Simulation and Management Research of Forest Carbon Sequestration

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Abstract: With the rapid development of the petroleum industry, the total amount of carbon dioxide emissions continues to increase. Forests are the main way to absorb carbon dioxide, while the absorption efficiency of mature trees is gradually decreasing. This study established a queuing theory model, which is based on the analytic hierarchy process, determines the index weight of the factors and the gray correlation degree analysis method to establish a decision matrix. Through the decision matrix, the best way to use the forest can be obtained, and the forest resources can be used to the maximum extent, reduce carbon dioxide concentration and improve self-economy. Carbon sequestration models use forests and their derivatives to minimize carbon dioxide concentrations and increase the economic benefits of forests.

Keywords: Queuing Theory Model; Simulation; Analytic Hierarchy Process; Optimization Decision Model

1. Introduction

With the continuous improvement of the speed of social development, the continuous improvement of countries and the continuous acceleration of industrial advancement, along with the rapid development, many problems are gradually exposed to people's vision: natural disasters such as acid rain, drought, mudslides and earthquakes are increasing.[1, 2] Although the advancement of science and technology can increase the average life expectancy of human beings, the resources available to human beings are always limited, and the increasing population has caused environmental pollution and resource scarcity to a level that cannot be ignored. [3]
carbon dioxide emitted into the atmosphere by various activities in the world every year is the direct cause of the greenhouse effect , and at the same time indirectly causes a large number of diseases, causing serious harm to human health. [4] Assume that at current consumption levels and lifestyles, all major industrial fuels on Earth will be exhausted by the year 2500. According to the "BP World Energy Statistical Yearbook" as of 2020, the global primary energy consumption has increased by 1.3%, and China is the largest driver of primary energy growth, accounting for more than three-quarters of the global net growth, as shown in Figure 1 :

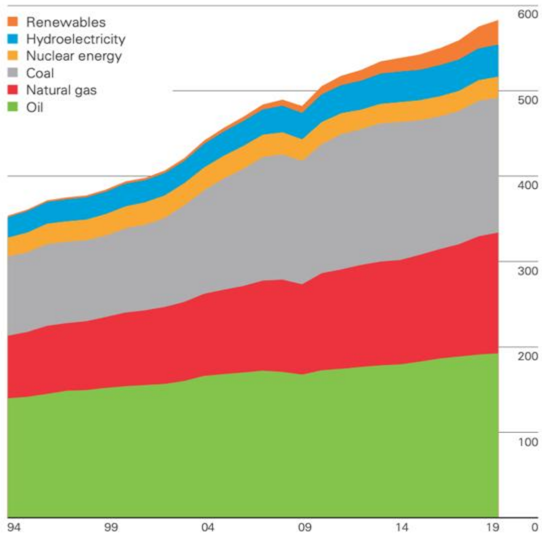


Figure 1. Global Energy Consumption (unit: million tons of oil equivalent)

Total global carbon dioxide emissions increased from 31,629,955 kilotons in 2009 to 35,753,306 kilotons in 2016. From all aspects of the world, the issue of greenhouse gases has reached a time when no country can escape and solve it. [5] Therefore, this study developed a carbon sequestration model to determine how much CO2 could be stored by forests and their products over time . At the same time, the best forest management plan is given.

2. Model Construction and Solution

2.1 Establishment and Solution of Carbon Sequestration Model

For the carbon sequestration of components in this study, according to the relevant literature, the carbon sequestration or carbon neutralization of plants is carried out through the photosynthesis of leaves, and chlorophyll is one of the important indicators affecting photosynthesis. The efficiency of chlorophyll in handling carbon dioxide is also affected by the gas concentration. If the gas concentration is too high, the efficiency will slow down, and if the gas concentration is too low, the efficiency will be excessive. Therefore, the queuing theory model is selected for simulation research. The queuing theory mainly includes two aspects, one is the queuing service desk providing the service, and the other is the customers waiting in the queuing to receive the service. Queuing theory, which emerged from the study of this phenomenon, has been widely used in other fields such as architecture, computer networks and transportation in recent years. [6] The most common single server queuing system is shown in Figure 2 below .

