Problem Chosen	2022	Team Control Number
E	MCM/ICM Summary Sheet	2222314

A Study on Optimal Harvesting Strategy of Forests based on BP Neural Network Algorithm

Summary

"Forest management" is a new forest management method based on whether to cut down forests in different regions, environments and climates and how to plant new vegetation to better manage forests, and thus expand the carbon sequestration of existing forests. By classifying the forests in different temperature zones, we can better decide the deforestation strategy. On the one hand, for the forest managers, unlike the traditional policy that prohibits deforestation, forest management includes the forest products generated from deforestation in the carbon sequestration category; on the other hand, for the forest harvesters, how to reasonably exploit the wood to maximize their own profit while protecting the forest, and to convince the group who support that no trees should ever be cut down is the main problem of this paper.

In this paper, firstly, 13 variables such as renewable terrestrial water resources and global annual carbon dioxide emissions of 11 countries in 2021 were selected for cluster analysis, and hence three different forest types of temperate, tropical and boreal zones were classified. Then, we conducted principal component analysis for each of the three types of forests to obtain a carbon sequestration evaluation model. A gray prediction GM (1, 1) model was used to predict the carbon sequestration of the three different forest types, and the goodness of fit of the model was calculated by comparing it with the actual situation. After that, we introduced the regional human development index, and developed a multi-objective linear programming model to calculate the optimal combination that ensures both number of forest stocks and forest products. Then, we used the scores of the carbon sequestration evaluation model to evaluate the degree of forest management in the region into three ranges of excellent, qualified and unqualified, and the thresholds were calculated to determine the transition points between forest management plans. Next, we selected a forest management plan for the Greater Khingan Mountains, compared the carbon sequestration and economic benefits of the optimized forest management with the original one using the BP algorithm, and drew a logging management schedule for the next 10 years based on the carbon sequestration evaluation model to optimize the current forest harvesting plan.

Finally, in conjunction with the analysis of the above issues, we wrote a newspaper article about changing from a total ban on tree cutting to a combined cutting and planting forest management strategy, thus convincing the local community that such an approach was a better way to manage the forest.

[Keywords] Cluster analysis, principal component analysis, carbon sequestration evaluation model, multi-objective linear programming model, GM(1, 1) model, BP algorithm

Contents

1. Introduction
1.1 Problem Background
With the development of social economy and industrialization, there is a growing concern about the greenhouse effect. Forests, as the "lungs of the earth", have a positive impact on the absorption of carbon dioxide and other greenhouse gases in the air. Therefore, forest conservation is becoming more and more important and advocated by people. In practice, people often prefer not to cut down trees in order to protect forests. In contrast, "forest management" takes into account the absorption of carbon dioxide by forest products such as furniture and paper that result from deforestation. It is a new method of forest management based on whether or not to cut down forests in different regions, environments, and climates, and how to plant new vegetation to better manage forests, thereby increasing the amount of carbon sequestered by existing forests. Forest extractors can further improve the carbon sequestration level of the forest system by making reasonable forest extraction and planting plans, and at the same time, unlike the traditional forest protection model, forest management also provides a strong support for local economic development. It is a hot issue to establish a reasonable integrated forest management model to further increase the carbon sequestration in the forest while protecting the forest and contributing to the local economy. Besides, finding a pilot forest for analysis and decision making, and convincing the local managers to support the new integrated forest management model as far as possible, is the problem that needs to be solved in this paper.

1.2 Restatement of the Problem
Problem 1: Develop a carbon sequestration model to determine how much carbon dioxide can be sequestered by a forest and its forest products.
Problem 2: Based on Problem 1, develop a forest management plan, evaluate and score the forest system to predict the future carbon sequestration capability of a forest.
Problem 3: Select a specific forest for analysis, develop a model that maximizes economic benefits while maintaining a sustainable increase in forest carbon sequestration, and develop a deforestation and planting schedule.
Problem 4: Write a newspaper article to convince local community forest managers to abandon their no-deforestation philosophy in favor of a new forest management system.

2. Model Preparation
2.1 Assumptions
1) The number in the forest management model has only one pathway to extinction through deforestation, without considering the effects of weather, natural disasters, etc. on forests.
2) Renewable land water resources, global carbon dioxide emissions, forest products production and trade statistics around the world, forest area of the world, forest coverage rate, forest coverage area, forest area, the proportion of forest cutting in forests accounts for the proportion of forest area, number of forest in various countries, greenhouse gas emissions, GDP, nature reserve area, and complete the number of primary school accounts for the total population can fully reflect the level of forest management in a country.
3) The average annual carbon sequestration of forests can measure the average carbon sequestration level of forests, and the variance can measure the reduction of carbon sequestration brought by forest product generation and deforestation to forests.
4) The annual carbon sequestration growth rate of trees remains constant.

2.2 Data Pre-processing

In order to improve the accuracy of the model and to show that the model developed is valid, the data need to be pre-processed before the solution is carried out. The purpose is to check whether the data can truly reflect the current state of forest management in a country, so that the level of forest management and the amount of carbon sequestration in a country can be accurately measured. Therefore, we checked the collected data to observe whether there are any missing, abnormal, or duplicate values, and pre-process these dirty data.

1) For missing data:

   In performing the processing and analysis of the data in the attachment, we found that the data of some variables are discontinuous and the parameters of the variables cannot be calculated, so we need to use the mean value method to process the discontinuous data.

2) For abnormal values:

   For the data we collected may have some wrong values, we can remove the data that are obviously higher than the average by calculating the partial variance of each group of data.

3) For duplicate values:

   For those with the same values in the collected data, we checked that if their attributes are also the same, they would be combined together.

4) Calculate the average annual increase of carbon sequestration for each forest, i.e., calculate the average of that increase for the year.
5) Calculate the variance of carbon sequestration in each forest throughout the year. The variance reflects the fluctuation of the data, which can reflect the forest harvesting level of forest products.
6) Calculate the standard deviation σ from the variance to facilitate later analysis of the standard deviation and the mean value.

3. Symbol Description

Symbol	Description
ρ	Explanation coefficients
x_i	The i^{th} impact factor
A	Decision matrix
B	Norm matrix
$R_i(x_i)$	Net income from investment in S_i Forest
$Q(x)$	The carbon consumption of the forest system by the x^{th} investment
$R(x)$	Return on total investment
y_t	Single indicator time series
α	Weighting factor
S_t	Smoothing index

4. Problems Analysis

Forest management is the combination of the forest's own carbon sequestration capacity and the sequestration capacity of the products produced by the forest, so that local managers can protect the forest and contribute to local economy, achieving a win-win situation for both economic development and environmental protection. To solve this problem, we need to establish a forest management evaluation model to classify and evaluate the existing forest management system. Then, a multi-objective linear programming model should be established to calculate the optimal deforestation ratio. And finally, a timeline for forest harvesting should be given.

In response to question 1: To build a forest evaluation model, the first step should be classifying and refining different categories of forests around the world. Through cluster analysis of 13 variables (Renewable land water resources, global carbon dioxide emissions, etc.), we classified forests into tropical, temperate and boreal types, and used principal component analysis to fit these variables into forest area factor, economic development factor, policy factor and cultural factor, thus establishing a carbon sequestration evaluation model. Finally, the effectiveness of the different factors was analyzed and ranked according to their weights for carbon sequestration, and an effective forest management plan was developed.

