Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
E		2203596

Summary

Due to economic development, human activities have greatly increased the concentration of greenhouse gases in the atmosphere. In the nearly 150 years after 1850, the concentration of carbon dioxide has increased by 20%. This phenomenon will cause further warming of the earth and the atmosphere, have a negative impact on the natural ecosystem and mankind, and threaten the survival and development of mankind. In recent years, the problem of greenhouse effect has attracted the attention of the world. How to make full use of the carbon sequestration capacity of forests to slow down the process of greenhouse effect and reduce the concentration of carbon dioxide in the atmosphere has become an important and urgent problem.

In order to solve this problem, this paper focuses on the carbon sequestration capacity of forests, forecasts its trend, and formulates a reasonable and effective forest management plan combined with economic value, environmental value and social value.

In order to accurately calculate and predict the carbon sequestration capacity of forests and determine the most effective forest management plan for carbon dioxide storage, we have developed a new carbon storage model called CCS (carbon absorption and storage) based on InVEST model and time series prediction model. We selected the data of four indicators of forest coverage, carbon content, biomass stock and wood removal in 43 countries to calculate the annual net carbon sequestration of forests after data preprocessing. Then we classify countries according to their different temperature zones, and use the time series model to predict the net carbon sequestration of forests in each country from 2020 to 2030. Through ranking, find out the top five countries with the best forest carbon sequestration capacity, analyze their forest composition and tree species information, and formulate the forest management plan with the best effect of absorbing carbon dioxide.

In order to fully consider other forest values and balance the needs of environment and economy, we established a decision-making model based on AHP (analytic hierarchy process model) and EWM (entropy weight method) to help forest managers make scientific and efficient forest management plans. According to the existing data, we select five quantifiable indicators, give weights to the indicators in combination with EWM (entropy weight method) and eigenvalue method, and get the importance of different indicators. AHP model is used to select the countries with the highest scores among the top five countries with the best forest carbon sequestration capacity, and study their forest management policies, so as to determine a forest management plan to balance various forest values.

In order to verify the adaptability of the model, we apply the model to tongas National Forest and Congo Basin forest in the United States, predict how much carbon dioxide the forest and its products will store in the next 100 years, and formulate corresponding forest management plans based on the data of the forest, local economic conditions and social and cultural customs.

Finally, we conducted a sensitivity analysis to discuss the advantages and disadvantages of the model, and completed a non-technical newspaper article to explain the scientificity of including reasonable deforestation in the forest management plan, so as to persuade local communities to accept our forest management plan.

Keywords: Carbon sequestration,The time series, EWM, AHP, InVEST,Pearson

Contents

1 Introduction

1.1 Problem Background

Since 1975, the average temperature of the earth's surface has risen by 0.9 degrees Fahrenheit. Global warming caused by the greenhouse effect has attracted people's attention. Among them, the emission of carbon dioxide and the reduction of forests have become the primary issues of sustainable development of the world environment. In order to mitigate the impact of climate change, we need not only to reduce greenhouse gas emissions, but also to absorb carbon dioxide in greenhouse gases through forest vegetation. How to manage forests can bring more carbon absorption, whether to cut down trees and what kinds of trees have become issues worthy of consideration. In response to this situation, the International Carbon Management Cooperation Organization (ICM) has been formed to develop guidance for forest managers around the world trying to figure out how to utilize and manage their forest ,so as to balance the value of forests between environment and economy.

Today, the development of the world economy is accelerating, and the global forests that live on tropical rain forests are being continuously destroyed by human beings. If there are no effective measures to solve these problems, it will bring devastating damage to the earth's environment, and mankind will also face severe survival problems. Therefore, it is of unprecedented significance to improve forest carbon sequestration capacity by improving forestry management without seriously affecting economic development.

1.2 Restatement of the Problem

In order to solve the problem of forest carbon sequestration, we have formulated corresponding plans. By increasing the carbon dioxide reserves of forests, we can reduce the content of greenhouse gases in the atmosphere and mitigate the impact of climate change on us.

Our mission:

1. Develop a carbon sequestration model to determine the amount of carbon dioxide a forest can sequester over time.

2. Develop a forest decision model to determine a management plan for a forest that balances economic and environmental values.

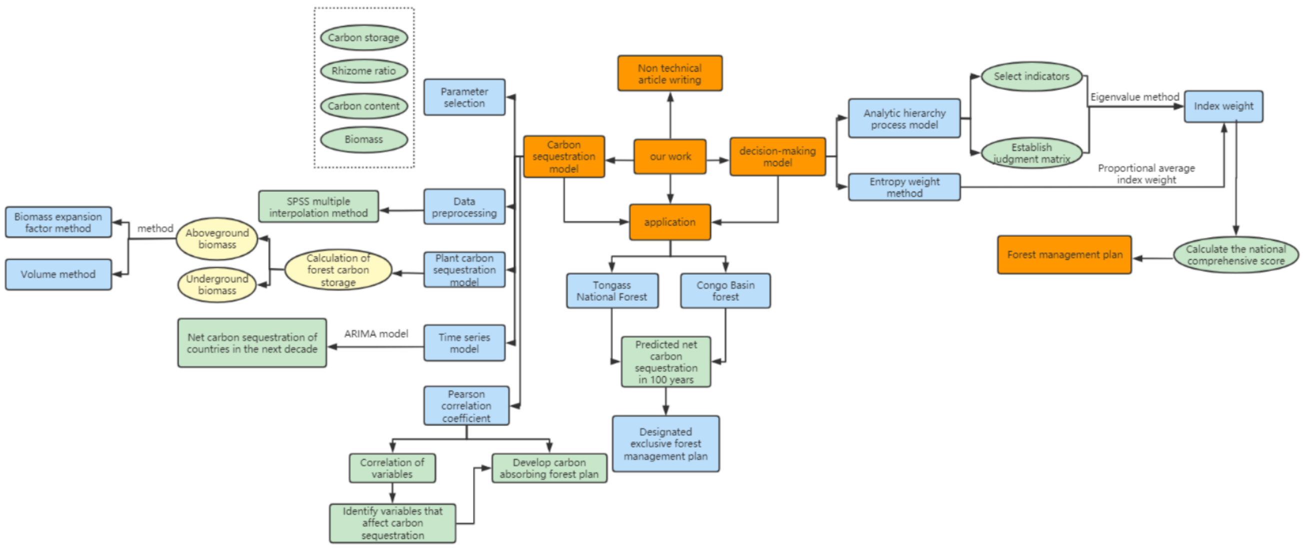
3. Apply carbon sequestration models to various forests and use decision models to optimize forest management plans to ensure that the feelings of forest managers and those who use forests are taken into account.

4. Write a one to two page non-technical newspaper article explaining the benefits and positive impacts of cutting down trees properly rather than never cutting down trees at all, persuade the local community to adopt optimized forest management plans, and collectively make decisions that are best for the forest and the planet.

1.3 Our work

Based on the method of forest resource inventory, we established a carbon storage model to calculate and predict the amount of carbon dioxide that can be stored in the forest. In addition, we established

Figure 1: Work flow chart



a forest decision-making model based on AHP and EWM. Using this forest decision-making model, a reasonable forest management plan is established for forest managers, which shows that appropriate deforestation can bring better environmental benefits, and advocates the scientific management of forests through reasonable deforestation to balance the needs of environment and economy. The whole modeling process is shown in the figure 1:

2 Assumptions and Symbols

2.1 Assumptions

In order to simplify the problem, highlight the key points and facilitate us to simulate the actual conditions, we make the following reasonable and correct assumptions.

- **We assume that the selected sample forests are all mature forests** with tree age above 60 and stable carbon sequestration effect.
- **We assume that all the data we get are reliable,** because the sources of the data are reliable, and we are confident that our indicators reflect an accurate picture.
- **We assume that the carrying capacity of the environment is stable** because the evolution of an ecosystem is a long-term process.
- **We assume that sudden changes in forests are negligible** because they are uncontrollable and unpredictable.
- **We believe that all regions will work together to actively address the issue of environmental change and are willing to take measures to improve it.** This assumption is based on the reflection of most countries.

