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An Empirical Study on the Relationship Between Energy Carbon Emissions and Economic Growth Based on EKC——Take Yunnan Province as an Example

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ABSTRACT
In the face of deeper international competition and the security of the energy environment in the future, "carbon peaking" has become an important starting point. This paper selects the data of Yunnan Province during the 20 years from 2000 to 2019, and calculates the carbon emission level of energy consumption in Yunnan Province based on the carbon emission coefficient and calculation method published by the IPCC, and uses Eviews8.0 software to verify the relationship between energy carbon emissions and economic growth in Yunnan Province. According to the characteristics of the environmental Kuzpitz curve, the per capita GDP of Yunnan Province's carbon peak is estimated based on the model; finally, the gray prediction model is used to predict the inflection point at which carbon emissions reach the maximum. The empirical results show that from 2000 to 2019, the total carbon emissions in Yunnan Province showed a fluctuating upward trend, and the carbon emission intensity showed a fluctuating downward trend. The relationship between carbon emissions and economic growth conformed to the shape of the environmental Kuzpitz curve, showing an inverted "U" The theoretical inflection point of carbon emissions is in 2021.

Keywords: *EKC curve, carbon emissions, economic growth, GM(1,1) model*

1. PREFACE

"Carbon peaking" means that the annual carbon dioxide emissions of a certain region or industry reach the highest historical emissions, and it is the turning point of the region or industry's carbon emissions from increasing to decreasing. The peaking target includes the value of carbon emissions. and time. my country is expected to achieve "carbon peak" in 2030, and then carbon dioxide emissions will no longer increase, and will decrease year by year. Environmental changes caused by global greenhouse gas emissions have posed a major threat to the sustainable development of the world. According to a report released by the Intergovernmental Panel on Climate Change (IPCC) in November 2018, in order to avoid extreme harm, the world must warm up the world. Keep it within 1.5 degrees Celsius to achieve the goal of achieving net zero greenhouse gas emissions by the middle of this century. Carbon emissions are closely related to economic development, and economic production activities are inseparable from energy consumption. From the perspective of per capita carbon emissions, my country is comparable to developed European countries. China's per capita carbon emission level accounts for only 45% of the United States, which has extremely high carbon emissions. However, in terms of total, China's carbon emission level has made it the world's largest carbon emitter. China's annual carbon dioxide emissions are 98 tons, accounting for 28% of global carbon emissions. With the rapid economic growth, carbon dioxide emissions are also increasing.

Yunnan is one of the main provinces in the southwest region. The reasonable and effective distribution control of energy consumption in the province is of great significance to its development. In the plan, Yunnan Province should take the lead in "carbon peaking" ahead of the whole country. The Standing Committee of the Yunnan Provincial Party Committee held a meeting to emphasize that achieving carbon peak and carbon neutrality is a broad and profound economic and social systemic change, which is closely related to Yunnan. It is necessary to thoroughly study and implement the spirit of General Secretary Xi Jinping’s important speech, effectively unify thoughts and actions into the decision-making and deployment of the Party Central Committee, firmly seize historical opportunities, and actively promote the construction of green Yunnan, so as to achieve my country’s carbon peak and peak by 2030 as scheduled. The goal of carbon neutrality by 2060 will make Yunnan's contribution. Since the 13th Five-Year Plan, Yunnan Province has actively controlled greenhouse gas emissions. In 2019, the carbon emission intensity per unit GDP of Yunnan Province was 0.2585 tons/10,000 yuan. Yunnan should take the initiative to further optimize energy and industry, improve energy utilization efficiency, and strive to reach the peak before the national peak. Under the guidance of EKC theory, this paper uses GDP per capita and carbon emissions per capita as economic and environmental indicators, discusses the type of EKC curve of carbon emissions and economic growth in Yunnan Province, and predicts the arrival time of the inflection point of the EKC curve, which is the coordination between the environment and economy of Yunnan Province. Development provides empirical evidence.

