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Green GDP Accounting and Green Economic Efficiency Analysis in Yunnan Province under the Double Carbon Background: Based on the Three-Stage DEA-Malmquist Model

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ABSTRACT

In the efforts to practice the dual carbon national strategic objectives under the premise, this paper takes Yunnan Province as the research object, firstly constructed the green GDP evaluation index system, on this basis, the use of entropy method to calculate the green GDP value and ECI index of Yunnan Province, the development of Yunnan Province on the economy and resources and environment between each other was briefly studied; then through the above data to further select the green economic efficiency input-output index application of three-stage DEA-Malmquist model of green total factor productivity in Yunnan Province to calculate and analyze, obtain the five-year green economic efficiency level of Yunnan Province; finally through a large number of data analysis of technical progress index is the most important factor affecting the green economic efficiency of Yunnan Province, and give appropriate countermeasures and suggestions.

KEYWORDS

Green GDP; Green economic efficiency; DEA-Malmquist model.

1. RESEARCH BACKGROUND

Dual carbon, namely carbon peak and carbon neutrality, is abbreviated as carbon peak and carbon neutrality. In the 2022 NPC and CPPCC, the Government Work Report pointed out that the work of carbon peak carbon neutrality should be promoted in an orderly manner and the carbon peak action plan should be implemented.Yunnan has obvious regional characteristics, rich green energy resources and superior development conditions. In the context of promoting the "Belt and Road" and the "dual carbon" goals, it is particularly important to study the green economy and sustainable development ability of Yunnan.In the 2021 China Green and Low-carbon City Index TOP50 report released by the Innovation Investment Special Committee of China Investment Association in May this year, we see that Kunming, the capital of Yunnan Province, ranks the 10th in the comprehensive ranking, and the high score of 80.1 in the green and low-carbon index exceeds the three major cities of Chengdu, Chongqing and Guiyang, ranking the first in the southwest region[1]. It can be seen that Yunnan has given full play to its natural advantages in balancing economic development and green and low-carbon, and has achieved remarkable results.Relying on the national dual carbon strategy, the study of green economic efficiency and total factor productivity analysis in Yunnan Province is conducive to the comprehensive construction of the green economic industry system with Yunnan characteristics, the optimization of Yunnan's economic structure, the improvement of green economic development efficiency, the acceleration of the construction of a clean, low-carbon, safe and efficient energy system, and the effective boost to the realization of the national carbon peak carbon neutrality goal [2].

2. GREEN GDP ACCOUNTING AND ITS EVALUATION MODEL CONSTRUCTION

2.1. Connotation and Accounting Basis of Green GDP

The so-called green GDP refers to the accounting of green gross domestic product[3]. In the past, when it comes to green GDP, it was considered from environmental factors, more precisely, it is the problem of negative environmental effects caused by external diseconomies. In recent years, green GDP has also taken into account resource consumption, and some scholars have also taken into account human factors. Specifically, green GDP refers to the Gross Domestic Product (GDP) after deducting resource and environmental costs, which quantifies the economic losses caused by factors such as resource consumption and environmental pollution in the process of economic development. By subtracting these losses from traditional GDP, the value of green GDP can be obtained.

This article adopts the entropy method to construct an evaluation index system that covers two major aspects: environmental pollution and natural resources, and includes 12 basic indicators. It attempts to incorporate environmental factors and natural resources into the economic accounting system and calculate the Environmental Comprehensive Index (ECI) that reflects the relative quality of the environment in Yunnan Province[4]. The larger the ECI, the lower the resource and environmental cost of economic development; The smaller the ECI, the greater the cost of resources and environment. Using this index to adjust traditional GDP, multiplying ECI with traditional GDP yields green GDP. This accounting method is based on the original national economic accounting system and adjusts traditional GDP using the environmental comprehensive index. It does not damage the original accounting system and comprehensively incorporates resources and environmental factors. It has strong operability and important practical significance.

2.2. Construction of Green GDP Evaluation Model

The construction of the indicator system must conform to the characteristics of the research area. Given that Yunnan Province is rich in resources, it is not only an important coal resource base in the southwest region, but also an important ecological resource base in China. Due to the implementation of the Western Development Strategy, Yunnan Province has seized development opportunities and achieved rapid industrial development, with green energy becoming the largest pillar industry. Summarize the methods for resources and environment in previous research results, and construct an indicator system based on the development characteristics and statistical data of Yunnan Province. Among them, environmental pollution mainly refers to the negative externalities introduced into the environment during the industrialization process in Yunnan Province, including gas pollution and water pollution; Natural resources mainly include the consumption of coal, oil, and natural gas[5].