2.2 Symbols

Table 1: The Symbol Table

define	symbol
CF	The carbon content $C \cdot g^{-1}$
C	Carbon storage
C_a	arbon storage in tree layer
C_s	Carbon storage in shrub layer
C_n	Carbon storage in vegetation layer
BCEF	Biomass transfer expansion factor
BEF	Conversion coefficient of biomass
B	The biomass
V	volume
R	Roots than
FSV	volume

3 CCS (carbon absorption and storage)

3.1 Model

InVEST model - integrated valuation of ecosystem services and trade-offs is jointly developed by Stanford University, the Nature Conservation Association (TNC) and the World Wide Fund for nature (WWF). It aims to simulate the changes in the quality and value of ecosystem services under different land cover scenarios, It provides a scientific basis for decision makers to weigh the benefits and impact of human activities.

We use the InVEST model to simulate the dynamic changes of carbon reserves and biomass stocks to help us calculate and predict the forest carbon reserves of various countries in the next decade.

3.1.1 Parameter selection and estimation

In the construction of the model, in order to calculate the forest carbon sequestration in different countries, we refer to the relevant scientific literature of forestry and select the parameter values required for calculation:

CF=0.45g $C \cdot g^{-1}$, representing the average carbon content of aboveground vegetation (tree layer). We use biomass weighted average carbon content method to obtain.

$$P = \frac{1}{\Pi} \Sigma P_i (i = 1, 2, \ldots, n) \tag{1}$$

SVD=0.443(t.d.m/m^3), It can be obtained by looking up the table.

Here, P is the average aboveground carbon content of a stand; P_i is the biomass weighted average carbon content of plot i of a stand (i=1,2. . . , n).

Table 2 shows the biomass of shrub layer and herb layer in different climates, as well as the estimated values of root and stem ratio and underground biomass:

Table 2: Biomass of shrub layer and vegetation layer, ratio of root to stem, and estimation of underground biomass in different climates

		biomass (t/hm^2)	ratio of root and stem	underground biomass (t/hm^2)
Tropical: mainly broad-leaved forest	Shrub layer	3.924	0.28	37.12
	Herbaceous layer	1.043		
Temperate zone: mainly mixed forest	Shrub layer	2.430	0.21	55.3
	Herbaceous layer	1.145		
Cold zone: mainly coniferous forest	Shrub layer	0.995	0.22	36.79
	Herbaceous layer	0.683		

Figure 2: Indicators and parameters used in carbon sequestration models

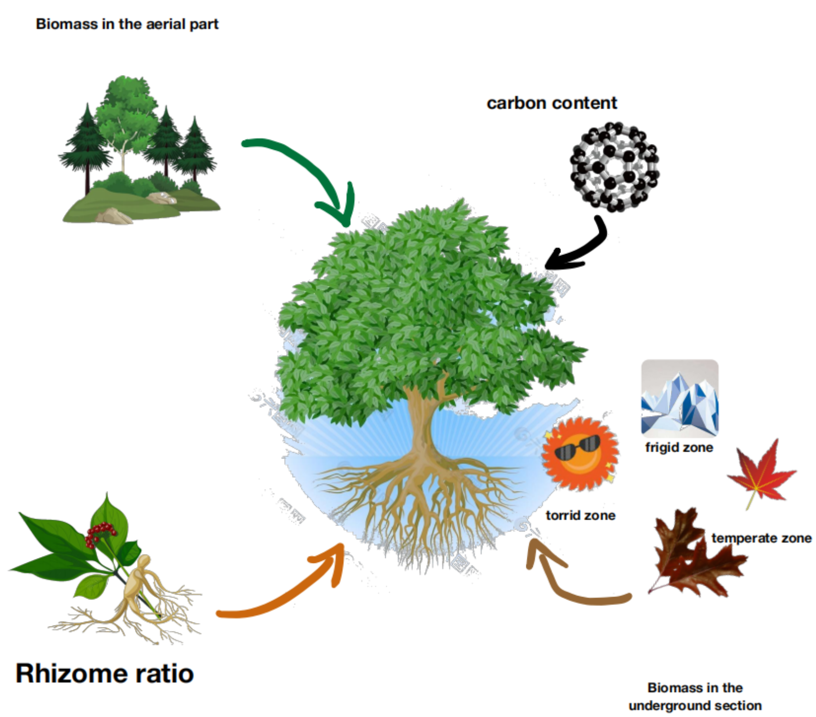


Figure 2 shows the indicators and parameters used in the carbon sequestration model.

3.1.2 Data preprocessing

We searched several websites such as the National Bureau of statistics, the carbon dioxide information analysis center and gapminder. First, we found a number of data such as the total area of forest land, the removal of forest products, the stock of forest biomass and carbon dioxide emissions in 43 countries. Some are missing statistical data. We use multiple interpolation of SPSS software to fill in the missing values to ensure the fluency of data processing and analysis.

3.1.3 Model establishment

According to the definition of terrestrial ecosystem carbon pool by the United Nations Intergovernmental Panel on climate change (IPCC), terrestrial ecosystem carbon pool includes aboveground biomass, underground biomass, dead wood, litter and soil organic matter. Among these five types, the carbon reserves of soil, litter and dead wood account for less. In order to highlight the key points and make the model concise, we choose the carbon reserves of soil, litter and dead wood not to be included in the calculation of this model. In the calculation, we need to clarify the concept of each index:

Biomass: total organic matter of forest (dry matter) (ton dry matter/m^3)

Forest carbon storage: the storage amount (or quality) of carbon elements in each carbon pool of forest ecosystem is the result of years of accumulation of forest ecosystem and belongs to the stock.

According to the formula, forest carbon storage = aboveground carbon storage + underground carbon storage. The following is the calculation formula and process.

Calculation of aboveground carbon reserves: The estimation methods of aboveground carbon reserves include biomass expansion factor method (BCEF method) and stock method (IPCC method). The formulas for calculating aboveground carbon reserves are:

C(carbon)=B(The total biomass)· CF(Carbon content of tree layer)

In the first mock exam, we only need to calculate all variables in the biomass expansion factor method. In this model, we choose biomass expansion factor to calculate the carbon storage of forest in different countries.

Biomass expansion factor method (BCEF method): Biomass expansion factor method is one of the main methods to estimate forest biomass. Biomass expansion factor is one of the important estimation parameters, which is mainly used for the conversion between trunk biomass, total forest biomass and each dimension biomass.

Biomass conversion factor (BEF) was used to convert the stock of two kinds of resources into biomass.

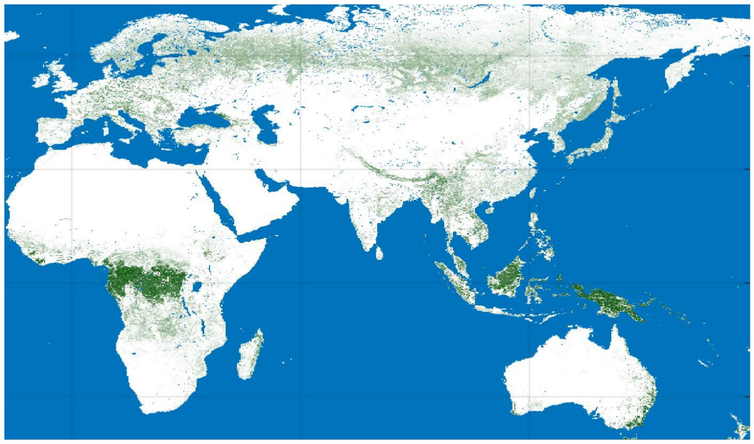
Total biomass = bef (biomass expansion coefficient) · SVD (total stock)

Calculation of underground carbon storage:

According to Figure 3, the global vegetation is concentrated in the cold zone, tropical zone and temperate zone. Due to the differences of forest tree species in different temperature zones, the parameters required for calculation are also very different. Therefore, we divide the 43 countries selected into tropical, temperate and cold zone countries according to longitude and latitude to calculate the forest biomass.