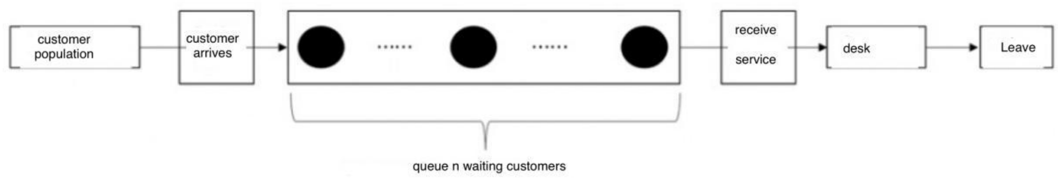


Figure 2. Schematic Diagram of a Single Service Desk System

In figure 2, the M/M/1/N/ ∞model ∞indicates that the number of customers is infinite, the customer arrival rate α, the maximum number of queues in a single service desk is N, and each customer arrival event is independent of each other and does not affect each other. The service time for each customer is also independent of each other, the service rate of the service desk β, and the service time obey the negative exponential distribution. [7]

2.1.1 M/M/1/N/∞ Cohort Model for Carbon sequestration

According to the above-mentioned M/M/1/N/∞ queuing model, it can be concluded that there is a relationship between the customer and the service desk, which is the relationship between processing and being processed. The number of customers and the time for customers to be processed can change with the research content. What is needed in the concept of carbon sequestration in China is this kind of balance relationship between dealing with carbon emissions and achieving carbon neutrality. Based on this, this study attempts to apply the M/M/1/N/ ∞ queuing model to the study of carbon sequestration in forests. Combined with the concept of carbon sequestration, carbon sequestration in the whole life cycle of the forest is equivalent to the absorption and neutralization of carbon emissions, and the capture of gas molecules containing carbon dioxide is the service provided by the service desk. The service desk corresponds to the plan for neutralizing carbon dioxide. The scheme is equipment instrument or biological means. [8]

Table 1: Comparison Table before and after the Change of M /M/1/N/ ∞Queuing Model Parameters

original parameters	parameters after carbonization
customer	carbon dioxide
Arrival rate	capture rate
service rate	Efficient

Note: The unit corresponding to carbon dioxide in the above table is kg

Compared with Table 1 above, the capture rate of carbon dioxide gas, the αmaximum amount of gas that can be stored at one time in the process of sequestering carbon dioxide is N, the efficiency of this scheme is β, and obeys the following negative exponential distribution.

$$f(x;\lambda) = \begin{cases} \lambda e^{-\lambda x}, x \geq 0 \\ 0, x < 0 \end{cases} \quad (1)$$

Combined with the concept of carbon neutrality, the queuing model under carbon sequestration is the M/M/1/N/C queuing model.

2.1.2 Establishment of M/M/1/N/C Queuing Model

Based on the relevant data of greenhouse gases in the actual forest, through reasonable programming, the moment when the first carbon dioxide gas molecule is captured is selected as the start moment of the system. Matrix is more systematic and convenient for data processing, so parameter events are established in matrix form. According to the characteristics of the M/M/1/N model, the carbon dioxide information table is established as shown in Table 2.

Table 2. Carbon Dioxide Information Table

matrix row	Parameter meaning
event(1,;)	capture time
event(2,;)	neutralization time
event(3,;)	waiting time
event(4,;)	Complete time
event(5,;)	punctuation

After the carbon dioxide information table is established, the model algorithm is as follows:

(1) Carbon dioxide information initialization

The capture time interval and neutralization time interval for each kilogram of carbon dioxide are determined according to the capture rate and efficiency. The captured time interval can be generated using the negative exponential function exprnd. The exprnd input parameters are not the capture rate and efficiency , but the average capture time interval $1/\alpha$ and the average neutralization time interval $1/\beta$.

Initialize the current carbon dioxide gas, the first captured carbon dioxide gas can be neutralized directly without waiting, and its completion time is equal to the sum of the neutralization time and the capture time.