In response to problem 2: We evaluated the accuracy of the model using the human development index and air quality coefficient, and built a multi-objective linear programming model to calculate a combination that maximizes both the number of forest stocks and the amount of forest products, thus enhancing the economic benefits of the region. Finally, we divided three score intervals of excellent, qualified, and unqualified to evaluate the forest management effectiveness based on the model scores.

In response to problem 3: We used the established model to evaluate and optimized the forest management in the Greater Khingan Mountains, and used the BP algorithm to compare the carbon sequestration and economic benefits before and after forest management optimization, and finally gave the harvesting schedule for forest optimization (Zhou et al. 2022:5).

In response to problem 4: After the model analysis, we wrote a non-technical newspaper article to change the belief that forests should never be deforested and to scientifically explain a new forest management model that combines logging and planting in a rational way.

5. Model Implementation and Application

5.1 Model Construction and Solution on Problem I

For the first question, we found 13 variations such as renewable terrestrial water resources in 2021 for 11 countries, including the United States, China, South Africa, France, Russia, Japan, Brazil, Australia, Sweden, Canada, and India, and then we performed cluster analysis on these 13 variations. And we also applied principal component analysis for each forest type in these countries, as shown in Figure 1.

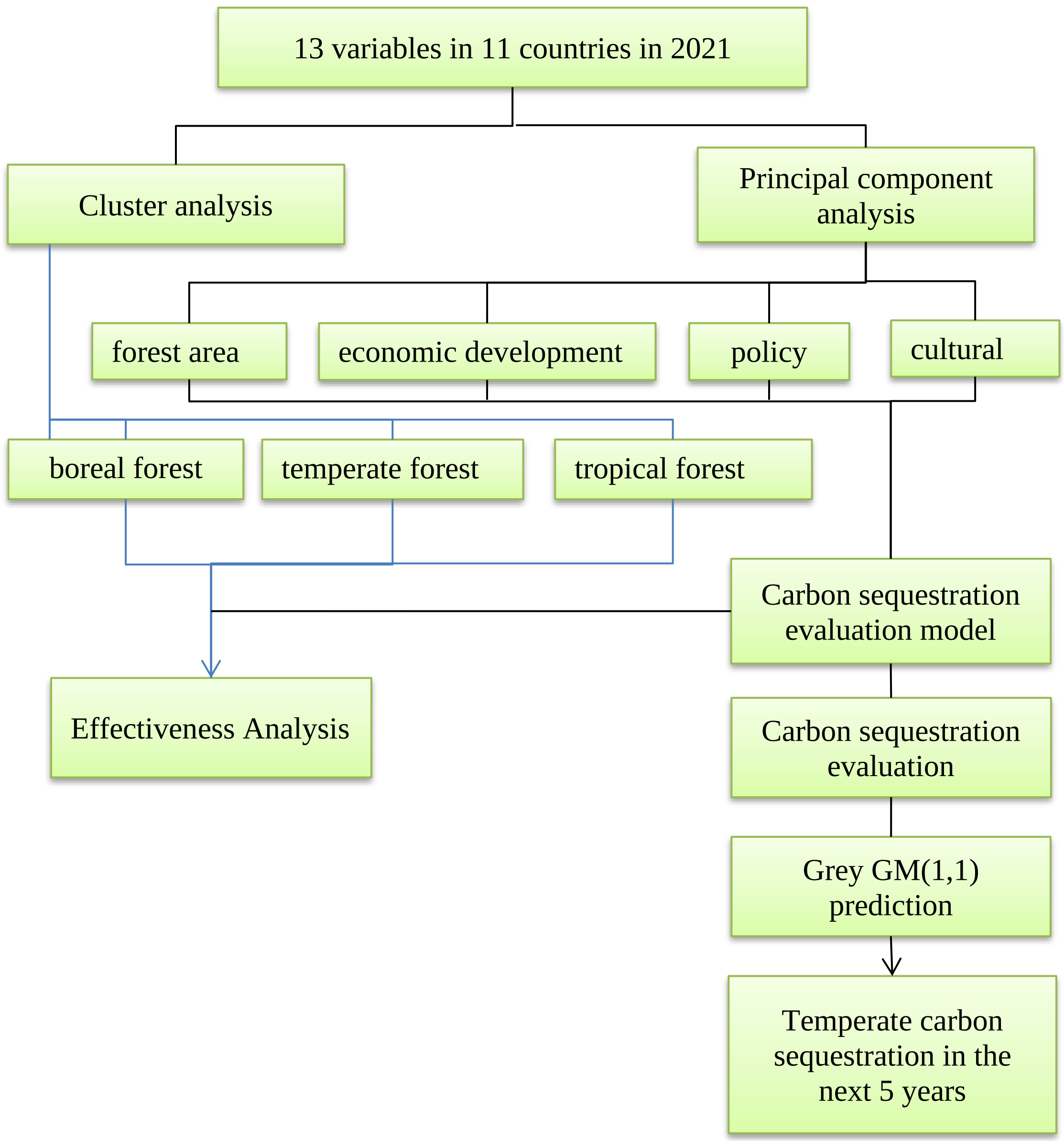

Figure 1: Flow Chart of Model 1

5.1.1 Cluster analysis

We first abbreviated the 13 variables, to simplify the procedure of the model, as shown in Table 1.

Variable name	Abbreviations in the article
Renewable land water resources	RLWR
Global carbon dioxide emissions	GCDE
Forest products production and trade statistics around the world	FPPTAW
Forest area of the world	FAOW
Forest coverage rate	FCR

Forest coverage area	FCA
Forest area	FA
The proportion of forest cutting in forests in all countries in the world accounts for the proportion of forest area	TPOFC
Number of forests in various countries	NOFVC
Greenhouse gas emissions	GGE
GDP all over the world	GOW
Nature reserve area	NRA
Complete the number of primary school accounts for the total population	CNPP

Table 1: Abbreviations of variables

We standardized the data by displaying the variables collected for these 11 countries in 2021 as follows:

$$X_{norm} = \frac{X - X_{min}}{Xmin_{max}}$$

Using Chebyshev distance to perform cluster analysis:

$$Dis\tan ce(Q_i, Q_j) = \underset{k=1}{\overset{n}{Max}}(Q_{ik} - Q_{jk})$$

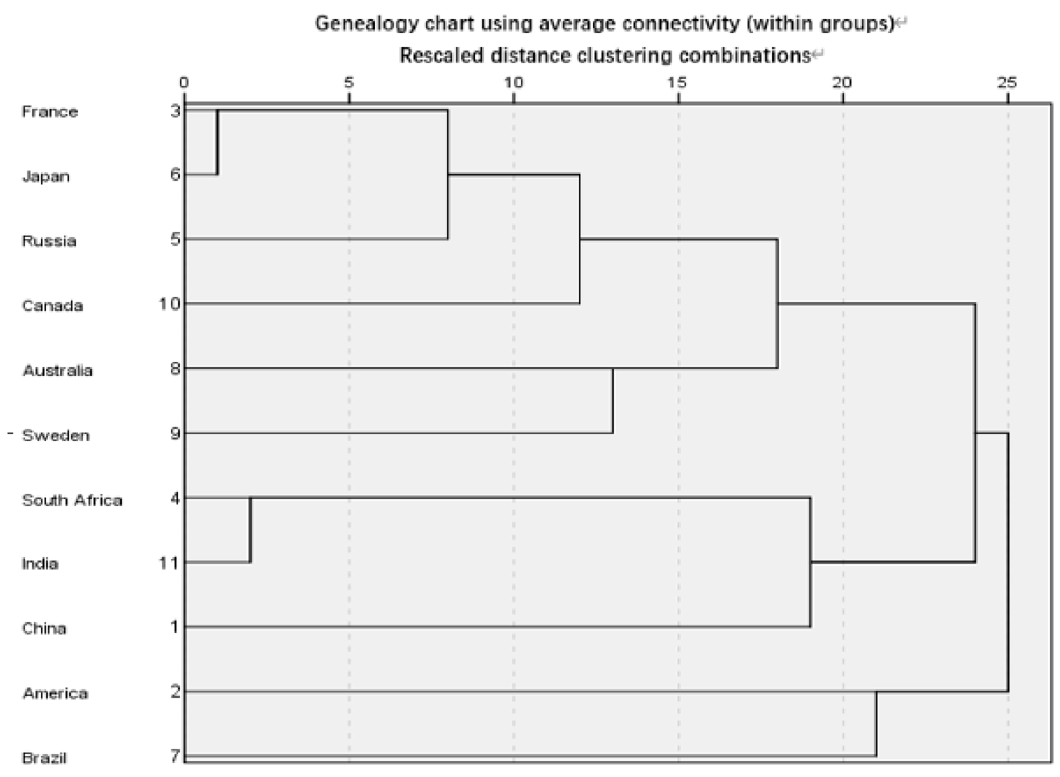

Figure 2: Genealogy chart

Based on the cluster diagram analysis, we can classify these 11 countries into 3 categories, noted as $class_i (i = 1,2,3)$, as shown in Table 2 below:

Class	Country
I	America, Brazil
II	South Africa, India, China
III	France, Japan, Russia, Canada, Australia, Sweden

Table 2: Classes of country

By combining the latitude and longitude of each country, with N:E as the positive time, as shown in Table3 below:

Countries	Latitude and Longitude
China	[104.20, 35.06]
America	[45.04, 40.07]
France	[2.21, 46.23]
South Africa	[22.94, -30.56]
Russia	[105.32, 61.52]
Japan	[37.23, 38.20]
Brazil	[138.25, 36.20]
Australia	[138.78, -25.27]
Sweden	[18.64, 60.13]
Canada	[-106.35, 56.13]
India	[78.96, 20.59]

Table 3: Latitude and longitude of each country

Through the analysis, the forest types of these 11 countries can be divided into three categories:

The category I: tropical forest types represented by the United States and Brazil.

The category II: temperate forest type represented by South Africa, India, and China.

The category III: the boreal forest type represented by France, Japan, Russia, Australia, and Canada.

5.1.2 Principal component analysis

Firstly, we selected 13 variables (RLWR, GCDE, etc.) to proceed factor analysis to obtain the scree plot, as follows:

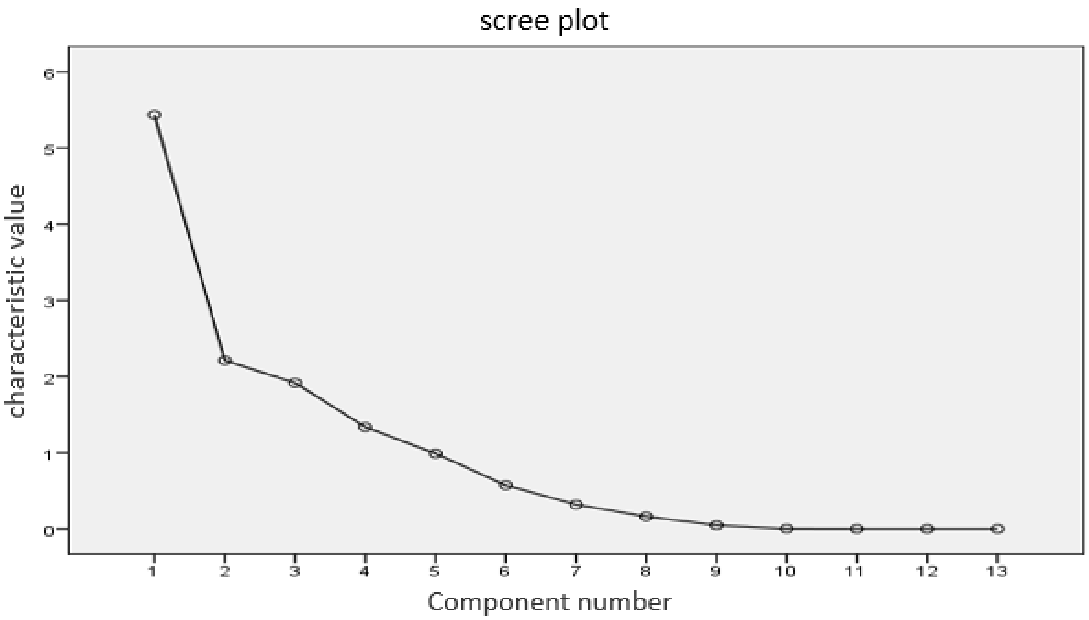

Figure 3: Scree plot

The representation of each variable is shown in Table 4 below:

Variable	Abbreviations
x_1	RLWR
x_2	GCDE
x_3	FPPTAW
x_4	FAOW
x_5	FCR
x_6	FCA
x_7	FA
x_8	TPOFC
x_9	NOFVC
x_{10}	GGE
x_{11}	GOW
x_{12}	NRA
x_{13}	CNPD

Table 4: Abbreviations of variables

The component matrix was obtained as shown in Table 5 below.

Component Matrix				
	Components			
	1	2	3	4
Z-score(RLWR)	.812	.407	-.125	.166
Z-score(GCDE)	.515	-.288	.144	.027
Z-score(FPPTAW)	.917	.074	-.303	.133
Z-score(FAOW)	.924	.005	-.183	-.257
Z-score(FCR)	.208	.802	.309	-.183
Z-score(FCA)	.958	-.015	-.104	.175
Z-score(FA)	.748	-.165	.302	.284
Z-score(TPOFC)	-.074	-.418	-.706	.203
Z-score(NOFVC)	.764	.320	-.309	-.447
Z-score(GGE)	.732	-.350	.302	-.087
Z-score(GOW)	.363	-.373	.684	.463
Z-score(NRA)	-.164	.784	.352	.291
Z-score(CNPP)	.104	-.368	.531	-.731
Extracting method: principal component analysis				
4 components extracted				

Table 5: Component Matrix

From the above table, we could conclude that the greatest influence by FCA can be seen as the forest area factor w_1, the greatest influence by NRA can be seen as the policy factor w_2, the greatest influence by GOW can be seen as the economic factor w_3, and the greatest influence by CNPP can be seen as the cultural factor w_4, as shown in Table 6 below.

Factor	**Factor Name**
w_1	Forest area factor
w_2	Policy factor
w_3	Economic factor
w_4	Cultural factor

Table 6: Factors

5.1.3 Regression analysis

We implemented regression analysis on the four factors after the factor analysis to construct the forest carbon sequestration evaluation model, and then used SPSS for regression analysis, and we obtained the student regression residuals, integrated P-P plots, and histograms of GGE, as shown in Figure 4 below.