1) Calculate the aboveground biomass (in addition to the tree layer, there are shrub layer and herb layer, which are calculated separately due to different carbon content):

Figure 3: the thermodynamic map of world forest cover distribution drawn by GPS



Shrub layer: B1 = shrub (unit biomass of shrub layer) · s (forest area)

$$B_1 = B_{us} \tag{2}$$

Herb layer: B2 = B herb (unit biomass of herb layer) · s (forest area)

$$B_2 = B_{un} \cdot S \tag{3}$$

2) Calculate the underground biomass (the biomass of shrub layer and herb layer)

   Shrub layer:$B_3 = B_1 \cdot R$(ratio of root and stem)

   Herb layer: $B_4 = B_2 \cdot R$(ratio of root and stem)

3) Calculated underground carbon storage (c)

   Shrub layer: C1 = B3 (underground biomass of shrub layer) · CF1 (carbon content of shrub layer)

$$C_1 = B_3 \cdot CF_1 \tag{4}$$

   Herb layer: C2 = B4 (underground biomass of herb layer) · CF2 (carbon content of herb layer)

$$C_2 = B_4 \cdot CF_2 \tag{5}$$

$$C = C_1 + C_2 \tag{6}$$

   [the biomass is estimated with the appendix, and the carbon content rate uses the default value of 0.4672) and the carbon storage of herb layer (the biomass is estimated with the appendix, and the carbon content rate uses the default value of 0.3270]

3.1.4 Forest net carbon sequestration

Forest carbon sequestration includes not only the growing trees, but also the carbon stored in wood products after being cut down. Wood products can be divided into long-term preservation products and non long-term preservation products through their service life. Wooden products with service life >

20 years are classified as long-term preservation products, and wooden products with service life < 20 years are called non long-term preservation products. The service life is roughly estimated according to its use. Among the wood produced by logging industry, long-term preservation products account for 57.9% and non long-term preservation products account for 42.1% [4].

Carbon removed from forests during logging operations, wooden products used to make long-term preservation products will remain in wooden products for a long time, while carbon made into non long-term preservation products will return to the atmosphere in a short time. Therefore, in calculating the net carbon sequestration of forest, we need to remove the carbon retained in non long-term products from the carbon sequestration of forest.

We will get the general formula for calculating the net carbon sequestration of forests:

CAN (annual net carbon sequestration) = CA (total forest carbon sequestration) - CE (carbon emission of non long-term preserved products)

The process of calculating non long-term storage products is as follows:

1. T (Annual net carbon sequestration, t) = Q (annual average resource consumption,wood removal)· B_0 (B_0 here represents the biomass of standing stock, with an average value of 1.9)

2. S (Total biomass of annual average resource consumption) = Q · q1 (yield rate of harvested forest resources, uniformly considered as 62%)·q2 (utilization rate of wood processing, uniformly considered as 60%) $/cdot$ q3 (proportion of wood products not stored for a long time, uniformly considered as 42.1%)· ρ (wood density, using a uniform value of 0.41)

3. $CE = k(T - S)$ [where k = 0.5 is the biological carbon content, and CE unit is t]

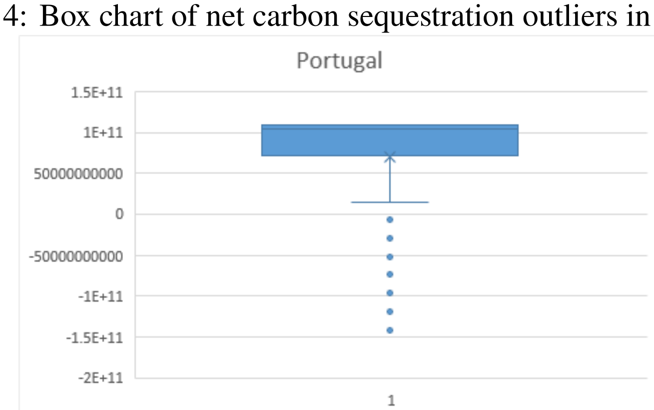
3.2 Prediction and application of the model

3.2.1 Time series prediction

We used the model to calculate the net carbon sequestration amount of 43 countries in the 30 years from 1990 to 2020, and established the data matrix X in MATLAB to predict the annual net carbon sequestration amount of 43 countries from 2020 to 2030 by using holt model, ARIMA model and Brown prediction model through the time series modeler.

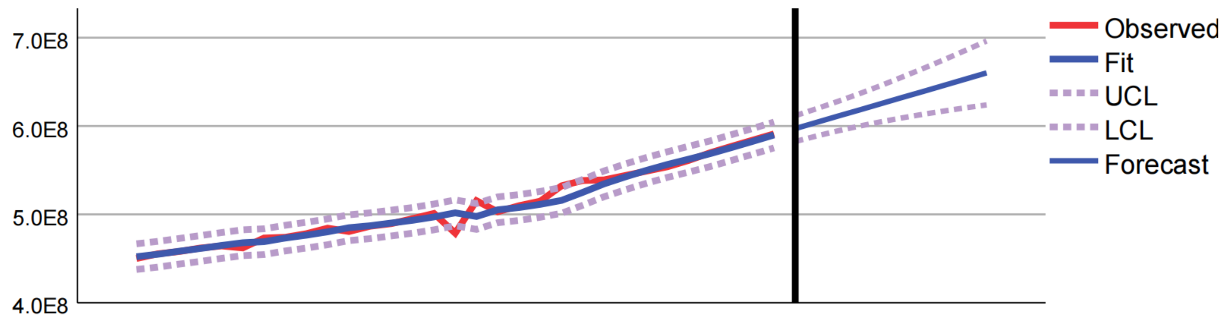
ARIMA model is one of the main methods of time series prediction analysis. In the post-forecast

Figure 4: Box chart of net carbon sequestration outliers in Portugal



data, we used the boxplot to find an anomaly in the Portuguese data, which showed a significant decline in forest area in 2019-2020. It can be seen from the boxchart that part of the data has exceeded the lower limit. According to data query, we found that there were several forest fires in Portugal in 2019, which did not meet the assumptions of our model and were classified as outliers and deleted. The figure above

Figure 5: Norway



shows a fitting of the predicted and measured values in Norway. It can be observed from the figure that the measured value has a high fitting degree with the predicted value. The confidence interval of the prediction model is 95%, 1-0.95=0.05, and the error is within an acceptable range, indicating that the prediction is accurate. Therefore, our prediction model is correct and effective.

In order to find the forest management plan with the best carbon dioxide absorption effect without considering economic factors, the net carbon sequestration amount of forests in each country from 2020 to 2030 predicted by the carbon sequestration model can be measured by simple calculation:

Forest carbon sequestration capacity = net forest carbon sequestration/forest cover area

Forest carbon sequestration capacity in cold, warm and tropical temperature zones was ranked in descending order, and the results were as follows:

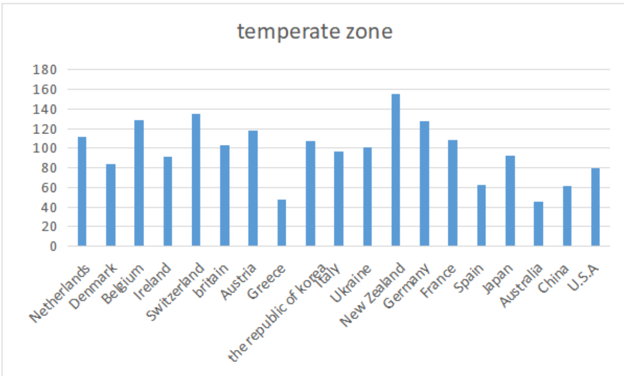
Cold zone carbon sequestration capacity < temperate zone carbon sequestration capacity < tropical carbon sequestration capacity

Through the literature, we found that the temperatures in the tropics than other high temperature zone, tree layer of photosynthesis, carbon sequestration rate increases, the magnitude of the net in the unit area of forest carbon sequestration is larger than the temperate zone and frigid zone, but we can find in the data, temperate forest area is large, small plantation age, carbon sequestration potential future [5]. To take a more comprehensive view, we chart the carbon sequestration capacity of forests in tropical and temperate countries as follows:

We have selected five countries as our main subjects in proportion to the number of countries, including three temperate countries and two tropical countries. Temperate countries: New Zealand, Switzerland, Belgium, tropical countries: Papua New Guinea, Congo.

3.2.2 Pearson correlation coefficient

In statistics, Pearson correlation coefficients (PCCS) are used to measure the correlation (linear correlation) between two variables X and Y. Pearson's correlation coefficient was used to observe the correlation between forest cover, biomass stock, biological carbon content and net carbon sequestration to determine the most effective forest management plan for carbon sequestration.