2. INTRODUCTION TO RESEARCH METHODS

In the past few years, the number of scholars studying the relationship between carbon emissions and economic growth has increased, and the results have been continuously enriched, and they have actively made suggestions for "carbon peaks". In the research on the relationship between environment and economic growth, scholars have made theoretical research on the environmental Kuzpitz curve. In recent years, more and more researches have been biased towards empirical research. First of all, among the scholars studying the EKC curve, Panayotou (1993), Grossman et al (1995) and other scholars first proposed the environmental Kuzpitch curve of the relationship between environment and economic development. The growth of GDP will destroy the ecological environment. First of all, the environment will continue to deteriorate with the growth of GDP. When the economy grows to a certain level, the environment will no longer deteriorate, and will gradually recover with economic development; this is economic growth and environmental development The environmental Kuzpitz curve is inverted "U" shape. [1-2]. Wang Yiming et al. (2016) conducted research on carbon emissions and found that for carbon emissions research, carbon emissions are linear, which does not conform to the hypothesis that the EKC curve is "inverted U-shaped" [3]; Liu Chuanjiang et al. (2015), Zhou Shaofu et al. (2015) conducted an empirical study on the development of China's environment and economy. The empirical results show that the environmental Kuzpitz curve of China's carbon emission economic growth is a positive U-shaped relationship. [4-5]; Wang Kai et al. (2018), Zhanhua (2018) and Jiang Li et al. (2019) conducted research on the relationship between environmental pollution and economic development in China, and the research showed that the relationship between environmental pollution and economic growth is in line with EKC The hypothesis that the curve assumes an inverted "U" shape further validates the environmental Kuzpinets curve hypothesis [6-8]. Ding Junsong et al. (2020) conducted a study on the relationship between China's ecological quality and economic growth, and the results showed that there is an "N" type relationship between the level of economic development and ecological quality [9]. Dai Yong et al. (2020) studied the urbanization rate and carbon emissions of Jiangsu Province and related research found that the EKC curve has an inverted "N"-shaped characteristic [10]. In the current research on the EKC curve, it has been found that there are five main curve characteristics of EKC: linear, positive "U", inverted "U", positive "N" and inverted "N" [11].

In recent years, more and more scholars have analyzed the relationship between the environment and the economy in my country and the region based on the EKC theory, and strive to provide useful suggestions for the coordinated development of the environment and the economy in my country. This paper conducts an empirical study on the EKC curve types of economic development and carbon emissions in Yunnan Province, as well as the timing of the inflection point of carbon emissions, providing empirical evidence for Yunnan Province to take the lead in "carbon peak".

3. MODEL CONSTRUCTION AND DATA DESCRIPTION

3.1 Data source and description

The data in this article are all from the Yunnan Provincial Statistical Yearbook, and the data from 2000 to 2019 are selected as the original data for calculation, and then the variables are empirically analyzed. Select the year-end energy consumption and total population of Yunnan Province from 2000 to 2019 as the original data to calculate the annual per capita carbon emissions. This paper intends to use raw coal, coke, crude oil, gasoline, kerosene, diesel, natural gas, etc. as carbon source indicators to calculate the total carbon emissions.

3.2 Carbon emission estimation model

Many scholars have used different methods to calculate carbon emissions in existing studies. This article uses the energy consumption method published by the IPCC to estimate the carbon emissions of Yunnan Province from 2000 to 2019. The energy consumption method calculates carbon emissions based on existing statistical data, based on the energy consumption data published by the Bureau of Statistics and the carbon emission coefficient published by the IPCC to estimate carbon emissions. The energy consumption method has the following advantages in calculating carbon emissions. The estimated data activity is strong; compared with the input and output method, the IPCC assumes that the carbon emission coefficient of a certain energy is basically constant, so the energy consumption method estimates It is more accurate, and the workload is small compared with the product life cycle method [12].

In the carbon emission calculation process, first, due to the inconsistency of the measurement units of the original data, energy consumption should be converted into a unified unit of "tons of standard coal". Then, the carbon emissions of Yunnan Province from 2000 to 2019 are estimated according to the United Nations Intergovernmental Panel on Climate Change. The carbon emission factor and calculation method issued by the committee. The specific conversion factor and carbon emission factor are shown in Table 1 and Table 2.

