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Calculation and Analysis of Carbon Emission in Sichuan Province

Yujie Huang

Department of Economic Management, North China Electric Power University, Baoding 071000, China

220191060911@ncepu.edu.cn

Abstract

The net carbon emissions of Sichuan province from 2004 to 2019 were calculated by accounting various carbon sources and sinks. Then the STIRPAT extended model was established to analyze the influencing factors of carbon emissions in Sichuan Province. The results show that population size plays the most important role in promoting carbon emissions, followed by industrial structure. Affluence, technology and energy structure have little impact on carbon emissions.

Keywords

Carbon Emissions; Influence Factor; STIRPAT Model.

1. Introduction

The massive emission of greenhouse gases, mainly carbon dioxide, has led to the rise of sea level and frequent occurrence of extreme weather, seriously threatening the security of the ecosystem and the normal order of human production and life. With the deepening of scientific research on global change, governments of all countries gradually focus on carbon emissions. At present, scholars mainly study carbon emission from the aspects of carbon emission accounting, emission reduction potential, spatial form, energy consumption prediction, etc [1,2,3,4]. The measurement methods of carbon emission include Emission-Factor Approach, Mass-Balance Approach and Experiment Approach[5]. In this paper, the net carbon emissions of Sichuan province were calculated by using IPCC method, and the relevant influencing factors were analyzed by STIRPAT extended model.

2. Carbon Emission Measurement

2.1. Measurement of Net Carbon Emissions

Carbon dioxide emission and absorption exist in various forms in human production and life. Afforestation, vegetation restoration and other measures can absorb carbon dioxide in the atmosphere. The amount of carbon dioxide absorbed in such activities is the carbon sink, represented by CE^{sink}. Industrial production, livestock, etc., produce carbon dioxide. The amount of carbon dioxide produced by them is the carbon source, represented by CE^{source}. By combing the emission and absorption scenarios of carbon dioxide, the amount of carbon source and carbon sink are calculated, and then the net carbon emission amount CE^{net} is obtained, as shown in Formula 1.

$$CE^{net} = CE^{source} - CE^{sink} \quad (1)$$

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2.2. Measurement of Carbon Source

From the perspective of industry and agriculture, carbon sources are sorted out. Energy consumption, industrial production, straw burning, livestock intestinal fermentation and manure management, industrial and domestic wastewater discharge, and methane emission from paddy fields all produce carbon dioxide. Therefore, the calculation formula of carbon source quantity is shown in Formula 2.

$$CE^{source} = CE^e + CE^c + CE^g + CE^i + CE^a + CE^j + CE^w + CE^s \quad (2)$$

In Formula 2, CE^e is the carbon dioxide emission from energy consumption, and the calculation formula is shown in Formula 3. CE^c is the carbon dioxide emission during cement production, and the calculation formula is shown in Formula 4. CE^g is the carbon dioxide emission during steel production, and the calculation formula is shown in Formula 5. CE^i is the carbon dioxide emission in the production of soda ash and pig iron, and the calculation formula is shown in Formula 6. CE^a is the carbon dioxide emission from intestinal tract and feces of livestock, and the calculation formula is shown in Formula 7. CE^j is the carbon dioxide emission during straw burning, and the calculation formula is shown in Formula 8. CE^w is the emission of carbon dioxide in industrial and domestic wastewater, and the calculation formula is shown in Formula 9. CE^s is the emission of methane converted into carbon dioxide in rice field, and the calculation formula is shown in Formula 10.

$$CE^e = \sum_{i=1}^{8} E_i \times LCV_i \times CC_i \times COR_i \times \frac{44}{12} \quad (3)$$

In Formula 3, i represents energy types, including coal, coke, crude oil, gasoline, kerosene, diesel, gas oil, and natural gas. E_i represents the consumption of energy i. LCVi represents the average low calorific value of i. CCi represents carbon content per unit calorific value. CORi represents the rate of carbon oxidation during fuel combustion.

$$CE^c = Q \times P \times C_c \quad (4)$$

In Formula 4, Q represents the output of cement. P represents the clinker proportion of cement (75%). $C_c$represents the CO_2 emission factor of cement clinker ($0.52tCO_2/t$ clinker).

