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T1 ________________	1916129	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
T4 ________________	E	F4 ________________

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Summary Sheet

To evaluate the unmeasurable cost of environmental services, our team introduces an accounting model to calculate the economic costs of ecosystem services. We divide the true economic costs of land use projects into three parts: natural resource consumption, cost of environmental pollution and cost of environmental degradation.

To measure the **natural resource consumption** more accurately, we discuss the non-market consumption and market consumption separately. For the non-market consumption, we express it with the ecological value of the natural resource we put in. For market consumption, we express it with the shadow price of the net primary production (NPP), which can be calculated by CASA model.

When it comes to **cost of environmental pollution**, we divide the environmental pollution into water pollution, air pollution and industrial waste. Then we consider the derivative effect of pollution by calculating the economic loss it causes.

As for the **cost of environmental degradation**, we divide it into the cost of vegetation depletion, land degradation and biodiversity decrease. We introduce the concept of ecological value to measure the cost of vegetation depletion, while the cost of land degradation is measured by its opportunity cost. Then we introduce Shannon Wiener Index to measure the biodiversity decrease.

To calculate the environmental degradation **cost** of land use projects, we regard the self-recovery process of ecosystem as a negative feedback process based on the feedback principle of BP nerve network. Then we construct a long-term ecological self-recover model. In order to weight different factors’ influence more accurately, we develop an **OBP (One-way back propagation) nerve network**, which is significantly simplified from the well-known BP nerve network. Firstly, we train the known data in the net without considering environmental recovery. After obtaining the weight of each factor, we use it in the **long-term ecological self-recover model** and calculate the cost of environmental degradation.

Then we cite three typical cases to conduct the **cost-benefit analysis**, which are House, Subway and Steel Mill. After our cost-benefit analysis, the House is not worth building considering the cost of ecosystem services, while it is worth building in the traditional analysis model. The Subway and Steel Mill is worth constructing in both the traditional way and our new model. From the cases, we can see the significance of considering the cost of ecosystem services for it may influence the decision of planners.

At the end of the paper, we have a further discussion about the cost of ecosystem services. We put forward an innovative expression of **Green GDP** with the model we built. Moreover, to relieve the externalities of land use projects, we consider **Pigou tax** and define it in a new way.

Key Words: ecological value, BP nerve network, long-term ecological self-recover model, cost-benefit analysis, Green GDP, externalities

CONTENT

1 Introduction

1.1 Background

Ecosystem services are the conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfil human life [1]. *Ecosystem services* provide a guarantee for the survival of all life on earth. In traditional economic theory, *Ecosystem services* tend to be ignored and make no difference to the calculation of some economic indexes, such as GDP. However, *Ecosystem services* can be limited or removed by the human activities, which can influence the biodiversity and cause environmental degradation cumulatively. Moreover, as a research shows, the value of the entire biosphere (most of which is outside the market) is estimated at between $16 trillion and $54 trillion per year, with an average of $33 trillion per year [2]. Therefore, it is necessary to put a value on the environmental cost of human activities that have a negative impact on environment.

1.2 Problem Restatement

In this paper, we are aimed to find out the negative impacts of human activities on environment and value the environmental cost of them. We need to solve the following problems:

- Create a model to calculate the environmental cost of land use development projects. It is consist of natural resource consumption, cost of environmental pollution and cost of *environmental degradation*.
- Use the model to conduct a cost-benefit analysis of actual land use development projects.
- Evaluate the effectiveness and timeliness of the model.

1.3 Symbol Description

Table 1. Symbol Description

Symbol	Description
C_{res}	Natural Resource Consumption
C_{pol}	Cost of Environmental Pollution
C_{deg}	Cost of Environmental Degradation
N	*Net Primary Production (NPP)*
Y	Total Output of an Economic Entity
A	Technology Level of the Economic Entity
L	Labor Put into Production
K	Capital Put into Production

2 Measurement of Natural Resource Consumption

2.1 Net Primary Production

Net primary production (NPP) is a significant indicator for evaluating the level of *ecosystem service*. It weighs the amount of *solar energy* that is fixed by vegetation per unit of time after expending the energy of its *metabolism*. *Net primary production (NPP)* reflects the regulatory capacity of an ecosystem. The higher the value of *NPP*, the more carbon dioxide fixed by vegetation through *photosynthesis* and more nitrogen deposited. It means lower carbon dioxide content in the atmosphere, which directly reduce the *greenhouse effect* [5].

2.1.1 CASA Model for NNP Assessing

By referring to conference, we find out a method to roughly estimate the value of *NPP.* It is the product of vegetation *absorbs photosynthetic effective radiation (APAR)* and *efficiency for solar energy utilization*.

$$NPP = APAR \cdot \varepsilon \quad [5] \tag{1}$$

Where, *NPP* is *Net Primary Production*, $APAR$ is vegetation *absorbs photosynthetic effective radiation* and ε is *efficiency for solar energy utilization*.

1) **APAR** is influenced by *fraction of photosynthetically active radiation (FPAR)*, *total solar radiation (TSR)* and effective radiation ratio, which is 0.5.

$$APAR = FPAR \cdot SOL \cdot 0.5 \quad [5] \tag{2}$$

Where, *FPAR* is *fraction of photosynthetically active radiation*, *SOL* is *total solar radiation,* which can be acknowledged by interpolating all of solar radiation stations in space.

$$FPAR = \frac{FPAR_{NDVI} + FPAR_{SR}}{2} \quad [5] \tag{3}$$

Where, FPAR_{NDVI} can be calculated by *NDVI image* and *NDVI pixel value*, FPAR_{SR} can be calculated by *SR index*. The value of NDVI depends on the type of the vegetation. The SR index can be calculated by *normalized difference vegetation index (NDVI)*.

