

Research on Shanxi's CO₂ Emissions Peak Based on STIRPAT Model*

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Abstract—The global greenhouse gas emissions peak has become a sensitive issue in the area of international climate governance. It is of great significance to study Shanxi's CO₂ emissions peak which affects China's CO₂ emissions peak target achieve by 2030 or earlier. Based on the brief analysis of the status quo of the social economy and the carbon emissions in Shanxi, this paper firstly makes the regression for the data of the carbon emissions, population, GDP per capita and carbon intensity from 2005 to 2014 based on STIRPAT model. Then, we set up 8 scenarios to estimate the peak time and peak amount of Shanxi's CO₂ emissions. If the rate of decline in carbon intensity is relatively faster than the rate of growth in per capita GDP, Shanxi's CO₂ emissions peak around 2030. Otherwise, it would not peak before 2040. In order to peak earlier, Shanxi should focus on improving energy saving technology and increasing the use of clean energy.

Keywords—CO₂ emissions; STIRPAT model; peak forecast

I. INTRODUCTION

Climate change governance is a long-term challenge for the sustainable development of human society. And how to reduce CO₂ emissions is the most difficult. To achieve emissions peak as soon as possible is not only the demand of China's efforts to maintain the image of a major country, but also a necessary measure to cope with various environmental

and economic issues exposed in the current rapid development. However, the cooperation and coordination of all provinces and cities are essential to realize China's CO₂ emissions peak target early.

Shanxi is a typical resource-based province in the central region of China with heavy industry as the dominant industry which leads to a high proportion of fossil energy consumption and large-scale CO₂ emissions. The coal-dominated road has failed to meet the new requirements for Shanxi's economic development in the new normal of economy. So, research on the peak amount and peak time of Shanxi's CO₂ emissions, for the country, will affect China's CO₂ emissions peak target achieve by 2030 or earlier. For itself, it will help to clear emission reduction targets, formulate energy-saving and emission reduction policies effectively and promote a smooth transition to low carbon type on the industrial structure, then leading to the healthy development of social economy and the achievement of the "Green Shanxi".

The outline of this paper is as follows. Section 1 presents the importance of studying Shanxi's CO₂ emissions peak. Section 2 offers a review of the domestic research on CO₂ emissions peak. Then, we analyze the status quo of Shanxi from three aspects including economic situation, energy consumption situation and CO₂ emissions situation by using three variables (population, per capita GDP and carbon emission intensity) in the STIRPAT model. Next, we make a time series regression analysis for the data from 2005 to 2014, and analyze the effect of the three variables on the carbon emission based on the STIRPAT model, then setting different scenarios to predict the peak amount and peak time

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of Shanxi's CO₂ emissions. Finally we summarize the analysis results.

II. LITERATURE REVIEW

This section summarizes the literature about CO₂ emission peak and the model used from the whole China and provincial regions.

On the national level, the EKC curve is the first tool used to predict CO₂ emissions peak. Zhu and Wang [1] calculate the future inflection point of China's energy consumption, and then predict CO₂ emissions peak based on improved EKC. Qu and Guo [2] use the scenario analysis method to simulate different scenarios and obtain the conclusion that the technology is the most important factor based on the STIRPAT model. They also consider that CO₂ emissions peak depends on the match between the decline in carbon intensity and the growth of social economy. If the former is faster than the latter, the technology will promote the peak to achieve early, on the contrary, China's CO₂ emissions would not peak before 2050. According to the current trend of China's carbon intensity decline and social economy development, that is, the carbon intensity declines reasonably relative to the steady development of the economy, China will peak in the period from 2020 to 2045. Chai and Xu [3] start with the logic of the reversed transmission and the multi-stage governance, then summarize the general trend by comparing the energy and emissions peak of the industrialized countries and setting four scenarios of dark-green, light-green, light-blue and dark-blue based on the GAMS platform and the IAMC model. The results show that China is expected to reach the carbon emissions peak in the period from 2025 to 2030 at about 12.5 billion tons and the per capita at slightly higher than 8 tons. At the same time, they conduct a coordinated and balanced analysis on the China's future energy and climate security, future economic and climate security, and put forward the policy recommendations to respond to the new situation of the energy production and consumption under the new normal of the economy. Zhou and Mi [4] establish the MARKAL-MACRO model to explore China's energy consumption trends, then set benchmark and optimization scenarios to forecast the peak value and peak time of China's CO₂ emissions under different energy consumption models. The results show that the peak will appear earlier in the optimization scenario than in the benchmark scenario, and China's CO₂ emissions peak in 2029 at 9.5 billion tons in the former while the latter in 2036 at 10.8 billion tons.

