Research on the value and economic value of forest ecological carbon sequestration

Zijie Ji *

College of Power and Energy Engineering, Harbin Engineering University, Harbin, Heilongjiang, 150001, China

*Corresponding author: jizijie2022@163.com

Abstract. Forest carbon sequestration plays a crucial role in climate change in the biosphere. we develop a carbon sequestration model, with three stages (early, middle and last stage) and five indicators; Besides, which can predict the carbon dioxide uptake of forest and its products, providing forest managers with the most effective carbon sequestration management plans. To make the model more comprehensive, we consider the various indicators of social scope, we used the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) based on the Entropy-weight Method to improve the model of evaluation and decision-making.

Keywords: EFB model, Carbon sequestration, Social benefits and sustainability.

1. Introduction

Forest carbon sequestration plays a crucial role in climate change in the biosphere [1-3]. Be-cause of the rationality and sustainability of Forest carbon sequestration management plans, its evaluation is helpful for improving and completing existing policies on management [4-6]. Moreover, it is important for analyzing the probable natural and social benefits [7-8]. In this paper, we designed several models for addressing the forest carbon sequestration evaluation problem [9-10].

2. Establish EFP preliminary evaluation model

2.1. Introduction to the method

2.1.1. EFB Primary Evaluation Model

In order to analyze and predict the carbon sequestration of a forest accurately and reasonably, we propose a method to be used in evaluating dynamic process: EFB indicators. As a scientific evaluation indicator, it is based on early factor (E), mid-term feedback (F), back benefits (B).

In a forest, the carbon sequestration is mainly affected by dynamic factors at sane time, while the sustainability of whole environment is from the response to medium term feedback and the analysis of later benefits. The composition of the evaluation model is shown in the figure 1.

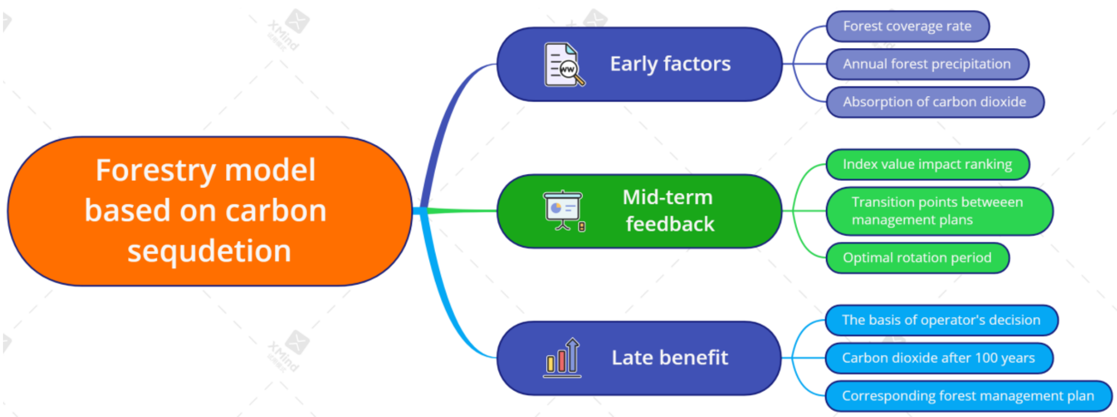


Figure 1. Composition of EFP evaluation model

2.1.2. Principal component analysis

Assume there are *n* samples and *p* Indicators, they can follow a $n \times p$ matrix:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & & \vdots \\ x_{n1} & x_{n2} & & x_{np} \end{bmatrix} = \left(x_1, x_2, \cdots x_p\right) \tag{1}$$

Set up a new set of variables $z_1, z_2, \cdots z_m \left(m \le p\right)$,then formulas below:

$$\begin{cases} z_1 = l_{11}x_1 + l_{12}x_2 + \cdots + l_{1p}x_p \\ z_2 = l_{21}x_1 + l_{22}x_2 + \cdots + l_{2p}x_p \\ \cdots \\ z_m = l_{m1}x_1 + l_{m2}x_2 + \cdots + l_{mp}x_p \end{cases} \tag{2}$$

(1) Coefficient l_{ij} should be designated for principles:

(2) $z_i, z_j \left(i \ne j, i, j = 1, 2, \cdots, m\right)$ are irrelevant.