As shown in Table 1.

2.3. Accounting and ECI (Environmental Comprehensive Index) Analysis of Green GDP in Yunnan Province

This article selects Yunnan Province as the empirical research object, because Yunnan Province, as a resource rich province in China, not only has a large quantity of resources, but also a variety of types. Moreover, Yunnan's economic development belongs to underdeveloped areas, and its economic operation is still dominated by high energy consuming industries[6]. This economic development model is very representative, making it easy to extend the model to other provinces. Due to the outbreak of the epidemic in 2021, many data are missing and not representative, and the calculation base and statistical indicators of wastewater discharge have changed since 2015; Due to the Kichen cycle theory, the calculated year and the research year generally differ by three to five years. Therefore, this article selects the five years from 2011 to 2015 as the research period.

Table 1. Green GDP Evaluation Indicator System

Primary indicators	Secondary indicators	X	Third level indicators	Unit	Indicator properties
Environmental pollution	Gas pollution	1	Carbon dioxide emissions	10000 tons	Negative direction
		2	Nitrogen oxide emissions	10000 tons	Negative direction
		3	Dust/particle emissions	10000 tons	Negative direction
	Water pollution	4	Total amount of industrial wastewater discharge	10000 tons	Negative direction
		5	Industrial wastewater treatment capacity	10000 tons	Forward
	Pollution improvement	6	Total investment in environmental pollution control	RMB100mn	Forward
		7	The proportion of investment in environmental pollution control to GDP	%	Forward
Natural resources	Energy consumption	8	Coal	10000 tons	Negative direction
		9	Petroleum	10000 tons	Negative direction
		10	natural gas	Billion cubic meters	Negative direction
	Environmental resource	11	Total water resources	Billion cubic meters	Forward
		12	Reduction in land resources	10000 acres	Negative direction

Table 2. Environmental Pollution Index

Environmental pollution							
Year/Indicator	Carbon dioxide emissions (10000 tons)	Nitrogen oxide emissions (10000 tons)	Dust/particle emissions (billion cubic meters)	Industrial wastewater treatment capacity (10000 tons)	Total amount of industrial wastewater discharge (10000 tons)	Total investment in environmental pollution control (100 million yuan)	The proportion of investment in environmental pollution control to GDP (%)
2015	58.37	44.94	31.26	128343	45933	140.8	1.03
2014	63.67	49.89	36.68	141438	40443	152	1.19
2013	66.31	52.37	38.69	174187	41844	197.1	1.68
2012	67.22	54.43	39.06	143693	42811	132.4	1.28
2011	69.12	54.85	38.22	145135	47228	119.2	1.34

Carbon dioxide emissions, nitrogen oxide emissions, dust/particle emissions, industrial wastewater treatment, industrial wastewater treatment, total industrial wastewater discharge, total investment in environmental pollution control, and the proportion of environmental pollution control investment to GDP. Data source: China Environmental Statistics Yearbook 2011-2015

Table 3. Natural Resource Index

Natural resources					
Year/Indicator	Coal consumption (10000 tons)	Oil consumption (10000 tons)	Natural gas consumption (billion cubic meters)	Total water resources (billion cubic meters)	Reduced land resources (10000 acres)
2015	3847.3	1123.85	6.19	1872	-31.3
2014	3857.75	1066.24	4.46	1726.63	13
2013	3684.01	997.07	4.26	1706.69	149.9
2012	3628.84	1069.15	4.3	1689.77	109
2011	3409.85	974.4	4.2	1480.19	78.8

Coal consumption, oil consumption, natural gas consumption, total water resources, and land resource reduction data source: Yunnan Survey Yearbook 2012-2016

2.3.1. Entropy method

Using the entropy method to calculate the green GDP of Yunnan Province, the specific steps are as follows [7].