On the provincial regions level, Deng and Sun [5] also use the STIRPAT model and build up the time series regression based on the data from 1990 to 2012 in Shanxi, Qinghai, Gansu, Ningxia and Xinjiang to predict the peak time and peak value of CO₂ emissions in five provinces in northwest, and conclude that the effect of technology on peak is more important that is similar with the viewpoint of Qu and Guo. The difference is that Deng and Sun explore the impact of wealth on the peak time by introducing the variable of wealth production in further, and find that the increase in per capita GDP will promote the peak realize early under the current case that the wealth ecological

resilience is rich. Qi and Lin [6] find that there is the co-integration relationship between economic growth and carbon emissions based on the panel data of six provinces nearly 20 years. Under the new normal of the economy, CO₂ emissions will peak before 2030 through improving technology, building a unified carbon trading market, establishing carbon finance centers, cross-regional cooperation and synergistic governance.

At present, the studies of CO₂ emissions peak mostly take China as a whole, with few provinces and cities as the research object. In the past two years, some scholars have begun to study CO₂ emissions peak in the region, such as the five provinces in northwest and the six provinces in central. But the specific province or city is still limited. Although few scholars have study CO₂ emissions peak in some municipalities or developed provinces, such as Beijing and Shanghai. There is still a lack of research on Shanxi province with the high energy consumption. Therefore, this paper will study the peak time and peak value of Shanxi's CO₂ emissions based on the existing research.

III. THE STATUS QUO OF SHANXI'S SOCIO ECONOMIC DEVELOPMENT AND CO₂ EMISSIONS

A. The Status Quo of Economy

This paper tries to explore the status quo of Shanxi's economy regarding the regional GDP as an important research index. The total GDP, population and per capita GDP in Shanxi from 2005 to 2014 are showed in "Table I".

TABLE I. TOTAL GDP, POPULATION AND GDP PER CAPITA IN SHANXI FROM 2005 TO 2014

Year	GDP (1000 Yuan)	Total population (10000 Yuan)	Per capita GDP (Yuan)
2005	42998417	3355.21	12854
2006	49600091	3374.55	14739
2007	61257757	3392.58	18104
2008	74271005	3410.64	21834
2009	73563828	3427.36	21516
2010	91888284	3574.11	26249
2011	112141991	3593.28	31292
2012	121265818	3610.83	33666
2013	126652500	3629.80	34984
2014	127614900	3647.96	35070

^a. Note: The data comes from Shanxi Statistical Yearbook 2015.

As showed in the "Table I", the GDP per capita has been generally rising from 2005 to 2014, reached to RMB 35070 in 2014. In this period, the GDP per capita declined only in 2009 because of the 2008 global economic crisis. The economic growth slowed around 2014 because our economy gets into the "New Normal". This means that China's economic development will enter a new cycle, which is no longer pursue the total GDP blindly and expand the economic scale unlimitedly. Instead, China pays more attention to optimize the industrial structure, maintain economic growth smoothly and emphasize high quality and adequate quantity. In the new normal, Shanxi that has been relying on the coal resources to develop economic mainly in the past years is undoubtedly facing a huge challenge, and carbon emissions trends will also be a new situation.

The population of Shanxi Province increased overall and rose more rapidly from 2009 to 2010. The rising rate is relatively stable before 2009 and after 2010. The number of resident population is 36.4796 million at the end of 2014. At the same time, the release of the second child policy and the change in the conception of child-bearing will affect the trend of the population in the future to some extent in Shanxi.

A. The Status Quo of Energy Consumption

The terminal energy in Shanxi mainly include the raw coal, coke, petroleum products, washing coal and other washing coal, electricity, natural gas, coal gas and other specific energy. "Fig.1" shows the changes of all kinds of energy consumption.