(3) z_1 has the biggest variance in any linear combinations of $x_1, x_2, \cdots x_p$.

(4) z_2 has the biggest variance in any linear combinations of $x_1, x_2, \cdots x_p$,which are irrelevant to z_1;

(5) In this order, z_m has the biggest variance in any linear combinations of $x_1, x_2, \cdots x_p$,which are irrelevant to $z_1, z_2, \cdots, z_{m-1}$.The new variables $z_1, z_2, \cdots, z_{m-1}$ are called NO.1, NO.2, ..., principal component.

2.1.3. BP Neural work

As the most successful neural network nowadays, BP neural network consist of a few layers, when it gets trained, it will have error analysis and modify the weights, and it optimizes the algorithm to gain the expected output value. It is made of put layer, hidden layer, output layer. The specific structure is as follows figure 2.

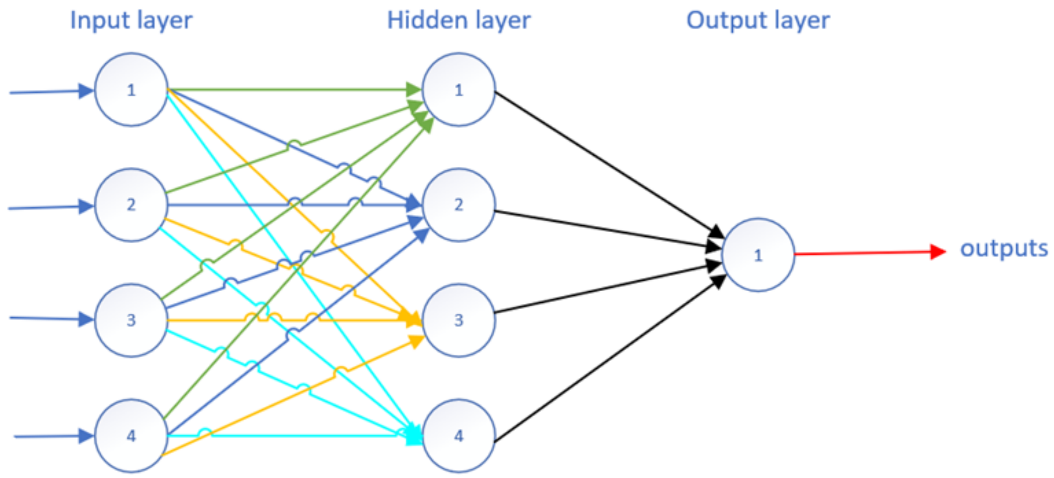


Figure 2. Schematic diagram of neural network

2.2. Model building and solving

Considering the condition of the global biosphere, forest products' sources and the situation characteristics of forests themselves, we applied the EFP model proposed by us to construct a model of carbon sequestration model. In order to select appropriate indicators, we choose Zhangjiajie forest to research and select indicators. However, there are some problems. For example, some indicators do have strong correlation, some indicators have little correlation between carbon sequestration, so instead of multiple linear regression analysis, we propose the EFB preliminary evaluation model, using the principal component analysis, i.e., CA, for each indicator to solve problems above. To confirm the core explanatory variables of carbon dioxide absorption of selected forests and products from them, we take the idea of Dimensionality reduction in the principal component analysis, thus the problem of covariance between variables can be effectively avoided. We substituted the five indicators (the original data) into the model, based on formulas, calculated the characteristic roots and variance. The results are shown in the table 1.

Table 1. Characteristic roots and variance contributions

	1	2	3	4	5
characteristic root	1.5760	1.1546	0.9854	0.8704	0.4136
Variance contribution	0.3152	0.2309	0.1971	0.1741	0.0827

In conclusion, the NO.1,2,3,4 have the variance contribution account for more than 90%, so they are sustainable for the previous data. We can inform 4 principal components to replace 5 before. The results are shown in the table 2.