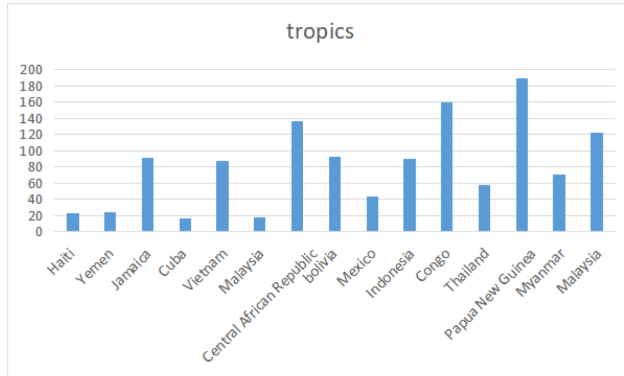
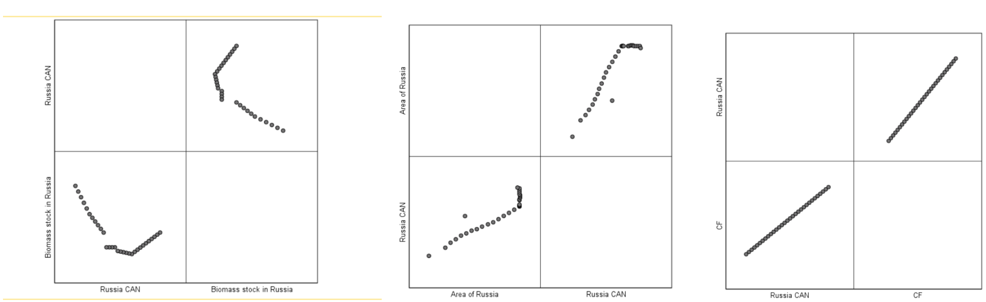


Table 3: Forest cover of different countries based on data

Country	Forest type	Main tree species	Forest area coverage
New Zealand	Coniferous and broad-leaved mixed forest	Radial pine 90%, North American yellow cedar 5%	30%
	Coniferous and broad-leaved mixed forest	Spruce, fir, beech	30%
Belgium	Temperate broad-leaved deciduous forest	Oak, pine, spruce	
	Tropical broad-leaved forest	African mahogany, eucalyptus, yanlanren	More than 60%
Papua New Guinea	Tropical broad-leaved forest	Teak and Araucaria	

We use SPSS to draw the stock of biomass, forest cover, biological carbon rate three variables respectively with net forest carbon sequestration scatterplot, determine whether there is a linear relationship between two variables, which can decide whether to use Pearson correlation coefficient method to calculate the correlation between two variables, so as to find out the factors that influence the ability of forest carbon sequestration To help us subsequently specify forest management plans that are most effective at absorbing carbon dioxide.



The scatter diagram of the relationship between biomass stock and forest net carbon sequestration in the figure above shows that there is a positive correlation between the two. Forest net carbon sequestration increases with the increase of biomass stock.

This is the scatter diagram of the relationship between forest cover area, biological carbon holding rate and forest net carbon sequestration respectively in Russia. It can be seen from the figure that there is a linear relationship between forest cover area, biological carbon holding rate and forest net carbon sequestration, and both of them are positively correlated with forest net carbon sequestration.

Next, we further determined the correlation between forest cover area, biological carbon content and forest net carbon sequestration through SPSS and Pearson correlation coefficient method. In the previous carbon sequestration model, we used the same formula to calculate the annual net carbon sequestration amount of forests in each country. To simplify the process, we selected the data of Russia as the representative.

The result is shown Table 4:

Table 4: Russia Area is associated with Russia CAN

		Russia CAN	Russia Area
Russia CAN	Pearson correlation	1	0.939**
	Sig.(two-sided test)		0.000
	The case number	31	31
Russia Area	Pearson correlation	0.939**	1
	Sig.(two-sided test)	0.000	
	The case number	31	31

**.At 0.01 level (two-sided test), the correlation was significant

The Table 4 shows the closeness of forest area and net carbon sequestration in Russia. According to the data calculated by Pearson's correlation coefficient method, ** represents P <0.01. According to Pearson's correlation coefficient, there is a strong correlation between forest area and net carbon sequestration. Combined with the positive correlation trend of the scatter chart, it can be seen that the larger the forest area, the greater the net carbon sequestration.

Table 5: Russia CAN is associated with Russia CF

		Russia CF	Russia CAN
Russia CF	Pearson correlation	1	1.000**
	Sig.(two-sided test)		0.000
	The case number	38	38
Russia CAN	Pearson correlation	1.000**	1
	Sig.(two-sided test)	0.000	
	The case number	38	38

**.At 0.01 level (two-sided test), the correlation was significant

The figure 5 above shows the correlation between forest carbon content and net carbon sequestration in Russia. Combined with the scatter diagram, it can be seen that the larger the forest carbon content, the larger the forest net carbon sequestration per unit area.

3.2.3 Best forest management plan for co2 sequestration

According to the carbon sequestration model established by us and Pearson correlation coefficient method, it can be known that forest carbon content rate and forest area are important indicators to measure forest carbon dioxide absorption capacity. In addition, the scientists also found that the height of a tree, total leaf area and per unit area, carbon content, index, and the whole plant carbon amount present significant positive correlation, especially the total leaf area per plant tree and solid carbon high correlation, this from one side shows that the more leafy plants, the carbon sequestration capacity will be higher.

Combining forest vegetation information from the five countries with the highest carbon sequestration capacity in tropical and temperate forests and the carbon content of each tree species, we identified the five trees with the highest carbon sequestration capacity.

[Because the tree layer accounts for the largest proportion when absorbing carbon dioxide, the other shrub layer and herb layer are not included in the consideration range this time. The data of tree species are selected from the tree layer of trees over 60 years old, and the carbon content rate can be measured by carbon density]

To consider forest management plans that best absorb carbon dioxide, we need to take into account the carbon density of tree species and the average height and DBH of individual trees. The average height of each tree determines whether it can absorb enough sunlight to engage in active photocooperation to absorb organic matter accumulated in the dioxide pond. Carbon density is a measure of how much carbon a tree species can store per unit volume, an important indicator of its ability to absorb carbon dioxide.

Combined with the data, the best forest management plans for carbon dioxide absorption are as follows:

(1) **The cultivation efforts of artificial forests should be increased, and artificial trees with high carbon sequestration should be selected in the tree layer according to the local climate.** In the selection of tree layer, we can choose 2 to 3 main trees from these five kinds according to the climate.

  - temperate and cold regions: spruce + fir, spruce / fir + larch
  - subtropical and tropical regions: beech + oak

(2) **Planting shrub layer and herb layer plants can increase the biodiversity of forest land.** In artificial afforestation, increasing the biodiversity of forest land through rational collocation of various plants can significantly improve the ecological stability of forest land, so as to ensure the stable and efficient absorption of carbon dioxide by forest, and achieve the effect of mitigating the greenhouse effect.

(3) **In the process of artificial cultivation, the way of mixing was adopted.** Mixing allows different forest species to exert their respective effects and reduce the extent of disaster damage.

(4) **Cut down trees regularly.** After the forest grows into overripe forest, its carbon sequestration capacity will gradually decline, and then human intervention is needed to cut down the forest to promote the replacement of the forest.

4 Forest Management Decision Model

We build a forest management decision model based on Analytic Hierarchy Process (AHP) model and Entropy Weight Method (EWM) to help forest managers make rational forest management plans.We use Analytic Hierarchy Process (AHP) model and Entropy Weight Method (EWM) to help us determine the importance of each indicator in forest management.

4.1 Hierarchy Analysis Model

Analytic Hierarchy Process, abbreviated as AHP, refers to the decision making method of qualitative and quantitative analysis based on the decomposition of the elements always related to decision making into objectives, criteria, schemes and other levels.

Figure 6: Eco and Envi

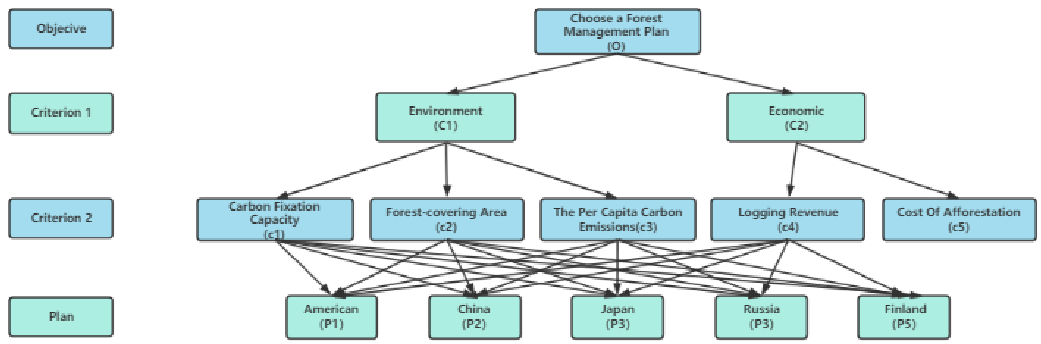
4.1.1 Index Selection

We use Python to draw word clouds from data related to forest management plans. As can be seen from the figure, five indicators - forest carbon sequestration capacity, forest cover area, per capita CO_2 emissions, logging benefits and afforestation costs - are often considered as the focus of forest management plans. Therefore, we choose these five elements as the indicators of our analytic hierarchy model.