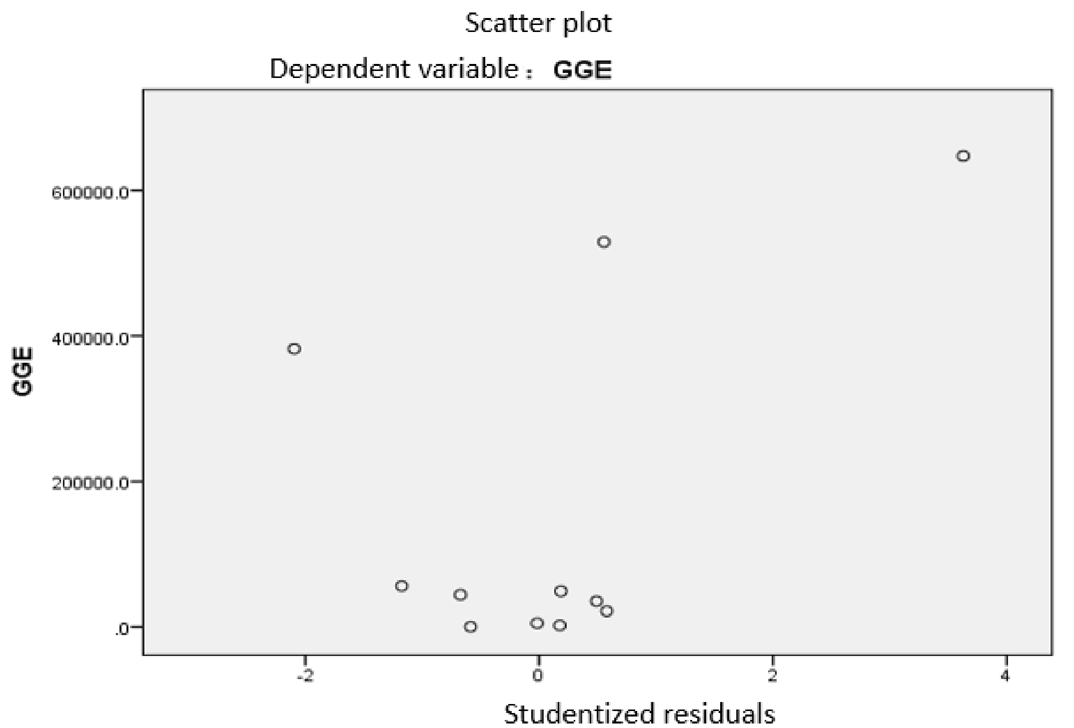

Figure 4: Scatter plot

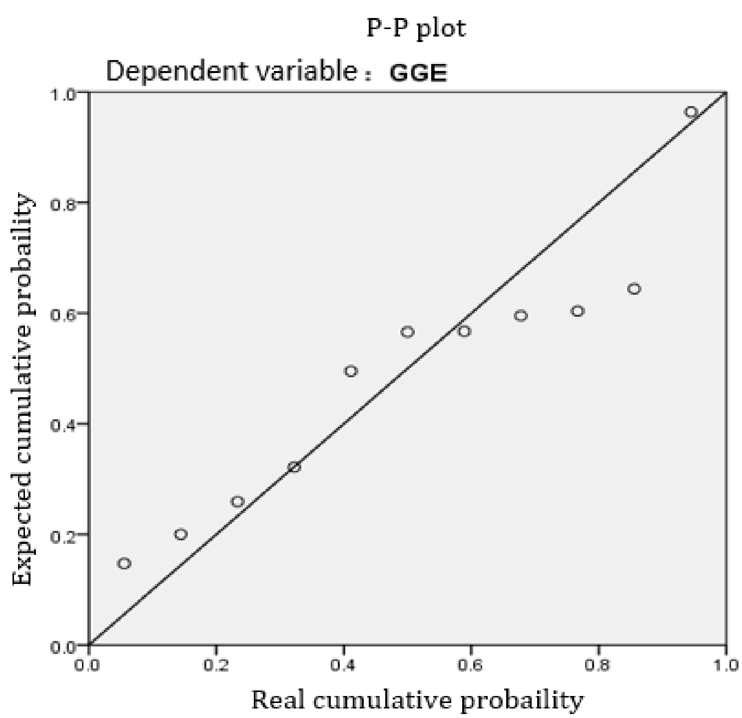

Figure 5: P-P plot

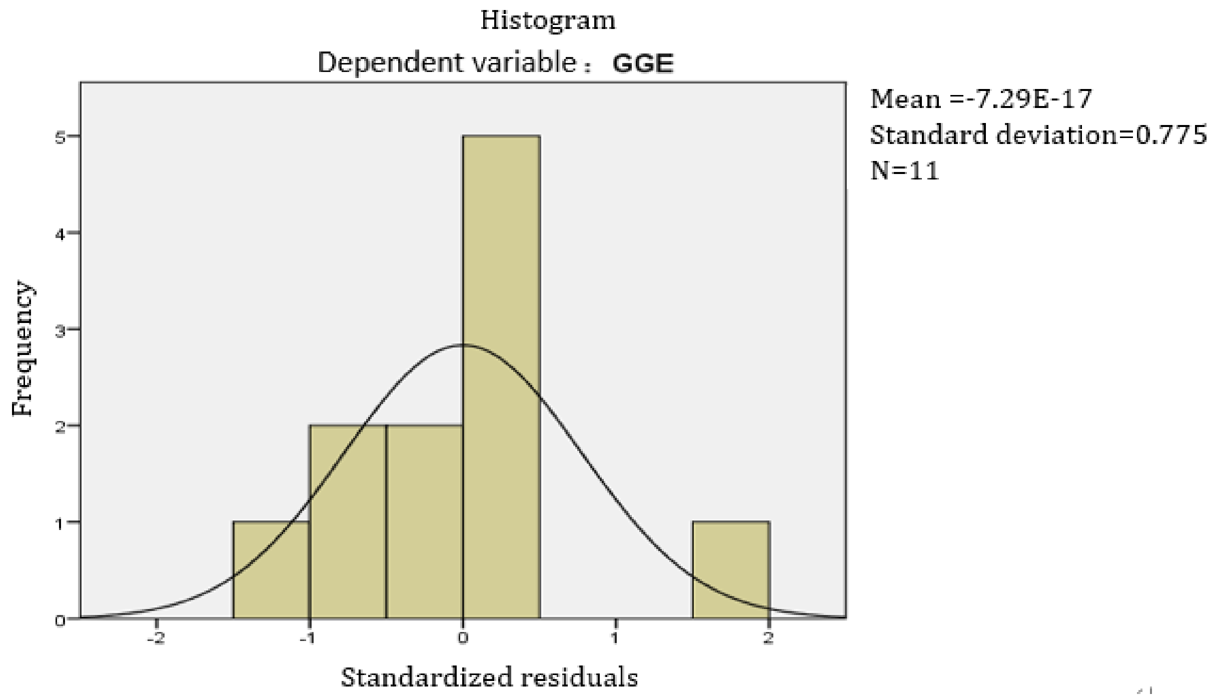

Figure 6: Histogram

The calculated parameter values are shown in Table 5.1.7 below.

θ_0	θ_1	θ_2	θ_3	θ_4
45842.98	0.468	0.624	-0.89	0.374

Table 7: Calculated parameter values

Solved using SPSS:

$$y = 0.468w_1 + 0.624w_2 - 0.89w_3 + 0.374w_4 + 45842.98$$

We could conclude from the model that the policy factor, forest area factor, and culture factor are positively correlated with the amount of carbon sequestered in forests, and the policy factor > forest factor > culture factor, and the economic factor is negatively correlated with the amount of carbon sequestered in forests.

Therefore, for the policy authorities, they should make more policies that are favorable to forest conservation, and at the same time, they should reasonably plan the impact of industrial production on carbon sequestration. In the following, we will establish a multi-objective linear programming model to find and optimize the balance between economic and carbon sequestration.