$$CE^g = \mathrm{BOF} \times EF_{BOF} + \mathrm{EAF} \times EF_{EAF} + \mathrm{OHF} \times EF_{OHF} \quad (5)$$

In Formula 5, BOF, EAF and OHF represent the amount of steel produced by basic oxygen converter, electric furnace arc and open furnace process respectively, accounting for 63%, 33% and 4%. EF_{BOF}, EF_{EAF} and EF_{OHF} represent the dioxide emission factors of basic oxygen converter, electric furnace arc and open furnace processes, which are 1.46, 0.08 and 1.72 tons of carbon dioxide per ton of steel respectively according to IPCC.

$$CE^i = \sum_{i=1}^{2} Q_i \times C_i \quad (6)$$

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In Formula 6, i stands for soda and pig iron. Q_i represents the output of i industrial products. C_i represents CO_2 emission coefficient of i industrial products, soda and pig iron of which is 0.138 tCO2/t, 1.35 tCO2/t according to IPCC.

$$CE^a = \sum A_i \times (C_{i1} + C_{i2}) \times \frac{11}{4} \tag{7}$$

In Formula 7, i stands for horse, goat, sheep, pig, etc. A_i represents the stock of type i livestock. C_{i1} and C_{i2} represent the methane emission factors of intestinal fermentation and fecal management of species i. $\frac{11}{4}$ represents the conversion coefficient between CH_4 and CO_2.

$$CE^j = \sum P_j \times N_j \times B_j \times F_j \times EF_j \tag{8}$$

In Formula 8, j represents the type of crops, including wheat, rice, corn, beans and oil. P_j represents crop yield of category j. N_j represents the ratio of grain to grass of j. B_j stands for open-air combustion ratio. F_j represents the combustion efficiency. EF_j represents CO_2 emission factor of various crops, which is 1.445g/kg according to IPCC.

$$CE^w = Q_{COD} \times V_{COD} \times \frac{11}{4} \tag{9}$$

In Formula 9, Q_{COD} represents discharge of chemical oxygen demand. V_{COD} represents the CH_4 emission factor of COD, which is $0.25tCH_4/t\ COD$ according to IPCC.

$$CE^s = \mathrm{S} \times EF \times \frac{11}{4} \tag{10}$$

In Formula 10, S represents the cultivated area of rice field. EF represents the mean of seasonal emissions per unit area of rice field, which is $224.6kg/hm^2$ according to IPCC.

2.3. Measurement of Carbon Sinks

Forests, orchards, arable land, urban green space and so on can absorb carbon dioxide. The calculation formula of carbon sink is shown in Formula 11.

$$CE^{sink} = CE^f + CE^o + CE^l \tag{11}$$

In Formula 11, CE^f is the absorption amount of forest carbon dioxide, and the calculation formula is shown in Formula 12. CE^o is the amount of carbon dioxide absorbed by orchard and urban green space, and the calculation formula is shown in Formula 13. CE^l is the amount of carbon dioxide absorbed by cultivated land, and the calculation formula is shown in Formula 14.

$$\begin{gathered} CE^f = \sum(S_i \times CI_i) + \alpha \sum(S_i \times CI_i) + \beta \sum(S_i \times CI_i) \\ CI_i = V_i \times \delta \times \rho \times \lambda \\ V_f = \sum_i S_i \times V_i \end{gathered} \tag{12}$$

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In Formula 12, S_i represents the area of category i forest. CI_i represents the amount of biological carbon sequestration in category i forest. V_i represents the volume per unit area of category i forest. δ denotes expansion coefficient of biomass savings. V_f stands for forest stock. ρ stands for volume density or dry weight coefficient. λ stands for carbon content. α denotes carbon conversion coefficient of understory vegetation. β represents the carbon conversion coefficient of forest land. In the calculation of forest carbon sink, the default values of $\delta, \rho, \lambda, \alpha, \beta$ are adopted according to IPCC, i. e. $\delta = 1.9, \rho = 0.5, \lambda = 0.5, \alpha = 0.195, \beta = 1.244$.

$$CE^o = \sum_i B_i \times C_i \quad (13)$$

In Formula 13, B_i represents the area of orchard and urban green space. C_i represents the carbon sink coefficient of orchard and urban green space, which is $7.262t/hm^2$ and $3.38kg/hm^2$ respectively according to IPCC.

$$CE^l = L_i \times C_i \quad (14)$$

In Formula 14, L_i represents the sown area of crops. C_i represents soil carbon sequestration coefficient of cultivated land, which is $892.07kg/hm^2$ according to IPCC.