Figure 7: Cloud

Five countries with the highest net carbon sequestration of temperate and tropical forests were selected as the scenario layer based on the prediction results of carbon sequestration model.

Figure 8: AHP



4.1.2 Judgment Matrix

1) We used the nine-point scale method to construct the judgment matrix of the second-level index and of the criterion layer [15], and the scale was suggested by experts.

2) We define: b_{ij}= the importance of index i/the importance of index j

   TableName[i represents row number, j represents column]

3) Obtain the judgment matrix A

$$Judgment\ Matrix\ A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1j} \\ a_{21} & a_{22} & \dots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \dots & a_{ij} \end{bmatrix}$$

4) Use MATLAB to calculate the weight P1 of each secondary index by arithmetic average method, geometric average method and eigenvalue method.

4.1.3 Consistency test

The consistency index CI=0.1002.

The calculated consistency ratio was CR=0.0895.

CR<0.1, the judgment matrix is considered to pass the consistency test.

4.1.4 Eigenvalue method

The weight matrix calculated by the eigenvalue method of analytic hierarchy Process is as follows Figure 6 :

Table 6: The weights are calculated by three methods

	arithmetic mean	geometric mean	eigenvalue method
Carbon sequestration capacity (mean value/area of carbon sequestration)	0.1359	0.1278	0.138
Forest cover area (ha)	0.1636	0.1503	0.1597
Carbon dioxide emissions (thousand tons)	0.0812	0.0796	0.0807
Logging earnings (USD)	0.3607	0.3744	0.3592
Afforestation cost	0.2586	0.2679	0.2624

4.2 the entropy weight method

4.2.1 Modified index weight

Since the determination of index weight by Analytic Hierarchy Process(AHP) relies on relevant data and expert judgment, it is highly subjective, so we adopt Entropy Weight Method (EWM) to modify index weight to make it more objective and real.

Table 7: The index weight

	AHP weight	EWM weight
ability of storage carbon (Average carbon sequestration/area)	0.138	0.0394
	0.1597	0.0738
Carbon dioxide emissions(kt)	0.0807	0.2302
	0.3592	0.3703
Afforestation cost	0.2624	0.2864

Final index weight = index weight of AHP *0.5+ index weight of EWM

4.2.2 Weighted average

Through index weight $/cdot$ corresponding national index, the score is calculated as follows:

$$A = \sum_{i=1,j=1}^{n} a_{ij} \cdot b_{ij}(n = 5) \tag{7}$$

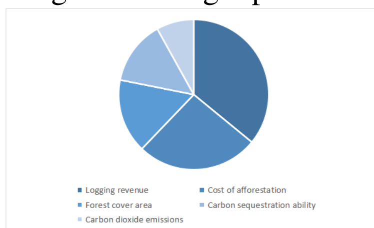
4.3 Forest management plan

Forest management may have different meanings under different backgrounds. In this paper, forest management is defined as the forest directly affected by human activities, and the forest management plan based on the decision model includes the management of deforestation, forest reengineering and forest protection, etc. [11].

Through our decision-making model, we can conclude that in terms of environment, carbon sequestration capacity and forest cover are important. On the economic side, which focuses on the benefits of logging and the costs of reforestation, a less important indicator is carbon dioxide emissions. Therefore, the top four weighted indicators will serve as the entry point for us to formulate forest management plans.

The pie chart below shows the weights of each index obtained by combining eigenvalue method and entropy weight method.

Figure 9: Weight pie chart



The United States and China are the two countries that do best in managing their forests, according to the analytical Hierarchy Process (AHP). The high overall score of the two countries also shows that their forest management systems are more mature and scientific than those of other countries, which balance economic and environmental needs well. We will study, analyze and compare the forest management plans of these two countries, and finally provide an optimized forest management plan based on our decision-making model.

As a strong forestry power in the world, the United States has a forest area of 213 million hectares and a forest coverage rate of 23.2%. Its state-owned forest establishment system has a long history, and there are laws to abide by in all aspects of the establishment of state-owned forest operation planning [10]. Forest management planning in the United States is revised at least every 15 years. After the National Forest Management Act was passed in 1976, the national forest planning legislation was revised successively in 1979, 1982, 2000, 2005 and 2012 [12]. The United States forest Management Program emphasizes sustainable management and aims to ensure the sustainable management of forests and contribute to ecological, social and economic sustainability. U.S. forest planning addresses climate change detection, forest cultural and heritage resource management, fire and fuel management, forest and timber management, and social and economic sustainability. According to different categories of detailed corresponding management regulations, put in place, effectively manage the forest to give full play to its economic and environmental benefits.

Most of China's territory is located in the temperate zone, forest area of 220 million hectares. China's forest area increased from 124.6 million hectares in 1990 to 220 million hectares in 2021, thanks to heavy government investment in artificial forestation. China's forest management plan is generally revised once every 10 years. In the 1950s, China began to implement the forest management plan, but the forest management plan revised in the 1970s has been used up to now [12]. Due to the lack of relevant legal constraints on forest management planning and the poor execution of China's management planning, the implementation of the planning is not good and the management relationship is not good. The preparation of China's forest management plan is not operable, does not attach importance to public participation, and the content is not detailed enough. Secondly, China attaches great importance to forest tourism and entertainment, fully considering the economic benefits brought by forests, but lacks protection for sustainable development of resources, which is easy to cause the destruction of state-owned forests.

Based on the forest management policies and decision-making models of the two countries, we have formulated forest management plans from the economic and environmental perspectives:

- **Protect forest ecological diversity.** Whether the forest ecosystem is stable determines whether the forest carbon sequestration rate is efficient. Protecting forest species diversity can effectively maintain the stability of forest ecosystem.
- **Increasing artificial afforestation and increasing forest coverage can effectively improve the net carbon sequestration of the forest.** The tree layer should be planted with high carbon sequestration species according to the climate conditions, and the shrub layer and herb layer should be planted with as many kinds of plants as possible.
- **The use of satellite remote sensing to monitor the growth state of the forest and environmental changes, through the monitoring of the forest can timely grasp the dynamic data of the forest, the first time to respond to the changes of the forest.** Quickly solve the various problems of forests, ensure their stable and safe growth, achieve sustainable absorption of carbon dioxide, alleviate the deterioration of the greenhouse effect.
- **Regularly cut down over mature forests:With the growth of trees, the forest will enter the over-mature stage, and the carbon sequestration rate of the forest will decrease with the increase of tree age.** Cutting down the over-mature forest can significantly improve the carbon sequestration capacity of the forest. At the same time, wood from the overripe forest can be used to produce wood products, creating economic benefits for the local area.
- **The government should properly subsidize the input of artificial afforestation.** In the process of artificial afforestation, a large amount of cost is needed, human and material resources need to be mobilized, and the follow-up management time span is long. The state should subsidize the artificial afforestation work in various regions to improve the enthusiasm of local afforestation, speed up the work efficiency, and improve the effect of artificial afforestation.
- **To strengthen public participation, in the state - owned forest management program preparation stage, fully listen to the suggestions of scientists and public opinions, strengthen the role of public participation.**
- **Improve the forest management plan of laws and regulations and policy system, through the refinement of management regulations and quantitative inspection indicators to standardize the forest management plan and its implementation to provide a basis for monitoring the local implementation of forest management measures.**
- **Attach importance to the protection of cultural heritage and historical sites in the forest,** and focus on the protection of historical sites left in the forest, should not be wantonly developed into tourist areas so as to destroy cultural and heritage resources; For the forests that have been developed as tourist areas, a reasonable reward and punishment system should be established to balance the relationship between recreation and forest cultural value. The development process should pay attention to the local culture and customs, respect the habits of the local people.