(2) Capture and complete the simulation

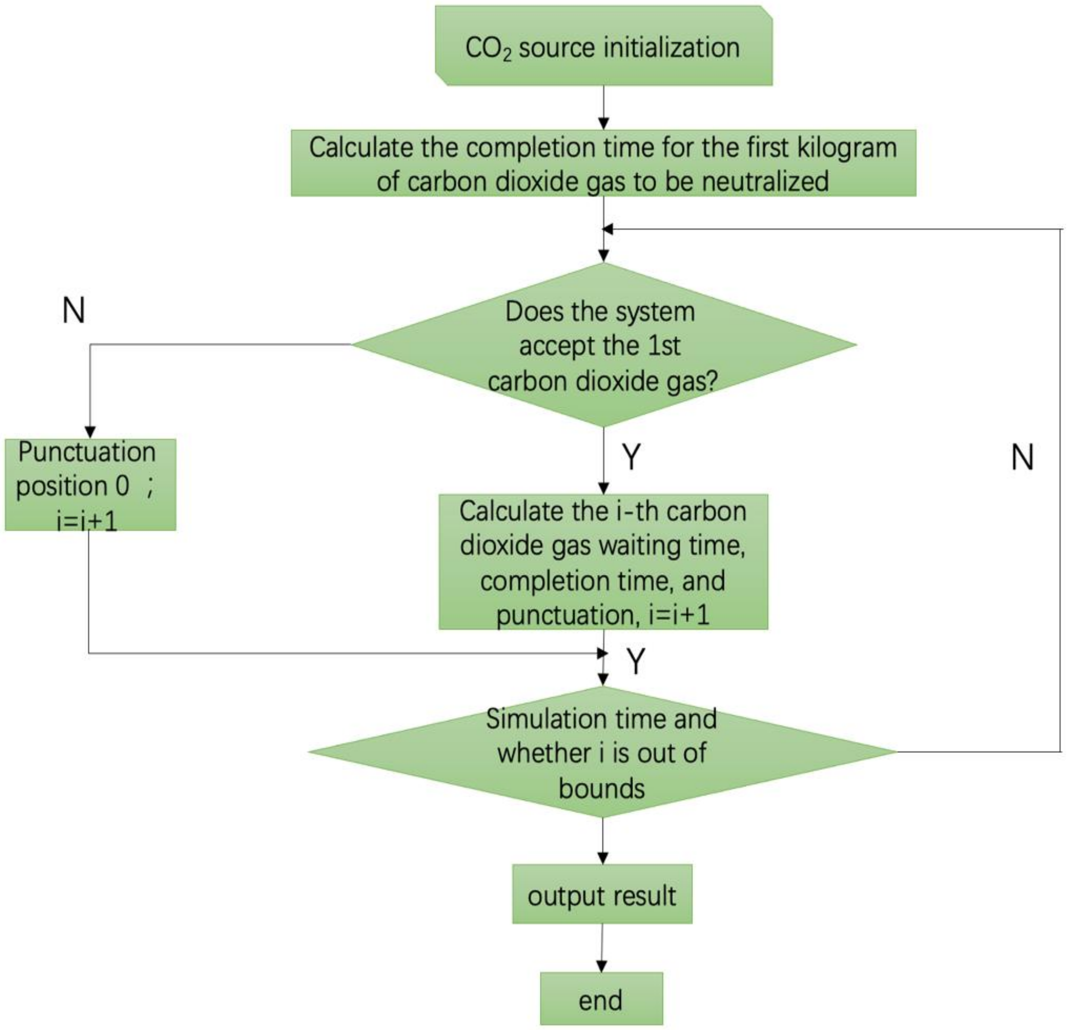


Figure 3. Schematic Diagram of the Simulation Process

When the current carbon dioxide gas is captured, it is determined whether to continue to store new carbon dioxide gas according to the existing carbon dioxide gas amount in the system. If it continues, the waiting time, completion time and punctuation position of the current carbon dioxide gas are determined according to the neutralization completion time of the previous carbon dioxide gas. If not continue, the punctuation position is 0. The specific flow chart of the simulation is shown in Figure 3 above. [9]

The neutralized carbon dioxide is completely converted to oxygen, as well as carbon sequestered in the plants. According to the Kelvin cycle formula, a portion of carbon dioxide can be converted into one-sixth of carbon sequestration materials.

$$6CO_2 + 12H_2O + Light \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O. \quad (2)$$

2.1.3 M/M/1/N/C Queuing Model Solution

This study randomly selected a forest in the world as an example, named Ziyun Forest Park. Ziyun Forest Park is in a temperate climate and has no fallen leaves all year round. The trees planted in the forest are all pagoda trees. The forest has a total of 200 Chinese locust trees, with an average tree height of 4m, covering an area of about 3,000 square meters. According to the literature search, the light and parameters of each stage of the life cycle of Sophora japonica are shown in table 3.

Table 3. Illumination and Parameters of each Stage of Sophora flavescens Life Cycle

tree age/a	Net photosynthetic rate/(g/d)	Intercellular carbon dioxide concentration/(g·mol -1 ·d)
2 0	$35.6 \pm 0.21a$	$1261.92 \pm 5a$
1 20	$18.04 \pm 0.23b$	$799.48 \pm 7.02b$
8 00	$16.9 \pm 0.35c$	$724.68 \pm 2.08c$

According to the relationship between different light sum parameters and tree age in each life cycle stage of Sophora chinensis in Table 3, the median value was used for calculation, and Matlab software was used for fitting, and the relationship curve between tree age, net light sum rate and intercellular carbon dioxide concentration was obtained as shown in figure 4.