Table 1 Conversion coefficients of various types of energy into units of "ton of standard coal"

Energy category i	Unit of measurement	Conversion factor	Energy category i	Unit of measurement	Conversion factor
Coal	ton	0.7143	Coke	ton	0.9714
Crude oil	ton	1.4286	Gasoline	ton	1.4714
Fuel oil	ton	1.4286	Diesel	ton	1.4571
Liquefied petroleum gas	ton	1.7143	natural gas	ten thousand cubic meters	11-13.3

Table 2 Carbon emission coefficients of various energy sources

Unit: ton of carbon/ton of standard coal

Carbon source category i	Carbon emission factor Bi	Carbon source category i	Carbon emission factor Bi
Coal	0.7559	Coke	0.855
Crude oil	0.5857	Gasoline	0.5538
Fuel oil	0.6185	Diesel	0.5921
Liquefied petroleum gas	0.5042	natural gas	0.4483

According to the IPCC Carbon Emission Guidelines, the calculation method of total carbon emissions is shown in formula (1):

$$EC = \sum_{i=1}^{8} Bi \times Ci \quad (1)$$

Among them, EC represents carbon emissions; i represents energy category; Ci represents the i-th energy consumption; Bi (104t C/104t standard coal) represents the i-th carbon emission coefficient.

3.3 EKC curve model

This paper selects the time series data of Yunnan Province from 2000 to 2019 to construct carbon emission data. Take carbon emissions per capita as the dependent variable and GDP per capita as the independent variable. Using Eviews8.0 to take the logarithm of the variables, establish an EKC model of per capita carbon emissions, and perform first, second, and third-order regressions on the model to test the shape of the EKC curve of the relationship between the economy and the environment in Yunnan Province. The modeling is as follows:

$$\mathrm{LnEC} = \alpha0 + \alpha1\mathrm{LnPGDP} + \varepsilon \quad (2)$$

$$\mathrm{LnEC} = \alpha0 + \alpha1\mathrm{LnPGDP} + \alpha2(LnPGDP)^2 + \varepsilon \quad (3)$$

$$\mathrm{LnEC} = \alpha0 + \alpha1\mathrm{LnPGDP} + \alpha2(LnPGDP)^2 + \alpha3(LnPGDP)^3 + \varepsilon \quad (4)$$

In the formula, EC represents per capita carbon emissions, PGDP represents per capita GDP, α0, α1, α2, α3 represent the regression coefficient of the equation, and ε represents the random error term.

3.4 Grey forecasting GM (1, 1) model

If the system has the ambiguity of hierarchy and structure, the randomness of dynamic changes, the incompleteness or uncertainty of index data, these characteristics are called gray. Such systems are called gray systems, and the predictive models of gray systems are called gray models. (Referred to as GM model). It builds a model to speculate on the future trend of things, revealing the process of continuous development and change of things in the system. The gray model is generally a GM (n, 1) model. Since only one variable needs to be studied when predicting GDP per capita, the GM (1,1) model is selected [17-18]. The steps of building a prediction model are as follows:

First, there is the original time series: X(0)={X^((0)) (i),i=1,2,3,…,n}

Then, the original practice sequence X(0) is accumulated once to generate an accumulated sequence: X(1)={X^((1)) (k),k=1,2,3,...,n}

The grey prediction model can be written as:

$$\hat{x}(k) = \left(X^{(0)}(1) - \frac{u}{a}\right) e^{-a(k-1)} + \frac{u}{a} \quad (5)$$

and, $\hat{a} = [a, u]^T = (B^T B)^{-1} B^T Y$

$$B = \begin{bmatrix} -\frac{1}{2}\left(X^{(1)}(1) + X^{(1)}(2)\right) & , & 1 \\ \vdots & , & 1 \\ -\frac{1}{2}\left(X^{(1)}(n-1) + X^{(1)}(n)\right) & , & 1 \end{bmatrix}$$

$$Y = \left(X^{(0)}(2), X^{(0)}(3), \ldots, X^{(0)}(n)\right)^T \quad (6)$$

Finally, the predicted value of GDP per capita is obtained by restoring the predicted series, that is, the restoring equation is:

$$\hat{x}(0)(k) = \hat{x}(k) - \hat{x}(k-1) \quad (7)$$

4. EMPIRICAL TEST AND RESULT ANALYSIS

4.1 Results of Carbon Emissions Measurement in Yunnan Province

Combining Table 1 and Table 2, according to equation (1), the carbon emissions of Yunnan Province from 2000 to 2019 can be calculated. The specific values are shown in Table 3.