The first step is to standardize the data processing. The standardization of traditional indicators is to eliminate the different results of selected indicators due to different units and dimensions. Standardization is to scale data to a specific range (0, n) in a certain proportion. Standardization of positive indicators:

$$x_{ij} = \frac{\max(V_{ij}) - V_{ij}}{maxV_{ij} - minV_{ij}} \tag{1}$$

Standardization of negative indicators:

$$x_{ij} = \frac{V_{ij} - minV_{ij}}{maxV_{ij} - minV_{ij}} \tag{2}$$

The second step is to determine the weight of the indicators. Set X_ Ij is the data of the jth index in the i-th unit, X_ The greater the data difference in the ij index, the more data information it contains, and the corresponding weight is greater. Based on this, calculate the information entropy values of each indicator, assuming e_ J is the information entropy of the j-th indicator, and its calculation formula is:

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} f_{ij}\ln(f_{ij}) \tag{3}$$

Step three, calculate the entropy value. Set W_ J is the entropy value of j,

$$W_j = \frac{1 - e_j}{n - \sum_{i=1}^{n} e_j}, j = 1,2, \dots n \tag{4}$$

Step four, obtain the rating value.

$$ECI_i = \sum_{i=1}^{n} w_j\, p_{ij} \tag{5}$$

In equation (5), [ECI]_ I is the comprehensive evaluation value of resources and environment.

Table 5. Entropy Method Calculation Results

Year/Indicator	Carbon dioxide emissions (10000 tons)	Nitrogen oxide emissions (10000 tons)	Dust/particle emissions (billion cubic meters)	Industrial wastewater treatment capacity (10000 tons)	Total amount of industrial wastewater discharge (10000 tons)	Total investment in environmental pollution control (100 million yuan)	The proportion of investment in environmental pollution control to GDP (%)	Coal (10000 tons)	Oil (10000 tons)	Natural gas (billion cubic meters)	Total water resources (billion cubic meters)	Reduced land resources (10000 acres)	*ECI*
2015	58.37	44.94	31.26	128343	45933	140.8	1.03	3847.3	1123.85	6.19	1872	-31.3	1.4536
2014	63.67	49.89	36.68	141438	40443	152	1.19	3857.75	1066.24	4.46	1726.63	13	1.4165
2013	66.31	52.37	38.69	174187	41844	197.1	1.68	3684.01	997.07	4.26	1706.69	149.9	1.6313
2012	67.22	54.43	39.06	143693	42811	132.4	1.28	3628.84	1069.15	4.3	1689.77	109	1.5147
2011	69.12	54.85	38.22	145135	47228	119.2	1.34	3409.85	974.4	4.2	1480.19	78.8	1.4288
Weight	*0.0726*	*0.0786*	*0.0761*	*0.0767*	*0.094*	*0.0856*	*0.0768*	*0.0799*	*0.0881*	*0.1222*	*0.0655*	*0.084*	

The entropy method can be used to calculate the fair value and fairness of indicators. By using Matlab software to calculate, the weights of each indicator and the comprehensive evaluation index of ECI resources and environment were obtained. It is not difficult to see that Yunnan Province's ECI fluctuated in a small range from 2011 to 2015, but overall environmental pollution continued to decrease, steadily developing towards an ecologically harmonious, environmentally friendly, and sustainable society.

The ECI index of Yunnan Province reached a peak in nearly five years in 2013, thanks to the continuous reduction of environmental pollution and natural resource consumption, as well as the increase in total government investment in environmental pollution. It is worth noting that in 2014, despite the continuous reduction of environmental pollution indicators such as carbon dioxide emissions, nitrogen oxide emissions, and dust particle emissions, the ECI index actually declined by 0.21, This is mainly due to the intensification of fossil energy consumption (coal, oil, natural gas), which invisibly increases the cost of resource and environmental development; But this situation began to improve in 2015, and data shows that the government has increased its efforts in water resource development, and land resources have also been restored and increased. Finally, it should be noted that the composite index here is only a relative index. The comprehensive indicator value only reflects the relative level of the quality of the resources and environment covered, not the absolute level. The higher the total score, the lower the resource and environmental costs; The lower the total score, the higher the resource and environmental cost. After obtaining a comprehensive score, traditional GDP can be adjusted through a comprehensive index to obtain green GDP.

