific countries.

## 9 Future Work

Uncontrovertibly, there are many drawbacks in our model, such as the few data to analysis. We have to do a lot more to improve our work.

- **More data is needed**

More statistical data will be needed in the future work, especially some extreme climate data and some long term climate change data. As a result, the prediction may not as precise as we anticipate

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