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CIRCULAR ECONOMY DEVELOPMENT PHASE RESEARCH BASED ON THE IPAT EQUATION: THE CASE OF SHAANXI

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In recent years, the worsening of the quality of the air has urged more people to attach great importance to circular economy. Shaanxi, abundant in natural resources, maintained the GDP growth rate of 14.9% during the period of the twelfth five-year plan. However, the fast economic growth under the extensive traditional economic growth mode renders Shaanxi inadequate in resources supply and noticeably worse in ecological environment issues. With the method of the IPAT equation, this paper quantitatively analyzes the developmental stage and the developmental level of the circular economy of Shaanxi to cover the shortage of the previous studies having only been focused on the policy study and the practice mode. The result shows that Shaanxi is in the intermediate stage of circular economy and the advanced stage has an apparent advantage over the intermediate one by comparing their energy consumption and solid pollutant discharge. The development experience of Shaanxi, a typical province of China, has guidance and reference significance to China and other developing countries.

Keywords: circular economy, IPAT equation, burden on the environment, stage of development, level of development

JEL Classification: Q56, Q57

INTRODUCTION

The average of 29.9 smog-affected days nationwide is reported this year, which is an increase of 10.3 days in comparison with the same period in the past years, reaching the highest historical record since 1961, according to the Green Book of Climate Change Annual Report on Actions to Address Climate Change, issued by the Chinese Academy of Social Sciences and China Meteorological Administration (2013). The PM 2.5 of the Xi'an City of Shaanxi Province has been found to exceed the limits frequently and its air quality has once been listed at the bottom nationwide. From January to October 2013, Xi'an ranked among the last ten cities with poor monthly air quality for 6 times amongst the 74 cities.

The worsening of the quality of the air urges more people to think about their ambient environment. Circular economy, as put forward by K. E. Boulding

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(1961), is a new business development model under the guidance of sustainable development, contrary to the traditional linear economy, characterized by resources-products-waste; the new mode is universally cherished and valued across the world for its increasing the efficiency of the utilization of ecological resources, reducing environmental pollution and tackling the long-standing contradiction among the resources shortage, environment pollution and economic growth.

During the period of the twelfth five-year plan, the GDP of Shaanxi Province maintained the growth rate of 14.9%. Shaanxi is abundant in natural resources; however, the fast economic growth under the extensive traditional economic growth mode renders Shaanxi inadequate in resources supply and noticeably worse in ecological environment issues. Recently, Shaanxi has spared no efforts in vigorously developing its circular economy. Due to the weak economic foundation, the development of the circular economy remains at a low level nationwide. The dissertation is centered on the research into the domestic circular economy theories and the empirical study.

Xu Jiu-ping and Li Bin (2010) put forward China's pattern of the circular economy of low carbon from energy conservation, emission reduction and energy structure. Qi Jian-guo (2005) indicates that, due to a small corporation scale, the lack of the scale support, the unreasonable economic mechanism and the policy system, the level of the development of China's circular economy is low and improves slowly. Li Ning, Ding Si-bao and Zhao Wei (2011) computed the space difference of the development of the circular economy in China and called for the quantitative measurement of circular economy. Ye Wen-Hu and Gan Hui (2009) analyze and integrate the existing perspectives of circular economy and point out the system construction and the evaluation of the regional circular economy, a relationship between circular economy and economic growth, a comprehensive analysis of the international experience are the emphasis of research. Jiang Tao and Zhang Tian-zhu (2007) establish the fuzzy comprehensive evaluation model of the coal industry to develop recycling economy and take Shanxi Province as an example for an empirical analysis. Tang Tian-zi (2005) summarizes the historical experience and a review of circular economy in developed countries. P. Wang, F. Che, S. Fan and C. Gu (2014) construct the enterprise circular economy accounting information disclosure model with Chinese characteristics and find that ownership governance and institutional pressures mainly determine the quality of circular economy. D. Giurco, A. Littleboy, T. Boyle, J. Fyfe and S. White (2014) explore future interlinked questions arising in circular economy for responsible supply chains, additive manufacturing and metals recycling.

The findings show that an overwhelming majority of the past research into the Chinese circular economy focus on the policy model and the practice model research, with few of them concentrating on the quantitative research of the development phase and the level of circular economy, and a specialized study of the development of circular economy in Shaanxi Province is none.