Drawing on the approach of Zhu Chengliang and others, using the formula:

$$ECI^* = \frac{ECI_i}{Max(ECI_i) - Min(ECI_i)} \times 0.4 + 0.6 \tag{6}$$

The green value can be obtained by multiplying the adjusted environmental comprehensive index with the traditional one. The green GDP adjusted by the environmental comprehensive index will not be higher than the traditional GDP, which means that after considering resource and environmental factors, the GDP will decrease, and the reduced part is the resource and environmental costs of economic development. In years with good overall environmental quality, the decrease in GDP is relatively small; Years with poor overall environmental quality will experience significant shrinkage. Table 6 shows the green GDP values of Yunnan Province from 2011 to 2015 (excluding price factors) adjusted using the Environmental Comprehensive Index.

Table 6. Comparison between Green GDP and Traditional GDP

Year/Indicator	Traditional GDP (100 million yuan)	Green GDP (100 million yuan)	Green as a percentage of traditional
2015	13717.9	13282.2	96.82%
2014	12814.6	12185.5	95.09%
2013	11720.9	11511.9	98.22%
2012	10309.8	9963.99	96.65%
2011	8750.95	8519.73	97.36%

Traditional GDP data source: Yunnan Provincial People's Government official website portal website

The adjusted green GDP from 2011 to 2015 accounted for 97.36%, 96.65%, 98.22%, 95.09%, and 96.82% of the traditional GDP. In 2013, the proportion of green GDP to traditional GDP was the highest, which coincided with the ECI index, reaching 98.22%. Since its decline in 2014, the proportion of green GDP has started to rise, which is also a result of the ECI index's upward response.

3. THE CONNOTATION AND CALCULATION ANALYSIS OF GREEN ECONOMIC EFFICIENCY

3.1. The connotation of green economic efficiency

Green economic efficiency is an effective quantification of the quality of green economic development, which evaluates and measures regional economic development under the premise of considering economic growth and environmental protection. The efficiency of green economy is embedded in the concept of green economy, and its purpose is to measure the efficiency of economic operation. It can be seen as the integration of green economy and economic efficiency. Compared to traditional total factor productivity, green economic efficiency considers the impact of resources and environment on production efficiency. Resource factors are considered in production inputs, and harmful parts to the environment are treated as unexpected outputs in outputs, aiming to comprehensively and objectively evaluate economic operational efficiency. This article selects the Malmquist index to measure the efficiency of green economy, which can be further divided into technological progress and comprehensive technical efficiency. Comprehensive technical efficiency can be further divided into pure technical efficiency and the product of scale efficiency. Technological progress measures changes in production efficiency driven by innovation, pure technological efficiency reflects improvements in management, institutional changes, etc., and scale efficiency reflects the impact of changes in production scale on production efficiency.

3.2. Calculation and Analysis of Green Economic Efficiency

The indicator used in this article to measure the efficiency of green economy is green total factor productivity. The difference between green total factor productivity and traditional total factor productivity lies in the selection of input and output variables. Traditional total factor productivity only considers capital and labor as input variables, while output variables only include actual GDP (expected output); Green total productivity adds energy consumption as an input indicator on the basis of traditional total factor productivity, and the output variable increases carbon emissions (unexpected output). Compared to traditional total factor productivity, green total factor productivity takes into account the impact of human activities on nature and incorporates the concept of sustainable development, which is in line with the concept of green economic development.

3.2.1. DEA Malmquist index method

The Malmquist index method used in this article is based on the basic DEA-CCR and DEA-BBC models to construct a directional distance function. The green total factor productivity index is established based on the distance from the decision-making unit to the production front, where the distance from the decision-making unit to the production front is numerically equal to the reciprocal of the efficiency values of DEA-CCR and DEA-BCC.

The Malmquist index method has two main advantages: (1) it is a non parametric method that does not require the setting of a production function, avoiding errors caused by improper production function setting; (2) it does not require clear input and output price information, avoiding errors caused by price changes, while reducing computational complexity and saving the calculation process. The biggest feature of the model is that it can decompose the Malmquist index into two major parts: technological progress (TC) and comprehensive technological efficiency (TEC) [7]. Technological progress indicates changes in the forefront of production, making it easier to measure technological progress or innovation in reality. The comprehensive technical efficiency measures the degree to which the decision-making unit is catching up with the forefront of production, and can be further divided into two parts: pure technical efficiency (PTEC) and scale efficiency (SEC). Management Technology vs. Pure Technology.