2) $\boldsymbol{\varepsilon}$ depends on the *maximum light utilization*, *temperature stress factor* and *image coefficients of water stress.*

$$\varepsilon = \varepsilon_{max} \cdot T_{\varepsilon} \cdot W_{\varepsilon} \quad [5] \tag{4}$$

Where, ε_{max} is *maximum light utilization*, which is a constant and depends on the type of the vegetation; T_{ε} is *temperature stress factor* while W_{ε} is *image coefficients of water stress.*

2.2 Modified Cobb-Douglas Production Function

Cobb-Douglas production function is an accounting equation measuring the total output of an economic entity. In classical economic theory, the contribution of *Ecosystem services* to the growth of output tend to be ignored. In this way, the traditional *Cobb-Douglas production function* has a form like this:

$$Y = A \cdot L^{\alpha} \cdot K^{\beta} \tag{5}$$

Where, Y is the total output of an economic entity, A is technology level of the economic entity, L is labor put into production, K is capital put into production, α, β are the *output elasticities* of labor and capital. *Output elasticity* measures the change of output introduced by the increase of unit factor input.

The environmental cost of human activities cannot be reflected in the above formula. Therefore, we introduce the *modified Cobb-Douglas production function*:

$$Y = A \cdot L^{\alpha} \cdot K^{\beta} \cdot N^{\lambda} \tag{6}$$ [3]

Where, N is *Net Primary Production (NPP)*, λ is the *output elasticities* of *Net Primary Production (NPP)*.

2.3 Measurement of Non-Market Consumption

It is hard for us to know the non-market consumption for there is no way to measure the consumers' willingness to pay. On this occasion, we introduce *ecological value* to represent the natural resource consumption. *Ecological value* can be divided into five parts: the value of fixed carbon dioxide, oxygen released, purifying the water quality, cleaning the dust and conserving the soil.

2.3.1 Value of Fixed Carbon Dioxide and Oxygen released

Vegetation has the ability to fix carbon dioxide and release oxygen by *photosynthesis*. The reaction equation is as follows:

$$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O \tag{7}$$

The ratio of NPP, the quality of carbon dioxide and oxygen is 100:163:120 [4]. In the method of *carbon tax approach* and *oxygen cost method*, we can calculate the value of fixed carbon dioxide and oxygen released with the following formula:

$$V_P = S \cdot (c_{O_2} \cdot m_{O_2} + c_C \cdot (m_C + H_S)) \tag{8}$$

Where, V_P is the value of fixed carbon dioxide and oxygen released, S is the floor space of vegetation, c_{O_2}, c_C are respectively the price of oxygen and coal per ton, m_{O_2}, m_C are respectively the amount of oxygen released and carbon fixed, H_S is carbon content of the soil.

The value of each constant can be seen in the following table:

Table 2. Value of Constants in Formula (8) [8]

Constant	Value
c_{O_2}	$198.6\ \$/\mathrm{kg}$
m_{O_2}	$0.05625\ \mathrm{kg/m^2}$
c_C	$150\ \$/\mathrm{t}$
m_C	$0.07755\ \mathrm{kg/m^2}$
H_S	$0.505\ \mathrm{kg/m^2}$

2.3.2 Value of Conserving the Soil

The roots of vegetation are firmly entwined with the soil, which can help conserve the soil. The value of conserving the soil can be calculated by the following formula:

$$V_s = \frac{S \cdot c_{soil} \cdot (x_2 - x_1)}{\rho} \quad [9] \tag{9}$$

Where, V_s is the value of conserving the soil, S is the floor space of vegetation, c_{soil} is the cost of digging up and transporting a unit volume of soil, x_2 is *soil erosion modulus* without vegetation, x_1 is *soil erosion modulus* with vegetation, ρ is *soil bulk density*.

The value of each constant can be seen in the following table:

Table 3. Value of Constants in Formula (9) [9]

Constant	Value
c_{soil}	$6\ \$/\mathrm{m^3}$
x_2	$38.02\ \mathrm{t/hm^2}$
x_1	$2.86\ \mathrm{t/hm^2}$
ρ	$1.09\ \mathrm{g/cm^3}$

2.3.3 Value of Purifying the Water Quality

The branches, leaves and soil of vegetation are able to filter the pollutant in the rainfall. The value of purifying the rainfall quality can be calculated by the following formula:

$$V_w = 10 \cdot S \cdot (c_{wat} + c_{poo}) \cdot (R - TR) \quad [10] \tag{10}$$

Where, V_w is the value of purifying the water quality, 10 is conversion ratio, S is the floor space of vegetation, c_{wat}, c_{poo} are respectively the cost of dealing polluted water and building reservoir per reservoir capacity, R is the amount of rainfall, TR is the amount of transpiration.

The value of each constant can be seen in the following table:

Table 4. Value of Constants in Formula (10) [10]

Constant	Value
c_{wat}	$0.417\ \$/\mathrm{t}$
c_{poo}	$0.147\ \$/\mathrm{a}$
R	$483.3\ \mathrm{mm/a}$
TR	$374.8\ \mathrm{mm/a}$

2.3.4 Value of Cleaning the Dust

Vegetation is able to absorb the hazardous substance in the atmosphere, such as SO_2, HF, NO_X and dust. The value of it can be calculated by the following formula:

$$V_d = S \cdot \sum_{i=1}^{4} c_i \cdot Q_i \text{ [10]} \tag{11}$$

Where, V_d is the value of cleaning the dust, S is the floor space of vegetation, c_i is the cost of controlling hazardous substance, Q_i is the amount of absorption per unit area, *i* can be SO_2, HF, NO_X and dust.