The terminal energy consumption increased overall, but the growth slowed down from 2007 to 2009 and after 2013. The change trends of the energy consumption and economic development are roughly the same. From the energy consumption structure, the electricity consumption is the most, while the washing coal and other washing coal consumption are the least. From the trends of all kinds of energy consumption, wash coal and other washing coal and oil products fluctuate slightly. The electricity consumption increases overall but slows down after 2013. The raw coal and coke have been slowing down in the recent years. On the contrary, the natural gas and coal gas are increasing because of the advocacy of environment protection, energy saving and green economy.

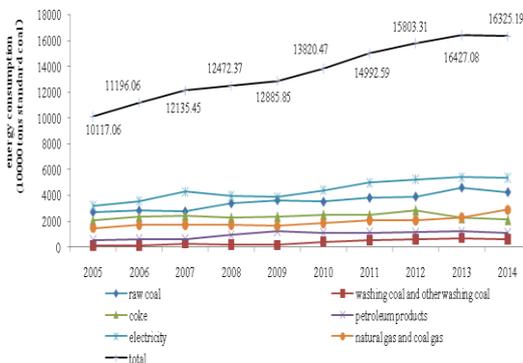


Fig. 1. The trends of terminal energy consumption from 2005 to 2014 in Shanxi Province.

B. The Status Quo of CO₂ Emissions

Most academic researches on the CO₂ equate energy-related CO₂ emissions to the actual CO₂ emissions for convenience. This paper intends to calculate Shanxi's CO₂ emissions through the way above.

The formula for calculating carbon emissions is:

$$I = \sum F_i \times EF_i \quad (1)$$

In the (1), *I* am the CO₂ emissions (unit: 10000 tons). *F_i* is the terminal energy consumption of the *i* (unit: 10000 tons of standard coal). *EF_i* is the discharge coefficient of the *i*; *i* is the kind of energy, including coal, coke, petroleum products, washing coal and other washing coal, electricity, natural gas

and coal gas. The terminal energy consumption is derived from the *Shanxi Statistical Yearbook* from 2006 to 2015. This paper adapts the emission factor of standard coal which comes from the energy research institute of the National Development and Reform Commission because the unit of the quantity of energy consumption is the standard coal.

It can be seen from "Fig. 2" and "Fig. 3" that Shanxi's CO₂ emissions increased by years from 2005 to 2013, reaching 403 million tons in 2013. There is a slight fall in 2014 which may due to the decrease of the raw coal and washing coal consumption and the increase of the natural gas consumption. The intensity of carbon emissions declined overall only increasing in 2009 because of the economic crisis. It shows that with the gradual improvement of the economic development level, the emission reduction will become more and more difficult and the rate of technological progress will decrease gradually.

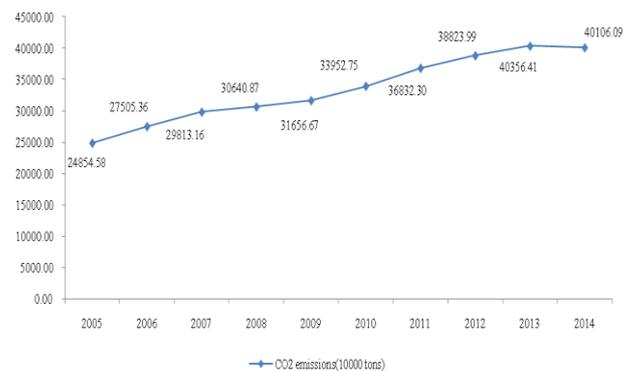


Fig. 2. The trend of carbon emissions in Shanxi Province from 2005 to 2014.

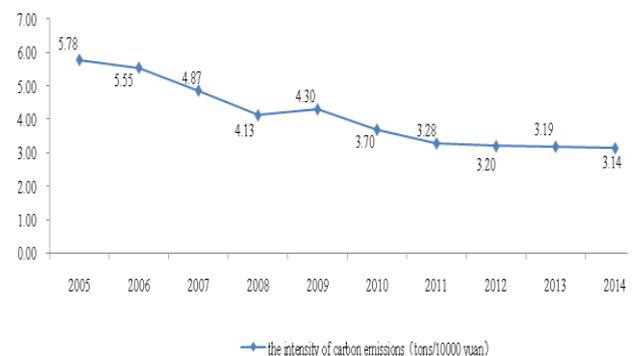


Fig. 3. The trend the intensity of of carbon emissions in Shanxi Province from 2005 to 2014.