Used for investment indicators$X_j{}^t = ({X_{1j}}^t, {X_{2j}}^t, \dots, {X_{mj}}^t)^T$

Output indicators used$y_j{}^t = ({y_{1j}}^t, {y_{2j}}^t, \dots, {y_{sj}}^t)^T$

J represents the decision-making unit, t represents the number of periods, m represents the input quantity, and s represents the output quantity. The set of production possibilities under variable production scale returns is:

$$S^t(C) = \{(x^t, y^t | x^t \geq \sum_{j=1}^{n} x_j^t \lambda_j, y^t \leq \sum_{j=1}^{n} y_j^t \lambda_j, \sum_{j=1}^{n} \lambda_j = 1, \lambda_j \geq 0，j = 1,2 \dots, n\} \tag{7}$$

In equation 7, A represents the weight of the observed values, λ A sum of 1 indicates that the return to scale remains unchanged. On the premise of unchanged returns to scale $D_c^t(x^t, y^t)$、$D_c^{t+1}(x^{t+1}, y^{t+1})$ represent separately(x^t, y^t) distance function in the direction of t and t+1 periods; Based on equation 7, equation 8 can be derived

$$\begin{cases} max_z = \left(D_c^t(x^t, y^t)\right)^{-1} \\ s.t \sum_{j=1}^{n} x_j^t \lambda_j \leq x^t \\ \sum_{j=1}^{n} y_j^t \lambda_j \geq z y^t, \lambda_j \geq 0，\sum_{j=1}^{n} \lambda = 1, j = 1,2 \dots, n, \end{cases} \tag{8}$$

Based on the technical conditions of phase t and the change in technical efficiency of phase t+1, equation 9 can be obtained

$$M^t = \frac{D_c^t(x^{t+1}, y^{t+1})}{D_c^t(x^t, y^t)} \tag{9}$$

In order to make the degree of productivity changes between the two periods closer to the actual situation, the Malmquist index is measured using geometric means and then derived equation 10.

$$M(x^t, y^t, x^{t+1}, y^{t+1}) = (M^t \times M^{t+1})^{\frac{1}{2}} = \left[\frac{D_c^t(x^{t+1}, y^{t+1})}{D_c^t(x^t, y^t)} \times \frac{D_c^{t+1}(x^{t+1}, y^{t+1})}{D_c^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} \tag{10}$$

The most significant feature of the Malmquist index method is that it can decompose green total factor productivity. Fare used the FNGZ model as early as 1994 to decompose it into the Technical Progress

Index (TC), Pure Technical Efficiency Change Index (PTEC), and Scale Efficiency Change Index (SEC). The Pure Technical Efficiency Change Index and Scale Efficiency Change Index are decomposed from the Comprehensive Technical Efficiency Change Index [8]. In the model, TE represents pure technical efficiency, TC represents technological progress, and SE represents scale efficiency.

$$\begin{aligned} & M_{FNGZ}(x^t, y^t, x^{t+1}, y^{t+1}) \\ & = \frac{D_v^{t+1}(x^{t+1}, y^{t+1})}{D_v^t(x^t, y^t)} \times \left[\frac{D_c^t(x^t, y^t)}{D_c^{t+1}(x^t, y^t)} \times \frac{D_c^t(x^{t+1}, y^{t+1})}{D_c^{t+1}(x^{t+1}, y^{t+1})}\right]^{\frac{1}{2}} \\ & \times \frac{D_c^{t+1}(x^{t+1}, y^{t+1})/D_v^{t+1}(x^{t+1}, y^{t+1})}{D_c^t(x^t, y^t)/D_v^t(x^t, y^t)} \\ & = TE_{FNGZ} \times TC_{FNGZ} \times SE_{FNGZ} \end{aligned} \quad (11)$$

3.2.2. Indicator Selection Explanation

When calculating the efficiency of green economy, it is necessary to first determine input and output indicators, which include capital stock, labor force, and energy consumption; The output indicators include actual GDP and carbon emissions, where carbon emissions are considered unexpected outputs to measure their impact on the environment. The data used comes from the China Statistical Yearbook, China Energy Statistical Yearbook, China Labor Statistical Yearbook, and Yunnan Provincial Statistical Yearbook.