5.2 Model Construction and Solution on Problem 2

For Problem 2, we introduced the human development index and air quality coefficient to evaluate the accuracy of the model. In order to ensure that the amount of carbon sequestered by the forest should be increased on the basis of the amount of carbon sequestered by forest products, so that the economic benefits of the region could be maximized. We established a multi-objective linear programming model to calculate the optimal combination of the guaranteed number of forest stock and the amount of forest products. And the effect of forest management is divided into three dimensions of excellent, qualified and unqualified according to the score calculation, and we also gave the corresponding score intervals for different dimensions The specific process is shown in Figure 7 below.

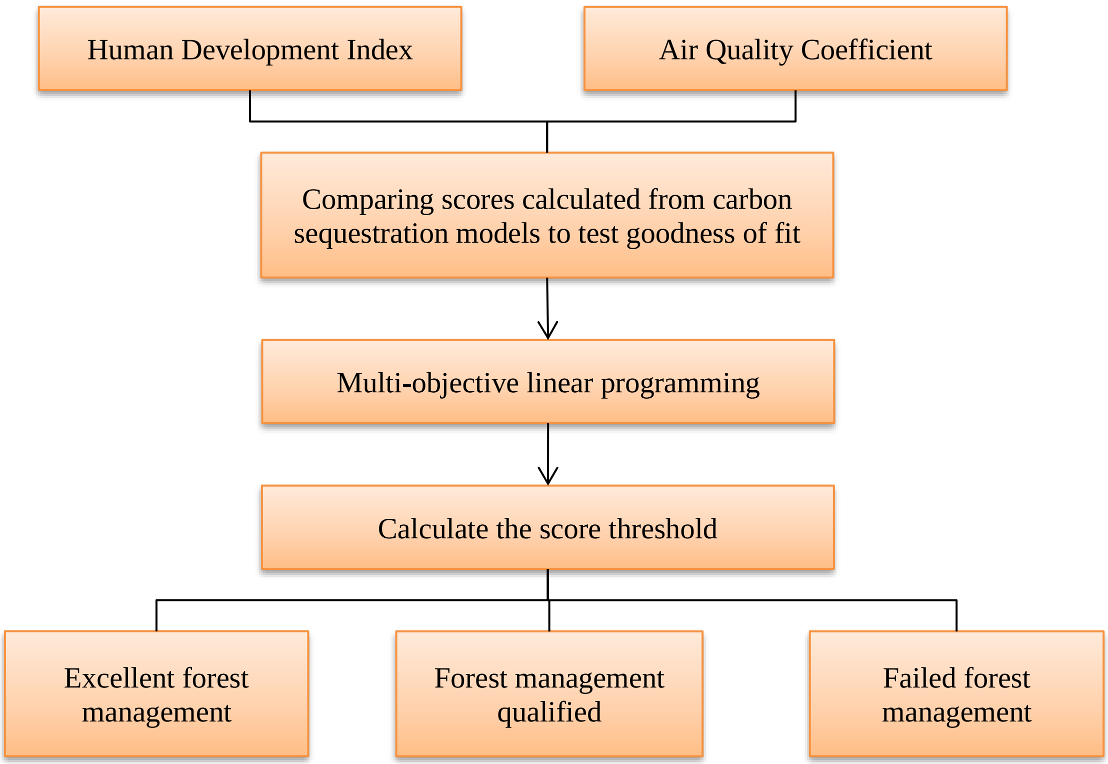

Figure 7: Process chart

5.2.1 Establishment of Multi-Factor Integrated Evaluation Model

1) Quantification of qualitative factors:
   The human development index of each country was quantified as shown in Table 5.2.1 below.

Score interval	Grade	Quantify
0.4-0.55	A	1
0.55-0.7	B	2
0.7-0.85	C	3
0.85-1	D	4

Table 8: Quantification of human development index

2) Multi-factor evaluation table:

The decision matrix is constructed with 11 countries as row vectors and GGE, FCA, NRA, GOW, CNPP, and human development index as column vectors.

$$A = \begin{bmatrix} 467496 & 90.21 & 15.45 & 17.38 & 98.3 & 3 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 49123 & 40.72 & 5.97 & 3.10 & 94.6 & 2 \end{bmatrix}$$

3) Attribute factors normalization

For FCA, NRA, CNPP, and human development index, we used the following formulas:

$$r_{i,j} = \frac{min\, i\,(a_{ij})}{a_{ij}}$$

For GOW:

$$r_{ij} = \frac{max\, i\,(a_{ij})}{a_{ij}}$$

In summary, we can obtain the normal matrix R, as shown in Table 9 below:

	x_1	x_2	x_3	x_4	x_5	x_6
d_1	0.0001	0.0356	0.3862	0.7032	98.3000	0.7500
d_2	0.0001	0.0320	0.4592	1.0000	99.3000	0.7500
d_3	0.0252	0.3138	0.2313	0.1243	97.3000	1.0000
d_4	0.0013	0.2052	0.7460	0.0144	92.0000	0.7500
d_5	0.0001	0.0267	0.6134	0.0709	105.0000	0.7500
d_6	0.0094	1.0000	0.2030	0.2416	99.1000	1.0000
d_7	0.0022	0.0359	0.2028	0.0690	85.2000	0.7500
d_8	0.0011	0.0372	0.3097	0.0636	92.3000	1.0000
d_9	1.0000	1.0000	0.6173	0.0357	105.0000	1.0000
d_{10}	0.0008	0.0360	0.6160	0.0785	94.5000	1.0000
d_{11}	0.0010	0.0788	1.0000	0.1253	94.6000	0.5000

Table 9: Normal matrix R

4) Setting the weight vector

According to the regression results, we could see that the economic factor has a negative effect on forest carbon sequestration, i.e., GOW, and the rest is positive, the policy factor NRA has a greater effect, and the cultural factor CNPP has a smaller effect, so we obtained the weight matrix as follows.

$$W = (0.2,0.3,0.4,-0.3,0.1,0.3)^T$$

5.2.2 Solving the Forest Carbon Sequestration Evaluation Model

We use MATLAB to solve and rank the scores of the 11 countries as follows Table 10:

Countries	**Scores**
Australia	3.568
France	0.898
America	0.556
Russia	0.504
Canada	0.420
Sweden	0.249
Japan	0.216
Brazil	0.213

South Africa	0.164
China	0.074
India	0.071

Table 10: Scores table

Based on the scores, the countries could be divided according to the ratio of 2:4:5 to determine the good and bad forest management systems, i.e., the top 2 countries' scores correspond to excellent, the 6th ranked country's score corresponds to qualified, and the 7th ranked over year's score range is unqualified, as shown in Table 5.2.4 below:

Forest Management System Rating	**Corresponding Score Interval**
Excellent	＞0.898
Pass	0.249～0.898
Fail	0～0.249

Table 11: Forest Management System Rating

5.2.3 Establishment of the Prediction Model of Carbon Sequestration in China

Do an accumulation of the original data $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(n)$

We get this formula:

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), \quad k = 1,2, \dots, n$$

Generate $x^1 = (x^{(1)}(1), x^{(1)}(2), \dots, x^{(1)}(n)$

Generate an equal-weighted series of immediately adjacent means of $x^{(1)}$.

$$z^{(1)} = \left[z^{(1)}(2), z^{(1)}(3), \dots, z^{(1)}(n)\right], \ \ k = 2, \dots, n$$