The value of each constant can be seen in the following table:

Table 5. Value of Constants in Formula (11) [10]

Constant	Value
Q_{SO_2}	37.3 kg/(hm².a)
Q_{HF}	1.68 kg/(hm².a)
Q_{NO_X}	6.00 kg/(hm².a)
c_{SO_2}	0.171 $/kg
c_{HF}	0.099 $/kg
c_{NO_X}	0.090 $/kg

2.4 Measurement of Market Consumption

In the factor market, the factor inputs can be adjusted over time. With the Modified Cobb-Douglas Production Function, we use the *shadow price* of *net primary production (NNP)* to represent the natural resource consumption. The *shadow price* reflects the *marginal contribution* of *net primary production (NPP)* to output. Based on formula (2), we can calculate the value of it by taking the partial of *net primary production (NPP)* with respect to output.

$$C_{res} = \frac{\partial Y}{\partial N} = A \cdot \lambda \cdot L^{\alpha} \cdot K^{\beta} \cdot N^{\lambda - 1} \text{ [3]} \tag{12}$$

Where, *Y* is *total output of an economic entity*, *N* is *Net Primary Production (NPP)*, *A* is technology level of the economic entity, *L* is labor put into production, *K* is capital put into production, α, β, λ are the *output elasticities* of labor, capital and *NPP*.

3 Cost of Environmental Pollution

The cost of environmental pollution is mainly consist of four parts: the control cost of water pollution, air pollution, industrial waste and the cost of derivative effects of pollution. It can be represented as the following formula:

$$C_{pol} = C_w + C_a + C_i + C_d \tag{13}$$

Where, C_{pol} is the cost of environmental pollution, C_w, C_a, C_i, C_d is respectively the control cost of water pollution, air pollution, industrial waste and the cost of derivative effects of pollution.

3.1 Cost of Water Pollution Control

Water pollution is mainly caused by *cyanide* and harmful metals. Moreover, high level of *chemical oxygen demand (COD)* is also an evidence of water pollution. Therefore, the cost of water pollution control comes from the three parts. The cost of each part is shown in the following table:

Table 6. Control Cost of Water Pollution [6]

Type of Water Pollution	Cost of Pollution Control ($/t)
COD	1671.43
Cyanide	357.00
Harmful Metals	225.57

The cost of control the water pollution can be calculated as the following formula:

$$C_w = 1671.43 \cdot n_{COD} + 357 \cdot n_{Cya} + 225.57 \cdot n_{met} \tag{14}$$

Where, C_w is the cost of water pollution control, n_{COD} is the difference of COD above the standard value, n_{Cya}, n_{met} respectively represent the amount of *cyanide* and harmful Metals.

3.2 Cost of Air Pollution Control

Air pollution is mainly caused by the pollutants SO_x, CO_2, NO_x, dust and smoke. The control cost of each part is shown in the following table:

Table 7. Control Cost of Air Pollution [6]

Type of Air Pollution	Cost of Pollution Control ($/t)
SO_x	92.86
CO_2	97.14
NO_x	432.86
Dust	32.86
Smoke	20.00

The cost of control the air pollution can be calculated as the following formula:

$$C_a = 92.86 \cdot n_{SO_x} + 97.14 \cdot n_{CO_2} + 432.86 \cdot n_{NO_x} + 32.86 \cdot n_{Dus} + 20 \cdot n_{Smo} \tag{15}$$

Where, C_a is the cost of air pollution control, $n_{SO_x}, n_{CO_2}, n_{NO_x}, n_{Dus}, n_{Smo}$ respectively represent the amount of SO_x, CO_2, NO_x, dust and smoke.

3.3 Cost of Industrial Waste Control

Industrial waste can be divided into general industrial solid waste and hazardous fixed waste. The actual cost of control industrial waste is composed of the treatment cost and storage treatment cost of industrial solid waste. The calculation formula is as follows:

$$C_i = C_{ctl} + C_{sto} \tag{16}$$

Where, C_i is the cost of industrial waste control, C_{ctl} is the treatment cost and C_{sto} is storage treatment cost.

The control cost of each part is shown in the following table:

Table 8. Control Cost of Industrial Waste [7]

Type of Cost	Type of Waste	Unit Control Cost ($/t)
Control Cost	General Industrial Solid Waste	3.14
	Hazardous Waste	214.29
Storage Cost	General Industrial Solid Waste	0.64
	Hazardous Waste	2.15

3.4 Cost of Derivative Effects of Pollution

The *derivative effects* of pollution mainly refer to greenhouse effect, ozone hole and acid rain. The cost of it is calculated by the following formula:

$$C_d = L_{GH} + L_{OH} + L_{AR} \tag{17}$$

Where, C_d is the cost of *derivative effects* of pollution, L_{GH}, L_{OH}, L_{AR} are respectively the economic loss caused by greenhouse effect, ozone hole and acid rain.

The main evaluation index of greenhouse effect is carbon dioxide emissions. The greater the carbon dioxide emissions, the severer the greenhouse effect. Therefore, we approximate the severity of the greenhouse effect in terms of carbon dioxide emissions. The loss of greenhouse effect can be calculated with the following formula:

$$L_{GH} = \alpha \cdot E_c \tag{18}$$

Where, L_{GH} is the loss caused by greenhouse effect, α is the *marginal rate of substitution* of capital for carbon dioxide emissions, E_c is the amount of carbon dioxide emissions.

4 Cost of Environmental Degradation

Environmental degradation refers to the deterioration or compromise of the natural environment through consumption of assets by either natural processes or human activities. The classic examples of *Environmental degradation* are vegetation depletion, land degradation and biodiversity decrease.

$$C_{deg} = C_{vege} + C_{land} + C_{biod} \tag{19}$$

Where, C_{deg} is the cost of environmental degradation, $C_{vege}, C_{land}, C_{biod}$ respectively are the loss of vegetation depletion, land degradation and biodiversity decrease.

Then we will have a further discussion about the cost of the losses.

4.1 Cost of Vegetation Depletion

Vegetation depletion weakens the ability of ecosystem to purify the air, which means it fails to absorb the harmful gas such as SO_x and NO_x. Moreover, vegetation depletion decreases the O_2 in the atmosphere and increases the CO_2 in the atmosphere. The loss of them can be measured by their *ecological value*. The way to calculate the ecological value of the loss is represented by the formula (7).