(1) Capital stock

Capital investment includes stock and flow, and capital flow refers to the amount of capital investment during a certain period of time; Capital stock is the amount accumulated by capital investment over the years. Due to the lack of direct statistical data on capital stock, capital investment is chosen for calculation, taking into account data availability and accuracy of results.

(2) Labor force

In the selection of labor force indicators, Chinese scholars use different statistical methods, such as urban employment numbers, the average number of employed people at the end of last year and this year, to measure changes in labor force numbers. In the analysis of factors affecting the efficiency of green economy in this article, the number of non agricultural employed population is used as a measurement indicator.

(3) Energy consumption

The demand for energy in social development is diverse, and energy consumption measures the energy consumption of a certain region for production and daily life within a certain time range. It can indirectly measure the quantity of material obtained by human society from nature during the development process, as well as the degree of dependence on nature. According to the China Energy Statistical Yearbook, eight main energy sources (coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil, and natural gas) are statistically analyzed. This article selects these eight main energy consumption sources to measure the energy consumption in the input indicators. To unify the unit, convert the 8 main energy sources into 10000 tons of standard coal according to the coal conversion coefficient attached to the annual energy statistics inspection for statistics. The coal conversion coefficients of these 8 main energy sources are 0.7143, 0.9714, 1.4286, 1.4714, 1.4717, 1.4571, 1.4286, and 1.2143, respectively.

(4) Green GDP

Using the 2011-2015 Yunnan Province Green GDP calculated through the ECI index as the measurement data indicator.

(5) Carbon dioxide emissions

Use the carbon conversion coefficient provided by the United Nations Intergovernmental Panel on Climate Change to calculate carbon dioxide emissions.

Carbon dioxide emission= $\sum_{i=1}^{8} E_i \times$ Carbon conversion coefficient

E_i in the formula_ I represents energy, with 8 main energy sources having carbon conversion coefficients: coal 1.9003, coke 2.8604, crude oil 3.0202, gasoline 2.9251, kerosene 3.0179, diesel 3.0959, fuel oil 3.1705, and natural gas 2.1622.

Table 7. Coal Conversion Coefficient

Year/Indicator	Coal consumption (10000 tons)	Coke consumption (10000 tons)	Crude oil consumption (10000 tons)	Gasoline consumption (10000 tons)	Kerosene consumption (10000 tons)	Diesel consumption (10000 tons)	Fuel oil consumption (10000 tons)	Natural gas consumption (billion cubic meters)
2015	7712.85	879.33	0.03	312.95	90.39	582.87	2.51	6.34
2014	8674.67	1133.78	0.04	297.74	77.3	569.13	3.82	4.63
2013	9783.09	1347.57	0.03	280.01	63.73	559.81	3.24	4.27
2012	9850	1338.87	0.02	287.51	56.06	650.89	2.61	4.3
2011	9664	1218.44	0.02	250.34	51.12	609.84	2.59	4.2
Coal conversion coefficient	0.7143	0.9714	1.4286	1.4714	1.4717	1.4571	1.4286	1.2143

Table 8. Energy Carbon Conversion Factors

Year/Indicator	Coal consumption (10000 tons)	Coke consumption (10000 tons)	Crude oil consumption (10000 tons)	Gasoline consumption (10000 tons)	Kerosene consumption (10000 tons)	Diesel consumption (10000 tons)	Fuel oil consumption (10000 tons)	Natural gas consumption (billion cubic meters)
Before conversion								
2015	7712.85	879.33	0.03	312.95	90.39	582.87	2.51	6.34
2014	8674.67	1133.78	0.04	297.74	77.3	569.13	3.82	4.63
2013	9783.09	1347.57	0.03	280.01	63.73	559.81	3.24	4.27
2012	9850	1338.87	0.02	287.51	56.06	650.89	2.61	4.3
2011	9664	1218.44	0.02	250.34	51.12	609.84	2.59	4.2
Energy carbon conversion coefficient	1.9003	2.8604	3.0202	2.9251	3.0179	3.0959	3.1705	2.1622
After conversion								
2015	14656.73	2515.236	0.090606	915.41	272.788	1804.507	7.957955	13.70835
2014	16484.48	3243.064	0.120808	870.9193	233.2837	1761.97	12.11131	10.01099
2013	18590.81	3854.589	0.090606	819.0573	192.3308	1733.116	10.27242	9.232594
2012	18717.96	3829.704	0.060404	840.9955	169.1835	2015.09	8.275005	9.29746
2011	18364.5	3485.226	0.060404	732.2695	154.275	1888.004	8.211595	9.08124