Table 2. Principal component score coefficient matrix

Indicators of Trees	Component			
	1	2	3	4
Average tree diameter at breast height (mm)	0.196	0.746	-0.475	0.028
Average Growing Rate (m/a)	-0.029	-0.619	-0.719	0.133
Local Annual Average Temperature (℃)	0.061	-0.023	0.438	0.067
Local Annual Average Rainfall (mm)	-0.466	0.079	0.208	0.817
Average life spans defined by government (a)	-0.608	-0.024	0.163	-0.556

From the Coefficients, we can infer the 4 principal components are listed as follows:

$$\begin{aligned} f_1 &= 0.196x_1 - 0.029x_2 + 0.061x_3 - 0.466x_4 - 0.608x_5 \\ f_2 &= 0.746x_1 - 0.619x_2 - 0.023x_3 + 0.079x_4 - 0.024x_5 \\ f_3 &= -0.475x_1 - 0.719x_2 + 0.438x_3 + 0.208x_4 + 0.163x_5 \\ f_4 &= 0.028x_1 + 0.133x_2 + 0.067x_3 + 0.817x_4 - 0.556x_5 \end{aligned} \tag{3}$$

The results show that the amount of Carbon Sequestration can be greatly influenced by climate and the trees own features. Besides, the average life spans defined by local government influence Carbon Sequestration little. This is critical for us to purpose and improve corresponding forest management plans.

2.3. Predict carbon sequestration and propose management plans

We develop a prediction model based on BP Neural Network that can be used to analyze and predict the intake of forests and it predicts. We can also identify an efficient forest management plan on Carbon Sequestration with the time passing by.

By using the only neuron on the output side and five evaluation indicators of Zhangjiajie forest as the neurons on the input side, we connect a BP Neural Network. The output is the total CO_2 intake of the forest and its products. Therefore, there is 1 neuron in this layer. For the number of neurons in the hidden layer, we take the middle value between the number of them in the input layer and the output layer. Here we set this number to 4.

The total process of BP neural network can be seen in figure 3.

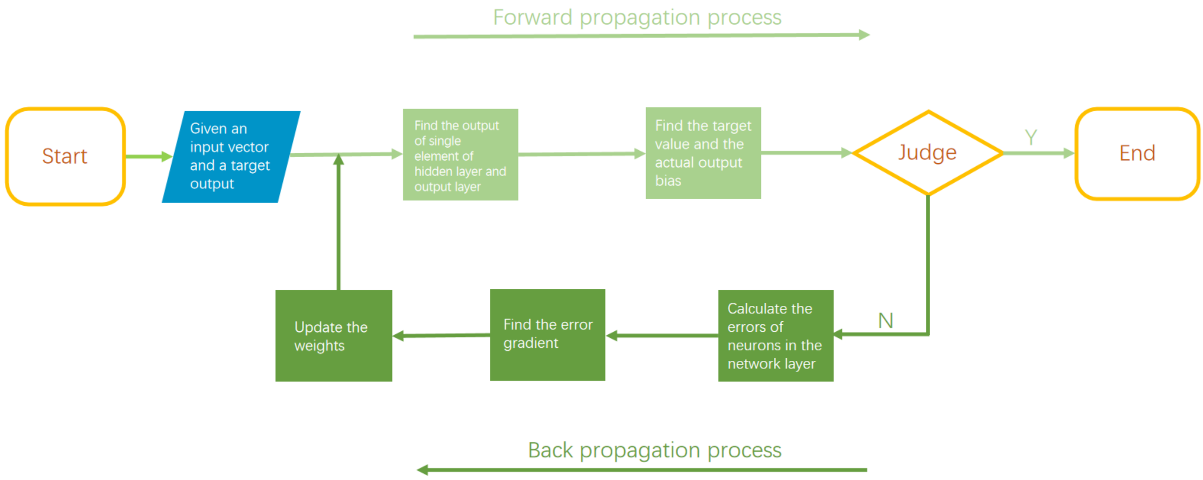


Figure 3. Total process of BP neural network

Using the Data of indicators as basses predict the evaluation indicators, i.e., carbon dioxide intake in the recent three years. The results are shown in figure 4:

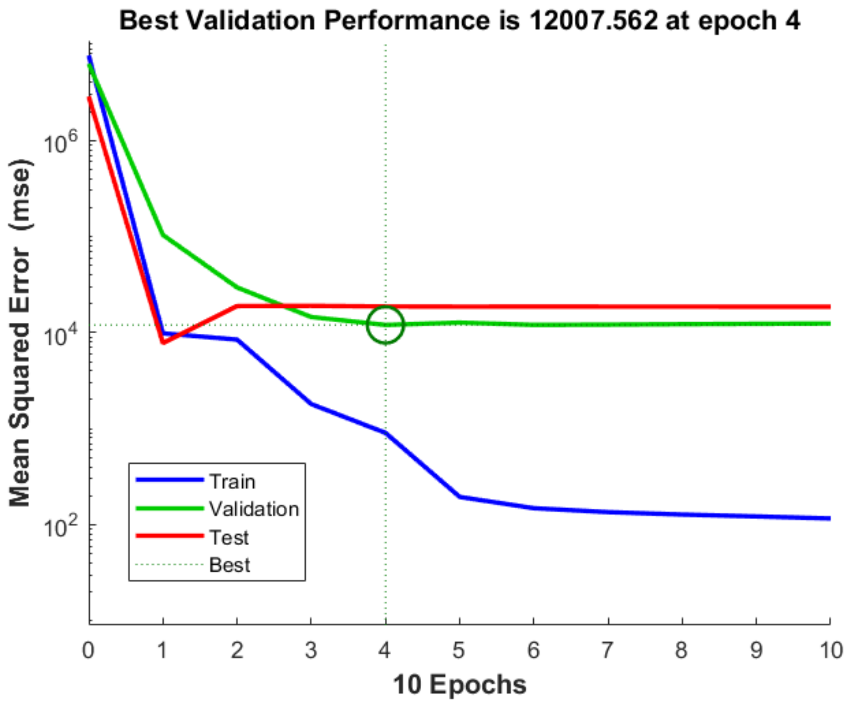


Figure 4. Neural network training diagram

Researching Zhangjiajie forest, based on PCA and BP neural network, our following plan is purposed:

➢Select superior-quality trees, may consider tree species with wide diameter to satisfy Zhangjiajie forest management plans.

➢Regulate artificial watering and water conservation

➢Strengthen managing to prepare for dominant events caused by people, such as fire.

➢Keep the stability of forest cover rate to make sure its coverage can increase.

3. Establish TOPSIS evaluation model

3.1. Introduction to the method

TOPSIS is also called the superiority and inferiority solution distance method. It is used for comprehensive comparison and selection of multiple indicators. Besides, it does not need to find the features and correlation of variables, so it can be wide used to all kinds of comprehensive quantitative problems including overall ones.

Entropy is an accurate measure of uncertainty, which is inversely proportional to uncertainty. It can decide the weights of variables.

Therefore, we use the TOPSIS model based on the entropy weight method to evaluate the EFB system. The steps are listed below:

First, turn the variables into a weighted standard matrix:

$$A=\left[Z_{ij}\right]_{m\times n} \tag{4}$$

the lines are indicator types and columns are individuals, their maximum and minimum are

$$\begin{aligned} Z^{+} &= \left(\max_{j=1,2,\cdots,n}\left\{z_{ij}\right\}\right)=\left(z_1^{+},z_2^{+},\cdots,z_m^{+}\right) \\ Z^{-} &= \left(\min_{j=1,2,\cdots,n}\left\{z_{ij}\right\}\right)=\left(z_1^{-},z_2^{-},\cdots,z_m^{-}\right) \end{aligned} \tag{5}$$

If define

$$d_j=1+\frac{1}{\ln n}\sum_{i=1}^{m}p_{ij}\ln p_{ij} \tag{6}$$

Weights are $\omega_1,\omega_2,\cdots,\omega_j$, then

$$\omega_j=\frac{d_j}{\sum_{j=1}^{n}d_j} \tag{7}$$

And define

$$\begin{aligned} D_i^{+} &= \sqrt{\sum_{j=1}^{n}\omega_j\left(z_{ij}-z_{ij}^{+}\right)^2} \\ D_i^{-} &= \sqrt{\sum_{j=1}^{n}\omega_j\left(z_{ij}-z_{ij}^{-}\right)^2} \end{aligned} \tag{8}$$