Among them, the functional relationship between the age of the tree and the increase of the net light and rate curve with time is:

$$y_j = -0.0001x^2 + 0.0672x + 15.1992. \quad (3)$$

The functional relationship between the age of the tree and the increase of the intercellular carbon dioxide concentration curve with time is:

$$y_b = -0.0058x^2 + 4.1414x + 523.6923. \quad (4)$$

The concentration of carbon dioxide in the air is about 0.04%. The air volume of Ziyun Forest Park is calculated to be 12,000 cubic meters. According to the density of carbon dioxide, the average distribution of carbon dioxide in each country is 47.52g, so the capture rate is 47.52g. N is the intercellular carbon dioxide concentration. Select 20 time nodes in the life cycle of Sophora japonica for simulation, and the specific parameters are shown in Table 4 below.

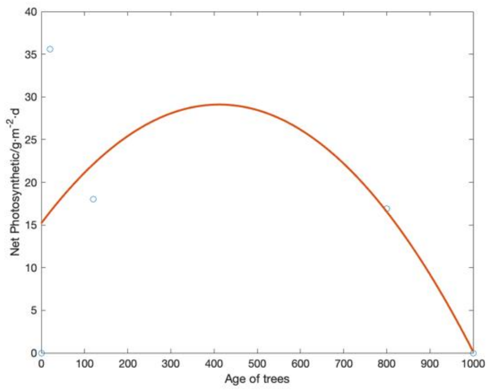


Figure 4. Relationship Between Tree Age and Net Speed of Light

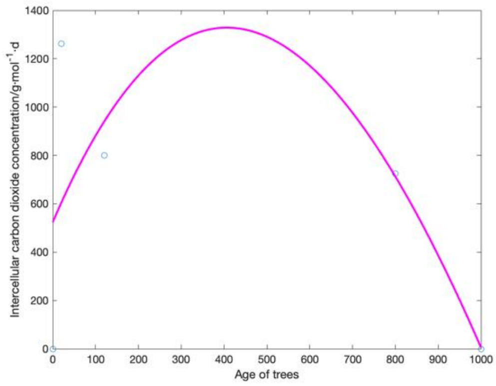


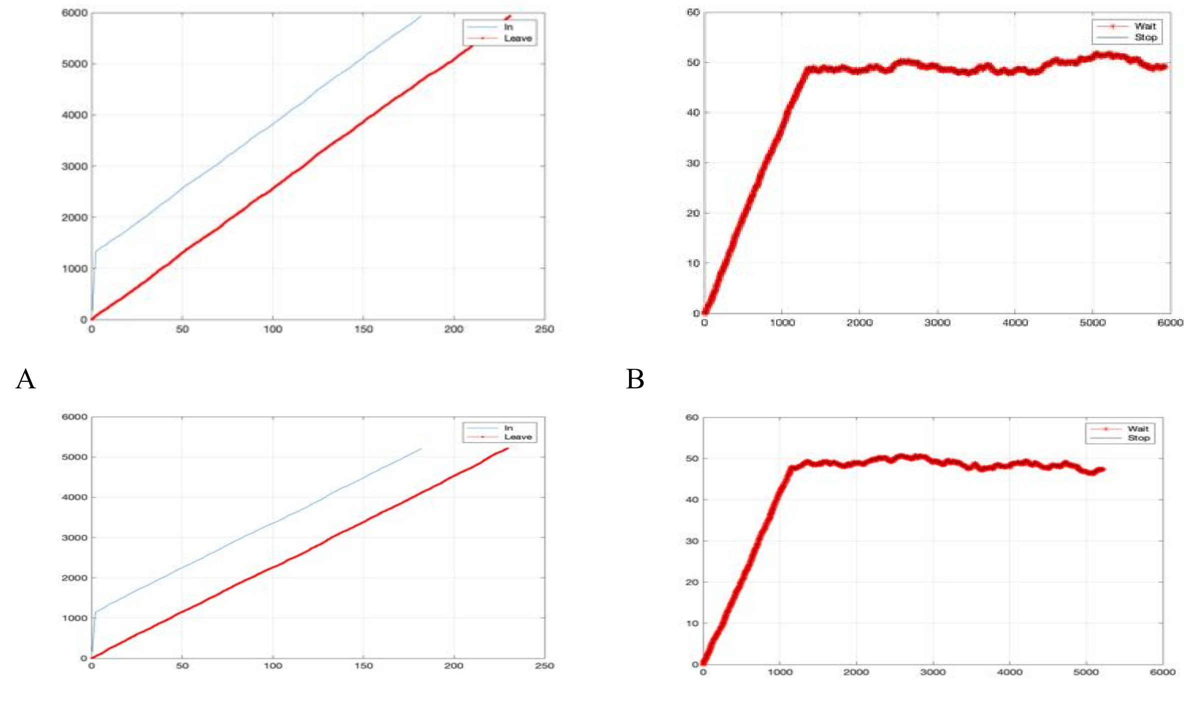
Figure 5. Relationship between Tree Age and Intercellular Carbon Dioxide Concentration