4.2 Cost of Land Degradation

Land degradation leads to loss of land nutrient substance and sediment hazards. Based on the theory of market value, we can calculate soil conservation value by the opportunity cost of land nutrient substance and the control cost of sediment hazards.

$$C_{land} = \Delta A \cdot (C_{nut} + C_{sed}) \tag{20}$$

Where, C_{land} is the total cost of land degradation, A is *soil retention*, C_{nut} is the unit opportunity cost of land nutrient substance, C_{sed} is the control cost of sediment hazards.

$$A = R \cdot K \cdot LS \cdot (1 - C \cdot P)^{[8]} \tag{21}$$

Where, *R* is *rainfall erosion*, which can be observed, *K* is *factor of soil erodibility*, *LS* is *slope length slope factor*, *C* is *land cover factor*, *P* is *soil conservation measures factor*. All of the parameters except R are constants.

4.3 Cost of Biodiversity Decrease

Misuse of *ecological services* leads to the decrease of biodiversity. To measure the biodiversity in a district, we adopt the *Shannon Wiener Index* formula with the method of *theory of information*.

$$H = -\sum P_i \cdot ln(P_i) \tag{22}$$

Where, H is *Shannon Wiener Index*, P_i is the proportion of species individualities in total number of individuals.

We can learn from the formula that biodiversity is proportional to *Shannon Wiener Index*. In case of species distribution uniformity, the *Shannon Wiener Index* is one. When there is only one species, the *Shannon Wiener Index* is zero. The decrease of species diversity is a long-term qualitative change process. Therefore, the large-scale land project during long period will have negative effects on biodiversity. The cost of ecological services due to biodiversity loss is approximately equal to the difference of *Shannon Wiener Index* over a long period of time multiplied the unit service value. The unit service value is shown in the following table:

Table 9. Unit Service Value of Biodiversity

Range of Shannon Wiener Index	Unit Service Value ($/hm^2)
$0 < H < 1$	428.57
$1 \le H < 2$	714.29
$2 \le H < 3$	1428.57
$3 \le H < 4$	2857.14
$4 \le H < 5$	4285.71
$5 \le H < 6$	5714.28
$6 \le H$	7142.86

5 Long-Term Ecological Self-Recover Model

All of the ecosystems have the ability to self-recover. It is reflected in the renewable nature of resources, the self-decomposition of waste and so on. Based on the feedback principle of BP neural network, we regard the self-recovery process of ecosystem as a negative feedback process, and thus construct the time evolution model of ecological self-recovery.

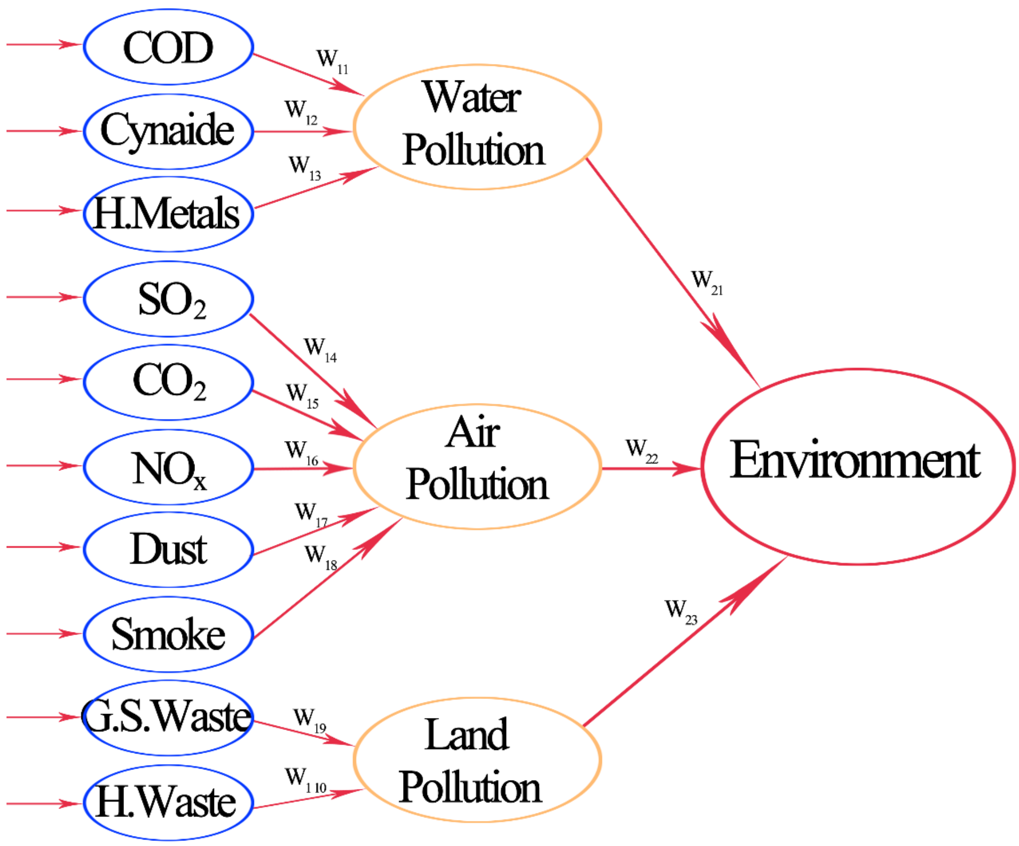
5.1 General Assumption

- The original ecological environment is not polluted.
- The resistance stability of environment is very rapid while the restorative stability is slow.

5.2 Weight Update Formula

Considering the practicability of the model, the weights of the new model cannot be randomly selected. At the same time, we give up the method of AHP to find the weights. Through our database, we establish a training set of 20 different engineering data set. We use *neural network machine learning method* under the condition of satisfying error accuracy to train a group of appropriate weight.

Figure 1. Hierarchical Structure of Neural Network



Note: *G.S. Waste = General Industrial Solid Waste*
H. Waste = Hazardous Waste

When we train the known training set, the process of *neural network back propagation* is influenced by only one "mother". We keep adjusting the weights until it is within the margin of error. The advantage of determining the weight in this way is that the unit influence of different parameters can be reflected in the weight.