The evaluation object scored as

$$S_i=\frac{D_i^{-}}{D_i^{+}+D_i^{-}} \tag{9}$$

3.2. Model building

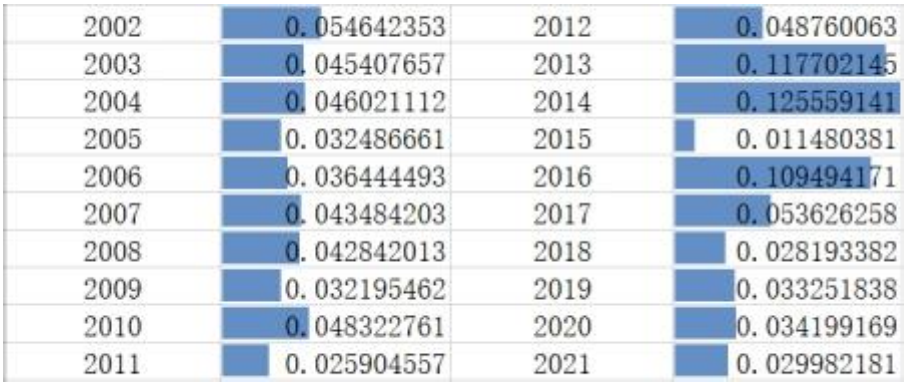
According to the present situation of global biosphere, the natural value and social benefits of forests, there must be a certain mutual effect between carbon sequestration and social benefits. If people just persuade for high-quantity carbon sequestration, the development of society will probably be impeded. Therefore, we put forward and improve the model on the original EFB model, adding three social indicators: forest cover ratio, the diversity of plants(species), wood harvest ($\times 10^4 m^3$). For the reason of that, we use 8 indicators at 3 levels to construct an improved decision model to evaluate and analyze the forest management plans in the recent 20 years. The results are shown in the table 3.

Table 3. Eight indicators in three latitudes

Goal	Dimension	Indicators
The evaluation score of forest management plan	Early factor (E)	Average diameter at breast height of trees (mm)
		Average growth rate of trees (m/a)
		Annual average temperature on the location (℃)
		Annual average rainfall on the location (mm)
	Mid-term feedback (F)	Forest cover rate Average life spans defined by local government (a)
	Late benefit (B)	The yield of wood harvesting ($\times 10^4 m^3$) Plant diversity

To begin with, we apply the entropy weight method to calculate the weight of all indicators. Then, with the TOPSIS model, we systematically evaluate the decision model built by the EFB model. With to the TOPSIS model, we will gain evaluation scores for management plans in different years.

The scores can be seen in the figure 5:



2002	0.054642353	2012	0.048760063
2003	0.045407657	2013	0.117702145
2004	0.046021112	2014	0.125559141
2005	0.032486661	2015	0.011480381
2006	0.036444493	2016	0.109494171
2007	0.043484203	2017	0.053626258
2008	0.042842013	2018	0.028193382
2009	0.032195462	2019	0.033251838
2010	0.048322761	2020	0.034199169
2011	0.025904557	2021	0.029982181

Figure 5. Last 20 years of management plan grading

Based on eight indicators in three dimensions of the EFB decision model, our evaluation results plan present management plans for forest managers, in order to make sure the biggest benefits from the expected quantity of carbon sequestration to wood harvest, and to late benefit on social level.

Besides, we reckon that there may be some conditions for permitting trees not to be cut down, maximizing carbon sequestration.However.it does not consider the social angle from the view of forest managers, resulting the endless expansion of forests. In conclusion, forests will lose the balance between carbon sequestration and social benefits, meaning the loss of value.

Considering the evaluation scores of management plans in the past 20 years, we speculate that among all forest management plans, there are a definite transition point. In carbon sequestration mode, However, we believe that the transition point is not the optimal solution, for the reason that its condition is both controllable factors such as tree species characteristics and uncontrollable factors such as location-climate characteristics get to the ideal critical value, while short of the universality of management plans to enhance the excess. Therefore, we believe that the transition point will be between ideal plans and plans need to be improved, then it can have transition influence on the gradually progressing forest management plans.