Table 4. Street Tree and Model Parameters

Sophora tree age/year	Neutralization rate/g/d	n	Capture rate/g/d	simulation time/d
1 0	15.86	564.5	5 70.24	1 82
56	18.69	740.4	5 70.24	1 82
103	21.09	890.7	5 70.24	1 82
150	23.04	1015.6	5 70.24	1 82
197	24.56	1115.	5 70.24	1 82

		1		
244	25.64	1189.1	5 70.24	1 82
291	26.28	1237.7	5 70.24	1 82
337	26.48	1260.8	5 70.24	1 82
384	26.25	1258.5	5 70.24	1 82
431	25.57	1230.	5 70.24	1 82
		7		
478	24.46	1177.5	5 70.24	1 82
525	22.9	1098.8	5 70.24	1 82
572	20.91	994.7	5 70.24	1 82

Substitute the data into the M/M/1/N/C queuing model for simulation, and the time chart of different tree ages.



A B C D

Figure 6. Neutralization and Departure Time Plots and Waiting and Dwell Time Curves for Trees of Different Ages

A Carbon dioxide neutralization departure time map of 384-year-old tree

B Waiting residence time of carbon dioxide at a tree age of 384 years

C The starting time map of carbon dioxide neutralization for 525-year-old trees

D Graph of CO2 waiting residence time for 525-year-old tree

In Figure 6, the neutralization and departure curve represents the carbon neutralization time and completion time of carbon dioxide gas. When the simulation time of the program ends, the corresponding ordinate on the departure curve is the last 1g of carbon dioxide sequestered in the year. [10] List the values of neutralized carbon dioxide corresponding to each year of the life cycle of the Chinese pagoda tree. According to Calvin's light and action formula, the proportion of carbon sequestered is one-sixth, and the simulation calculation time is half a year, so the final result Both are multiplied by 2. As shown in table 5. According to Table 4 and Figure 7, we can get the amount of carbon dioxide that Ziyun Forest can neutralize and sequester over time. When the trees in Ziyun Forest grow to about 337 years old, the amount of carbon dioxide neutralized by trees reaches the maximum, and the amount of carbon sequestration also reaches the maximum, and the ability of trees to sequester carbon dioxide will decline as time goes by. [11] Therefore, at this age stage, appropriate harvesting can be carried out to ensure that trees in other growth cycles have sufficient nutrients, and at the same time, a large amount of sequestered carbon is stored in forest products, which plays the best role in regulating the protection of the environment.

Table 5. Ziyun Forest Annual Carbon Sink

tree age/year	Annual carbon content/kg	Annual carbon fixation/kg	Annual carbon sequestration of the whole forest/kg
10	6.84	1.14	228
56	8.04	1.34	268
103	9.22	1.53	306
150	10.18	1.69	338
197	11.20	1.86	372
244	12.02	2.00	400
291	12.04	2.00	400
337	12.20	2.03	406
384	11.96	1.99	398
431	11.70	1.95	390
478	11.40	1.90	380
525	10.50	1.75	350
572	9.40	1.56	312