Table 9. Carbon dioxide emissions

Carbon dioxide emission	
2015	20186.43
2014	22615.96
2013	25209.49
2012	25590.56
2011	24641.63

3.3. Calculation and analysis of green economic efficiency in Yunnan Province

Based on the data and indicators of Yunnan Province from 2011 to 2015, the results of calculating green total factor productivity using DEAP2.1 software are as follows:

Table 10. Investment Indicators

input indicators			
Year/Indicator	Total energy consumption	Capital investment amount	Employment numbers
2015	7817.599	1306939120000	76320
2014	8689.944	1107381230000	76349
2013	9628.445	962183290000	76301
2012	9799.37	755351250000	76254
2011	9427.598	593274990000	76196

Table 11. Output Indicators

Output indicators		
Year/Indicator	Green GDP	Carbon dioxide emissions
2015	132822400	20186.427
2014	121855317	22615.955
2013	115119290	25209.495
2012	99639877	25590.561
2011	85197322	24641.626

From Table 13, it can be seen that the total factor productivity of Yunnan Province from 2011 to 2015 came from the value of technological progress. From the traditional total factor productivity perspective, the total factor productivity is generally in a downward trend in fluctuations, due to the decrease in the value of technological progress. From the green total factor productivity value, it can be seen that the green total factor productivity rate also showed a downward trend from 2011 to 2014, which is also a consequence of the decrease in the value of technological progress, However, in the last year of 2015, there was a slight increase, obviously due to the increase in technological progress.

In the comparison between green total factor productivity and traditional total factor productivity, it can be found that their technical efficiency and scale efficiency have two efficiency values of 1.0, both of which are at the effective frontier; The decline in traditional total factor productivity is a major trend, with average values less than 1; Although the average value of green total factor productivity is also less than 1, thanks to the slight increase in technological progress in 2015, green total factor productivity has also begun to show an upward trend. It is not difficult to analyze that Yunnan Province's independent innovation and technology introduction are the main factors to improve green total factor productivity, thereby driving the growth of green economic efficiency.

Table 12. Traditional Total Factor Productivity

MALMQUIST INDEX SUMMARY OF ANNUAL MEANS					
Table of Traditional Total Factor Productivity in Yunnan Province from 2011 to 2015					
Year/Indicator	Technical efficiency change value	Technological progress value	Pure technical efficiency value	Scale efficiency value	Total factor productivity
2012/2011	1.000	0.975	1.000	1.000	0.975
2013/2012	1.000	0.954	1.000	1.000	0.954
2014/2013	1.000	0.972	1.000	1.000	0.972
2015/2014	1.000	0.892	1.000	1.000	0.892
Average	1.000	0.947	1.000	1.000	0.947

Table 13. Green Total Factor Productivity

MALMQUIST INDEX SUMMARY OF ANNUAL MEANS					
Green Total Factor Productivity Table of Yunnan Province from 2011 to 2015					
Year/Indicator	Technical efficiency change value	Technological progress value	Pure technical efficiency value	Scale efficiency value	Total factor productivity
2012/2011	1.000	0.976	1.000	1.000	0.976
2013/2012	1.000	0.954	1.000	1.000	0.954
2014/2013	1.000	0.956	1.000	1.000	0.956
2015/2014	1.000	0.957	1.000	1.000	0.957
Average	1.000	0.961	1.000	1.000	0.961

4. RESEARCH CONCLUSIONS AND POLICY RECOMMENDATIONS ON GREEN GDP AND ECONOMIC EFFICIENCY IN YUNNAN PROVINCE

4.1. Effectively improving the green GDP accounting level in Yunnan Province

Yunnan Province should establish a coordination mechanism for green GDP accounting, and provincial government departments should establish a guidance group for the implementation of green GDP accounting work, collaborate with relevant departments, establish a separation mechanism, use economic and administrative means, supervise energy conservation and emission reduction of various units and institutions, and consciously assume the responsibility and obligation of protecting the ecological environment.