2.4. Data Sources and Results

This paper collected more than 30 data, such as coal consumption and forest area, from The National Bureau of Statistics of China, IPCC National Greenhouse Gas Emission Inventory (2006) and Sichuan Statistical Yearbook and so on. Main parameters of carbon emission calculation from straw burning are shown in the Table 1. The calculations found that energy consumption and forests had the greatest impact on net carbon dioxide emissions, with other factors contributing less. Carbon dioxide from energy consumption, carbon dioxide absorbed by forests and net carbon dioxide emissions in Sichuan province from 2004 to 2019 are shown in the figure 1.

Table 1. Main parameters of carbon emission calculation from straw burning

Crop types	Ratio of grain to straw	Open combustion ratio/%[6]	Combustion efficiency[7]
wheat	1.37	30	0.86
rice	0.63	30	0.89
corn	2.00	30	0.92
beans	1.50	30	0.68
oil	2.00	30	0.82

Note: the ratio of grain to straw comes from China Rural Energy Industry Association.

Net carbon dioxide emissions increased at a rapid rate from 2005 to 2010. Because of the implementation of "western Development strategy", Sichuan's economy has developed in an all-round way, which has greatly accelerated the rise of steel, chemical and other heavy and chemical industrial enterprises in Sichuan, and increased their dependence on energy, leading to a straight rise in total direct carbon emissions. The rate of growth slowed after 2010, and net carbon dioxide emissions reached the peak in 2014. Then net carbon dioxide emissions declined from 2014 to 2018, but increased in 2019 compared to 2018. The absorption of carbon dioxide by forests is relatively stable, and energy consumption determines the trend of net carbon dioxide emissions. Therefore, the use of renewable energy should be increased.

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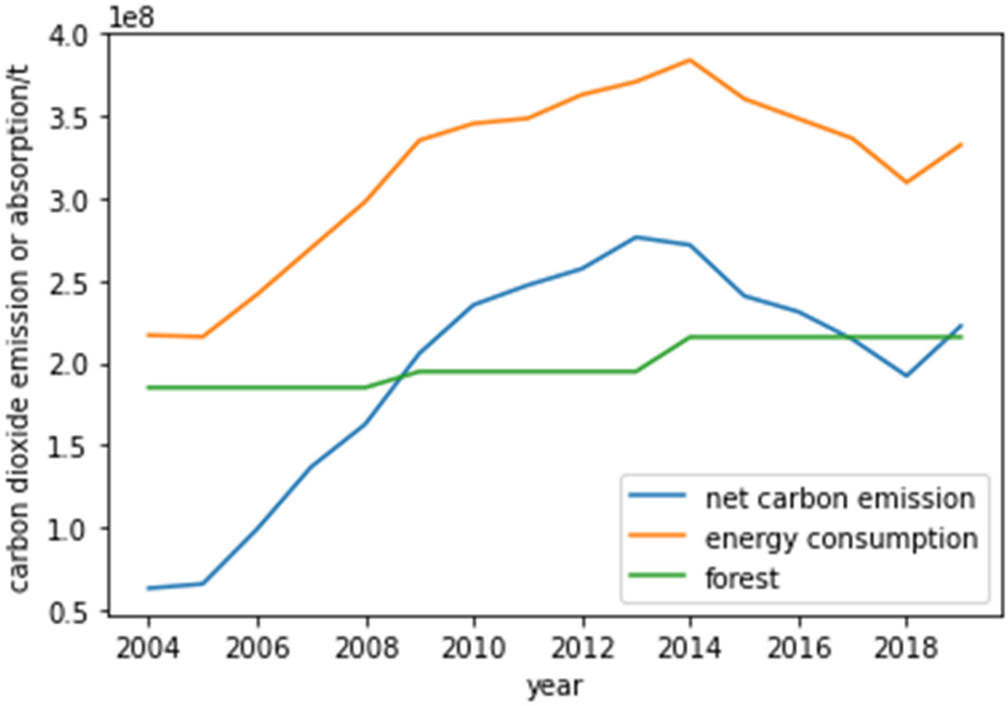

