For office use only		Team Control Number	For office use only	
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2019
MCM/ICM
Summary Sheet

Balance of Interest strategy based on ecosystem services assessment

In an era of endless construction projects, we pursue high returns and low costs, but we rarely pay attention to the impact of our actions on the biosphere. To achieve sustainable development, we establish an ecosystem service assessment model that incorporates the impact of land use projects on ecosystem services into cost considerations. The idea of this model is to normalize the data, establish a neural network model, calculate the MIV(Mean Impact Value), and extract the independent variables. Use the weighted method of vector similarity to evaluate the weight of indicators with the sample data. Afterwards,the established model uses the weighted linear summation to calculate the ecological service evaluation index.

Then, we apply the data from US states to this model to analyze the ecological status of each state, and draw conclusions that the southeastern states and parts of the western region have excellent ecosystem service capabilities. After comparing with the results from the InVEST model. We can find that the ecological assessment indexes of the US states are coincide with each other, which proves the validity of the model.

Next, according to the concept of green GDP, this paper divides the environmental cost into the total value of natural resource loss and the total value of environmental pollution loss. We compare the environmental cost calculations for projects of different sizes. Small projects are distinguished from large projects by their insignificant impact and easier to adjust features, so their impact on the original ecosystem service functions can be ignored. After considering ecological services, enterprises, governments and society form a game relationship. We have established a *gear model* to find the optimal solution for cost allocation. The model shows that in the relationship between the selective cost and the transitional cost, the optimal cost allocation appear when the ratio of the transitional cost reduction rate to the selective cost increase rate is close to 1.Project planners and managers should actively approach this goal. In addition, the paper also introduces the positive regulatory role of the government.

Considering time changes, the evaluation model should be extended to a dynamic model. We replace the original standardized indicator with the energy value index of the non-monetized accounting, at the same time, by establishing the differential equation of land type changing over time, the linear equation group of index weight is established by using the predicted result of specific index of ecological service from 2019 to 2025 and the value of ecological service. Then the weighted optimal solution of *particle swarm optimization* algorithm is used to calculate the total energy indicator. This article takes California as an example, based on historical data from 10 indicators to predict changes in the next 8 years and determine the ecological service value per unit of land area.

Key words: ecological service assessment model environmental cost gear model vector similarity non-monetary accounting

Contents

Introduction

Background

In the traditional economic theory, in general, the difference between the price of construction and the construction materials and workers' wages is the benefit of building a building. The destruction of the soil during the construction process and the pollution of the air are rarely considered. These changes often require non-negligible inputs to correct, and some changes are even irreversible. We need a new means to consider the true cost of an economic activity. Ecosystem services assessments are currently being developed as a means of integrating ecological understanding and economic considerations to correct traditional neglect of ecosystem services in policy decisions. The emphasis on ecosystem services is conducive to attracting political support for ecological protection, as well as facilitating the commercialization of more and more ecosystem services and providing tremendous support for solving environmental problems. Exploring a more scientific and effective assessment method of ecosystem services and balancing the economy and the environment are urgent need of today's economic society.

Our work

Our work begins with the establishment of an ecological service assessment model. Screen indicators, quantify the ability of ecological services, calculate the ecological civilization index, and evaluate the level of ecological civilization construction.

The benefit analysis of the land use development project, that is, the environmental cost to analyze the green GDP, is not enough under the premise of the known ecological service capacity assessment, and the environmental pollution loss accounting is also required. The second part of the article is to complete this work.

From small community projects to large-scale national projects, land-use development projects of different scales are slightly different when using the ecological service evaluation model. The third part of the article takes a case of a large-scale project for application.

Next, we compare the results of the InVEST model with the results of the ecological service evaluation model we established, and analyze the effectiveness of the model. In order to reflect the game relationship between the costs of all parties and find the optimal environmental cost, we reclassify the environmental cost using the gear model to understand the optimal real cost and the impact on planners and managers.

At the end of the paper, we analyze the changes of the model we built over time. Due to the spread and accumulation of pollution, the model is not static over time.

Assumption

- The data we find is real and effective
- The construction of the land use development project covers part of the area of the local ecosystem, and the ecological services that can be provided in the area are deemed to be unavailable.
- The results obtained by the InVEST model are close to the real situation and can be used to verify the validity of the model.
- When discussing the optimal cost, the production and operation level of the enterprise remains unchanged, that is, the degree of pollution under the same output is discussed.

Nomenclature

We use the nomenclature in Table1 to describe our model. Other symbols that are used only once are described later.

Table 1: Table of symbols

Symbol	Definition
Q_i	Standard value of the i-th indicator
S_i	Target value of the i-th indicator
C_i	Status value of the i-th indicator
W_k	The k-th weight vector from main and objective weighting method
X	Reference vector
Y	Comparison vector
θ	Vector angle
α	Length similarity
β	Direction similarity
γ	Similarity
ω_i	Index Weight
y	Composite index

Task1: Model of ecosystem services assessment

Ecosystem services [1] are an important basis for ecosystem management and decision making, and indicator systems are the primary tools for conducting assessments. By drawing on the experience of the construction of relevant indicator systems, and based on the characteristics of ecosystem services, the principle of establishing an indicator system has been formed. After the establishment of the indicator system, the data is normalized. Then, based on the information amount of the sample data, the weight of the evaluation index is objectively determined by the combination weighting method based on the vector similarity. Finally, we use the weighted linear sum method to establish the system comprehensive development level index model, calculate the ecological civilization index, and evaluate the level of ecological civilization construction.

Construction of indicator system

Principles for the establishment of an indicator system

By drawing on the experience of the construction of relevant indicator systems, standing on the shoulders of giants, according to the characteristics of ecosystem services, the existing research results are summarized and the following establishment principles of indicator systems are formed.

- Use indicators that are appropriate for regional and national scales. Adopt the final ecosystem service indicator classification system. From a practical point of view, the ecosystem final service is directly related to human welfare Health, safety, factors of production and natural diversity.
- There is no distinction between ecosystem types. Different ecosystem types may have common functional or attribute characteristics.
- Typicality. Most of the evaluation indicators used are indicators used by well-known international organizations or national assessments.
- Quantitative. Quantitative indicators can be used to calculate for objective judgments
- Data is available. The direct observation data of the indicator or the data required for parameter calculation should be easy to collect, and there is an authoritative and reliable data source.
- Scale. Use indicators that are appropriate for regional and national scales.

Ecosystem service evaluation indicator system

In the construction of the ecosystem service indicator system, the evaluation indicators of the international ecosystem services and their practical application capabilities in the United States are considered. We have comprehensively considered the direct reference or quantitative relationship of various ecosystem attribute parameters to ecosystem service indicators, and the human benefit linking with health, safety, production factors and natural diversity. In the end, we build the ecosystem service evaluation indicator system. Each level is divided into the following table

Table 2

Indicator category (Primary indicator)	Subject indicator (Secondary indicators)	Specific indicators (Three-level indicator)
A. Supply service	1.Freshwater	1)Water production
	2.Food	2)Crop yield
		3) Grassland pasture production (livestock)
		4) Aquatic production (aquatic products)
	3.Wood and fiber	5) Forest aboveground biomass
	4.Genetic and biological resources	6)Species richness
B.Adjustment service	1.Climate change mitigation	7.Ecosystem carbon fixation
	2.Regional microclimate regulation	8) Actual evapotranspiration
	3.Air quality adjustment	9) Oxygen release and dust retention
	4.Natural disaster regulation	10) Forest cover rate
	5.Flood regulation	11) Wetland and impact plain area / flood Risk area
	6.Erosion regulation	12)Soil retention
	7.Water quality regulation	13) Vegetation coverage
	8.Pest control	14) Vegetation species richness
C. Cultural service	1.Leisure and Entertainment	15) Green and wetland landscape coverage
	2.Cultural heritage	16)World Heritage
	3.Cultural diversity	17)Species richness
		18)Ecosystem type diversity
D. Support service	1.Circulation of nutrients	19)--------
		20)--------
	2.Primary production of photosynthesis	
	3.Refuge	21) Breeding area, migratory area

Screening of indicator systems

Use neural network to screen indicators

First, standardize the ecological civilization construction indicators, namely:

$$Q_i = 1 - \frac{C_i}{\max S_i}(Inverse\ indicator) \qquad Q_i = \frac{C_i}{\max S_i}(Positive\ indicator)$$

where Q_i is the standard value of the i-th indicator. S_i is the target value of the i-th indicator. C_i is the status value of the i-th indicator.
Second, normalize the processed data:

$$X' = \frac{X - X_{\min}}{X_{\max} - X_{\min}}$$

where X_{max} and X_{min} represent the maximum and minimum values in the group data. The obtained result is used as the input and output data of the neural network, and then the MATLAB is used to realize the neural network screening model, and the MIV value is obtained, and 10 main indicators are selected according to the numerical value, as shown in Table 3.