It can be seen from Table 3 and Figure 1 that the carbon emissions of Yunnan Province from 2000 to 2019 generally showed a fluctuating upward trend, especially during the period from 2000 to 2012, with the rapid economic growth and the rapid growth of carbon emissions. It eased after 2012, and during the period 2012-2015, the carbon emissions of Yunnan Province showed a downward trend. It can be seen from Figure 2 that the per capita carbon emissions of Yunnan Province from 2000 to 2019 generally showed an upward trend, but compared with the rising speed of per capita carbon emissions, the per capita GDP of Yunnan Province has risen faster, especially in 2010 Years later, the per capita GDP of Yunnan Province has experienced rapid growth. It can be seen from Figure 3 that the carbon emission intensity of Yunnan Province is in a fluctuating downward trend, and the rate of decline is relatively fast, especially after 2006, the carbon emission intensity of Yunnan Province is in a stage of rapid decline. It can be seen that in the 20 years from 2000 to 2019, the carbon emissions in Yunnan Province did not have a peak. The carbon emissions in 2019 reached a maximum of 60,032.7 million tons. Carbon emissions are closely related to economic development.

Table 3 Carbon emissions in Yunnan Province from 2000 to 2019

Year	Carbon emissions (ten thousand tons)	Year	Carbon emissions (ten thousand tons)	Year	Carbon emissions (ten thousand tons)	Year	Carbon emissions (ten thousand tons)
2000	2060.664	2005	3620.412	2010	5074.888	2015	5413.127
2001	2253.802	2006	4184.987	2011	5609.977	2016	5530.835
2002	2469.551	2007	4481.048	2012	5976.435	2017	5676.073
2003	2647.14	2008	4534.212	2013	5631.329	2018	5791.263
2004	3149.411	2009	4891.446	2014	5486.179	2019	6003.227

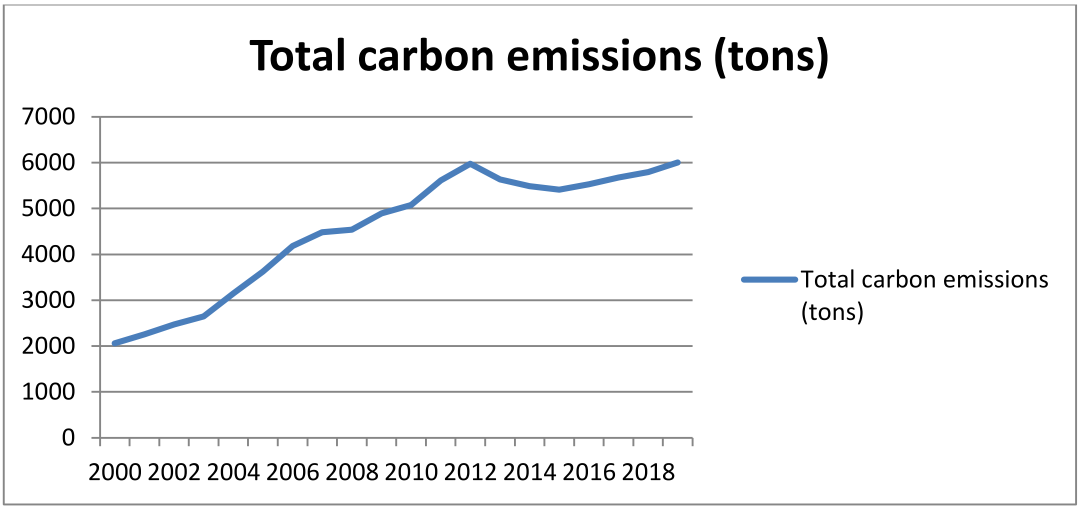

Figure 1 The change trend of carbon emissions in Yunnan Province from 2000 to 2019