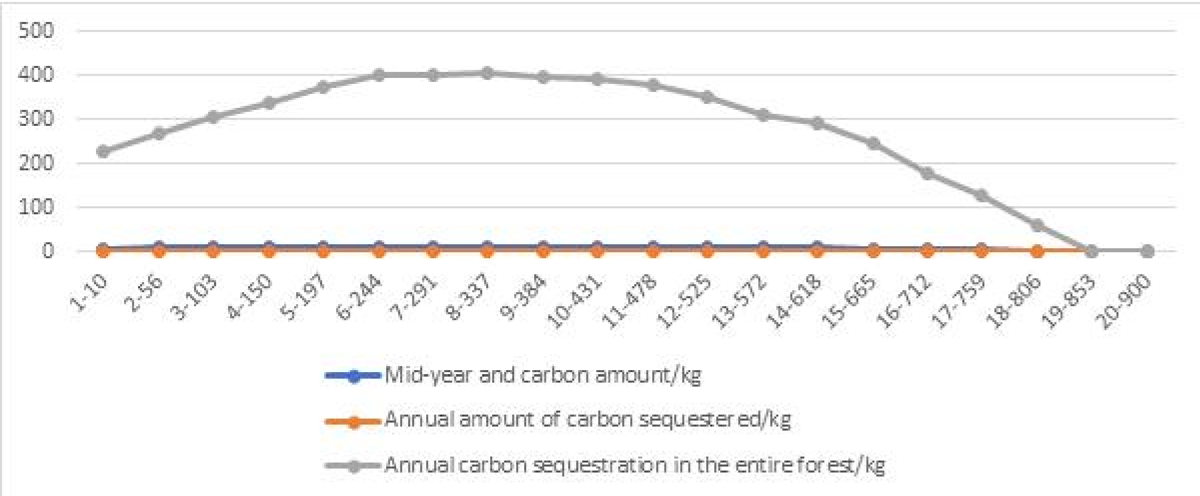


Figure 7. Line Chart of Annual Carbon Sequestration in Ziyun Forest

2.2 Establishment and Solution of Carbon Sequestration Decision -Making Model

Based on the characteristics of forest management evaluation, this study conducts in-depth research on decision-making theory and methods from a practical point of view. It uses the analytic hierarchy process to determine the factor index weights and the gray relational degree method to establish a decision-making matrix to achieve a decision-making model for forest management.

2.2.1 Establishment of Project Evaluation Index Matrix

Forest management planning has different evaluation indicators at different angles and levels, and generally presents a multi-objective, multi-level structure, called the evaluation target tree.

Assuming that the domain of decision-making $U = \{u_1, u_2, ..., u_m\}$ is a collection of management plans $V = \{v_1, v_2, ..., v_n\}$ and a collection of evaluation indicators, the element pairs constitute (u_i, v_j) the conditional product scene set of the Cartesian product of n evaluation indicators. The element pair is expressed (u_i, v_j) as f_{ij}, and then m×n f_{ij} constitutes the evaluation index matrix F =(f_{ij})m×n of the design scheme.

2.2.2 Standardization of Evaluation Indicators

Evaluation indicators can generally be divided into the following four types: extremely large (the bigger the better), extremely small (the smaller the better), fixed index type (the closer to a fixed value, the better) and interval type (to fall within a certain value). A fixed interval is preferable). In order to eliminate the influence of different indicators and different dimensions, different normalization methods are adopted for different types of indicators. Normalize it to a very large index belonging to the [0, 1] interval. [12]

For very large metrics:

$$f_{ij}^{'} = \frac{f_{ij}}{f_{0j}} = \frac{f_{ij}}{m_k axf_{kj}} \quad (5)$$

where is f_{0j} the optimal value of m policies with respect to index v j

For very small metrics:

$$f'_{ij} = \frac{f_{0j}}{f_{ij}} = \frac{m_k inf_{ij}}{f_{ij}} \quad (6)$$

For fixed-index indicators:

$$f'_{ij} = \begin{cases} 1 & f_{ij} = f_j^* \\ 1 - \frac{|f_{ij} - f_j^*|}{m_k ax|f_{kj} - f_j^*|} & f_{ij} \neq f_j^* \end{cases} \quad (7)$$

For interval indicators:

$$f'_{ij} = \begin{cases} 1 - \frac{f_{jmin} - f_{ij}}{max\{f_{jmin} -- m_k inf_{kj}, m_k axf_{kj} - f_{jmax}\}} & f_{ij} < f_{jmax} \\ 1 & f_{ij} \in [f_{jmin}, f_{jmax}] \\ 1 - \frac{f_{ij} - f_{jmax}}{max\{f_{jmin} - m_k inf_{kj}, m_k axf_{kj} - f_{jmax}\}} & f_{ij} > f_{jmax} \end{cases} \quad (8)$$

2.2.3 Establishment of Decision-making Models

According to the theory of gray relational decision-making, the correlation degree between the index vector of the evaluation plan and the index vector of the relative optimal plan is used as the criterion for evaluating the pros and cons of the plan.

Assuming that the relative optimal scheme is u 0 =(f 01 , f 02 ,..., f 0n), then after normalization processing, u 0 =(1,1,...,1), the evaluation of design scheme u i The gray correlation degree between the index v j and the evaluation index v_j relative to the optimal scheme u_0.

$$\Upsilon_{ij} = \frac{\xi_{m_i axm_j ax}|f_{ij} - 1|}{|f_{ij} - 1| + \xi_{m_i axm_j ax}|f_{ij} - 1|} \quad (9)$$

The steps of AHP to determine the weight of evaluation indicators are as follows:

(1) For specific decision-making problems, establish an evaluation target tree.