Assign weights to important metrics

Combination weighting method based on vector similarity

1. Principle of multi-attribute decision making

   In a multi-attribute decision model, program collection $S=\{S_1, S_2, \cdots, S_m\}$,attribute collection $P=\{P_1, P_2, \cdots, P_n\}$,attribute weight collection $\omega=\{\omega_1, \omega_2, \cdots, \omega_n\}$.In the formula, $\sum_{j=1}^{n}\omega_j = 1, 0 < \omega_j < 1$. Decision matrix $A = [a_{ij}]_{m \times n}$, a_{ij} is the evaluation value of the program S_i under the attribute P_j. Generally, attributes are classified into benefit type, cost type, fixed type and interval type, and the dimensions of different attributes may be different. To facilitate calculation, the decision matrix must be normalized. Let the decision matrix be the matrix $B = (b_{ij})_{m \times n}$ obtained by the dimensionless processing, which is called the normalized decision matrix.
2. Determination of weight
   - Weight determined by the primary and objective weighting methods

     The weights of the indicators determined by the decision makers by one main and objective weighting method are:

$$W_k = (w_{k1}, w_{k2}, \cdots w_{kn}), k = 1, 2, \cdots, l$$

where $\sum_{j=1}^{n} w_{ki} = 1, w_{ki} \geq 0$. W_k is the weight vector obtained by the kth main and objective weighting method

- Vector similarity calculation [4]

The size and direction can usually be used to comprehensively characterize the similarity of two vectors. The definition is as follows:

Definition 1: Let $X=(x_1,x_2,\cdots x_n)$ be the reference vector, $Y=(y_1,y_2,\cdots y_n)$ be the comparison vector, Then the length similarity α between the vector X and Y is :

$$\alpha(X,Y)=\begin{cases} 1-\left|\dfrac{\|X\|-\|Y\|}{\|X\|}\right| & \|Y\|\le 2\|X\| \\ 0 & \|Y\|\le 2\|X\| \end{cases} \quad (1)$$

Definition 2: Let $X=(x_1,x_2,\cdots x_n)$ be the reference vector, $Y=(y_1,y_2,\cdots y_n)$ be the comparison vector, Then the direction similarity β between the vector X and Y is :

$$\beta(X,Y)=1-\frac{\theta}{90} \quad (2)$$

Definition 3: Let $X=(x_1,x_2,\cdots x_n)$ be the reference vector, $Y=(y_1,y_2,\cdots y_n)$ be the comparison vector, Then the similarity γ between the vector X and Y is :

$$\gamma(X,Y)=\alpha\cdot\beta \quad (3)$$

- Combination weighting method based on vector similarity

Usually, the weight vectors calculated by the principal and objective weighting methods are different. From the similarity principle analysis, some weight vectors are similar, and some are similar. If the vector obtained by one weighting method is similar to the vector obtained by other weighting methods, it means that most decision makers hold similar subjective preferences or the weights obtained from the original data processing are relatively stable and reliable. These weight vectors are combined. A larger proportion should be obtained in the vector. Therefore, the relative importance of various weighting methods can be measured by the relative magnitudes of the weight vector and the total similarity of other weight vectors.

The total similarity between any weight vector W_k and other vectors is:

$$\gamma=(\gamma_1,\gamma_2,\cdots\gamma_l)$$

In the formula,

$$\gamma_k = \sum_{i=1, i \neq k}^{l} \gamma(W_i, W_k) \tag{4}$$

Therefore, the weight coefficient vector of any weight vector W_k is:

$$\theta = (\theta_1, \theta_2, \cdots \theta_l)$$

$$\theta k = \frac{\sum_{i=1, i \neq k}^{l} \gamma(W_i, W_k)}{\sum_{k=1}^{l} \sum_{i=1, i \neq k}^{l} \gamma(W_i, W_k)} \tag{5}$$

Get the weighted results as shown in the following table

Table 3

Indicator category	Specific indicators	MIV absolute value	Weights
A. Supply Service 0.25	1. Water production		0.107
	2. Crop yield (food)		0.087
	3. Forest aboveground biomass		0.056
B. Adjustment service 0.501	4. Ecosystem carbon fixation		0.109
	5. Actual evapotranspiration		0.094
	6. Oxygen release and dust retention		0.114
	7. Forest cover rate		0.098
	8. Vegetation species richness		0.086
C. Cultural service 0.132	9. Species richness		0.132
D. Support service 0.117	10. Primary production of Photosynthesis		0.117

System comprehensive development level index model

Use threshold method to make x_{ij} dimensionless:

$$x_{ij}^* = x_{ij} / \max_{1 \le i \le n} x_j$$

Among them, x_{ij}^* is called standard observation, $\max_{1 \le i \le n} x_j$ represents the maximum value of n evaluated objects in the jth indicator. The processed standardized data is then combined with the weighted linear sum method to synthesize the ecological quality index, economic harmony index, social development index and ecological civilization index. The weighted linear sum method is calculated as:

$$y = \sum_{i=1}^{n} \omega_i x_{ij}^{*}$$

where y represents the composite index. ω_i indicates the index weight.
The specific data can be brought into the model to obtain the ecological civilization construction index, and the level of ecological civilization construction in each region can be judged according to the index ranking.
In the United States, for example, an ecosystem service assessment is conducted for each state. The results obtained by applying the model are as follows:

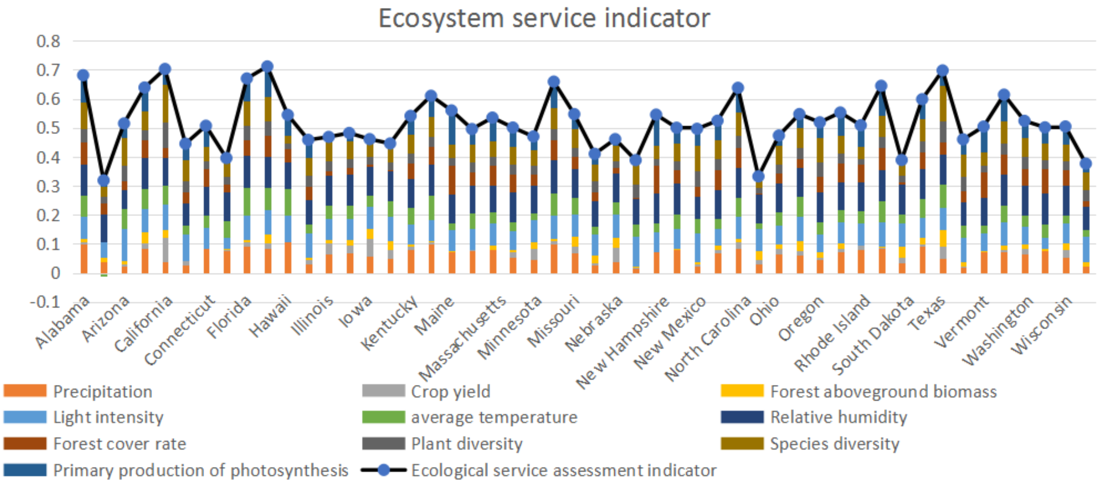

Figure 1: Ecosystem service indicator of every state

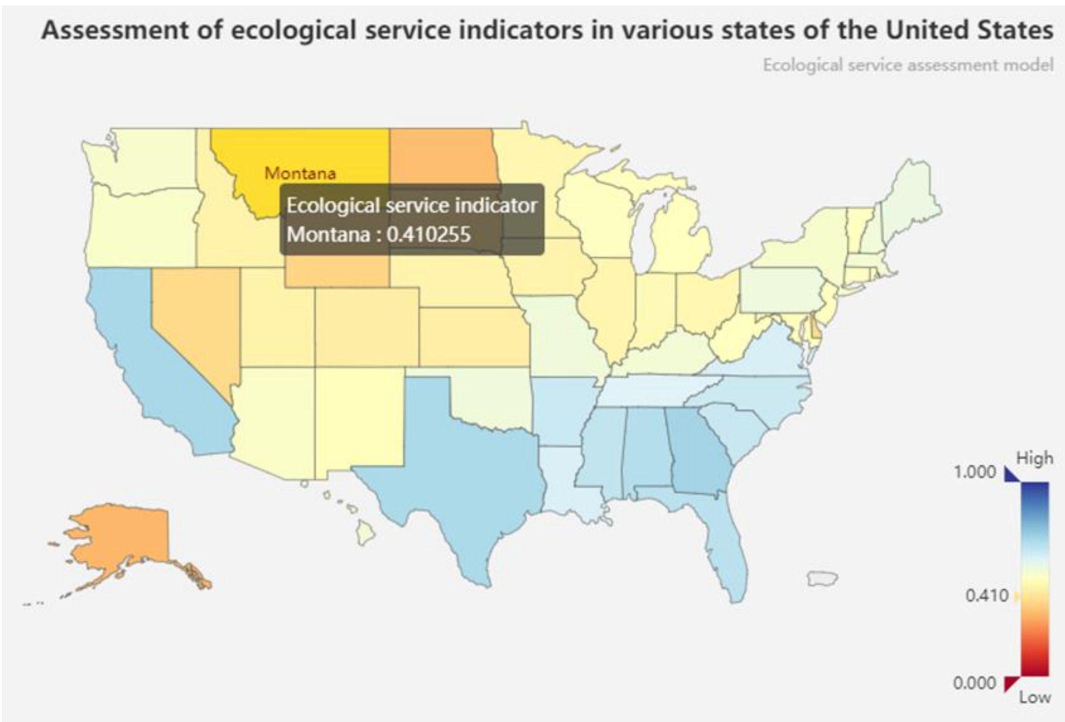

Figure 2: Ecosystem assessment index map for each state

Table 4: Ecological service level assessment

Ecosystem service division type	US state
Ecological advantage	Georgia、California、Texas、Alabama、Florida、Mississippi
Environmental potential	Arkansas、North Carolina、Virginia、Louisiana、Tennessee、Maine、Pennsylvania、Oklahoma、Missouri、New Hampshire、Hawaii、Kentucky
Relatively balanced	Massachusetts、New York、Washington、Oregon、Arizona、Rhode Island、Connecticut、Wisconsin、Vermont、West Virginia、Michigan、New Jersey
Low equilibrium	New Mexico、Maryland、Indiana、Ohio、Minnesota、Illinois、Nebraska、Iowa、Utah、Idaho
Service deficiency	Kansas、Colorado、Montana、Delaware、South Dakota、Nevada、Wyoming、North Dakota、Alaska

The Southeastern United States has a high ecosystem service assessment index. When this part is stationed in the same project, thanks to the innate conditions of the ecosystem, the environmental costs are much lower than in the northwest. The state's ecological service assessment index is clear at a glance, and this result can be used as a reference when considering a project in a state.

Model advantages and disadvantages analysis:

Advantages: Our model apply reasonable indicators and have achieved the objective and comprehensive evaluation to ecological service capabilities. Besides, it implement the output of the model visualization.
Disadvantages: We need lots of data to seek results from the model.

Task2: The valuation of environmental costs

Calculate the cost-effectiveness of land-use development projects, that is, consider environmental costs to analyze green GDP [5,6].

Green GDP = Traditional GDP - (Total value of natural resource loss + Total value of environmental pollution loss)

Note: 1. The sum of the total value of natural resource loss and the total value of environmental pollution loss is called environmental cost. The total value of natural resource losses can be considered;

2.Because the construction of the project covers part of the local ecosystem, the ecological services that can be provided in the area are now unavailable. Therefore, the loss of natural resources is regarded as the ecological service that the original place can provide.

The following is an estimate of the total value of environmental pollution losses. The environmental damage value is divided into two parts: environmental degradation value and environmental damage value. In the environmental degradation value accounting, the main accounting costs of the "Industrial three wastes" and "three wastes of life" and the total funds for environmental protection inputs in each year. In the environmental damage value accounting, it mainly accounts for the loss of environmental value caused by pollution accidents, the loss caused by casualties and the depreciation of fixed assets due to environmental pollution.

● Environmental degradation value accounting

The value of environmental degradation caused by pollution can be expressed by the total input cost of pollution control, including the actual governance costs that have been invested in governance and the virtual governance costs that have not yet been invested. According to the calculation formula of virtual governance cost proposed by Liao Mingqiu:

Virtual governance cost=Total pollutant emissions× (1 − Pollutant discharge compliance rate) ×Unit governance cost

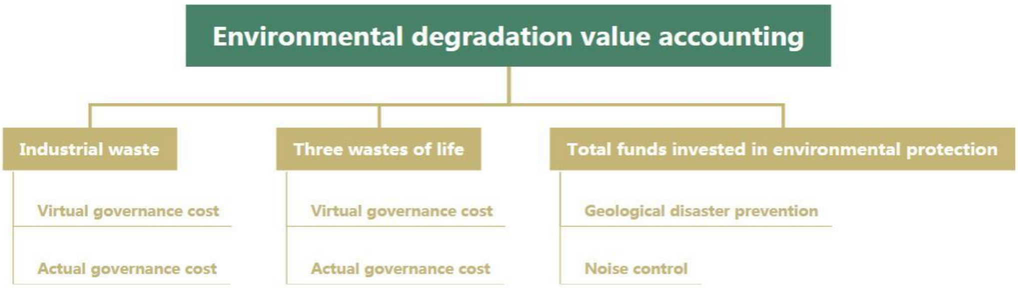

Figure 3: Environmental degradation value accounting

Table 5: Take New York as the representative, the cost of industrial three waste treatment **Unit: million**

Years Types	Domestic wastewater	Domestic waste gas	Domestic garbage	total
2014	460.3	913.2	926.5	2300
2015	454.5	1358.7	681.86	2500
2016	480.53	913.6	1305.87	2700
2017	591.7	788.6	------	2300 Valuation
2018	884.1	------	600.2	2100 Valuation
2019	586.3	773.9	939.8	2300

Table 6: The cost of living three wastes

Unit: million

Years Types	Domestic wastewater	Domestic waste gas	Domestic garbage	total
2014	------	99.3	106.6	1074.8 Valuation
2015	952.1	91.6	336.7	1380.4
2016	352.3	77.6	89.4	519.3
2017	------	76.3	104.5	766.3 Valuation
2018	331.3	62.3	79.2	472.8
2019	407.8	46.3	93.2	547.3

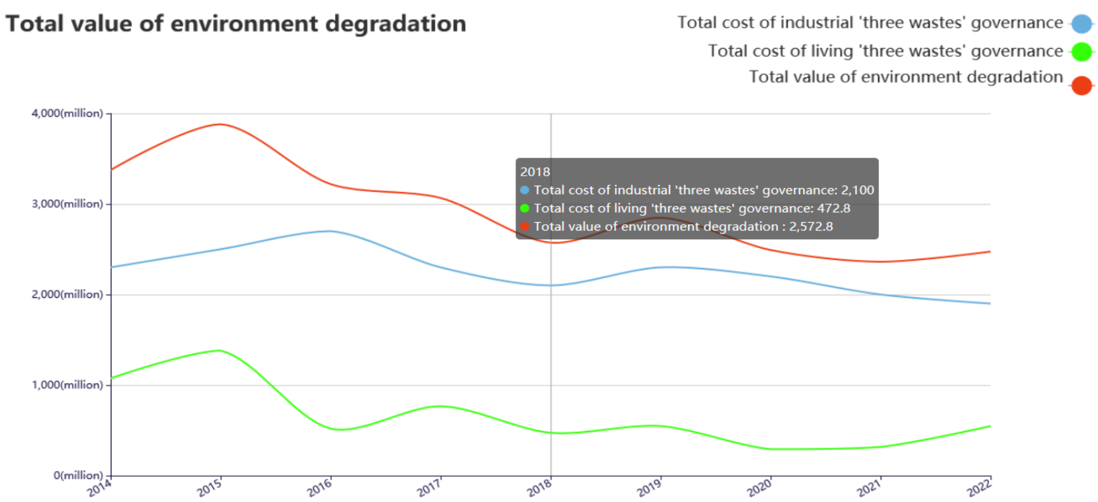

Figure 4: Total value of environment degradation

● Environmental damage value accounting

The accounting for the value of environmental damage is mainly carried out from the aspects of human health loss caused by environmental degradation, accelerated depreciation of assets and loss of production efficiency.