Based on those studies, this paper puts forward the concept of the development phase of circular economy and the measure, taking Shaanxi Province as an example, and calculates the phase of the development of the circular economy of Shaanxi Province. Besides, the environment load is predicted through the IPAT identity in the actual stage (assuming that the environment load drop speed remains the same) and the advanced stage (assuming that the GDP growth remains the same); thus, differences between the two stages can intuitively be compared in order to highlight the importance of developing circular economy.

IPAT EQUATION

The equation was first put forward by demographer P. R. Ehrlich (Ehrlich & Raven, 1964). M. R. Chertow (2000) tracks the various forms the IPAT equation has taken over 30 years as a means of examining an underlying shift among many environmentalists toward a more accepting view of the role technology can play in sustainable development. Jiao Wen-xian and Chen Xing-peng (2012) analyze the characteristics of carbon emissions from energy consumption and its composition of Gansu Province from 1990 to 2009, and explore the utility of the IPAT identity in an environment impact assessment. X. Ru, Y. Liu, L. Su and S. Chen (2012) find the evolutionary process of carbon dioxide emissions driven by technical advances over time to generally follow in sequence the three inverted U-shape curves in the long run, based on the IPAT equation. T. Yue, R. Long, H. Chen and X. Zhao (2013) determine the optimal CO_2 reduction path for Jiangsu Province will have achieved the target of 40–45% reduction of the CO_2 emissions intensity by 2020, based on the 2005 level, using the IPAT model combined with the scenario analysis.

The IPAT equation describes the multiplicative contribution of the population (*P*), affluence (*A*) and technology (*T*) to the environmental impact (*I*):

$$I = P \times A \times T \tag{1}$$

In the equation (1), *I* stands for the environmental impact (resources, energy depletion and waste discharge); the variable *P* represents the population of an area; the variable *A* stands for affluence, namely the GDP *per capita*, $A = GDP/P$. The variable *T* in the equation represents the environmental impact generated by the per-unit GDP.

If wastewater is taken as an example, the equation (2) is listed as below:

$$\begin{matrix}Wastewater\\production\end{matrix} = P \times \frac{GDP}{P} \times \frac{Wastewater\ production}{GDP} \tag{2}$$

If resources depletion is taken as an example, the IPAT equation is listed as below:

$$\begin{matrix}Resources\\consumption\end{matrix} = P \times \frac{GDP}{P} \times \frac{Resources\ consumption}{GDP} \tag{3}$$

Cause $P \times A = GDP$, therefore, *G* represents the GDP, so the IPAT equation will be:

$$I = G \times T \tag{4}$$

The environmental impact is the GDP multiplying the environmental impact per unit of the GDP.

Assuming the environmental impact of the benchmark year is I_0, then:

$$I_0 = G_0 \times T_0 \tag{5}$$

In the equation (5), G_0, T_0 respectively represent the environmental impact of the GDP and per unit of the GDP in the Benchmark Year, so the environmental impact in the Year *n* after the Benchmark Year should be:

$$I_n = G_n \times T_n \tag{6}$$

In the equation (6), G_n, T_n respectively stand for the environmental impact of the GDP and per unit of the GDP in the Year *n* after the Benchmark Year:

$$G_n = G_0 \times (1 + g)^n \tag{7}$$

In the equation (7), *g* represents the annual GDP growth rate from the Benchmark Year to the Year *n*:

$$T_n = T_0 \times (1 - t)^n \tag{8}$$

In the equation (8), *t* stands for the annual declining rate of the environmental impact per unit of the GDP from the Benchmark Year to the Year *n*.

Substitute the equations (7) and (8) into (6), so:

$$I_n = G_0 \times (1+g)^n \times T_0 \times (1-t)^n \tag{9}$$

$$= I_0 \times (1+g)^n \times (1-t)^n \tag{10}$$

The equations (9) and (10) are the other forms of the IGT equation. Given the Benchmark Year I_0 or G_0, T_0 and *g*, the *t* value, the I_n of the environmental impact in the Year *n* could be calculated.