The weight update formula from hidden layer to output layer is as follows:

$$\frac{\partial E_{total}}{\partial W_{11}} = \frac{\partial E_{total}}{\partial W_{out}} \cdot \frac{\partial W_{out}}{\partial W_{ne}} \cdot \frac{\partial W_{ne}}{\partial W_{11}} \tag{23}$$

$$W_{11}{}' = W_{11} - \eta \cdot \frac{\partial E_{total}}{\partial W_{11}} \tag{24}$$

Where, E_{total} is the *binary norm* of the total error between the output and the actual value of the output layer neural unit, W_{out} is the output of the neuron, W_{ne} is the linear summation of output values of hidden layer, $\frac{\partial W_{out}}{\partial W_{ne}}$ is to find derivative of the activation function, η is the learning rate.

The weight formula updating the first layer is as follows:

$$\frac{\partial E_{total}}{\partial W_{11}} = \frac{\partial E_{total}}{\partial W_{ow}} \cdot \frac{\partial W_{ow}}{\partial W_{ne}} \cdot \frac{\partial W_{nw}}{\partial W_{11}} \tag{25}$$

$$\frac{\partial E_{total}}{\partial W_{ow}} = \frac{\partial E_{w}}{\partial W_{ow}} \tag{26}$$

$$W_{11}{}' = W_{11} - \eta \cdot \frac{\partial E_{total}}{\partial W_{11}} \tag{27}$$

Where, E_w is the overall error of hidden layer (water pollution) nerve cell, W_{ow} is the output if nerve cell (water pollution), W_{nw} is the linear summation of output values of input layer, $\frac{\partial W_{ow}}{\partial W_{ne}}$ is to find derivative of the activation function, η is the learning rate.

5.3 Simulation Process

Firstly, based on the life cycle theory, we divide the project into five cycles, which are the planning and design period, the raw material processing period, the construction period, the operation period and the end of life period. Here, we consider the evolution law of the pollution discharge with time in the raw material processing period, construction period and operation period.

We can substitute the weights trained by *BP neural network* into our ecological self-recover model. The pollutants discharged in the projects must be treated before they flow into the *ecosystem*. The pollutants flowing into the *ecosystem* are partly eliminated by the resistance of *ecosystem* while the others remain there. In the long term, this part could be purified because of the self –recover ability of *ecosystem*. Furthermore, something needs to be noticed.

- When the level of pollution exceeds the critical value that the *ecosystem* can withstand (k/2), the pollutant will not be purified.

- The stability of *ecosystem* decreased with the increase of pollution degree, and the stability of resilience increases with the increase of pollution degree.

The pollutant of the first year can be calculated by the following formula:

$$E_1 = \sum_{i=1}^{3} x_{1i}(1-\beta_i)) \cdot (1-\lambda) \tag{28}$$

The pollutant in year *m+1* can be calculated by the following formula:

$$E_{m+1} = \sum_{i=1}^{m+1} E_n \cdot f(m+1-n,\gamma) + \cdot \sum_{i=1}^{3} x_{1i}(1-\beta_i)) \cdot (1-\lambda) \tag{29}$$

Where, $\gamma = \mathrm{g}(\sum E), \lambda = \mathrm{h}(\sum E)$

As the system evolves, the ecosystem collapses because either the pollution level exceeds k/2, or it will reach a dynamic equilibrium. When it reaches the dynamic equilibrium, the status can be represented by the following formula:

$$E_{m+1} \cdot \big(1 - f(1)\big) = \sum_{n=1}^{m-1} E_n \cdot f(m+n-1,\gamma) + \left(\sum_{i=1}^{3} x_{1i} \cdot (1-\beta)\right) \cdot (1-\lambda) \tag{30}$$

Where, $\mathrm{f(a,b)}$ is a function that reflects the ecosystem restoration changed with recovery capability and time, $\mathrm{g(E)}$ is the function that reflects the ecosystem restoration increases with the pollution level increasing, $\mathrm{h(E)}$ is the ecosystem resilience decreases with the pollution level increasing.

5.4 Practical Application of the Model

Using our model, we can calculate the environmental degradation cost in different years more accurately. Then we use four practical examples to apply the model, the details of the data can be seen in the appendix. The computed results are as follows:

Figure 2. Environmental Degradation Cost of Bridge and Steel Plant

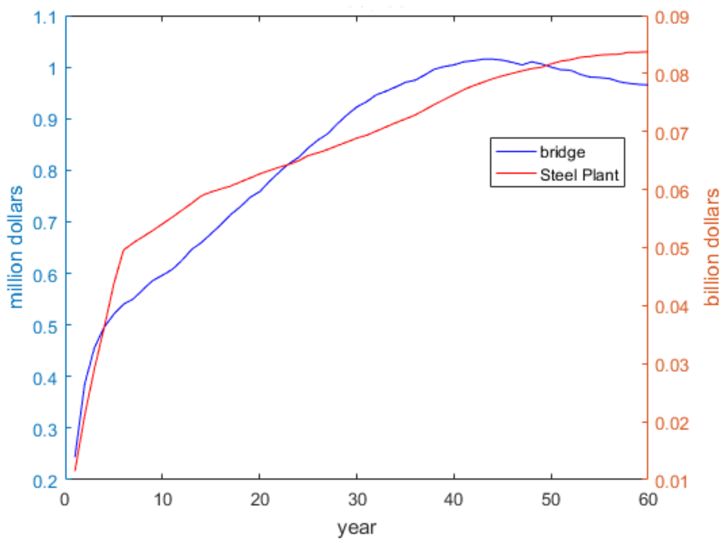
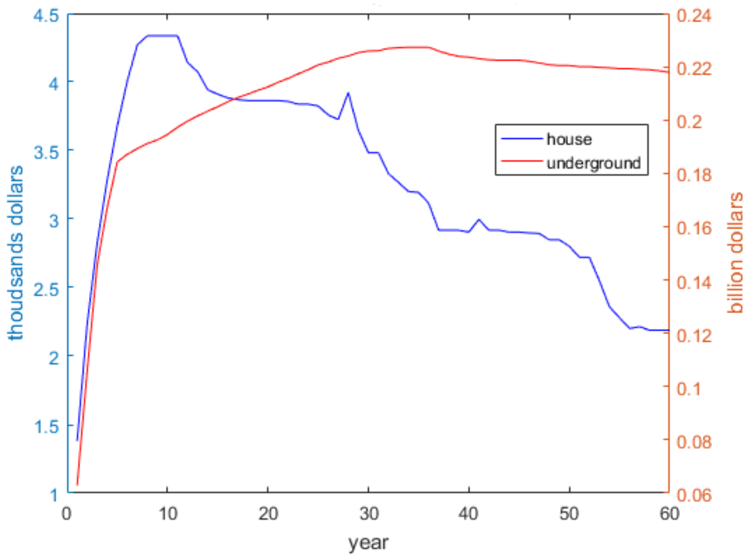