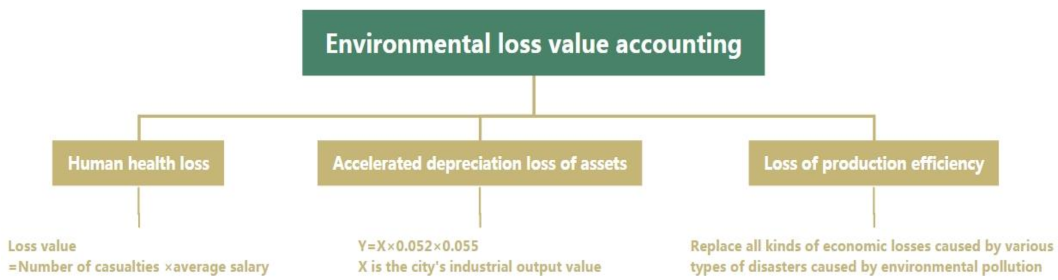

Figure5: Environmental loss value accounting

Task3: Cost-benefit analysis of land use development projects of different scales

A large national project

For a large national project, we take the reconstruction of the New York and Newark rail system as an example. The Gateway Program (originally Gateway Project) is the planned phased expansion and renovation of the Northeast Corridor (NEC) rail line between Newark, New Jersey, and New York City, New York. The right-of-way runs between Newark Penn Station and New York Penn Station (NYP). The project would build new rail bridges in the New Jersey Meadowlands and new tunnels under Bergen Hill (Hudson Palisades) and the Hudson River, and expand NYP through conversion of part of the James Farley Post Office into a train station and construction a terminal annex.

PP: The Gateway Program's first phase includes the construction of a new tunnel under the Hudson River, the rehabilitation of the existing tunnel, the completion of a concrete casing on the West Side of Manhattan to preserve right-of-way for the future tunnel to PSNY, and the replacement of the Portal Bridge.

Later phases of the Gateway Program would include the replacement of the Sawtooth Bridges located in Harrison, New Jersey, and the expansion and modification of PSNY, Newark Penn Station and Secaucus Junction Station ("Bergen/Secaucus Loop") in New Jersey.

According to the plan, we have drawn the following road map:

Figure 6: Roadmap for the project plan

Project investment:

The original construction cost plan was $24.1 billion

When considering ecological services and environmental costs, the project spans three continents, and the impact on the ecosystem is obvious, so the value provided by the original environment is destroyed, such as reducing the area of green space and lake, and also making the natural environment. The reduction in the plant diversity or the species diversity has led to a reduction in the value provided by environmental potential, which has led to an increase in environmental costs. When the project is built, it will have waste discharges, which makes it costly to treat the waste, which also increases environmental costs. Therefore, the investment shown in Figure 9 above is far from the cost of building the project. It needs to be calculated in conjunction with the environmental cost accounting part of this paper. The calculation method has been given in the foregoing, and will not be repeated here for redundancy.

Cost of the Gateway Program

Billions of dollars.

Phase	Project	Cost
Phase 1	Portal North Bridge	1.6
Phase 1	Trans-Hudson Tunnel Entrance	0.3
Phase 1	Trans-Hudson Tunnel	7.7
Phase 1	Sawtooth Bridge Replacement	1.1
Phase 2	Moynihan/Penn Station	5.9
Phase 2	Portal South Bridge	1.9
Phase 2	Secaucus Junction Renovation	1.8
Phase 2	Secaucus Loop Construction	1.3
Phase 2	Newark-Secaucus Embankment	0.3
	Subtotal, Projected Cost	**21.9**
	Plus 10 percent overage	2.2
	Total Cost Estimate	**24.1**

Source: Multiple news accounts of Amtrak's January 2016 presentation to USDOT, plus the official FTA cost estimate for Portal North Bridge from May 2017.

Figure 7: Cost of the gateway program

A small project

For example, a small steel mill in California. California Steel Works in Fontana Area, California, USA, formerly known as Kaiser Steel. It is mainly equipped with two 210-ton top-blowing oxygen converters and one single-flow slab continuous casting machine with an annual output of 650,000 tons. The annual output of steel is 255~3 million tons. The factory mainly adopts steel structure. The main buildings are: main building of steelmaking and continuous casting, scrap steel room, bulk raw material room, secondary dust removal room, water supply and drainage pumping station and cooling tower, distribution transformer room, converter sewage treatment and continuous casting water.

When considering the ecological service and calculating the environmental cost, the self-purification ability of the environment plays a big role because the project is small and the floor space is relatively small. Therefore, when using the previous environmental cost accounting method, there is a clear difference between the environmental damage value accounting for larger national projects. Relying on environmental self-purification capabilities, the environment will not be downgraded to cause major disasters and other accidents. Therefore, when environmental cost accounting is performed, human health loss, asset accelerated the depreciation loss and production efficiency loss caused by environmental degradation can be ignored. Environmental costs are expressed as the sum of the total value of natural resource losses and the value of environmental degradation.

Task4: Analysis of the effectiveness of the ecosystem service evaluation model

InVEST model application

The InVEST model [7]is built into ArcGIS. From InVEST 2.3.0, the evaluation module is continuously independent and can support the direct startup of the Windows operating system. The InVEST model quantifies, maps, and evaluates some of the service functions in terrestrial, freshwater, and marine ecosystems.

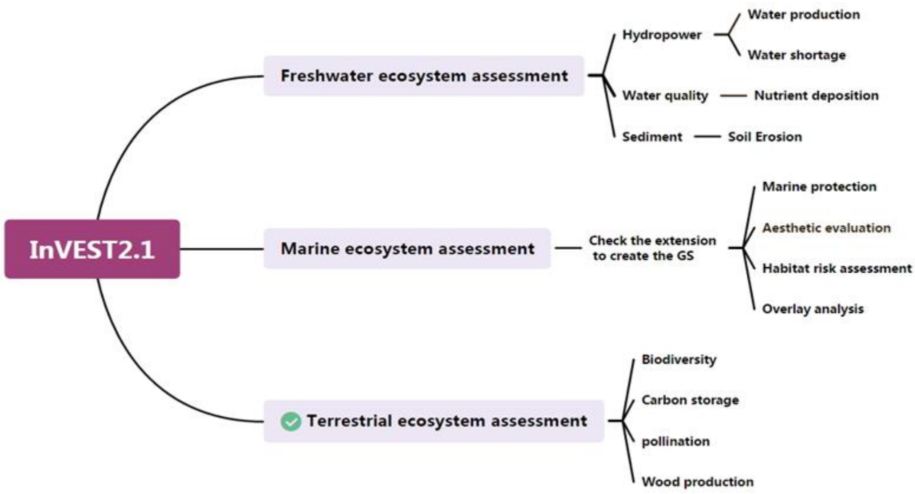

Figure 8: InVEST model

The processing of model data applies spatial differentiation feature analysis. The spatial correlation structure pattern of each service is revealed by visualizing the distribution map to analyze the spatial differentiation law of multiple services in the basin. The specific formula is detailed in the reference, and the process of model evaluation is:

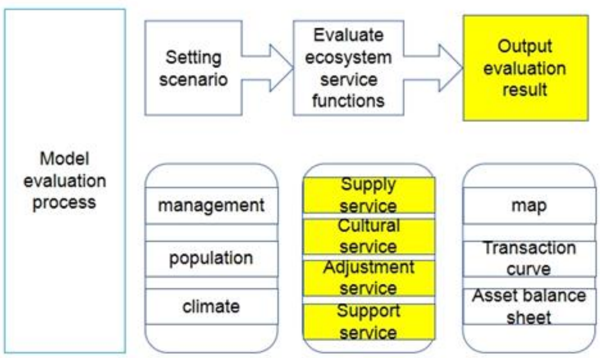

Figure 9: Model evaluation process

Model's result:

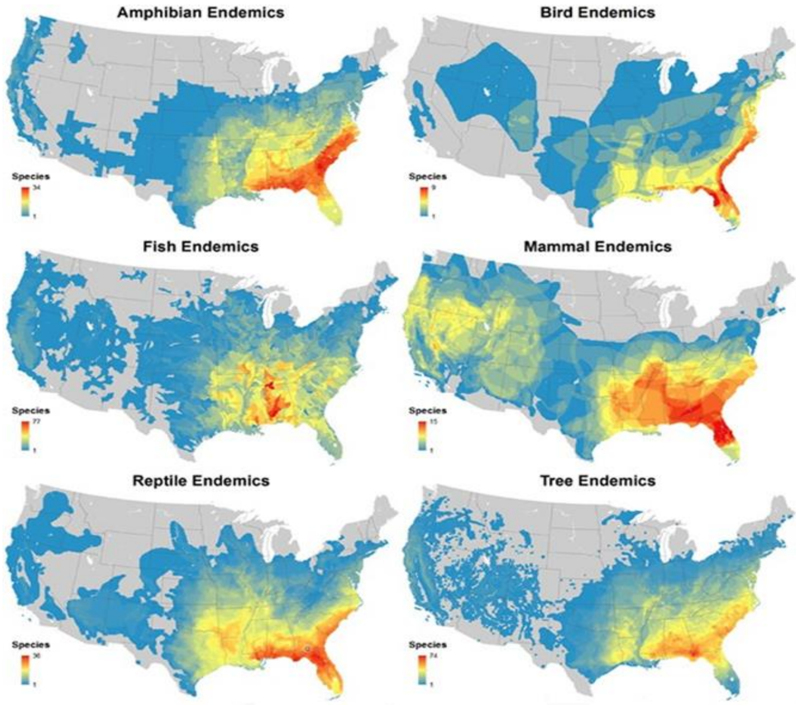

Figure 10: Model’s result

Model validity analysis

The eco-service assessment model is used to judge the state's ecological service capacity, and an indicator is used to measure its ecological service capacity. The larger the indicator is, the better the contribution value of the state's ecological service is.

Figure 2 of our ecosystem services assessment model: clearly, a small portion of the southwest and much of the southeast of the United States is blue (with a large indicator), with Georgia, Mississippi, and California in particular being the bluest

For example, in the case of Abe endemics, the reddish color indicates more diversities of mammals. It can be seen that some parts of the southeast and west of the United States are darker in red (the richer the mammals are), with Georgia, Alabama and Mississippi being the most reddish. The same is true of other graphs, such as Tree Endemics, which is most reddish in the southwest (especially Alabama and Mississippi).

It can be seen from the comparison of the two figures that the index value of both figures is large in a small part of southwest and southeast of the United States, which means that the ecological service contribution ability is strong. Therefore, from the results, the inVEST model output is consistent with our ecological service evaluation model output, which verifies the validity of our model.

Task5: The true cost of the project and its impact on project planners and managers

Real economic cost

Here, in order to facilitate the analysis of the impact of changes in environmental costs, we integrate the "people-oriented" thinking, the loss of people's welfare as the ultimate cost of damage to the environment, the environmental costs are divided into selective costs, transitional costs and punitive costs, three the interactions together constitute the "gear model" of environmental cost accounting.

The selective cost refers to the expenses actually paid by the enterprise to maintain the natural resources at the level before consumption reduction or downgrading.The transitional cost mainly refers to the depletion of natural resources and the deterioration of the ecological environment directly caused by the economic activities of enterprises. The punitive cost mainly refers to the loss of human physiological and psychological welfare caused by the depletion of natural resources and the deterioration of the ecological environment.

"Gear Model" and Optimal Environmental Cost

Under the above classification method, there is a close relationship between the three costs. The increase in selective costs will inevitably reduce the damage caused by pollution to the ecological environment, which will directly lead to the reduction of transitional costs. The transitional cost is the additional load caused by the production and operation activities of the enterprise to the ecological environment, which is reflected in the double damage of the quantity and quality of natural resources, which in turn will lead to the loss of human welfare, that is, the punitive cost. Once the problem involves its own welfare spending, the expenditure on environmental governance will rise. Punitive costs can be counterproductive to selective costs, allowing them to continue to increase to reduce punitive costs. The three types of environmental costs interact with each other and cause each other, similar to the principle of gear rotation. We refer to the mutual change relationship of three types of environmental costs as the "gear model" of environmental cost control.

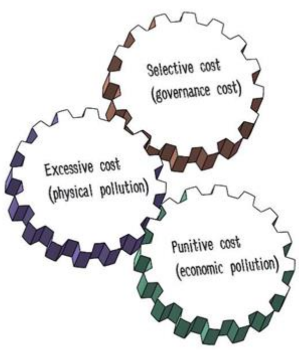

Figure 11: Gear Model

The relationship between the three costs is shown in the figures.

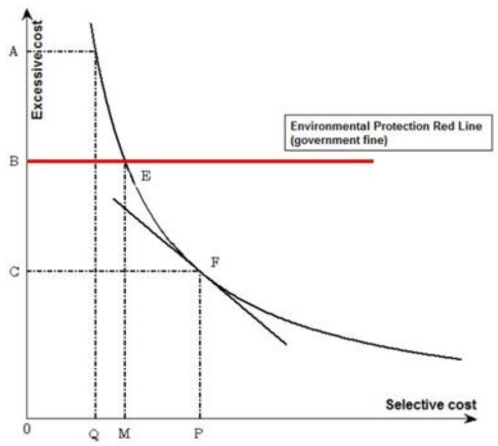

Figure 12: Optimal selectivity cost

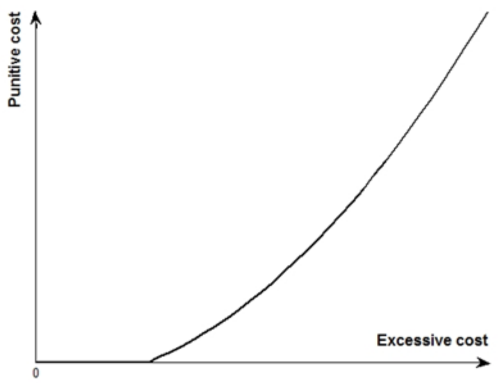

Figure 13: The relationship between transitional costs and punitive costs

Using this relationship, to make the sum of the selective cost and the punitive cost small, it is necessary to find a selective cost input that satisfies both and small in the relationship between the selective cost and the transitional cost. As shown in Figure 2, the curve is convex toward the origin, indicating that as the cost of selectivity increases, the transitional cost continues to decrease, but the rate of decline continues to slow. The result of the two non-equal changes is that the total cost is decreasing. Assume that the enterprise is currently in the E state. When the selective cost increases from Q to P, the transitional cost decreases from A to C, and the rate of decline is slowing down. When the point P is reached, the rate of decline and the rate of increase of selective cost are just equal. The total cost is small, that is, point F is excellent, and point P is excellent selective cost. It is not difficult to find that the government's task is to move the environmental cost from point E to point F, that is, the input of selective cost should increase from Q to P. To achieve this transformation, policy guidance is crucial. If the government uses a transitional cost level B between A and C as the fine, a fine for transitional costs above B (That is, the AB part of the figure) would force companies to move selective costs from Q to Q. M. At this point, the government will give the company a certain subsidy for the remaining MP parts to reach the F point status.

Impact on planners and managers

In order to achieve the minimum environmental cost, it is necessary to actively cooperate with the government (public) and enterprises to form a non-zero-sum game transition from zero-sum game to cooperation.

For the government: policy guidance for enterprises, take the initiative to bear part of the selective environmental costs. The government can promote enterprises to improve production processes and update equipment through industry subsidies to reduce waste of resources and share part of the selective cost burden of enterprises. It also increases the cost of the company's excessively excessive costs, namely the internalization of complete external costs. By increasing the charges for pollutant emissions, the government can guide enterprises to shift from passive government fines to active environmental governance.

For planners: When planning land use projects, take into account the results of ecological service assessments, and formulate plans with long-term vision to appropriately undertake additional selective costs to seek a win-win situation for profit and environment.