- **Strengthen the awareness of forest management among forest managers.** Popularize advanced forest management ideas and methods to forest managers, promote the implementation of forest management planning content, and improve the efficiency of forest management.
- **Establish a Joint Forest Management Committee [13].** Establish a participatory partnership between local communities and governments based on forest protection and management to achieve effective implementation of forest management plans.
- **Take into account the growth cycle and adaptation of forests when changing forest management plans.** Select an authoritative forestry agency to assess the state of the forest. Because of the long growth cycle of the forest, it is not recommended to change the forest management plan frequently. Take the tree from young age to maturity as a cycle, observe the effectiveness of the forest plan, and consider the transition to another forest management plan after the evaluation is ineffective.
- **If the forest type is virgin rainforest, it is not recommended to cut down and develop.** Virgin forests are mainly distributed in Asia and northern North America, Southeast Asia, Congo River basin in Africa and Amazon basin in South America. Virgin rainforests are the most carbon-sequestering of all forests and play an important role in the earth's ecosystem. We should protect them.

5 Case analysis

5.1 Tongass National Forest Park

In this part, we select the Tungas National Forest of the United States as the case study and optimize the forest management plan for it.

The Tungas National Forest is the largest national forest in the United States, covering 6.8 million hectares and comprising 19 nature preserves, Adelmerti Islands National Memorial Park, and Fogfjord National Scenic Area. It is rich in flora and fauna and contains nearly one-third of the world's remaining pristine temperate rain forests. Using forest data from the Tungas National Forest Park as input, we projected the net carbon sequestration of the Tungas National Forest over the next 100 years using a carbon sequestration model (CCS), with a total net carbon sequestration of 6.1 billion tons over the next 100 years.

The following figure shows a line chart of the net carbon sequestration of Tongass forest. The curve shows an upward trend and the carbon sequestration capacity is constantly strengthening.

Then the forest decision model is used to score its indicators.

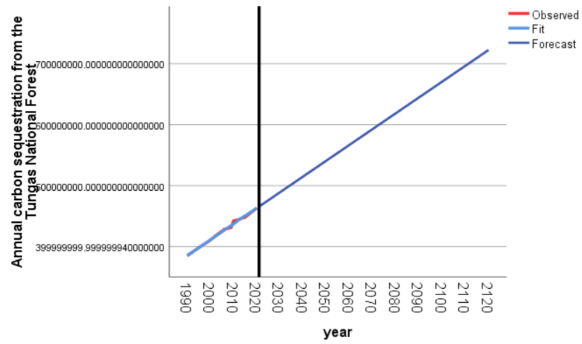
In terms of environmental benefits, its carbon sequestration ability index score is higher than the average level, and its carbon sequestration ability is strong. The forest structure does not need to be artificially adjusted.

In terms of economy, about 1/5 of the tungas forest area has been rationally developed, with certain economic benefits and without destroying the carbon sequestration capacity of the forest, balancing the economic and environmental needs.

Our proposed forest management plan for The Tungas National Forest Park is:

- Maintain the current forest management plan.

Figure 10: Trends of carbon sequestration over the past 100 years



- Regular training for forest managers to make them receive advanced scientific management methods and ideas and improve the efficiency of forest management.
- The transition from the old forest management plan to the new forest management plan needs to seek professional assessment of the forest condition, should follow the forest growth cycle , not rush.
- When choosing a new forest management plan, it is necessary to consider the will of local residents or private forest managers, and unite the public to jointly protect the forest.

5.2 Congo Basin forests

Congo Basin has a forest area of more than 1 million square kilometers, accounting for a quarter of the world's total tropical rainforest area. With abundant species, it is the "second lung of the earth" [14]. The economic benefits of forest harvesting industry account for a large proportion of national economic benefits.

Using the data of forest area in Congo Basin from 1990 to 2010 as input, we use carbon sequestration model to simulate and predict the change of forest area in Congo Basin in the next two decades. It is concluded that the forest area in Congo Basin will be reduced by two-thirds in 2040 at the current reduction rate (4 hm^2/year).

The Figure 11 below shows the net sequestration of forests in the Congo Basin over the next 100 years using carbon sequestration models. Congo Basin forests will absorb about 170.118 billion tons of co2 in the next 100 years. However, the population surge and the expansion of agricultural production lead to the economic development to the forest, so the forest area in the Congo Basin is decreasing year by year, and the carbon sequestration capacity of the forest is declining and gradually degraded.

The chart below shows the projected trajectory of world carbon dioxide emissions As carbon dioxide emissions increase, the destruction of virgin rainforests will exacerbate the greenhouse effect. Congo Basin forests, as virgin forests, play an important role in absorbing carbon dioxide. In order to protect Congo Basin forests and balance local economic development, we used a forest decision model to evaluate them. It is found that the stability of its ecosystem is low, because of human interference, the species decrease, so that its ecosystem becomes fragile. Deforestation has reduced the area of forests. The Congolese people derive great economic value from forests, but they destroy the

Figure 11: Carbon sequestration of forests in the Congo Basin in the next 100 years

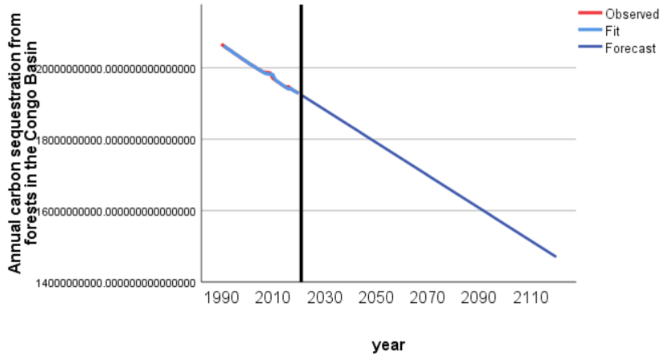
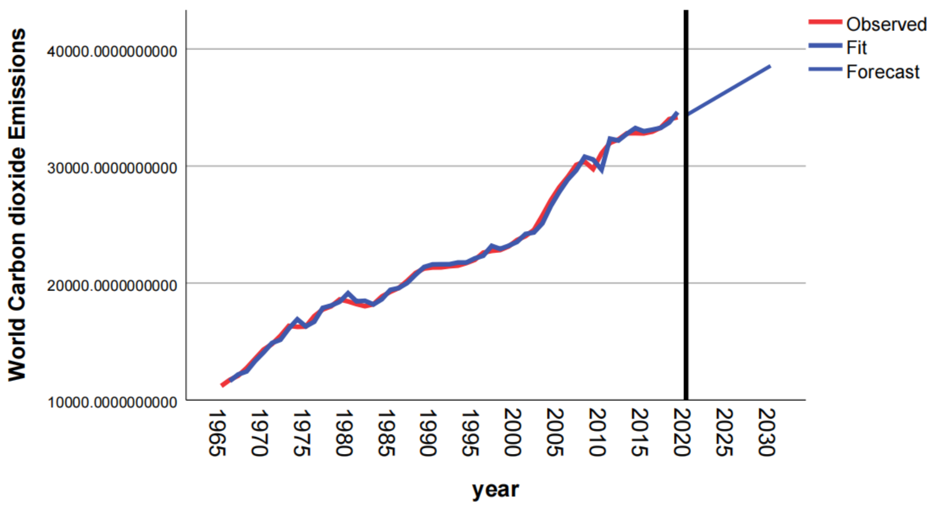


Figure 12: the projected trajectory of world carbon dioxide emissions



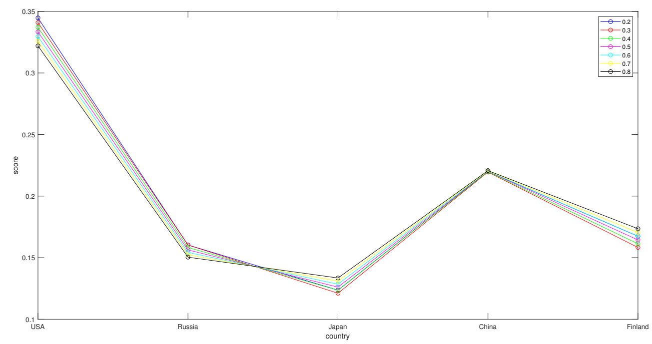
environment of forests and cannot achieve sustainable development. We need to implement systematic forest management plans to develop with forests scientifically and effectively.

- Perfect legislation to provide legal guarantee for primeval forest protection.
- To set up nature reserves, the government should participate in the protection of rainforests. Local residents should not be allowed to cut down and burn forests at will, and the occurrence of vicious logging events should be restricted through government intervention.
- Advocate artificial afforestation. It will increase forest area and bring local jobs. Increase economic sources by planting fast-growing forests.
- Publicize and answer questions about forest protection to local residents. The government should cooperate with the residents to protect the forest.