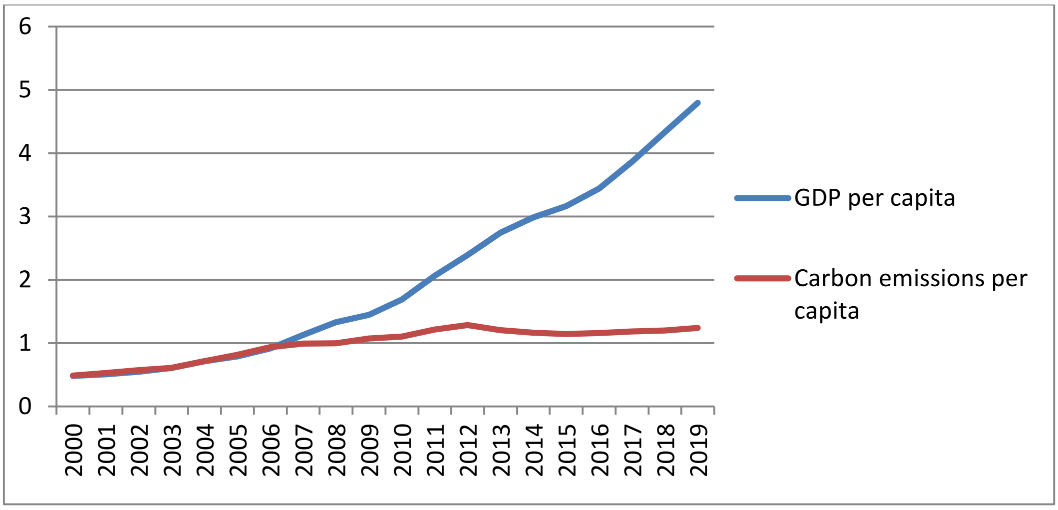

Figure 2 Trend map of per capita carbon emissions in Yunnan Province from 2000 to 2019

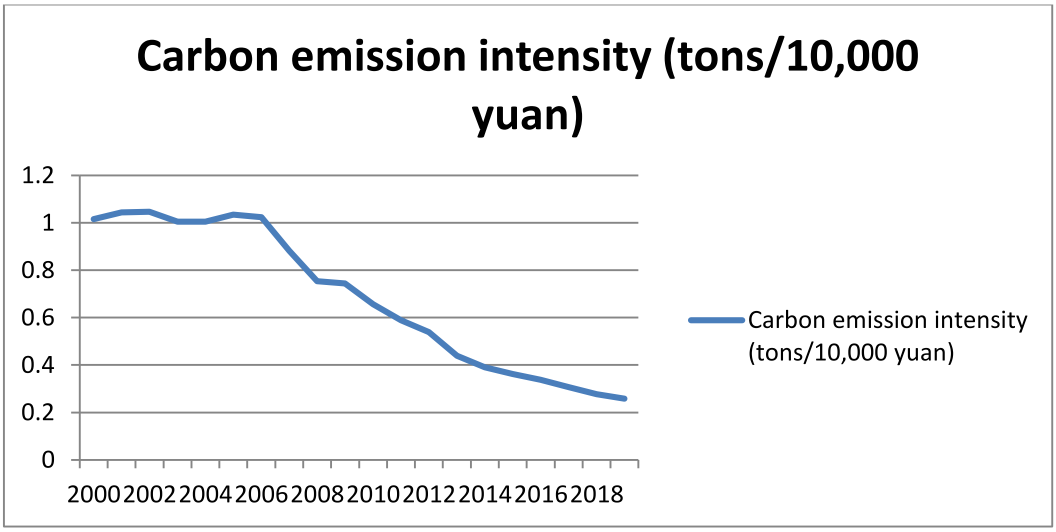

Figure 3 The carbon emission intensity trend of Yunnan Province from 2000 to 2019

4.2 Analysis of EKC model test results

Use Eviews8.0 to fit regression models (2) (3) (4) respectively, and the fitting results are shown in Table 5.

First of all, we must judge the shape characteristics of the curve, according to the sign of the regression coefficient, the regression result of the coefficient represents different meanings. The specific situation is analyzed according to Table 4.