4.2. Comprehensively promote the standardization of environmental and economic accounting

Establish a unified green GDP accounting system. Verify and supplement the statistical content and basic data required for green GDP accounting, establish a unified and scientific accounting framework and indicator system, and reasonably determine the indicator baseline. Firstly, it is necessary to strengthen the standardization construction of accounting frameworks, define statistical concepts, definitions, and standards within the framework of ecological civilization construction system reform, such as resource auditing and evaluation. Secondly, the standardization construction of accounting methods, whether it is traditional GDP or green GDP, has certain shortcomings in accounting methods. It is necessary to develop a more acceptable method as much as possible. Green GDP accounting must be synchronized with traditional GDP accounting and extended to cities, counties, and towns.

4.3. The impact of technological progress on green economic efficiency

After using the three-stage DEA Malmquist model to calculate the green economic efficiency of Yunnan Province and analyzing its influencing factors, it can be concluded that technological progress is the most crucial factor in improving the green economic efficiency of Yunnan Province. Technological progress is worth improving and effectively drives the improvement of green total factor productivity.

Firstly, in terms of technology sources, Yunnan Province should adhere to independent innovation and the introduction of new technologies, thereby promoting the transformation of Yunnan's green economic growth mode. The level of technological innovation has an inherent driving effect on the growth of green economic efficiency. The government should encourage labor-intensive industries to transform into technology intensive industries through independent innovation and technology introduction, improve the growth of green total factor productivity, and promote the progress of green technology and green economy.

Secondly, in terms of technological research and development, Yunnan Province should encourage enterprises to invest in independent research and development and provide appropriate government R&D subsidies to further improve their technological level [9], thereby improving total factor productivity. Technological research and development is developing towards an environmentally friendly direction, playing a good intermediary role in improving the efficiency of the green economy in Yunnan Province as a whole.

Thirdly, in terms of technological innovation, Yunnan Province should increase basic and application innovation. Technological innovation can improve the technological progress index. The calculation results show that it plays a decisive factor in both traditional economic efficiency and green economic efficiency. The development of industry in Yunnan Province faces the problem of choosing technological innovation methods. Basic innovation, product innovation, and process innovation are all included in the entire process of technological innovation. Choosing appropriate technological innovation methods for different industries is particularly important. The further improvement of green economic efficiency in Yunnan Province cannot be achieved without the continuous drive of technological innovation.

REFERENCES

[1] T T L. [Strengthening scientific and technological support for health adaptation action to climate change under the 'double carbon' goal].[J].Zhonghua yu fang yi xue za zhi [Chinese journal of preventive medicine],2022,56(10):1353-1355.

[2] Jian H, Lin C, Na Z. A Statistical Review of Considerations on the Implementation Path of China’s “Double Carbon” Goal[J].Sustainability,2022,14(18):11274-11274.

[3] Baoyu C, Feng L Comprehensive Accounting of Resources, Environment, and Economy Integrating Machine Learning and Establishment of Green GDP[J]. Mathematical Problems in Engineering,2022,2022.

[4] Gu W ,Li Q ,Li Y .Environment-friendly PCN derivatives design and environmental behavior simulation based on a multi-activity 3D-QSAR model and molecular dynamics[J].Journal of Hazardous Materials, 2020, 393 (prepublish):122339.

[5] Zbigniew A, Nikoletta N, Małgorzata S, et al. Editorial: Physiological response to environmental stressors in invertebrates[J]. Frontiers in Physiology,2022,131002192-1002192.

[6] Hui H Minna C, Minghao Z .Study on high energy-consuming industrial agglomeration, green finance, and carbon emission.[J].Environmental science and pollution research international,2022,30(11):29300-29320.

[7] Zhuyuan L, Xiaolong W, Run Z, et al. Evaluation Analysis of the Operational Efficiency and Total Factor Productivity of Container Terminals in China[J]. Sustainability,2022,14(20):13007-13007.

[8] Ye-Cheng W, Yuan-Wei D. Evaluation of resources and environmental carrying capacity of marine ranching in China: An integrated life cycle assessment-emergy analysis[J]. Science of the Total Environment, 2023, 856 (P1): 159102-159102.

[9] Guanglan Z ,Zhening Z ,Yulian F .How to Evaluate the Green and High-Quality Development Path? An FsQCA Approach on the China Pilot Free Trade Zone[J].International Journal of Environmental Research and Public Health,2022,19(1):547-547.