IV. THE ANALYSIS OF CARBON EMISSIONS FACTORS AND PEAK FORECAST

A. STIRPAT Model

The prediction methods of CO₂ emissions peak used to be EKC curve, LEAP model, IAMC model, IPAT model (including derived IPACT model) and STIRPAT model. The

latter two are commonly used. The IPAT model usually studies the effect of the variants on the dependent variable by changing the factor while keeping other factors fixed. However, the STIRPAT model can analyze the nonlinear effect of various factors on carbon emissions and add random items which make up the limitation of IPAT model. This is why the STIRPAT model is used in this paper.

The basic expression of the STIRPAT model is:

$$I_i = aP_i^b A_i^c T_i^d e_i \quad (2)$$

After logarithmic transformation, the expression is:

$$\ln I_i = a + b \ln P_i + c \ln A_i + d \ln T_i + e_i \quad (3)$$

In the (2) and (3), I is energy-related CO₂ emissions. a is the fixed effect. P is the total population, calculated as the resident population. A is the wealth, expressed as per capita GDP. T is the technology i.e. the intensity of carbon emissions (the total CO₂ emissions divide by the total GDP), as shown in "Table II".

TABLE II. THE DESCRIPTION OF THE VARIABLES USED IN THE MODEL

Variables	Definition	Unit
CO ₂ emissions (I)	energy-related emissions	CO ₂ 10000 t
Population (P)	total population	10000
GDP per capita (A)	total GDP/ population	Yuan
carbon intensity (T)	CO ₂ emissions / total GDP	tons/10000 Yuan

^b Note: The data comes from Shanxi Statistical Yearbook 2015.

Next, this paper explores the overall trend and the key factors of Shanxi's CO₂ emissions based on the time series regression for the data from 2005 to 2014. Then, this paper sets different scenarios to study the peak value and time.

A. Analysis of the CO₂ Emission Factors

Use the time series data of the CO₂ emissions shown in "Fig. 2", the total population, and the per capita GDP shown in "Table I" and the carbon intensity shown in "Fig. 3" from 2005 to 2014 to research the effect of the last three factors on the overall carbon emissions in Shanxi.

Form of the original model:

$$\ln I_i = a + b \ln P_i + c \ln A_i + d \ln T_i + e_i \quad (3)$$

In this paper, the EViews is used to regress the data generated after logarithmic transformation. The result is as follows:

$$\ln I_i = -7.800 + 0.7331 \ln P_i + 1.057 \ln A_i + 1.058 \ln T_i + e_i \quad (4)$$

(-4.055) (3.383) (13.725) (8.889)

^c Note: The brackets are t values, $p = 0.000$.

R^2 is 0.99988 referring that the model has better fitting goodness and indicating that in the period from 2005 to 2014, 99.98% of $\ln I_i$ changes can be explained by the change of the other three variables, which can be tested by the overall significance of the model. In this paper, the significance level is 0.01, $t_{0.005}(8) = 3.355$, the t test values of the above three variables are greater than 3.355, which illustrates that the three variables are significant.

Comparing the coefficients of the three variables in the regression model (2), it can be seen that the factors of Shanxi's CO₂ emissions are carbon intensity, per capita GDP and population in order, and the effect of the population is relatively small. Therefore, in the following paper, we explore Shanxi's CO₂ emissions peak focusing on the situation that the technology and economy are at different development rates.

B. Scenario Analysis and Forecast of Shanxi's CO₂ Emissions Peak

1) *Scenarios setting*: Herman used the scenario analysis [8], [9] for the first time in "2000" in 1967. The scenarios refer to the different development patterns set to achieve the intended target at a given time in the future. In the different patterns of development, the models are given different parameter values to predict the corresponding target values. This paper sets up the scenarios reasonably according to the three factors influencing the CO₂ emissions in the STIRPAT model. Then, using the regression model 2 above to measure the specific CO₂ emissions from 2015 to 2040, analyze and compare the peak time under different scenarios.