Figure 3. Environmental Degradation Cost of House and Subway



There is a turning point in both figures. The curve before the turning point is our raw material and construction. In this part of curve, a large amount of pollutant emission rises rapidly. Therefore, there is a little bit steep. The curve after the turning point is the operating period. In this part of curve, we find that because of the purification of ecosystem, the houses and bridges in the projects with less pollution will self-recover over time. However, for the steel mill and subway project with more pollution, the purification of the annual quantity is less than new emissions pollution. Without man-made management, pollution become more serious.

6 Cost-Benefit Analysis of Land Use Project

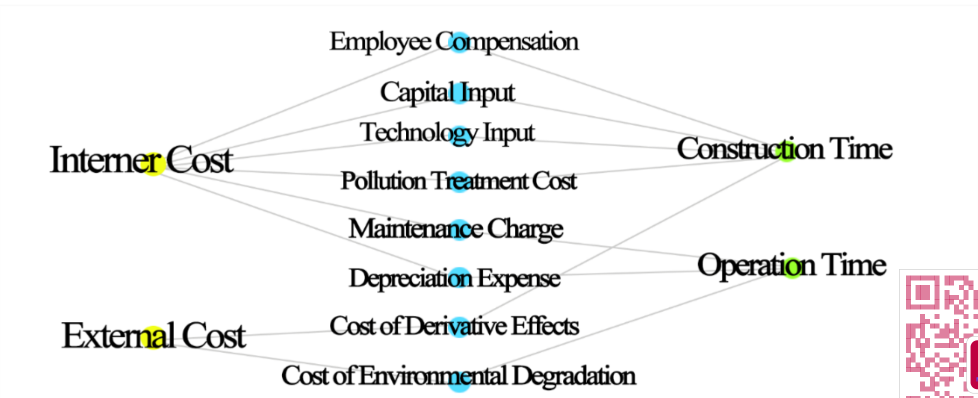
6.1 General Assumption

- Net cash flow (NCF) is the same every year.
- The depreciation method is linear depreciation.

6.2 Cost Analysis of Land Use Project

In order to simplify the model, we use *factor cost* to calculate the main cost of projects. The components of long-term costs of land use project are shown in the table below:

Figure 4. Components of Main Long-Term Costs of Project



6.2.1 Cost in Construction Time

Considering the lifetime of the project, we introduce the concept of *present worth*, which is calculated by *expected cash flow*, *present value factor* and *discount rate*. By adopting the present value approach rather than simply adding the *cash flow* of each year together, we can get a more accurate cost figure. In this way, we fully account for the *time cost* of the input factor.

$$C_1 = \sum_{i=1}^{t_1} \frac{w_i + k_i + T_i + C_{con,i}}{(1+r)^{t_1}} \tag{31}$$

Where, C_1 is the cost in construction time, t_1 is the construction period, r is *discount rate*, $w_i, k_i, T_i, C_{con,i}$ are respectively the employee compensation, capital input, technology input and pollution treatment cost in year *i*.

6.2.2 Cost in Operation Time

Likewise, we take the lifetime of the project into consideration. The depreciation method is linear depreciation. The cost in operation time can be calculated by the following formula:

$$C_2 = \sum_{j=1}^{t_2} \frac{m_j + d_j}{(1+r)^{t_2}} \tag{32}$$

Where, C_2 is the cost in operation time, t_2 is the operation period, which is equal to expected useful life of the asset, r is *discount rate*, m_j, d_j are respectively the maintenance charge and depreciation expense. The depreciation expense can be calculated according to formula (20).

$$d_j = \frac{K}{t_2} \tag{33}$$

Where, K is constructed assets that need to be depreciated， t_2 is the expected useful life of the asset.

6.3 Benefit Analysis of Land Use Project

The long-term benefit of land use project is mainly consists of future inward cash flow and estimated *net residual value* of the project.

Considering the time cost, we calculate the benefit by the following formula:

$$I = \frac{I_O}{(1+r)^{t_2}} + \sum_{j=1}^{t_2} \frac{I_j}{(1+r)^{t_2}} + I_{un} \tag{34}$$

Where, I is the total benefit of the project, I_O is expected *net residual value*, r is *discount rate*, t_2 is the operation period, I_j is inward cash flow in year *j*, I_{un} is the non-market benefit, which depends on the type of projects.

6.4 Cost-Benefit Ratio

Cost-benefit ratio is to reflect the profitability of the project, which can help decision makers to determine whether the project is beneficial to conduct. The cost-benefit ratio can be calculated by the following formula:

$$r = \frac{C}{I} \tag{35}$$

Where, r is cost-benefit ratio, C is the financial cost, I is inward cash flow.