Table 4 The economic significance table of the function

Coefficient symbol	Curve shape	Explanation of economic significance
α2=α3=0,α1>0	A monotonously rising straight line	Carbon emissions increase with economic growth
α2=α3=0,α1<0	A monotonously decreasing straight line	Carbon emissions decrease with economic growth
α3=0,α1>0,α2<0	Inverted "U"-shaped curve	Carbon emissions increase first and then decrease with economic growth
α3=0,α1<0,α2>0	Positive "U"-shaped curve	Carbon emissions decrease first and then increase with economic growth
α1>0,α2<0,α3>0	Positive "N"-shaped curve	Carbon emissions first rise with economic growth, then fall, and then rise again
α1<0,α2>0,α3<0	Inverted "N"-shaped curve	Carbon emissions first decrease with economic growth, and then increase, only enough to decrease here

Second, choose a model. First, compare the correlation coefficients of the regression indicators of the three equations. The fitting effect of the model can be judged by the size of A-R2 (A-R2>0.9, indicating that the correlation between the two is established; A-R2 tends to 1, Indicates that the fitting effect of the model is better). It can be seen from the regression results that the A-R2 of the three models are 0.621787, 0.963839, and 0.975467 respectively; obviously, the fitting effect of the third-order is better than the second-order than the first-order. Second, compare the size of the F test value of the curve regression ($P<0.05$), indicating that the regression result is very significant, and the regression of the equation has a high degree of statistical significance). The regression results show that the F-values tested by the first-order and second-order equations are close to 0, so compared with the third-order regression equation, the first-order and the second-order have a higher degree of fit. Based on the analysis of R value and P value, the function with the best fitting effect can be obtained as:

$$\mathrm{LnEC} = -0.528678 + 0.023085\mathrm{LnPGDP} - 0.552928(LnPGDP)^2 \quad (8)$$

According to the characteristics of the quadratic equation in one variable, the only inflection point of the equation can be found to be approximately (6.37, 0.0012), and the corresponding per capita GDP is 63,700 yuan. At this time, the EKC curve is in the inverted "U" shape.

Table 5 EKC model regression test results

Fit type	Poly 1	Poly 2	Poly 3
α0	0.674181***	-0.528678***	0.441120**
α1	0.152890***	0.023085***	0.489848*
α2		-0.552928***	-0.462270*
α3			-0.118277*
Adjusted R-squared	0.621787	0.963839	0.975467
F-statistic	32.23618	254.2137	252.8193
Curve shape	Monotonous rise	Inverted "U"-shaped curve	Inverted "N" curve

4.3 Analysis of the forecast results based on GM (1, 1) per capita GDP

Selecting the data of Yunnan Province from 2000 to 2019 as the original data series, according to the GM (1, 1) model, the prediction model of the per capita GDP of Yunnan Province can be obtained as:

$$\hat{x}(1)(k) = 4.889157e^{-0.11889(k-1)} - 4.40776 \quad (9)$$

$$\hat{x}(0)(k) = 4.889157e^{-0.11889(k-1)} - 4.889157e^{-0.11889(k-2)} \quad (10)$$

Among them, k=1,2,3,...,n. Put n=9,10,...,24 into the above formula to get the predicted value of GDP per capita

Table 6 Forecast results of per capita GDP in Yunnan Province

Year	2020	2021	2022	2023	2024
GDP per capita (ten thousand	5.907875	6.6537	7.4937	8.43967	9.505103

yuan/person)

The posterior error test is mostly used in gray prediction models to judge the pros and cons of the original data and the predicted data. According to the comparison between the value of the posterior difference ratio and the accuracy grade table, the accuracy and reliability of the data prediction can be judged according to Table 7. The posterior difference ratio C=0.1088<0.35, indicating that the prediction accuracy grade is good, and the accuracy test result meets Claim.

The preliminary test results of the EKC curve show that the theoretical inflection point of Yunnan's carbon emissions is at 33,72,326 yuan per capita GDP, which means it will reach its maximum value in 2021.