Using the forecasting path scheme set up by Qu and Guo in the study of China's CO₂ emissions peak [2], we suppose that three basic modes of Shanxi's social and economic development from 2015 to 2040 are: low mode, medium mode and high mode. The medium mode refers to the normal rate of change according to current economic policy planning. In the low mode three variables are set with a lower increase compared to the medium mode while the high mode is set with a slightly higher speed. Next, the combination of low, medium and high modes will lead to another six development modes: high-low mode, high-medium mode, medium-low mode, medium-high mode, low-medium mode and low-high mode. Among them, the high, medium and low are relative. The high-medium model is set in which the rate of increase in population and per capita GDP is faster than the rate of decline in carbon intensity, namely, population and per capita GDP grow at the higher rate meanwhile the intensity of carbon emissions declines at moderate rate. The high-low mode is set in which the population and per capita GDP have the higher rate, carbon intensity with the lower rate. According to this method, the first two variables as a whole increase with the same rate and the intensity of carbon emissions as a separate variable declines with the rate different from the previous two, setting up other modes. For the last low-high model, since the carbon emissions fluctuates slightly when the population and per capita GDP grow at a lower rate, the carbon intensity will not decline at a higher rate. So there are eight scenarios excluding the last one that does not meet the actual situation, specifically with reference to "Table III", the five new modes derived are intended to focus on the impact of the growth rate of technology on carbon emissions.

TABLE III. THE PRESENTATION OF 8 SCENARIOS

Scenario	The explanation of the growth rate
<i>low mode</i>	all variables with low rate
<i>medium mode</i>	all variables with medium rate
<i>high mode</i>	all variables with high rate
<i>high-medium mode</i>	high rate (Variable 1 and variable 2), medium rate (Variable 3)
<i>high-low mode</i>	High rate (Variable 1 and variable 2), low rate (Variable 3)
<i>medium-high mode</i>	medium rate (Variable 1 and variable 2), high rate (Variable 3)
<i>medium-low mode</i>	medium rate (Variable 1 and variable 2), low rate (Variable 3)
<i>low-medium mode</i>	low rate (Variable 1 and variable 2), medium rate (Variable 3)

^d. Note: the population as variable 1, per capita GDP as variable 2, and carbon intensity (technology).

The setting of the population growth rate in the scenarios must take into account the "two-child" policy that began in October 2015 and a series of realistic factors. The liberalization of comprehensive two-child policy will stimulate a part of couples with fertility to give birth to the second child, thereby increasing the second child's fertility rate. However, some reality factors can hinder the unrestricted rise in the second child's fertility rate, such as the high parenting costs, the disadvantages of the social support environment, and the heavy work pressure. According to the "Shanxi Statistical Yearbook 2015", we can see that the natural population growth rate shows a general trend of decline from 2005 to 2014. The average resident population is 3501.632 million per year with the average natural growth rate of 5.6 ‰, slightly higher than the national rate of 5.02 ‰ in the same period. In this paper, the population is expected according to the "Chinese population may peak in 2030" mentioned in the world population outlook made by the United Nations in 2013. Because of the above factors, after the implementation of a comprehensive

two-child policy, the average annual growth rate of Shanxi is 6 ‰ from 2015 to 2020, 5 ‰ from 2021 to 2025, 3.5 ‰ from 2026 to 2030, 2.5 ‰ from 2031 to 2035, 1‰ from 2036 to 2040.

The annual growth rate of GDP should be set considering the trend of economic slowdown in the new normal of economy, and according to the Shanxi Provincial Government Work Report in 2016, the data of the macroeconomic operation laboratory of the Chinese Academy of Social Sciences and the economic forecasting department of National Information Center. The GDP growth is set at 6.5% from 2015 to 2020, 5.5% from 2021 to 2025, 4.5% from 2026 to 2030, 4% from 2031 to 2035 and 3.5% from 2036 to 2040.

The expected setting of the three variables above is the growth or decrease of the medium mode, the low mode is slightly lower and the high mode is slightly higher, as shown in "Table IV".

TABLE IV. THE COMBINATION OF PARAMETER SETTINGS TO THE POPULATION GROWTH, ANNUAL GDP AND CARBON INTENSITY PREDICTION PARAMETERS FROM 2015 TO 2020