Fig 1. Results

3. Analysis of Influencing Factors

3.1. STIRPAT Extended Model

In the 1970s, Ehrlich et al. put forward the IPAT model and believed that the environmental impact factors were mainly technological level, affluence and population[8]. However, Ehrlich believes that the factors affecting the environment are complex, and the IPAT model has limitations in explaining the factors affecting the environment[9]. Subsequently, Dietz et al. retained the multiplicative structure of IPAT model and established a stochastic model, namely STIRPAT, on its basis to analyze the non-proportional impact of these factors on carbon emissions[10]. STIRPAT model is an expandable stochastic environmental impact assessment model, which can make up for the deficiency of IPAT model. Relevant influencing factors can be added, modified or decomposed. STIRPAT model is an effective method to quantitatively analyze the environmental drive caused by economic and population factors, as shown in Formula 15:

$$I = \mathrm{a}P^{b}A^{c}T^{d}e \tag{15}$$

In Formula 15, I represent environmental factor. P represents population factor. A represents wealth degree. T represents technological effect. a represents constant term, b, c, d are parameters to be estimated, and e represents error term. This model is a nonlinear model with multiple independent variables, and Formula 16 is obtained after taking logarithms on both sides of the model.

$$\ln I = \ln a + \mathrm{b}\ln P + \mathrm{c}\ln A + \mathrm{d}\ln T + \ln e \tag{16}$$

The reference of elastic coefficient in STIRPAT model explains the relationship between the change of driving factors and the influence of environmental pressure. Based on the STIRPAT model, this paper extends the STIRPAT model by citing two independent variables, industrial structure and energy structure. The extended STIRPAT model is shown in Formula 17:

$$\ln CE = \ln a + \mathrm{b}\ln P + \mathrm{c}\ln A + \mathrm{d}\ln T + \mathrm{e}\ln S + \mathrm{f}\ln E + \ln e \tag{17}$$

In Formula 17, CE represents carbon emission. P is population, expressed as permanent population at the end of the year. A is affluence, expressed in GDP per capita. T is technology level, expressed by the ratio of total energy consumption to GDP. S is the industrial structure, represented by the proportion of the added value of the secondary industry in GDP. E is the energy structure, represented by the ratio of coal consumption to total energy consumption.

3.2. Results of Influencing Factors

SPSS was used to carry out ordinary least square's regression analysis and multicollinearity test for carbon emissions and all influencing factors. The results showed that the variance inflation factor (VIF value) of all variables was greater than 10, especially the VIF value of affluence was as high as 384.56, indicating that there was serious multicollinearity among variables. The specific fitting results were shown in the table 2.

Table 2. The results of regression analysis

variates	coefficient	Standard error	Standardized Coefficients	Student's t test	VIF
Population size	3.968	3.236	0.498	1.334	15.111
Affluence	0.349	0.44	1.67	0.887	384.56
Industrial structure	1.443	1.051	1.416	1.526	93.512
Technical level	0.124	0.574	0.344	0.235	231.489
Energy structure	0.073	0.35	0.243	0.226	125.677
constant	-18.422	26.861		-0.752	

Note: R-squared is 0.936.

From the regression coefficient, population size, affluence, industrial structure, technological level, energy structure and carbon emissions are all positively correlated. Population size plays the most important role in promoting carbon emissions, followed by industrial structure. Affluence, technology and energy structure have little impact on carbon emissions.

4. Conclusion

In this paper, we calculate the net carbon emissions of Sichuan province from 2004 to 2019 by calculating various carbon sources and sinks. STIRPAT extended model is used to analyze the dynamic effect relationship between carbon emissions and various influencing factors in Sichuan province, which is expected to promote the development of energy conservation and emission reduction and the realization of green and low-carbon life in Sichuan Province.

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