Table 7 The results of the posterior error test of the prediction results

Original value	Predictive value	Residual	Standard deviation and test result
0.4814	0.4814	0	S1= 1.348463062
0.5063	0.617212748	-0.110912748	
0.5472	0.695130391	-0.147930391	
0.6048	0.782884448	-0.178084448	
0.7136	0.881716676	-0.168116676	S2=0.146756
0.789	0.993025599	-0.204025599	
0.9158	1.118386287	-0.202586287	
1.1287	1.259572652	-0.130872652	C= 0.108832319
1.3286	1.418582546	-0.089982546	
1.4427	1.59766603	-0.15496603	
1.6866	1.799357219	-0.112757219	
2.0629	2.026510133	0.036389867	
2.3891	2.282339092	0.106760908	
2.7447	2.570464192	0.174235808	
2.9874	2.894962534	0.092437466	
3.1642	3.260425918	-0.096225918	
3.4416	3.672025818	-0.230425818	
3.8629	4.13558656	-0.27268656	
4.3366	4.657667741	-0.321067741	
4.7944	5.245657048	-0.451257048	

Table 8 Comparison table of accuracy grades of posterior difference

Posterior difference	<0.35	<0.5	<0.65	<0.7
Accuracy grade	Good	Passed	Barely	failed

5. CONCLUSIONS

5.1 Research conclusion

This article mainly uses measurement methods to conduct empirical research on energy consumption carbon emissions and economic growth in Yunnan Province. For per capita carbon emissions and per capita GDP, a regression model is constructed through econometric methods, and the first, second, and third-order regression are performed. Based on the regression results, determine the shape of the curve that changes the relationship between carbon emissions and economic growth in Yunnan Province. Then, the gray forecast model GM(1,1) is used to predict the per capita GDP of Yunnan Province, and the reliability of the forecast data is tested by the posterior error. The following conclusions can be drawn:

Firstly, Estimating the amount of carbon emissions in Yunnan Province, the results show that from 2000 to 2019, the total amount of carbon emissions in Yunnan Province basically showed a fluctuating upward trend, and from 2000 to 2012, the total amount of carbon emissions in Yunnan Province showed a rapid upward trend. There was a short period of decline from 2012 to 2015. After 2015, although the total carbon emissions of Yunnan Province have been rising, they have risen slowly. From a per capita perspective, Yunnan's per capita carbon emissions are rising very slowly. Compared with per capita carbon emissions, Yunnan's per capita GDP has risen very fast. From the perspective of carbon emission intensity, the overall carbon emission intensity of Yunnan Province showed a downward trend. Before 2006, the carbon emission intensity of Yunnan Province declined very slowly, and after 2006 it entered a stage of rapid decline.

Sencondly, The Kurtz Pinch curve between carbon emissions and economic growth in Yunnan Province has shown an inverted "U" shape after verification. Theoretically, Yunnan Province's carbon emissions will peak in 2021, and there will be an inflection point.

5.2 Countermeasures

Aiming at the current status of carbon emissions and economic development in Yunnan Province, combined with the empirical analysis results of this article, this article provides suggestions for the economic development and carbon peak realization path of Yunnan Province from the following perspectives.

First, adhere to the path of sustainable development. Under the premise of ensuring stable economic growth, it must be related to the environmental damage caused by household carbon emissions. The EKC theory shows that in the short term, the economy can grow rapidly with the increase of carbon emissions, but in the long run, the negative impact of carbon emissions on economic growth is very significant [19]. Faced with the negative impact of environmental changes on economic development, taking the road of sustainable development is the trend, and green development is deeply rooted in the hearts of the people. Moreover, stable and efficient economic development can also promote the high-quality development of the industry, further restrain regional carbon emissions, and improve the regional environmental quality. Contribute to the coordinated development of my country's economy and environment.

Second, encourage the high-quality development of the industry and adhere to the connotative high-quality development path. Studies have shown that the added value of the tertiary industry has an inverse relationship with the growth of regional carbon emissions. Therefore, promote the development of the tertiary industry, and promote the three major industries to upgrade to high-end, to ensure the sustainability of the economic growth mode [20]. Specifically, efforts can be made in terms of core technology research and development, industrial project training, and the use of information technology. As an important tourism province in my country, Yunnan should make good use of its geographical and resource advantages, adjust the relationship between the province's environment and economic development, and contribute to my country's carbon neutrality.

Third, optimize emission reduction strategies and promote economic development. To achieve emission reduction targets, it is necessary to stabilize economic development as a prerequisite, give full play to the advantages of current economic development, formulate phased goals, reduce the negative impact of energy-saving measures on economic growth, and achieve environmental quality improvement after "carbon peak". And the coordinated development of environment and economy.

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