Based on the gray theory, we establish the GM(1,1) model

$$\frac{dx^1}{dt} + ax^{(1)} = b$$

where a, b are parameters to be determined, and apply the least squares method

$$\left(\hat{a}, \hat{b}\right) = (B^T B)^{-1} B^T Yn,$$

$$\text{where } B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \cdots & \cdots \\ -z^{(1)}(n) & 1 \end{bmatrix}, \qquad Y_n = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \cdots \\ x^{(0)}(n) \end{bmatrix}$$

After finding $\hat{a}, \hat{b}$, we can find:

$$\hat{x}^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{\hat{b}}{\hat{a}}\right] e^{-\hat{a}k} + \frac{\hat{b}}{\hat{a}} \text{ }, k = 1,2, \dots, n$$

$$\sum\nolimits_{0}^{(0)}(i) = x^{(0)}(i) = x^{(0)}i - \hat{x}^{0}(i) \quad (i = 1,2, \dots, n)$$

Relative error:

$$w^{(0)}i = \left|\frac{x^{(0)}(i) - \hat{x}^{(0)}(i)}{x^{(0)}(i)}\right|,$$

P value of the small error probability	C-value of variance ratio	Prediction accuracy level
> 0.90	0.3	Good
> 0.80	< 0.5	Qualified
> 0.70	< 0.65	Barely qualified
≤ 0.70	≥ 0.65	Not qualified

Table 12: Accuracy level

Taking China's carbon sequestration from 2008-2018 as a series, we used the GM(1,1) model to build a prediction model for China's carbon sequestration.

$$\hat{x}^{(0)}(k+1) = 651.97e^{0.0371}k$$

Again, by using the share of China's carbon sequestration in the total carbon sequestration of 11 countries from 2008-2018, we establish the prediction model

$$\hat{y}^{(0)}(k+1) = 2.5381e^{0.0324k}$$

$$\begin{cases} \hat{x}^{(0)}(k+1) = 651.97e^{0.0371k} \\ \hat{x}^{(0)}(k+1) = 651.97e^{0.0371k} - 2.5381e^{0.0324(k-5)} \geq 5 \end{cases}$$

5.2.4 Solving the Prediction Model for Carbon Sequestration in China

We obtained the solution using MATLAB as shown in Figure 8:

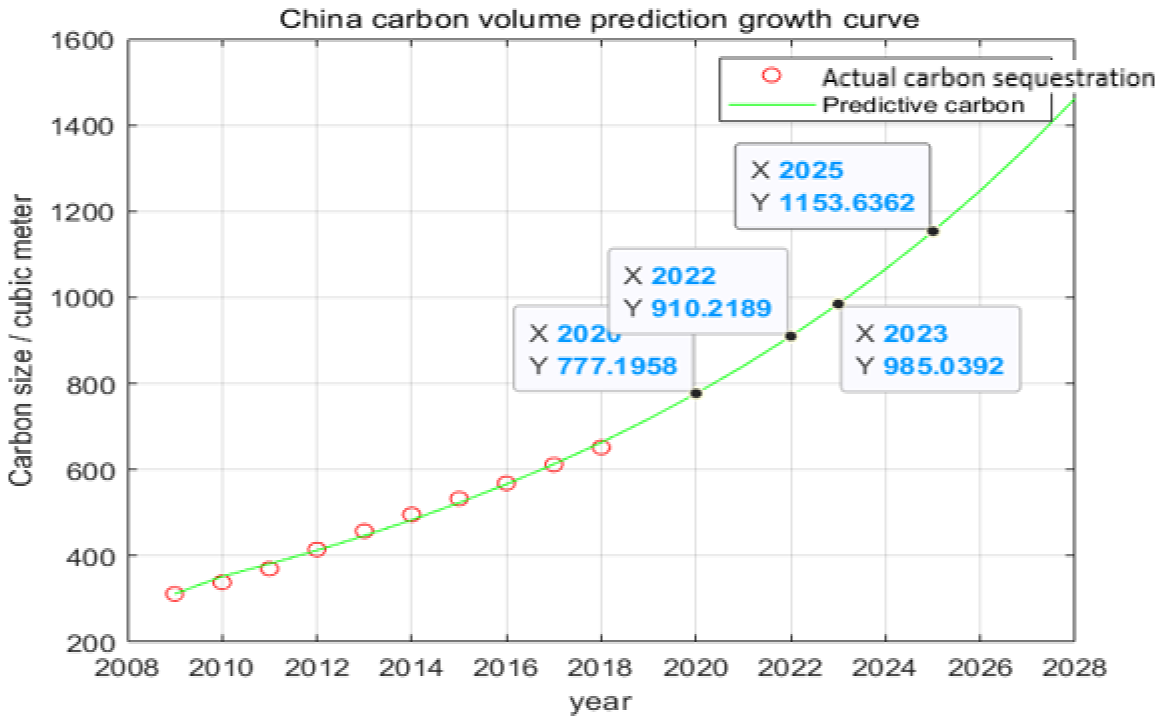

Figure 8: Predicted carbon sequestration in China from 2019 to 2028

Finally, the predicted values of China's carbon sequestration from 2019 to 2028 are given in Table 13 below:

Year	Amount of carbon sequestration (m^3)
2019	718.1626

2020	777.1958
2021	841.0816
2022	910.2189
2023	985.0392
2024	1066.0098
2025	1153.6362
2026	1248.4655
2027	1351.0898
2028	1462.1499

Table 13: Amount of carbon sequestration from 2019 to 2028

We could see from the table that there is a vast market for carbon sequestration in China, which is suitable for forest management as well as forest optimization.

5.3 Model Construction and Solution on Problem 3

Figure 9 below shows the vegetation sparsity map of the world using ArcGIS, which is used to represent the level of carbon sequestration around the world:

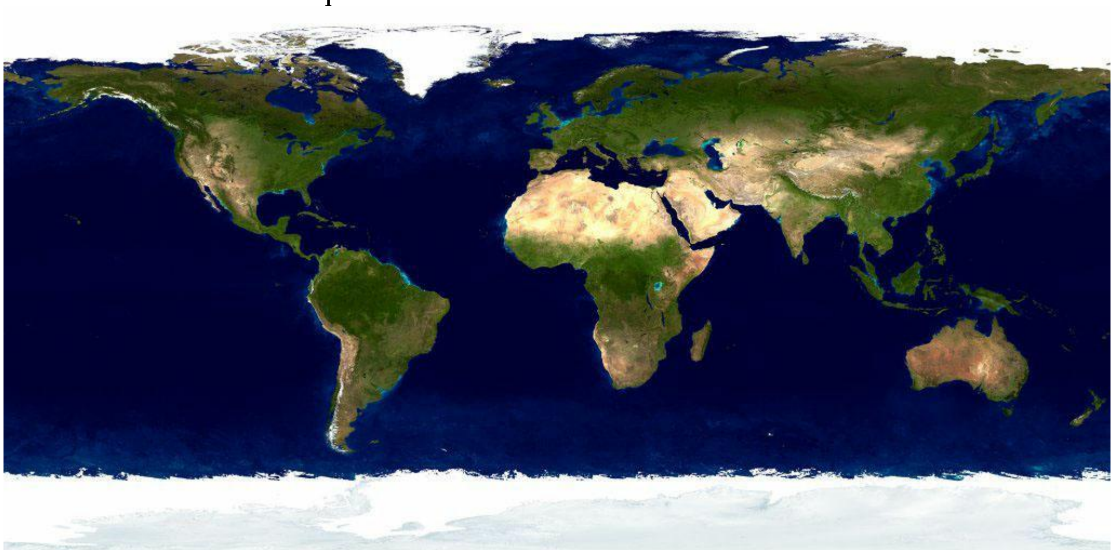

Figure 9: Vegetation sparsity map of the world

From this figure, we selected the Greater Khingan Mountains in China as the pilot of the integrated forest management model for a comprehensive analysis of its economics and carbon sequestration.