For managers: When the ecological service assessment is included in the planning considerations, the natural resource environment changes during the operation of the project, the environmental degradation slows down or even achieves sustainability, which provides external protection for the management process and adds a stable cornerstone. To a certain extent, it has achieved the "long-term stability" in management.

Task6: Model changes over time

Since pollution is diffusive, cumulative, etc., the model changes over time. The following is to study the change.

Firstly, introduce the energy value [9]:

In the establishment of the ecosystem service evaluation model, we standardize the specific indicators. Actually, we still use the system of currency quantity accounting methods for traditional economic value assessment. When we expand the evaluation model into a dynamic model, we consider the accumulation of metric error and the narrowness of monetary quantification, so each specific indicator is converted into emergy analysis. The energy value of the specific indicator is obtained by using the energy value currency ratio, the relevant accounting principle and the specific indicator data based on the original ecological service evaluation model.

Calculating the ecosystem from the perspective of the supplier using the solar value is a measure of the amount of available energy that is directly or indirectly applied in the formation of a product or service. Its advantage is that it can convert different levels and different types of substances or energy into a unified measure by energy conversion rate [19-22], that is, solar energy value, thus to solve the lack of common metrics in the current ecosystem service value accounting problem. Emergy analysis is not only an important method of environmental accounting, but also a detailed analysis of material flow and energy transfer, which makes it an important tool for system analysis and evaluation. It allows quantification of the environmental workload that supports each traffic or storage, and evaluates each resource from an endowment value perspective (donor side), not just based on human preferences and market contingency.

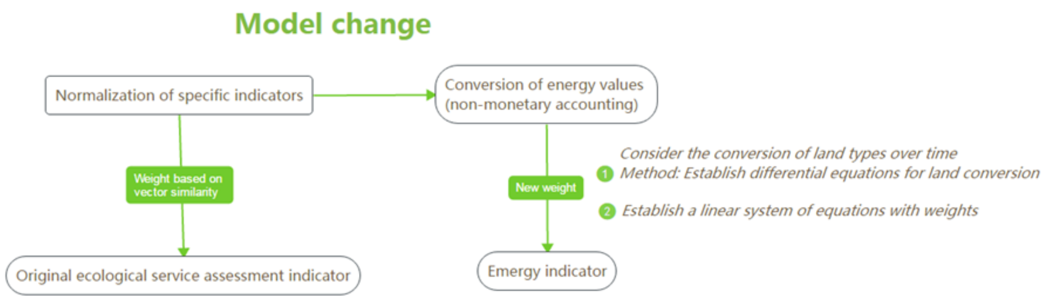

Figure 14: Model change

Due to the limitations of the Markov model itself, the process of predicting the change of the object is required to be stable. During the forecast period, the predicted object is required to maintain a certain fixed transition probability, but in practice, the land cover is changed over time. Being influenced by many natural or human factors is not a true Markov process. In order to truly consider the adjustment of land change trends such as policies, positive government influences, natural disasters and other factors, this paper establishes the following Pacth-Dynamics model to consider the system response to describe the change of land type (To some extent, it also reflects the degradation of the environment or better situation):

Y_i indicates the area of the i-type land cover type at the initial time. Y_{it} is the area of the type i land cover type after the elapsed time, a_{ji} is the percentage (probability) of the type j land cover type converted to the type i land cover type during the period. So,

$$Y_{it} = \sum_{j=1}^{n} a_{jt} Y_j$$

Therefore, the change of the type I land cover type in time t is :

$$Y_{it} - Y_i = \sum_{j=1}^{8} a_{ji} Y_j - Y_i = (a_{ji} - 1) \cdot Y_i = \sum_{j=1,\, j \neq i}^{8} a_{ji} Y_j$$

Assuming t is the unit time, the rate of change of the i-type land area per unit time is:

$$r = \frac{Y_{it} - Y_i}{Y_i} = \frac{Y_{it}}{Y_i} - 1 = \frac{\sum_{j=1}^{8} a_{ji} Y_j}{Y_i} - 1 \quad \text{So,} \quad \frac{dY_i}{dt} = Y_i r = Y_i \cdot \left(\frac{\sum_{j=1}^{8} a_{ji} Y_j}{Y_i} - 1 \right) = \sum_{j=1}^{8} a_{ji} Y_j - Y_i$$

Determination of the ecological service value per unit of land area:

The value of regional ecological service is the main indicator for quantitatively characterizing the function of regional ecosystem services. We quote the research results of Costanza and so on, and appropriately adjust the data in the literature to obtain the ecological value table of the unit area of each land cover type:

Table 7: The ecosystem service values of each land use type

Unit: (dollar·(hm³·a)-1)

Indicator category	Land cover type	Arable land	Shrub	Sparse woodland	Grassland	Permanent snow cover	Resident construction land	Water body
Supply function	454	634	571	317	558	96	---	12764
Adjustment function	54	1966	1769	983	979	163	---	48896
Support function	322	504	453	252	374	62	---	8

(continue)

Cultural function	---	314	282	157	97	16	165	1840
total	830	3418	3076	1709	2009	337	165	68008

- Fitting predictions for specific indicators: This article uses California as an example to predict changes over the next eight years based on historical data from 10 indicators. (Note: In order to visually represent each indicator in the graph, we have scaled the curve)

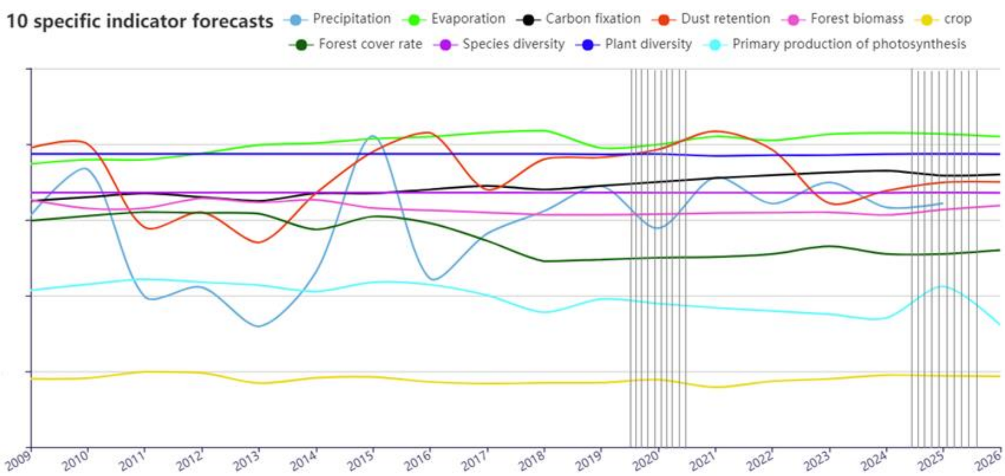

Figure 15: 10 specific indicator forecasts

- Take 10 sets of approximate values from 2020 and 2025and analyze the energy value indicators. Let the weight of the specific indicator be $w_1 w_2 ... w_9 w_{10}$ .According to the service evaluation model, the following formula is established:

$$\begin{bmatrix} X_1^1 & X_2^1 & \cdots & X_{10}^1 \\ X_1^2 & X_2^2 & \cdots & X_{10}^2 \\ \vdots & \vdots & \ddots & \vdots \\ X_1^{10} & X_2^{10} & \cdots & X_{10}^{10} \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \vdots \\ \omega_{10} \end{bmatrix} = \begin{bmatrix} y' \\ y' \\ \vdots \\ y' \end{bmatrix}$$

The optimal solution of $w_1 w_2 ... w_9 w_{10}$ can be obtained by particle swarm optimization algorithm [10] or neural network algorithm.
The weighted linear sum method is calculated as :

$$y = \sum_{i=1}^{n} \omega_i x_{ij}^*$$

Where: y represents the energy value synthesis index. ω_i is the updated indicator weight.