6 Sensitivity Analysis

Although we combined the results of AHP and EWM to obtain the final weight of ρ for each indicator, we set 1=0:8 and 2=0:2. Here we will analyze the sensitivities of 1 and 2. We set 1= 0:2;0:3;0:4;0:5;0.6;0:7;0:8, the results are as follows:

Figure 13: Sensitivity Analysis



In the figure 13, we can see that when the value of 1 changes, the scoring rankings of all countries have the same change trend, and there is no completely different trend of each broken line after the value of 1 changes, which means that our decision-making model is stable.

7 Strengths and Weaknesses

7.1 Strengths

Our Carbon Sequestration Model is based on InVEST model and time series prediction model.

Scientific and rigorous forestry and ecological formulas are used in the calculation and prediction, and the fitting of time series prediction is good, and the accuracy of prediction results is high.

When we calculate the net carbon stock of the forest, we take into account the amount of carbon retained by cutting down wood to make wood products, This gives a more accurate estimate of net carbon storage,it is also of positive significance to correctly evaluate the forest carbon sequestration capacity and establish a decision model.

The decision model is based on Analytic Hierarchy Process (AHP) and Entropy Weight Method (EWM).

When measuring indicators,we use weighted average method combined with AHP and EWM to calculate the index weight.The weight under the entropy weight method varies from sample to sample.Therefore, the modification of entropy weight method effectively makes up for the lack of strong subjectivity of AHP.

Our model is proved to be effective.

Remote sensing satellites have actually observed that the forest area in the Congo Basin is decreasing year by year,the trend data are in hight agreement with the results predicted by our carbon sequestration model,this shows that our model is reasonable and effective.

The model we built is very adaptable.

The application of carbon sequestration model to forests in different temperature zones can accurately predict the development trend of different forests,combined with decision models, different forest management plans can be created for different forests,provide effective assistance to forest managers.For different types of forests in the world, our model can be adapted and analyzed effectively.

7.2 Weaknesses

In our modeling process, due to the lack of time , we were not able to collect a wide range of data from all forests in the world, so there was a certain deviation in calculating and predicting the net carbon sequestration of forests.

In modeling, we excluded forest emergencies, such as malicious deforestation, sudden reduction of forest area caused by sudden fires, and destruction of forest balance caused by abrupt changes in ecosystem.Without specific and detailed forest information and sufficient samples, our model cannot be applied accurately in the above situations.

8 Conclusions

AHP and EWM are combined to establish the index system, and finally we use the comprehensive score to measure the effectiveness and rationality of a national forest management plan. Our decision - making model is proved to be reasonable. We used a carbon sequestration model to analyze the current and future carbon sequestration capacity of forests in The Tongass National Forest park and the Congo Basin in the United States. Based on the trends in carbon sequestration capacity helped us optimize existing forest management plans. Our model proved to be scalable for application and extension. Finally, through sensitivity analysis, we can see that our model is stable.

9 Non-technical newspaper articles

A new discovery! Cutting down trees is better for the environment!

Studies have found that reasonable deforestation can improve the carbon sequestration capacity of forests.

The issue of whether we should cut down forests has a long history, and people often have different ideas and thoughts on this issue. Some people think that forests should be cut down to get the most economic benefits, while others think that forests should be protected and refuse to cut down forests to any extent. But scientists have found that cutting down overgrown parts of a forest can significantly improve its ability to sequestration carbon, have a more positive impact on the environment than never cutting down trees in a forest, and can also increase local revenues by selling the wood. It has realized the goal of friendly coexistence of economy and environmental protection.

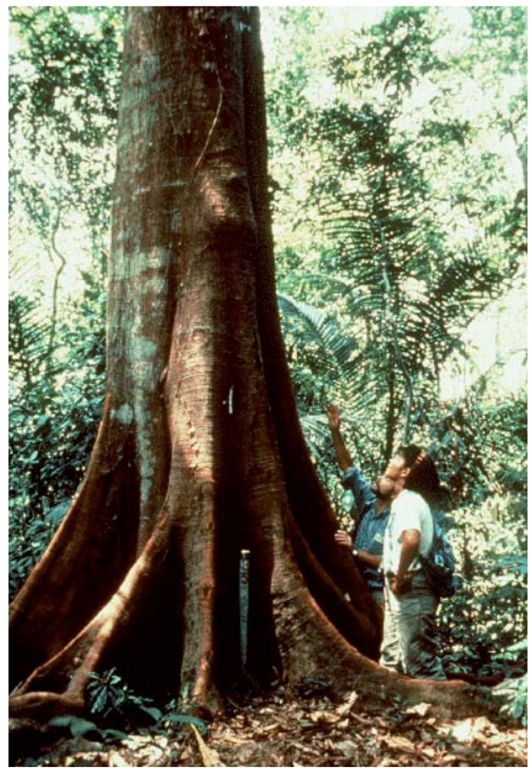


Figure 14: Scholars in panama's barro Colorado tropical forest field, photo source: NASA

Forest is the largest carbon pool in terrestrial ecosystem. In the context of temperature warming, the impact of forest carbon pool has attracted the attention of scientists and institutions all over the world.In many literatures, forest logging carbon pool is regarded as forest carbon emissions, but in practice, 57.9% of wood products are classified as long-term preserved wood products, that is, durable goods with a useful life of more than 20 years. The remaining 43.1% of wood products are considered as non-long-term preserved wood products,but with durable years of 10 years,only when it reaches its durable years does the carbon stored in wood products return to the atmosphere as carbon dioxide.The portion of harvested wood that is not used to make wood products is left in the forest, buried deep underground and classified as long-term preservation wood products.Therefore, it is unreasonable to include deforestation in the carbon emissions of forests in the literature.Carbon in wood products does not quickly return to the atmosphere, but is stored for a long time.This is very beneficial to alleviate the greenhouse effect and protect the environment.

Scientists through the investigation of trees before and after deforestation, according to the actual cutting wood carbon emissions, studied the dynamic change of forest carbon before and after cutting, the results show that retained the cutting wood in the forest and preserved by chips to make wood into the rate at which carbon dioxide from large to small, completely transformed into carbon dioxide to the atmosphere to eighty years. According to the calculation method in many literatures, the carbon sequestration capacity of forests can be calculated by taking the cut wood directly as the carbon dioxide released by forests,it takes 20 years for a forest to return to its pre-cut level.In practice, however, the carbon stored by felled wood should be part of the carbon dioxide absorbed by forests.The capacity of deforestation to absorb carbon dioxide has been calculated to be stronger than before it was cut down.

In forests, the main force for absorbing carbon dioxide is the tree layer. According to the growth cycle of the dominant species in the tree layer, the forests growing for less than 40 years were divided into young forests. The forest of 41-60 years was divided into middle age forest. The forests from 61 to 80 years were divided into perennially mature forests. The forests from 81 to 120 years old were divided into mature forests. Trees over 121 years old are classified as overripe forests. The capacity of a forest to absorb carbon dioxide increases with tree age until it reaches the mature stage. As a mature forest grows, its capacity to absorb carbon dioxide levels off and then declines. After entering the overripe forest stage, the amount of carbon dioxide emitted by the forest will exceed the amount of carbon dioxide absorbed.

Therefore, it is better to reduce the greenhouse effect and protect the environment to cut down the forest and promote its replacement than to leave the forest intact. At the same time, the timber obtained from logging has high economic value and can effectively mobilize the local economic development. People should also change their stereotypical misconceptions about deforestation and embrace advanced forest management thinking, recognizing that incorporating regular and rational deforestation into forest management plans is the best decision for the forest.