Mode	Variable	2015-2020	2021-2025	2026-2030	2030-2035	2036-2040
<i>Low</i>	P (%)	0.5	0.4	0.25	0.15	0
	A (%)	5.5	5	4	3.5	3
	T (%)	-4	-3.5	-3	-2.5	-2
<i>Medium</i>	P (%)	0.6	0.5	0.35	0.25	0.1
	A (%)	6.15	5.5	4.5	4	3.5
	T (%)	-5.5	-5	-4.5	-4	-3.5
<i>High</i>	P (%)	0.7	0.6	0.45	0.35	0.15
	A (%)	7	6	5	4.5	4
	T (%)	-7	-6.5	-6	-5.5	-5
<i>High-medium</i>	P (%)	0.7	0.6	0.45	0.35	0.15
	A (%)	7	6	5	4.5	4
	T (%)	-5.5	-5	-4.5	-4	-3.5
<i>High-low</i>	P (%)	0.7	0.6	0.45	0.35	0.15
	A (%)	7	6	5	4.5	4
	T (%)	-4	-3.5	-3	-2.5	-2
<i>Medium-high</i>	P (%)	0.6	0.5	0.35	0.25	0.1
	A (%)	6.15	5.5	4.5	4	3.5
	T (%)	-7	-6.5	-6	-5.5	-5
<i>Medium-low</i>	P (%)	0.6	0.5	0.35	0.25	0.1
	A (%)	6.15	5.5	4.5	4	3.5
	T (%)	-4	-3.5	-3	-2.5	-2
<i>Low-medium</i>	P (%)	0.5	0.4	0.25	0.15	0
	A (%)	5.5	5	4	3.5	3
	T (%)	-5.5	-5	-4.5	-4	-3.5

2) *Scenarios analysis*: According to the above scenario setting modes, we calculate the total amount of GDP, the total population, the per capita GDP and the carbon intensity in each period, and then predict Shanxi's CO₂ emissions by the regression model 2. The results obtained are shown in "Table V".

TABLE V. THE CARBON EMISSIONS PEAK TIME AND PEAK AMOUNT OF SHANXI FROM 2015 TO 2040 UNDER 8 SCENARIOS

Mode	Peak time	Peak amount (million tons)
<i>Low</i>	Can't reach the peak before 2040	-
<i>Medium</i>	2028	49704.20
<i>High</i>	2023	49568.81
<i>High-medium</i>	Can't reach the peak before 2040	-
<i>High-low</i>	Can't reach the peak before 2040	-
<i>Medium-high</i>	2025	48948.05
<i>Medium-low</i>	Can't reach the peak before 2040	-
<i>Low-medium</i>	2029	49632.90

According to "Table V" and "Table IV", it can be seen that Shanxi's CO₂ emissions peak before 2040 under the medium, high, medium-high and low-medium modes. On the contrary, the peak will not appear before 2040 under the low, high-medium, high-low and medium-low modes. Since the 8 scenarios are set according to the match between the rate of economic growth and the rate of decline in carbon emission intensity, there is no peak in the short period when the decline rate of carbon emission intensity is lower than the growth rate of the economy, such as the high-low and medium-low mode in Table 6. In addition, if the decline of the carbon emission intensity is faster than the growth of the economy, it will push the peak arrive as soon as possible, such as the medium and high modes.

Under the modes that Shanxi's CO₂ emissions peak before 2040, the peak value is about 500 million tons, while some scholars estimate the peak value of Shanxi about 600 million tons. It should be noted that in this paper, the actual CO₂ emissions is equivalent to energy-related CO₂ emissions. And for the convenience of calculation, the basic unit of energy consumption is 10,000 tons of standard coal. For the above two reasons, Shanxi's CO₂ emissions peak predicted in this paper is slightly smaller.

V. CONCLUSION

According to the analysis of the factors and the forecast of the peak of Shanxi's CO₂ emissions in this paper, it can be found that the effect of carbon emission intensity on CO₂ emissions is critical, reflecting the pace of technological progress. China's emissions reduction commitment to the world means that provinces and cities are facing a new stage of emission reduction. For Shanxi with high energy consumption and carbon emissions, how to maintain a reasonable decline in carbon emission intensity is particularly important. We put forward two suggestions. Firstly, Shanxi should improve the annual energy efficiency and the replacement rate of the renewable energy and increase the use of clean energy. Secondly, Shanxi should establish the carbon trading centers, making carbon trading systems and regarding the carbon emissions as a kind of invisible goods to constrain high emissions behavior.

It is worth noting that, technological progress plays a key role in the early arrival of the peak. However, we must not allow carbon emissions peak sudden collapse and ignore the risks which bring in the development of the social economy. In order to achieve carbon emissions peak, we need to consider the various fields of the social and economic development combining with the actual situation of Shanxi and pay attention to gradual realization of low-carbon transition so as not to have too much negative impact and make the emission reduction implement smoothly.

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