Reference

[1] ZHAO Wenjie, WU Xiaoman, ZHU Jiaming.Evaluation of Provincial Ecological Civilization Based on System Comprehensive Development Index Model[J]. Journal of Baoji University of Arts and Science (Natural Science Edition),2016,36(02):85-88+92.
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[9] Yang, Q., Liu, G., Casazza, M., Campbell, E., Giannettia, B., Brown, M., December2018. Development of a new framework for non-monetary accounting on ecosystem services valuation. Ecosystem Services 34A, 37-54
[10] Wang Lirong, Zhai Yunwei.Improvement of Particle Swarm Optimization Algorithm Based on Function Optimal Solution Problem[J]. Computer Technology and Development,2013,23(02):49-51+56.

Appendix：

Summary of chart data sources:

1. Table 2 data sources
Average precipitation:
https://www.currentresults.com/Weather/US/average-annual-state-precipitation.php
Average temperature:
https://www.currentresults.com/Weather/US/average-annual-state-temperatures.php
Average humidity:
https://www.currentresults.com/Weather/US/annual-average-humidity-by-state.php
Average illumination:
https://www.currentresults.com/Weather/US/average-annual-state-sunshine.php
Forest cover rate:
https://en.wikipedia.org/wiki/Forest_cover_by_state_and_territory_in_the_United_States
Crops (grain)：http://beef2live.com/story-states-produce-food-value-0-107252
Species diversity, plant species diversity:
https://www.researchgate.net/publication/269111849_States_of_the_Union_Ranking_America's_Biodiversity
Forest aboveground biomass (replaced by hay):
https://www.usda.gov/nass/PUBS/TODAYRPT/cropan16.pdf

2. Table 5,6 data sources：
https://www.wm.com/sustainability/pdfs/2016SustainabilityReport_WM.pdf
http://www.columbia.edu/~sc32/documents/ALEP%20Waste%20Managent%20FINAL.pdf
http://www.nyc.gov/html/planyc2030/downloads/pdf/140422_PlaNYCP-Report_FINAL_Web.pdf
http://www.columbia.edu/~sc32/documents/ALEP%20Waste%20Managent%20FINAL.pdf
http://www.nyc.gov/html/nycwaterboard/pdf/blue_book/bluebook_2015.pdf
http://s-media.nyc.gov/agencies/planyc2030/pdf/planyc_2011_solid_waste.pdf

3. Figure 15 data sources (10 indicator data sources for California from2009-2018)
https://www.ggweather.com/sf/monthly.html
http://www.laalmanac.com/weather/we13.php
https://www.ggweather.com/sf/almanac.html
https://www.usclimatedata.com/climate/winters/california/united-states/usca1252

https://www.usclimatedata.com/climate/winters/california/united-states/usca1252/2008/1
https://oehha.ca.gov/media/downloads/climate-change/report/2018indicatorssummary.pdf
https://www.arb.ca.gov/cc/inventory/pubs/reports/2000_2015/ghg_inventory_trends_00-15.pdf
https://www.arb.ca.gov/cc/inventory/pubs/reports/2000_2016/ghg_inventory_trends_00-16.pdf
https://www.timeanddate.com/sun/usa/california-city
http://www.climateassessment.ca.gov/state/docs/20180827-SummaryBrochure.pdf
https://www.wunderground.com/history/monthly/KCQT/date/2009-5
https://www.wunderground.com/history/airport/KF70/2015/3/20/MonthlyHistory.html?hdf=1
https://s.giannini.ucop.edu/uploads/giannini_public/19/41/194166a6-cfde-4013-ae55-3e8df86d44d0/a_history_of_california_agriculture.pdf
https://www.nass.usda.gov/Statistics_by_State/California/Publications/Annual_Statistical_Reviews/2017/2016cas-all.pdf

Code description:

1.Since the code uses echarts, you need to download echarts.js or echarts.min.js.
In order to visualize the first eco-service assessment model, a map of the United States is used, so you also need to download the json file for the US map (such as us-states.json or USA.json);
2. Use echarts to map, development tools: webStorm debugging tools: chrome browser Language: json, js, html.
Ecological service assessment model：

```
<!DOCTYPE html>
<html>
<head>
	<meta charset="utf-8">
	<title>Ecological service assessment model</title>
	<!--Introducing echarts.js -->
	<script src="js/echarts.min.js"></script>
</head>
<body>
	<!-- Prepare a Dom with size (width and height) for ECharts -->
	<div id="main" style="width: 900px;height:600px;"></div>
	<script type="text/javascript">
	// Initialize the echarts instance based on the prepared dom
	var myChart = echarts.init(document.getElementById('main'));
	var uploadedDataURL = "js/usa_json-master/us-states.json";

	myChart.showLoading();
```

```
    $.getJSON(uploadedDataURL, function (usaJson) { //Since the json data request
is used, the server needs to be configured on the running computer.
        myChart.hideLoading();

        echarts.registerMap('USA', usaJson, {
            Alaska: {      // Move Alaska to the lower left of the US main continent
                left: -131,
                top: 25,
                width: 15
            },
            Hawaii: {
                left: -110,                // Hawaii
                top: 28,
                width: 5
            },
            'Puerto Rico': {             // Puerto Rico
                left: -76,
                top: 26,
                width: 2
            }
        });
        option = {
            backgroundColor:'',
            title: {
                text: 'Assessment of ecological service indicators in various states
of the United States',
                subtext: 'Ecological service assessment model',
                left: 'right'
            },
            tooltip: {
                trigger: 'item',
            },
            visualMap: {
                left: 'right',
                min: 0,
                max: 1,
                inRange: {
                    color: ['#a50026', '#d73027', '#f46d43', '#fdae61', '#fee090',
'#ffffbf', '#e0f3f8', '#abd9e9', '#74add1', '#4575b4','#313695']
                },
                text:['High','Low'], // Text, default is numeric text
                calculable: true,
                precision:3
```

```
},
toolbox: {
	show: true,
	left: 'left',
	top: 'top',
	feature: {
		dataView: {readOnly: false},
		restore: {},
		saveAsImage: {}
	}
},
series: [
{
	name: 'Ecological service indicator',
	type: 'map',
	roam: true,
	map: 'USA',
	itemStyle:{
		emphasis:{label:{show:true}}
	},
	textFixed: {
		Alaska: [20, -20]
	},
	data:[
	{name: 'Alabama', value: 0.681164},
	{name: 'Alaska', value: 0.318677},
	{name: 'Arizona', value: 0.514899},
	{name: 'Arkansas', value: 0.638782},
	{name: 'California', value: 0.702709},
	{name: 'Colorado', value: 0.445057},
	{name: 'Connecticut', value: 0.50698},
	{name: 'Delaware', value: 0.395627},
	{name: 'Florida', value: 0.66992},
	{name: 'Georgia', value: 0.711528},
	{name: 'Hawaii', value: 0.544395},
	{name: 'Idaho', value: 0.458353},
	{name: 'Illinois', value: 0.468485},
	{name: 'Indiana', value: 0.482097},
	{name: 'Iowa', value: 0.460833},
	{name: 'Kansas', value: 0.445783},
	{name: 'Kentucky', value: 0.540981},
	{name: 'Louisiana', value: 0.610306},
	{name: 'Maine', value: 0.55981},
	{name: 'Maryland', value: 0.49558},
```

```
                {name: 'Massachusetts', value: 0.535038},
                {name: 'Michigan', value: 0.500843},
                {name: 'Minnesota', value: 0.469937},
                {name: 'Mississippi', value: 0.659069},
                {name: 'Missouri', value: 0.547063},
                {name: 'Montana', value: 0.410255},
                {name: 'Nebraska', value: 0.460862},
                {name: 'Nevada', value: 0.388381},
                {name: 'New Hampshire', value:0.545302},
                {name: 'New Jersey', value: 0.500125},
                {name: 'New Mexico', value: 0.496457},
                {name: 'New York', value: 0.524324},
                {name: 'North Carolina', value: 0.637768},
                {name: 'North Dakota', value: 0.332317},
                {name: 'Ohio', value: 0.473327},
                {name: 'Oklahoma', value: 0.54722},
                {name: 'Oregon', value: 0.51842},
                {name: 'Pennsylvania', value: 0.552684},
                {name: 'Rhode Island', value: 0.508686},
                {name: 'South Carolina', value: 0.64468},
                {name: 'South Dakota', value: 0.388774},
                {name: 'Tennessee', value: 0.598384},
                {name: 'Texas', value: 0.697704},
                {name: 'Utah', value: 0.46009},
                {name: 'Vermont', value: 0.504052},
                {name: 'Virginia', value: 0.614138},
                {name: 'Washington', value: 0.523786},
                {name: 'West Virginia', value: 0.501405},
                {name: 'Wisconsin', value: 0.504464},
                {name: 'Wyoming', value: 0.376489},
                ]
            }
            ]
        };

        myChart.setOption(option);
    });
</script>
</body>
</html>
```