(2) Construct the judgment matrix. In order to reduce the subjectivity of a single expert, the judgment matrix of multiple experts can be determined using the Delphi method.

(3) Consistency check of single-level sorting and judgment matrix.

(4) Determine the weight of the evaluation index. The weight of each evaluation indicator relative to the overall goal.

$$w_i = l_i \prod_{j=1}^{k} a_{ij} \qquad i = 1,2,\cdots,n \quad (10)$$

From the above analysis, it can be seen that the m×n gray relational degree matrix that constitutes the multi-objective decision-making of the product plan is .

$$\gamma = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1n} \\ \gamma_{21} & \gamma_{22} & \cdots & \gamma_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \gamma_{m1} & \gamma_{m2} & \cdots & \gamma_{mn} \end{bmatrix} = (\gamma_{ij})_{m\times n} \quad (11)$$

The weight vector W = (w 1 , w2 , ..., wn) of n evaluation indicators relative to the overall goal, then the weighted correlation γ i of each design scheme ui and the relative optimal scheme u0 constitutes a correlation vector γ '

$$\gamma' = \gamma W = (\gamma_1, \gamma_2, \cdots, \gamma_i, \cdots, \gamma_m) \quad (12)$$

According to the physical meaning of formula (8), the larger γi is, the closer the product design scheme ui is to the relatively optimal scheme u0. Therefore, when γi = max(γ1 , γ2 , ... , γm), the scheme ui is the optimal scheme among the design schemes. [13]

2.2.4 Solve a Decision Model

The purpose of the optimal use of forests is to expand forest resources, increase forest coverage, promote the development of forestry production and produce the most products with the least consumption, continuously meet the growing needs of society, and obtain the best economic, ecological and social benefits. (Scientific and reasonable forest management plans can adapt to regional development, unify environmental protection and improve people's living standards, and coordinate the interests of all parties.)

According to the social, economic, and ecological benefits of forests, comprehensively consider the relevant requirements of the national and regional socio-economic systems on forestry economy, society, and ecology, and on the basis of referring to existing research results, systematically analyze the optimization of the plan and establish a hierarchical analysis model, as shown in Figure 8.

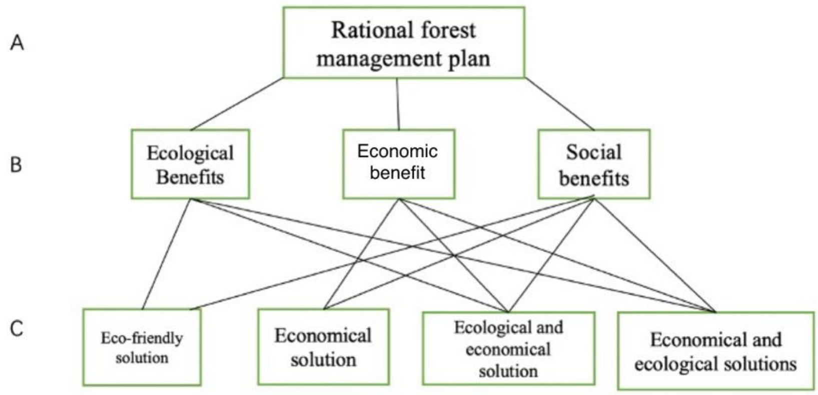


Figure 8. Hierarchical Analysis Logic

Select Ziyun Forest Park for hierarchical sorting and consistency check . According to the principle of "very important, important, general, unimportant, and very unimportant", a_{ij} the scores of "9, 8, 7, ..., 1" and their inverses 1, 1/2, ..., 1/9 are assigned respectively Carry out quantization and construct a judgment matrix A. From this the agreement ratio was calculated $C_R = {C_I}/{R_I}$. Among them: R_I it can be obtained from the random consistency index table. When the consistency ratio is high, $C_R < 0.1$ the judgment matrix is considered to have satisfactory consistency, and the importance judgment of each evaluation index is reliable. [14]

By inviting the leaders of the forestry bureau, experts from the management department, and forestry scientific and technological personnel to compare and analyze each pre-selected plan and assign points, the comprehensive results form a judgment matrix, as shown in Tables 6 to 10.