We selected the total carbon dioxide emissions from spring to autumn in the year of 2017 in China to indirectly measure its carbon sequestration to study the change of carbon sequestration in the Greater Khingan Mountains. A scatter plot was made using MATLAB, as shown in Figure 10 below:

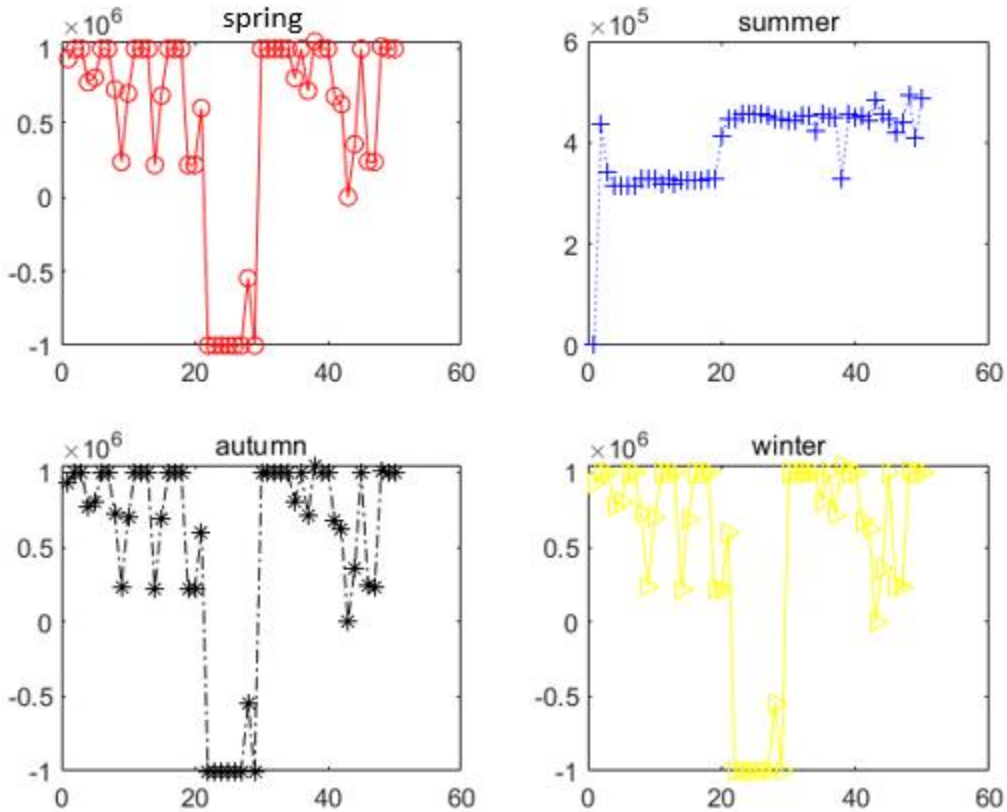

Figure 10: Scatterplot of carbon sequestration in Greater Khingan Mountains for four seasons in 2017

Figure 10 showed that there is an increase and decrease in forest carbon sequestration in different seasons, thus, it is necessary for forest managers to take the economic factor, i.e., the production of forest products, into account in the formulation of forest management policies to ensure that their forest carbon sequestration loss is relatively small and the economic gain is relatively large.

5.3.1 Modeling of Integrated Forest Management

We applied the Markowitz Mean-Variance Model, using the mean to represent the average return and the variance to represent the risk, to construct the idea of asset allocation model (Cai 2014: 90). As well as using the mean to represent the average amount of carbon sequestered by the forest, and using the variance to represent the loss to the amount of carbon sequestered by the forest from the production of forest products, to construct an integrated forest management model with the aim that the forest generates the most profit when it is least polluted. The profit here includes the growth of carbon sequestration and economic gain.

Let the amount of carbon sequestered by the forest be S_i, The investment for logging is x_i, The average rate of return on investment S_i is r_i. The net rate of return on investment for S_i is:

$$R_i(x_i) = r_i x_i$$

For the risk of investment in S_i , i.e., the reduction in carbon sequestration caused to the forest:

$$Q_i(x_i) = q_i x_i$$

Forest management portfolios $X = (x_1, x_2, \ldots, x_0)$ total net revenue:

$$R(x) = \sum_{i=1}^{n} R_i(x_i)$$

Profit risk from investments:

$$Q(x) = \max_{1 \le i \le n} Q_i(x_i)$$

Let n_i be the utility generated by investing in the i^{th} combination and p_i be the probability of its generation, then the expected value of utility $E(n)$:

$$E(n) = \sum_{i=1}^{n} p_i n_i$$

The utility value of the forest management portfolio at a benefit rate of R:

$$E(R) = pR - qR^2$$

$$r_i = \frac{(seq_i - s_i) - (f_i - l_i)}{con_i - \Delta_i} \times 100\%$$

r_i: Earning rate this year; seq_i: Carbon sequestration this year; s_i: Soil consumption of carbon this year; f_i: Forest products yield; l_i: Losses from deforestation; con_i: Carbon consumption this year; Δ_i: Increase in carbon sequestration from new forest plantations and forest products

$$E(r) = \sum_{i=1}^{n} p_i r_i$$

$E(r)$: Expected yield
p_i: Probability of occurrence of this case
r_i: The earning yield that occurs in this case
Total net revenue:

$$i = \frac{1}{n} \sum_{i=1}^{n} r_i$$

X is the weight ratio:

$$E(rp) = x_A E_r(A) + x_B E_r(B) + \cdots x_i E_r(i)$$
$$x_A + x_B + \cdots + x_i = 1$$

Average deviation degree σ^2:

$$\sigma^2 = \sum_{i=1}^{n} [r_i - E(r)]^2 p_i$$

Take two numbers of forest investments as an example:

$$\sigma p^2 = x_1 r_1 + x_2 r_2 + \cdots x_n r_n = \sum_{i=1}^{n} x_i r_i$$
$$E(rp) = \sum_{i=1}^{n} x_i E_r(i)$$

Considering the loss of carbon sequestration due to logging:

$$r_i = a_i + b_i F + \varepsilon_i$$

b_i indicates the sensitivity of forest i to factor F (reflecting the loss of carbon sequestration):

$$\sigma_i^2 = b_i^2 \sigma_F^2 + \sigma^2(\varepsilon_i)$$
$$\sigma_{ij} = b_i b_j \sigma_E^2$$

Let the total number of units invested be 1 and the proportion of funds spent on the number i is x_i. $x = (x_1, x_2, \dots, x_n)$:

$$\begin{cases} x_1 + x_2 + \cdots + x_n = 1 \\ 0 \le x_i \end{cases}$$

r_{jk} represents the growth rate of carbon sequestration in year k under the j^{th} tree type of the forest.