To prove the existence of transition point and calculate it, we apply a cluster analysis of eight significant indicators. By divide each evaluate objects(year) into a class and calculate the distance between two of them. The two classes with the nearest distance are grouped. Then repeat until all objects are grouped. We use SPSS to calculate and get the spectral graph of clusters, as shown in Figure 6:

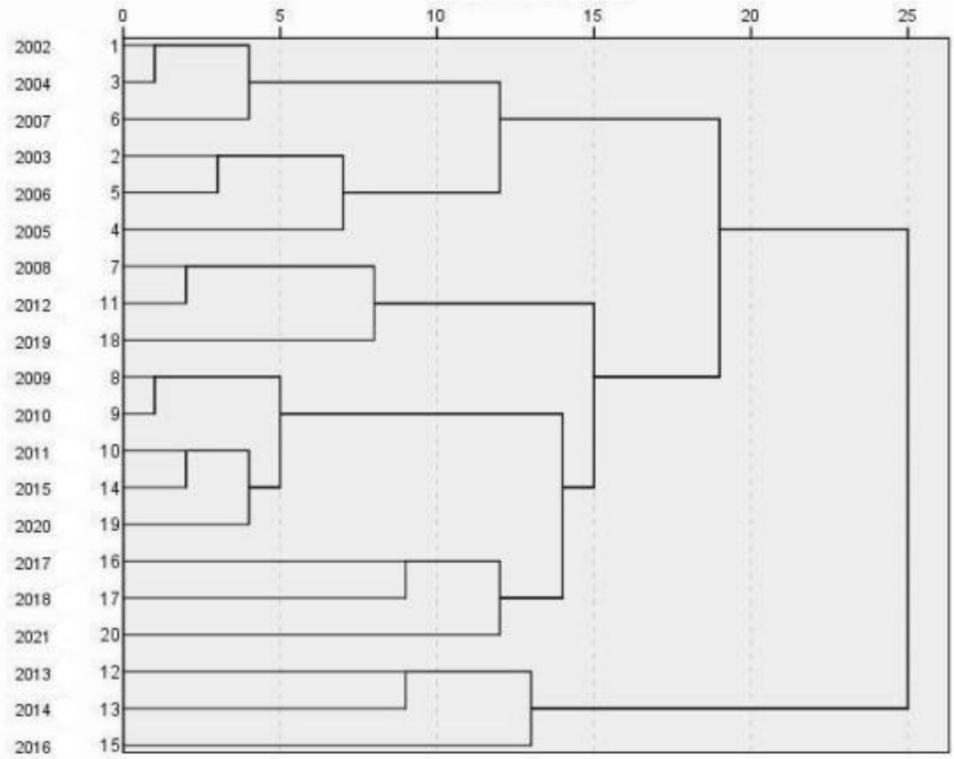


Figure 6. Cluster analysis pedigree diagram

We reckon that the transition exists between the two groups in the final step before completing. From the spectral graph,2013,2014,2016 are more ideal, while management plans in other years need to be promoted. The boundary years are 2002, 2016.Through EFB decision model, the score of the transition point is 0.0548.

After calculating the transition point, we discovered that it is policy that influenced the wood harvesting quantity in 2013,2014,2016, which were controllable factors. We then propose that forest managers should increase the quantity of wood cut, balancing carbon sequestration and social benefits, in order to increase the greenhouse intake of Zhangjiajie.

In conclusion, the evaluation valve is near 2002

4. Conclusions

We established a primary evaluation model with three stages (early, middle and last stage) and five indicators. We used this model to calculate the cumulative contribution rate. And we analyzed the main factors of carbon dioxide uptake with the management plans of Zhangjiajie forests. Besides, we predict the carbon dioxide uptake of forest and its products, providing forest managers with the most effective carbon sequestration management plans.

Considering the various indicators of social scope, we used the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) based on the Entropy-weight Method to improve the model of evaluation and decision-making, and obtained the score of the Zhangjiajie Forest Management Plan in the past 20 years, finding that appropriately increasing the wood harvesting can develop the value of the forest better. We used Cluster Analysis to identify the transition points between the plan of Zhangjiajie Forest's management. Then we calculated the corresponding scores. Therefore, this article provides some reasonable suggestions for Zhangjiajie's new management plan.

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