Industrial three waste curve:

```
<!DOCTYPE html>
```

```
<html lang="en">
<head>
	<meta charset="utf-8">
	<title></title>
	<script src="js/echarts.min.js"></script>
</head>

<body>
	<div id="box" style="width: 1500px; height:500px;"></div>
	<script>
	// Get to this DOM node and then initialize

	var myChart = echarts.init(document.getElementById("box"));

	// The content inside the option basically covers all the content of the chart you
want to draw.
	var option = {
		// Define styles and data
		title:{
			text:'Industry "three wastes" governance costs'
		},
		backgroundColor: '',
		tooltip: {
			trigger: 'axis'
		},
		toolbox:{
			show:true,
			feature: {
				saveAsImage: {
					show: true
				}
			}
		},
		legend: {
			textStyle:{
				fontSize:18
			},
			data: [{
				name:'Industrial wastewater',
			},{
				name:'Industrial waste gas',
			},{
				name:'Industrial waste solids',
			}
```

```
        ],
        itemHeight:28,
        itemWidth:30
},

calculable: true,


xAxis: [{
        axisLabel: {
                rotate: 30,
                interval: 0
        },
        axisLine: {
                lineStyle: {
                        color: '#180c40'
                }
        },
        type: 'category',
        boundaryGap: false,
        data: ["2014", "2015", "2016", "2017", "2018",
                "2019","2020","2021","2022"]
}],
yAxis: [{

        type: 'value',
        axisLine: {
                lineStyle: {
                        color: '#180c40'
                }
        },
        axisLabel: {
                formatter:'{value}(million)'
        }
}],
series: [{
        name: 'Industrial wastewater',
        type: 'line',
        symbol: 'none',
        smooth: 0.3,
        color: ['#66AEDE'],
        data: [460.3, 454.5, 480.53, 591.7, 884.1, 586.3, 721, 799.1,735.5]
}, {
        name: 'Industrial waste gas',
```

```
            type: 'line',
            symbol: 'none',
            smooth: 0.3,
            color: ['#35ff08'],
            data: [913.2, 1358.7, 913.6, 788.6, 615.7, 773.9, 766.7, 612.3,591.9]
        },{
            name: 'Industrial waste solids',
            type: 'line',
            symbol: 'none',
            smooth: 0.3,
            color: ['#ec3e14'],
            data: [926.5, 681.86, 1305.87, 919.7, 600.2, 939.8, 712.3, 588.6,572.6]
        }
        ]
    };
    myChart.setOption(option);
</script>
</body>

</html>
```

State/indicator	Annual precipitation (mm))	Crop production (percentage)	Forest above ground biomass (replaced by hay, unit: 1000 tons)	Average temperature (representing evaporation, unit ^c)	Light (representing carbon fixation)
Alabama	1480	1.40%	2044	17.1	58
Alaska	572	0.00%	2678	-3	41
Arizona	345	1.00%	2254	15.7	85
Arkansas	1284	2.40%	6777	15.8	61
California	563	11.30%	4295	15.2	68
Colorado	405	1.90%	100	7.3	71
Connecticut	1279	0.10%	44	9.4	56
Delaware	1160	0.30%	812	12.9	30
Florida	1385	2.10%	1425	21.5	66
Georgia	1287	2.50%	4860	17.5	66
Hawaii	1618	0.20%	8	21.1	71
Idaho	481	1.90%	1,533	6.9	64
Illinois	996	5.00%	1,656	11	56
Indiana	1060	3.10%	3,939	10.9	55
Iowa	864	8.10%	5,890	8.8	59

Kansas	733	4.10%	5,689	12.4	65
Kentucky	1242	1.30%	1,075	13.1	56
Louisiana	1528	1.00%	273	19.1	57
Maine	1072	0.20%	532	5	57
Maryland	1131	0.60%	159	12.3	57
Massachusetts	1211	0.10%	2,604	8.8	58
Michigan	833	2.10%	1368	6.9	51
Minnesota	693	5.20%	3,979	5.1	58
Mississippi	1499	1.60%	1,564	17.4	61
Missouri	1071	2.50%	6,398	12.5	60
Montana	390	0.90%	4,680	5.9	59
Nebraska	599	6.20%	6,360	9.3	61
Nevada	241	0.20%	1,100	9.9	79
New Hampshire	1103	0.00%	98	6.6	54
New Jersey	1196	0.30%	180	11.5	56
New Mexico	370	1.00%	1,091	11.9	76
New York	1062	1.30%	2,449	7.4	46
North Carolina	1279	3.00%	1,868	15	60
North Dakota	452	2.20%	4,975	4.7	59
Ohio	993	2.50%	2,532	10.4	50
Oklahoma	927	1.80%	5,914	15.3	68
Oregon	695	1.20%	3,072	9.1	48
Pennsylvania	1089	1.70%	3,010	9.3	58
Rhode Island	1218	2.20%	14	10.1	58
South Carolina	1264	0.70%	600	16.9	64
South Dakota	511	2.50%	6,580	7.3	63
Tennessee	1376	1.00%	3,901	14.2	56
Texas	734	5.80%	9,720	18.2	61
Utah	310	0.40%	2,459	9.2	66
Vermont	1085	0.20%	281	6.1	49
Virginia	1125	0.90%	2,645	12.8	63
Washington	976	2.40%	2,856	9.1	47
West Virginia	1147	0.20%	1,035	11	30
Wisconsin	829	3.10%	4,073	6.2	54
Wyoming	328	0.40%	2,315	5.6	68

(continued)

State/indicator	Humidity (representing the amount of dust)	Forest cover rate	Species diversity	Plant diversity (represented by vascular plant diversity)

Alabama	84	70.57%	4533	2902
Alaska	77	35.16%	1853	1354
Arizona	53	25.64%	4759	3512
Arkansas	85	56.31%	3415	2202
California	76	32.71%	6717	5418
Colorado	60	34.42%	3597	2550
Connecticut	79	55.24%	2497	1823
Delaware	79	27.26%	2244	1598
Florida	87	50.68%	4368	3038
Georgia	86	67.28%	4436	2994
Hawaii	71	42.53%	1418	1249
Idaho	68	40.55%	3205	2438
Illinois	83	13.64%	3258	2155
Indiana	83	21.06%	3098	2063
Iowa	78	8.43%	2533	1583
Kansas	80	4.78%	2778	1778
Kentucky	79	49.35%	3258	2085
Louisiana	87	53.20%	3495	2385
Maine	82	89.46%	2352	1601
Maryland	77	39.36%	3148	2234
Massachusetts	75	60.57%	2765	1958
Michigan	84	55.62%	3135	2097
Minnesota	78	34.08%	2817	1809
Mississippi	91	65.07%	3580	2369
Missouri	82	35.16%	3340	2095
Montana	71	27.45%	2921	2239
Nebraska	82	15.89%	2587	1561
Nevada	71	3.20%	3872	2875
New Hampshire	84	84.32%	2327	1631
New Jersey	83	41.72%	3022	2074
New Mexico	60	31.99%	4583	3305
New York	82	62.88%	3333	2215
North Carolina	83	59.73%	4131	2771
North Dakota	80	1.72%	1889	1201
Ohio	80	30.92%	3152	2062
Oklahoma	79	28.80%	3616	2355
Oregon	85	48.51%	4136	3161
Pennsylvania	77	58.60%	3135	2202
Rhode Island	78	54.38%	2078	1392
South Carolina	86	68.19%	3701	2582

South Dakota	83	3.93%	2406	1504
Tennessee	84	52.83%	3772	2407
Texas	82	37.33%	6273	4509
Utah	67	34.48%	3892	2966
Vermont	77	77.82%	2274	1622
Virginia	84	62.93%	3803	2580
Washington	83	52.74%	3375	2476
West Virginia	83	79.01%	2873	1897
Wisconsin	84	48.98%	2869	1890
Wyoming	63	18.42%	3184	2286