Projected average carbon sequestration growth rate for the j^{th} investment:

$$\overline{r_j} = \left(\sum_{k=1}^{T} r_{jk} \right) \Big/ T$$

The loss of carbon sequestration to the forest from the j^{th} investment is:

$$q_j = \left[\sum_{k=1}^{T} (r_{jk} - \overline{r_j}) \right] \Big/ T$$

The return of portfolio $x = (x_1, x_2, \dots, x_n)$ in the k^{th} year is:

$$R_k(x) = \sum_{j=1}^{n} x_j r_{jk}$$

The average return of the portfolio is:

$$R(x) = \frac{1}{T} \sum_{k=1}^{i} R_k(x) = \frac{1}{T} \sum_{k=1}^{i} \sum_{j=1}^{n} x_i r_{jk}$$

Risk of portfolio $x = (x_1, x_2, \dots, x_n)$:

$$Q(x) = \frac{1}{T} \sum_{k=1}^{T} [R_k(x) - R(x)]^2$$

$$= \frac{1}{T} \sum_{k=1}^{T} \left[\sum_{j=1}^{n} x_j r_{jk} - \frac{1}{T} \sum_{k=1}^{T} \sum_{j=1}^{n} x_j r_{jk} \right]^2$$

$$= \frac{1}{T} \sum_{k=1}^{T} \left[\sum_{j=1}^{n} x_j (x_{jk} - \overline{r_j}) \right]^2$$

Controlling carbon sequestration losses to maximize investment returns:

$$\begin{cases} \max R(x) \\ s.t. \begin{cases} Q(x) \le \sigma \\ x_1 + x_2 + \cdots + x_n < 100000000 \\ x_i \ge 0 \end{cases} \end{cases}$$

5.3.2 Solution of the Integrated Forest Management Model

For this problem, we have to calculate the average annual carbon sequestration and the difference between carbon sequestration and carbon consumption of forest products in the Greater Khingan Mountains for four seasons from 2008-2017, and then standardize them.

For the sequences x_1, x_2, x_3, x_4

$$y_i = \frac{x_i - \bar{x}}{S}$$

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{1} x_i$$

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

We perform the normalization F_n , set σ to 0.2 and substitute into the solution using MATLAB to obtain:

```
Local minimum found that satisfies the constraints.

Optimization completed because the objective function is non-decreasing in
feasible directions, to within the value of the optimality tolerance,
and constraints are satisfied to within the value of the constraint tolerance.

<stopping criteria details>
x = 4×1
      0.4358
      0.2673
      0.1016
      0.1953

favl = 1.1854
```

Figure 11: MATLAB solution graph

Season type	**Spring**	**Summer**	**Autumn**	**Winter**
Logging allocation ratio	0.4358	0.2673	0.1016	0.1953

Table 14: Table of optimal allocation ratio for logging

The optimal yield obtained by MATLAB is 1.1854, which means that the amount of carbon sequestered using this model is 118.52% of the original amount of carbon sequestered.

5.3.3 Logging Schedule

Based on the benefit-maximizing harvesting approach, we show the harvesting schedule in Table 15 below:

Year	**Forest product manufacturing ratio**	**Tree planting ratio**	**Yield**
2022	44%	26%	0.3584
2023	26%	10%	0.9344
2024	10%	19%	1.6634
……	……	……	……
2121	19%	44%	33.7216

Table 15: Harvesting schedule

From the table, we can find that the carbon sequestration in Greater Khingan Mountains decreases in the first two years when the strategy of deforestation and tree planting is implemented simultaneously, especially in the first year the decrease is more than 60%, which is the reason why most people oppose deforestation, but from the third year onwards the carbon sequestration increases significantly, and in the long term the effect is much higher than simply not deforesting.

Finally, it can be concluded that the total amount of carbon sequestration and economic benefits of the Greater Khingan Mountains will be 33.7216 times higher in 100 years according to the integrated forest management model. Finally, using ArcGIS, the carbon sequestration map of the Greater Khingan Mountains after 100 years is shown in Figure 12 below:

Figure 12: Carbon sequestration map of the Greater Khingan Mountains after 100 years

6. A newspaper article to local community

Why harvesting forests is more crucial and environment-friendly?

The management of forest is becoming a hot spot of society. What kind of forest conservation measures should human take to protect our planet and reduce the concentration of greenhouse gases in the air? These have been widely discussed by everyone. In order to protect forests across the whole world in the coming future, countries all over the world have established nature reserves to protect forests resources, as well as strict laws have been enacted to combat illegal logging. Our team felt very happy about this, and we have already started to pursue a healthier, more environment-friendly lifestyle. This is a symbol of a certain level of economic development and open-mindedness of each human being. However, we believed environmental protection should be synchronized with economic development. In many areas where forest resources are highly developed, the level of local economic development is seriously lagging behind due to harsh logging policies. This has caused these regions to suffer from backward and poor development status while contributing to global environmental quality, and we felt quite painful and sad.

A new study showed that forests degrade greenhouse gases such as carbon dioxide in two main ways. On the one hand, the forest itself absorbs carbon dioxide, and on the other hand, the forest products itself sequester carbon dioxide. Thus, we studied forest types around the world, scored the forest management of each country, and designed an integrated forest management system.

We calculated that the amount of carbon sequestered by the forest would increase significantly after a few years when logging and forest planting are implemented simultaneously. In the case of Greater Khingan Mountains, the ratio of logging to planting was found to be 1:2, and the amount of carbon sequestered in Greater Khingan Mountains declined in the first two years of this forest management plan, especially in the first year when the decline magnitude was more than 60%. This is the reason why most people oppose logging, but from the third year onwards, the amount of carbon sequestered increased significantly, and in the long term, the effect is much higher than that of no logging at all. Finally, it can be concluded that the total amount of carbon sequestration and economic benefits of the Greater Khingan Mountains will be 33.7216 times higher in 100 years according to our integrated forest management model. This vividly illustrated that integrated forest management is more reasonable than the traditional environmental approach of banning logging. In the future, we will continue our research to make more adequate recommendations.

Here our team suggested that a part of the forest trial field could be set up to continuously track the amount of carbon sequestered using traditional methods and new forest management models over a period of 5 years to get a better and more in-depth understanding of this system. The government and local community should take some measures to liberalize the logging policy in order to achieve environmental and economic development together.

7. Strengths and Weaknesses

7.1 Strengths

1) Factor analysis was used to be able to fit variables with high correlation to new variables to eliminate serial correlation between variables, thus making the evaluation model more accurate.
2) Using a multi-factor integrated evaluation model, the influence of into GGE, FCA, NRA, GOW, CNPP, and HDI on the forest management system is considered, and our model is more objective and highly accurate.
3) Based on the theories of Markowitz Mean-Variance Model, we designed an integrated forest management model to measure the reduction of carbon sequestration in forests during tree cutting more at a more accurate degree.

7.2 Weaknesses

1) Due to the limitation of existing datasets, we only considered the effect of logging on the amount of carbon sequestered by forests, while the effect of natural disasters and other factors on forests were in a lack of consideration.
2) When we establishing the weight vectors of the multi-factor evaluation model, the setting of the weight vectors is highly subjective, which may cause some biased issues.

8. Further discussion

The construction of the integrated forest management model in this question provides a new way for future forest management and planning, a new channel for environmental protection and organic recycling, and a new way of thinking for solving forest management problems. In this problem, we only consider the impact of logging ratio on forest management. In the future, we can further study the impact of different types of trees and different manufacturing uses of forest products on forest carbon sequestration, which cannot be elaborated in more detail in this paper due to space, but the optimization of these problems will have a positive impact on the future forest management system.

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