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A Code appendix

- The code for calculating carbon sequestration is as follows:

```
% carbon content of forest = aboveground + underground
%bio :Biographitic stock ;CA: forest carbon content ;CE: annual release
% aboveground biomass = biographystock * carbon content
% Underground carbon storage = underground biomass * carbon content ...
    underground biomass = aboveground biomass (calculated by biomass ...
    stock) * ratio of roots to stems
CA1=bio1.*1000000.*0.45+area1.*36.79.*0.45; %Frigid zone
CA2=bio2.*1000000.*0.45+area2.*55.3.*0.45;  %temperate zone
CA3=bio3.*1000000.*0.45+area3.*36.79.*0.45; %tropical

%%T: total annual biomass of resources S: biomass of non-long-term ...
    storage and wood products
%CE=0.5(T-S);T=wood.*1.9; S=wood.*0.62.*0.6.*0.421.*0.41;
CE1=(wood1.*1.9-wood1.*0.62.*0.6.*0.421.*0.41).*0.5;
CE2=(wood2.*1.9-wood2.*0.62.*0.6.*0.421.*0.41).*0.5;
CE3=(wood3.*1.9-wood3.*0.62.*0.6.*0.421.*0.41).*0.5;
CAN1=CA1-CE1;%CAN2=CA2-CE2;CAN3=CA3-CE3;

% Sequestration rate = carbon storage/area/time
CS1=CAN1./area1;
CS2=CAN2./area2;
CS3=CAN3./area3;
```

- The core code of AHP is as follows:

```
disp('Enter the judgment matrix A')%input A
A=input('A=');
[n,n] = size(A);
%Next, three methods are used to calculate the weight
 % % % % % % % % %Method 1: arithmetic average method% % % % % % % %
Sum_A = sum(A);
SUM_A = repmat(Sum_A,n,1);
Stand_A = A ./ SUM_A;
disp('The weight result1 is:');
disp(sum(Stand_A,2)./n) %evaluation
% % % % % % % % %Method 2: Geometric average method% % % % % % % %
Prduct_A = prod(A,2);
Prduct_n_A = Prduct_A .^ (1/n);
disp('The weight result2 is:');
disp(Prduct_n_A ./ sum(Prduct_n_A)) %evaluation
% % % % % % % %Method 3: Eigenvalue method % % % % % % % % % % %
[V,D] = eig(A);
Max_eig = max(max(D));
[r,c]=find(D == Max_eig , 1);
disp('The weight result3 is:');
disp( V(:,c) ./ sum(V(:,c)) ) %evaluation
% % % % % %To calculate the consistency ratio CR% % % % % %%
```

```
CI = (Max_eig - n) / (n-1);
RI=[0 0.0001 0.52 0.89 1.12 1.26 1.36 1.41 1.46 1.49 1.52 1.54 1.56 ...
    1.58 1.59];  %Table query yields RI values
CR=CI/RI(n); %The smaller the CR value is, the better the consistency ...
    of judgment matrix is
disp('CI=');disp(CI);
disp('CR=');disp(CR);
if CR<0.10
     disp('because CR<0.10,Can accept');
else
     disp('because CR ≥ 0.10,Need to modify');
end
```

- EWM calculates the weight, and topsis calculates the score code as follows:

```
clc
% X is the data code that has been entered
%% Step 2: Determine if you need to forward,
[n,m] = size(X);
disp(['There are 'num2str(n)' evaluation objects and 'num2str(m)' ...
    evaluation indicators'])
Judge = input(['Whether the 'num2str(m)' index needs to be forward ...
    processed, please enter 1 instead of 0:']);

%Deal specifically with different indicator types for each column
if Judge == 1
     Position = input('Enter the column of the indicator to be ...
        normalized in the form of an array: ');
     disp('Enter the indicator type for these columns (1: extremely ...
        small, 2: intermediate, 3: interval) ')
     Type = input('Enter as an array');
     for i = 1 : size(Position,2)  %You need to know how many times ...
        the loop is processed
         X(:,Position(i)) = ...
             Positivization(X(:,Position(i)),Type(i),Position(i));
     end
     disp('The positive X= ')
     disp(X)
end

%% Step 3: Standardize the matrix after the forward transformation
Z = X ./ repmat(sum(X.*X) .^ 0.5, n, 1);
disp('Normalized matrix Z = ')
disp(Z)

disp("Enter whether you want to increase the weight vector. Enter 1 ...
    instead of 0")
Judge = input('Please input: ');
if Judge == 1
     Judge = input('Please input 1 to determine the weight using ...
        entropy weight method, otherwise enter 0: ');
     if Judge == 1
```

```
        if sum(sum(Z<0)) >0   % In the presence of negative numbers, ...
            we renormalize X
            disp('X restandardization')
            for i = 1:n
                for j = 1:m
                    Z(i,j) = [X(i,j) - min(X(:,j))] / [max(X(:,j)) - ...
                        min(X(:,j))];
                end
            end
            disp('The normalization matrix Z obtained by the ...
                re-normalization of X is: ')
            disp(Z)
        end
        weight = Entropy_Method(Z);
        disp('EWM weight is:')
        disp(weight)
    else
        disp(['The input weights']);
        weight = input(['You need to enter the weight 'num2str(m)'. ...
            Please enter the 'num2str(m)' weights as row vectors:']);
        OK = 0;
        while OK == 0
            if abs(sum(weight) -1)<0.000001 && size(weight,1) == 1 && ...
                size(weight,2) == m
                OK =1;
            else
                weight = input('error,please input again: ');
            end
        end
    end
else
    weight = ones(1,m) ./ m ; % If no weight is required, the default ...
        weight is the same, that is, 1/m
end

%Step 4: Calculate the distance from the maximum and the distance ...
    from the minimum, and calculate the score
D_P = sum([(Z - repmat(max(Z),n,1)) .^ 2 ] .* repmat(weight,n,1) ,2) ...
    .^ 0.5;   % D+ max
D_N = sum([(Z - repmat(min(Z),n,1)) .^ 2 ] .* repmat(weight,n,1) ,2) ...
    .^ 0.5;   % D- min
S = D_N ./ (D_P+D_N);    % Scores not normalized
disp('Last Score:')
stand_S = S / sum(S)
[sorted_S,index] = sort(stand_S ,'descend')
```

B Data appendix

- The annual carbon sequestration calculated for each country is as follows:

year	**Frigid zone**				**Temperate zone**	
	Norway	Finland	Canada	Russia	Japan	Australia
2019	584069802.5	1067052736	8570833758	44503658626	1298092334	5039948889
2020	591155628.2	1068369068	11252226867	43264047309	1415475489	5159025397
2021	597196298.5	1070090198	13933403450	42024522781	1532841449	5278101905
2022	604186404.1	1071811327	16614580039	40784998252	1650208772	5397178413
2023	611176509.6	1073532456	19295756628	39545473723	1767576095	5516254921
2024	618166615.2	1075253585	21976933217	38305949194	1884943418	5635331430
2025	625156720.7	1076974714	24658109806	37066424664	2002310740	5754407938
2026	632146826.2	1078695843	27339286395	35826900135	2119678063	5873484446
2027	639136931.8	1080416972	30020462984	34587375606	2237045386	5992560954
2028	646127037.3	1082138102	32701639573	33347851077	2354412709	6111637462
2029	653117142.8	1083859231	35382816162	32108326548	2471780031	6230713970
2030	660107248.4	1085580360	38063992751	30868802019	2589147354	6349790478
2031	667097353.9	1087301489	40745169340	29629277489	2706514677	6468866986
2032	674087459.4	1089022618	43426345929	28389752960	2823882000	6587943495
2033	681077565	1090743747	46107522518	27150228431	2941249322	6707020003
2034	688067670.5	1092464876	48788699107	25910703902	3058616645	6826096511
year	**Temperate zone**		**Tropical**			
	China	U.S.A	Congo	Thailand	Malaysia	Jamaica
2019	12280155911	23569711355	20556391602	1152054450	2770962175	54632421.8
2020	12441379377	23707793620	20514814640	1150704450	2718888192	54698782.7
2021	12584774003	23827450283	20464256599	1149323644	2666818938	54721687.92
2022	12728168630	23948412838	20413698557	1147944521	2614749658	54744593.13
2023	12871563256	24069375393	20363140516	1146565398	2562680378	54767498.35
2024	13014957882	24190337948	20312582475	1145186275	2510611098	54790403.57
2025	13158352508	24311300503	20262024433	1143807152	2458541819	54813308.78
2026	13301747135	24432263059	20211466392	1142428029	2406472539	54836214
2027	13445141761	24553225614	20160908351	1141048905	2354403259	54859119.21
2028	13588536387	24674188169	20110350310	1139669782	2302333979	54882024.43
2029	13731931013	24795150724	20059792268	1138290659	2250264699	54904929.64
2030	13875325640	24916113279	20009234227	1136911536	2198195420	54927834.86
2031	14018720266	25037075835	19958676186	1135532413	2146126140	54950740.08
2032	14162114892	25158038390	19908118145	1134153290	2094056860	54973645.29
2033	14305509518	25279000945	19857560103	1132774166	2041987580	54996550.51
2034	14448904145	25399963500	19807002062	1131395043	1989918300	55019455.72