In the traditional cost-benefit analysis, the decision maker may underestimate the total cost by ignoring the cost of *ecosystem services.*

In the developed cost-benefit analysis, we take the cost of *ecosystem services* and the social benefit into consideration. The developed formula can be represented as follows:

$$r = \frac{C + C_e}{I + I_s} \tag{36}$$

Where, r is cost-benefit ratio, C is the financial cost, C_e is cost of *ecosystem services*, I is inward cash flow and I_s is social benefit.

6.5 Case Analysis

In this part, we will conduct cost-benefit analysis of three different size projects using the self-recover model. Details of cost of *ecosystem services* and pollution are listed in the appendix. Moreover, we assume that the *discount rate* is 3%.

6.5.1 House of One Hundred Square Meters

The construction time of residential building is around one year, while the lifetime of it is around twenty years. The expected *net residual value rate* is about 5%. The cost and benefit can be seen in the following table:

Table 10. Cost Analysis of House

House	Cost/$
Employee Compensation	2,914.29
Capital Input	25,714.29
Technology Input	7,142.86
Maintenance Charge	2,571.43
Cost of Derivative Effects of Pollution	41,214.72
Cost of Environmental Degradation	699.00
TOTAL	**80,256.59**

Table 11. Benefit Analysis of House

House	Annual Payment/$	Present Value of Annuity/$
Rent Income	5,142.84	76,512.60
Net Residual	1,917.74	1,061.85
Social	0	0
TOTAL		**77576.45**

The cost-benefit ratio calculated in the traditional way is 0.49, which means the project is worth conducting. However, the cost-ratio calculated considering the *ecosystem services* is 1.03, which means the project is not worth conducting.

6.5.2 Subway of Forty Kilometers

The construction time of subway is around five years, while the lifetime of it is around sixty years. The *rate of depreciation* of subway is 1%. The cost and benefit can be seen in the following table:

Table 12. Cost Analysis of Subway

Subway	Annual Payment/$	Present Value of Annuity/$
Employee Compensation	137,142,857.14	626,742,857.14
Capital Input	274,285,714.29	1,253,485,714.29
Technology Input	45,714,285.71	208,914,285.71
Maintenance Charge	1,142,857.14	5,222,857.13
Cost of Derivative Effects of Pollution	9,300,938.57	42,595,508.37
Cost of Environmental Degradation	125.71	575.73
TOTAL		**2,136,961,798.37**

Table 13. Benefit Analysis of Subway

Subway	Annual Payment/$	Present Value of Annuity/$
Service Charge Income	81,428,571.43	2,253,581,612.85
Net Residual Value	835,657,142.86	141,838,669.05
Social Benefit	4,428,571.43	122,563,210.56
TOTAL		**2,517,983,492.46**

The cost-benefit ratio calculated in the traditional way is 0.83, which means the project is worth conducting. However, the cost-ratio calculated considering the *ecosystem services* is 0.84, which means the project is worth conducting as well.

6.5.3 Large-Scale Steel Mill of Twenty-Three Square Kilometers

The construction time of a steel mill is around five years, while the lifetime of it is around twenty years. The *rate of depreciation* of steel mill is 1%.The cost and benefit can be seen in the following table:

Table 14. Cost Analysis of Steel Mill

Steel Mill	Annual Payment/$	Present Value of Annuity/$
Employee Compensation	141,181,111.74	646,567,137.44
Capital Input	988,267,782.17	4,525,969,962.01

Technology Input	282,362,223.48	1,293,134,274.87
Maintenance Charge	27,697,106.54	126,844,438.84
Cost of Derivative Effects of	38,696,421.71	177,218,002.52
Cost of Environmental Degradation	719.67	3,295.89
TOTAL		**6,769,737,111.57**

Table 15. Benefit Analysis of Steel Mill

Steel Mill	Annual Payment/$	Present Value of Annuity/$
Revenue from Operations	1,858,571,428.60	51,437,011,900.24
Net Residual Value	0	0
Social Benefit	0	0
TOTAL		**51,437,011,900.24**

The cost-benefit ratio calculated in the traditional way is 0.13, which means the project is worth conducting. However, the cost-ratio calculated considering the *ecosystem services* is 0.13, which means the project is worth conducting as well.

7 Sensitivity Analysis

In order to test the robustness of the model, we added 1% noise value to the above index parameters of our model and observed the change rate of output cost. The results are shown in the following table.

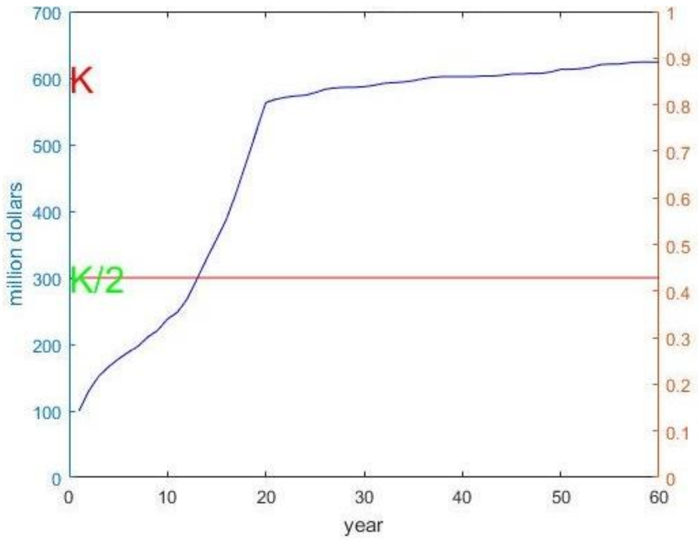
Table 16. Error of the Ecological Cost Corresponding to the Different Input Error

Parameter	Housing	Bridge	Subway	Steel Plant
H(1%)	0. 025%	0. 003%	0. 02%	0. 56%
SO_x(1%)	0. 15%	0. 14%	0. 05%	0. 13%
NO_x(1%)	0. 14%	0. 21%	0. 12%	0. 20%
Cyanide (1%)	0. 11%	0. 12%	0. 19%	0. 10%
General Industrial Waste (1%)	0. 14%	0. 17%	0. 14%	0. 13%
Hazardous waste (1%)	0. 09%	0. 12%	0. 10%	0. 09%

When we apply the model to practice, the margin k/2 is much higher than the damage caused by the project. Therefore, the ecosystem can always reach a dynamic balance. In order to verify the accuracy of the model, we replace k/2 value with a lower value, which can be reached more easily. We can see from the graph that once the degree of pollution surpasses the values of k/2, it stops to increase. It means that *ecosystem* collapsed under the weight of pollution.