It can be seen from the data in Table 6 that the largest characteristic root is 0.6369, and the normalized characteristic vector is: W= (ω_1 , ω_2, ω_3, $\ldots, \omega_n$) = (0.2582, 0.1047, 0.6369), $C_R = 0.03319 < 0.1$. It can be seen that the results have a satisfactory consistency. [15]

Table 6. Judgment Matrix AB

one	Ecological BenefitsB_1	economic benefitsB_2	social benefitsB_3	Feature vector
Ecological BenefitsB_1	1	3	1/3	0.2582
economic benefitsB_2	1/3	1	1/5	0.1047
social benefitsB_3	3	5	1	0.6369

Table 7. Judgment Matrix B_1-C

B_1	ecological type	Ecological Economy	Environmentally friendly and economical	Feature vector
ecological type	1	3	7	0.6694
Ecological Economy	1/3	1	3	0.2426
Environmentally friendly and economical	1/7	1/3	1	0.0876

Table 8. Judgment Matrix B_2-C

B_2	economy	Ecological Economy	Environmentally friendly and economical	Feature vector
economy	1	5	4	0.6869
Ecological Economy	1/5	1	2	0.1864
Environmentally friendly and economical	1/4	1/2	1	0.1265

Table 9. Judgment Matrix B_3-C

B_3	ecological type	economy	Ecological Economy	Environmentally friendly and economical	Feature vector
ecological type	1	3	1/3	1/5	0.1 178
economy	1/3	1	1/5	1/7	0.0550
Ecological Economy	3	5	1	1/3	0.2634
Environmentally friendly and economical	5	7	3	1	0.5638

Table 10. Hierarchical Total Ranking List

grade	Ecological BenefitsB_1	economic benefitsB_1	social benefitsB_1	Tiered Total Rank Weight
	0.2582	0.1047	0.6369	
Environmentally friendly and economical	0.0876	0.1265	0.5638	0.3949
Ecological Economy	0.2426	0.1864	0.2634	0.2499
ecological type	0.6694	0	0.1178	0.2478
economy	0	0.6869	0.0550	0.1069

In the selection of various factor indicators and the determination of values, among the four management schemes, the weight of the economic ecological type is the largest, and it is the most suitable for forest management. [16] From the consistency test results, it can be seen that among the four business plans, economic and ecological considerations have the largest weight of 0.3949, which is the most suitable among all plans.

2.3 Application of Decision-Making Problems

According to the establishment and solution process of the model, it is applied to Ziyun Forest, and the carbon sequestration model is simulated and solved as follows:

The best management plan for Ziyun Forest is a development model that takes into account both economy and ecology. This decision is more in line with the needs of managers. For the ten-year bumper harvest in the forest, through the above research, combined with the actual situation, during the 10-year transitional period of the Ziyun Forest, infrastructure should be set up around the forest to attract tourists. Through economic development, forests can go faster after a 10-year transition period. Develop carbon sequestration capacity.

3. Conclusion

This paper finds that the CO_2 fixation efficiency of trees is not a constant rate, and when the trees enter the mature stage, the rate of CO_2 fixation will decrease with the increase of tree age. Therefore, timely felling of trees will not only have a better carbon dioxide fixation effect in the area, but also help to promote the economic development of the area. As the tree grows, the carbon dioxide absorbed in the body is converted into organic carbon, making it impossible for this carbon dioxide to escape. The products produced by felling trees contain these substances, which prevent carbon dioxide from escaping. These products can also be sold externally, generating certain economic benefits. At the same time the replanted trees absorb carbon dioxide again.

According to different views on forests, this paper roughly divides forest management into four types: ecological type (only protecting trees without cutting down), economical type (regardless of whether trees have reached the maximum value of fixed carbon) carbon dioxide, and not only considering biodiversity nature, considering the economic benefits brought by trees), ecological economy (while paying attention to ecology, the economic benefits brought by forests should also be considered), economy and ecology (more emphasis on economic development than ecology), through consultation with forestry bureau leaders, management Departmental experts and forestry scientific and technical personnel evaluate the four situations to see which one is most suitable for forest management. In the end, it was found that a scheme that pays equal attention to economy and ecology is more suitable for forest management. This shows again that not cutting down any trees is not the best idea. On the contrary, the coexistence of economy and environmental protection, the mutual development of both is the best choice.

In forest management, it is better to maximize the value of the forest than to leave it intact, and if trees are not cut down, the forest itself is affected. Cutting down trees will also improve land use efficiency and provide a lot of convenience for our human life. Therefore, it is too absolute not to cut down trees. We should take appropriate actions to cut down old and diseased trees and turn them into economic benefits instead of letting them rot in vain.

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