Equation (9) can be simplified as follows:

$$I_n = G_0 \times T_0 \times (1 + g - t - g \times t)^n \tag{11}$$

Conferring from the equation (11), the I_n variation could be figured out in three conditions while increasing the GDP growth: (1) when $1+g-t-g \times t>1$, I_n goes up annually; (2) when $1+g-t-g \times t=1$, I_n remains the same; (3) when $1+g-t-g \times t<1$, I_n declines annually. Therefore, the condition (2) is the critical condition to keep I_n the same and the economic development level has nothing to do with the environmental impact; the critical value of *t* could be calculated as:

$$t_k = \frac{g}{1+g} \tag{12}$$

or

$$g = \frac{t_k}{1 - t_k} \tag{13}$$

On the basis of t_k, changes in the environmental impact in the course of economic growth are available on three occasions: (1) $t < t_k$, the environmental impact per unit of the GDP increases every year; (2) $t = t_k$, the environmental impact per unit of the GDP remains the same, i.e. namely it decouples with economic growth; (3) $t > t_k$, the environmental impact per unit of the GDP declines every year.
Looking at the equation (12) $t_k = g / (1+g)$: while the g value goes up, the t_k value is greater, but smaller than g. Please refer to Table 1 through the formula (12).

Table 1 The $t_k = g / (1+g)$ calculation

g	0.01	0.02	0.03	0.04	0.05	0.06	0.07
t_k	0.0099	0.0196	0.0291	0.0385	0.0476	0.0566	0.0654
g	0.08	0.09	0.10	0.11	0.12	0.13	0.14
t_k	0.0741	0.0826	0.0909	0.0991	0.1071	0.1150	0.1228

Source: Authors

Judging from Table 1, with the g value going up, t_k becomes greater and the gap between $g - t_k$ is greater. The more rapid the GDP growth, the more difficult the decoupling becomes (Geng & Doberstein, 2008; Geng, Sarkis, Ulgiati & Zhang, 2013; Su, Heshmati, Geng & Yu, 2013). No matter how simple the equation may seem, it is of great importance to build a resources-conservative and environment-friendly society.

THE ESTABLISHMENT OF THE DEVELOPMENT PHASE OF CIRCULAR ECONOMY

The Relationship between Circular Economy and Decoupling

Circular economy is an eco-economic model requiring resources conservation and environmental protection in the course of economic development. It might be expressed in terms of two indicators: economic growth and the environmental impact (Li Dong, 2004). Fu Xiu-yong (2008) analyzes the relationship between economic growth and environmental pollution in an underdeveloped area by the regression method and finds a strong positive relationship between economic development and environmental pollution. Zhang Jun, Zhao Xiao-gui, Chen Dong-ge and Wu Zhu-dong (2009) calculate the environment load with the GDP and energy consumption as the parameters in Shaanxi Province in 2000-2007. The existing studies have revealed a strong relationship between economic growth and the environmental impact but have rather paid little attention to their limits and prediction.

The development of circular economy is primarily guided by the three principles of reducing, reusing and recycling, to increase the utilization of resources and diminish environmental pollution with the intention of bringing about the harmony of economic returns and a contribution to the society and environmental protection. The decoupling value is the critical value of the environment impact during the development of an economy. The environmental impact value can specifically refer to the value of energy depletion, an exhausted fume emission and solid waste disposal, which are important indexes used to evaluate circular economy. Therefore, the environmental impact value is in other words the import development index for circular economy. Based on the analysis of the environmental impact value, the development status could be analyzed on macro-economic circular development. The decoupling value is reached when the environmental impact reaches the critical value; when such things occur, economic growth will no longer give rise to an increase in the environmental impact. The development of circular economy could be deemed to be serving its purpose when it brings about the harmony of economic returns and environmental protection. In this sense, decoupling can be considered to be the index value in a certain phase of the development of circular economy (Deng Hua & Duan Ning, 2004).

The Model of the Development Phase of Circular Economy

Since the first proposal for speeding up the development of circular economy by the Central Economic Working

Conference in 2004, certain progress has been made regarding it; however, a great deal of issues still remains. Different development phases of circular economy still exist all over the country, with some regions reaching a relatively high level of development and the majority of regions still on the threshold. As per the economic development planning issued by the Central Government, the specific development will be measured by concrete development indexes. On account of various development levels among different regions, the difficulty of implementing and fulfilling the indexes will vary respectively. Some of the indexes are inappropriately laid down for those regions with the poor foundation of the development of circular economy. Consequently, this dissertation, based on the IPAT equation, puts forward the concept of the circular development phases aiming at providing more accurate references for relevant authorities to formulate development indexes. Simultaneously, the dissertation intends to urge relevant authorities or organizations to become fully aware of their status of circular development and tackle development issues, promoting a sound and rapid circular economy through an analysis of the development phases of circular economy.