The results can be seen by the following figure:

Figure 5. Results with Different *K*



8 Strength and Weakness

8.1 Strength

- The model comprehensively considers multiple factors such as *ecosystem services* and environmental degradation.
- We estimates the value of *ecosystem services* by opportunity cost and shadow cost, which can reflect real value objectively.
- We use the *negative feedback* form of *artificial neural network* to construct our ecosystem self-recover model originally.
- Based on the model we conducted, we have a further discussion about the *Green GDP* and talk about the expression of *Pigou tax* for the *externalities* problem.

8.2 Weakness

- Limited by our knowledge, there exists some factors that we fail to consider.
- We do not consider the factor of *inflation*. Therefore, there may be errors in project costs.
- Due to the limitation of space and data, we cannot do the cost analysis of land engineering in different zones.
- The cost-benefit analysis of steel mill could be not representative for we selected a steel mill with high profit rate for example.

9 Further Discussion

9.1 Pigou Tax for Externalities of Natural Resources

Externality refers to the non-marketable influence of economic activities of economic subjects (including manufacturers and individuals) on others or society. Environmental pollution we discussed above is a typical negative externality, which do harm to the *ecosystem* and society. Both policy makers and business decision makers should consider the cost of *Ecosystem services* while making decisions. Then we will discuss the establishment of the *Pigou tax* levied on polluters.

The target of *Pigou tax* is to equalize the gap between the private and social costs of polluters' production by the way of levying. From the model we built above, the *Pigou tax* can be formulated as the following formula:

$$\mathrm{T}_p = \mathrm{C}_{deg} + \mathrm{C}_d \tag{37}$$

Where, T_p is *Pigou tax* for a specific land use project, C_{deg} is the cost of environmental degradation, C_d is the cost of *derivative effects* of pollution.

9.2 Inspiration to the Expression of Green GDP

9.2.1 Traditional Accounting of Green GDP

Green GDP refers to *Gross domestic product (GDP)* accounting considering the *ecosystem services*. Based on the traditional GDP accounting system, the value of Green GDP is the value of GDP after deducting the cost of natural resources and cost of environmental pollution. It can be represented by the following formula:

$$\mathrm{EDP} = \mathrm{NDP} - \mathrm{C}_{res} - \mathrm{C}_{pol} \tag{38}$$

Where, EDP is Green GDP, NDP is net domestic product, C_{res} is the non-market consumption of natural resources, and C_{pol} is the cost of environmental pollution.

9.2.2 Innovative Expression of Green GDP

In the previous section, we put forward the concept of *natural resources consumption*. We use it to represent the **initial production cost**, which can reflect the total natural resource input in the entity district.

9.2.2.1 General Assumption

- All of the capital input come from nature.
- All of the labor input come from the consumption of natural resources consumption.
- All of the labors are put into production.
- There is no natural resources escaping from the *ecosystem*.

9.2.2.2 Process of Calculability

Firstly, we replace the capital input and labor input with the previous natural resources consumption. GDP can be calculated with the total natural resources consumption.

$$\mathrm{GDP}_n = \sigma(\mathrm{C}_{res,n} + \sum_{i=o}^{n} \delta \cdot \mathrm{C}_{inp,i}) \tag{39}$$

Where, GDP_n is GDP in year *n*, $\mathrm{C}_{res,n}$ is the natural resourced consumption in year *n*, σ is *production efficiency*, δ is resource depreciation rate, and $\mathrm{C}_{inp,i}$ is the natural resources input generated in year *i*.

On this basis, the value of Green GDP in year *n* is the previous results minus the pollution treatment costs, pollution derivative effects and environmental degradation losses generated in all processing processes. The following formula represent the whole process:

$$\mathrm{EDP}_n = \mathrm{GDP}_n - \mathrm{C}_{pol,n} - \mathrm{C}_{deg,n} \tag{40}$$

Where, GDP_n is GDP in year *n*, $\mathrm{C}_{pol,n}$ is the cost of environmental pollution in year *n*, $\mathrm{C}_{deg,n}$ is the cost of environmental degradation in year *n*.

Appendix

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II. Cost of Ecological Service Data Sheet

Cost of Ecosystem Services	House	Subway	Steel Mill
Oxygen	159.57	114.86	5,874.30
Carbon Dioxide	94.86	68.29	3,485.70
Water Purified	225.29	225.14	4,142.90
Soil Fertilizer	80.14	124.86	2,234.30
Dust Clean	9.14	7.14	674.30
Biodiversity	130.00	88.29	8,777.10
Cost of Pollution	699.00	628.57	25,188.60
COD	171.43	4,646,571.43	57,497,142.90
Cyanide	2,428.57	10,174,500.00	157,794,000.00
Harmful Metals	371.43	800,778.57	22,557,142.90
SO	1,200.00	2,925,000.00	216,357,142.90

CO	44.29	476,000.00	9,646,285.70
NO	242.86	6,319,714.29	328,971,428.60
Dust	3,142.86	7,162,857.14	153,771,428.60
Smoke	1,057.14	838,000.00	38,200,000.00
General Industrial Solid Waste	28,571.43	7,685,000.00	222,600,000.00
Hazardous Waste	3,285.71	5,475,642.86	146,955,000.00
TOTAL	**41,913.72**	**46,505,321.44**	**1,354,399,948.80**