Judging from the foregoing analysis, we are aware of the fact that industrial economic growth and the environmental impact will hold their decoupling status in case circular economy development has reached a certain level. Assuming that the current annual economy growth rate of the GDP is g, according to the equation (12), the following conclusion will be made: $t_k = g/(1+g)$, which is a critical status. At such a moment, economic growth is deemed to have decoupled with the environmental impact with t_k as the decoupling value, whereas in actual development, the annual decline rate t of the environmental impact per unit of the GDP constantly changes. The discussion is divided into four circumstances:

1. Let $t=t_1$, and t_1 is much smaller than t_k, for example, $t=0$ or $t<0$, g remains the same, then, in the equation (11) $I_n = G_0 \times T_0 (1+g-t-g\times t)^n$, $(t+g_t)$ is almost zero or greater than zero, energy consumption per unit of the GDP is more and more substantial or even increases without any decline. The environmental impact increases every year, and does so in a huge amount.
2. Let $t=t_2$, and $t_1<t_2\le t_k$, g is the same, then in the equation (11) $I_n = G_0 \times T_0 (1+g-t-g\times t)^n$, $(t+g_t)$ will have an effect on I_n but it cannot reach the status of decoupling. It demonstrates that certain environmental protection is formed, but still under environmental pressure.
3. Let $t=t_3$ and $t_3=t_k$, g remains the same, then in the equation (11) $I_n = G_0 \times T_0 (1+g-t-g\times t)^n = G_0 \times T_0 = I_0$. I_n remains the same. In the same period, economic growth and the environmental impact basically decouple.
4. Let $t=t_4$, and $t_4>t_k$, g remains the same. Then, in the equation (11) $I_n = G_0 \times T_0 (1+g-t-g\times t)^n < I_0$. The environmental impact declines every year. Economic growth and the environmental impact completely decouple.

According to the four circumstances, circular economy is divided into four phases: the initial phase, the intermediate phase, the advanced phase and the super phase.

1. Initial Phase: $t=t_1$. It refers to that in spite of the fact that a production loss is controlled according to circular economy requirements, the standard is not highly set, efforts are not intensified and control is not strictly carried out. The rules and stipulations as well as the requirement of circular economy are not practically implemented with the low resource-production rate and environmental efficiency. In this phase, resource consumption is great in intensity and the circular economy system is not soundly established, which is still within the scope of poorly sustainable or unsustainable development. This mode normally concentrates on the impetus of an infinite expansion of economic factors, a full play of production competitiveness, financing, marketing, labor productivity and management to fuel a rapid growth of the system and allow favorable factors to dominate and play the leading role. After turning resources into waste continuously to achieve economic quantitative growth, people spare no efforts in the exploitation of resources and energy and discharge into the

environment the waste and pollution generated in production and the consumption process, giving rise to low resource efficiency and intensive energy consumption. Such a phase, with the unbalanced development of production and consumption and economic growth and environment protection, is hard to continue.

2. Intermediate Phase: $t = t_2$. The production loss is basically controlled pursuant to the circular economy requirements, together with setting up an intermediate standard, implementing rules, stipulations and requirements, increasing the production rate and environmental efficiency, reliving and improving the intensity of resource consumption; however, the production loss is still on the high side, the cost of economic growth is still tremendous, the burden of the resources environment is insufferable. With the sluggish development of circular economy, the restricted factors of the resources environment constraints do not bring its role into full play, restricting sustainable development. Especially, the turning point of the environmental impact or the decoupling of economic growth and resources occurs late, and the gap with developed nations is not bridged but it rather widens. Thus, the pressure of the resources environment under the intermediate phase is still burdening, with unobvious sustainability.

3. Advanced Phase: $t = t_3$. In this phase, the production loss is controlled as per circular economy with the stipulated standards set, relevant requirements fully met, the resource production rate and environment efficiency of a high level, the environmental impact remaining the same, namely reaching the status of decoupling, in which economic growth will have no effect on the environment entering a zero growth period. Circular economy has reached an excellent level and sustainable development is fulfilled. Consequently, under the value of t, the development phase of circular economy is in conformity with China's economic development, which is now referred to as the advanced phase of circular economy development.

4. Super Phase: $t = t_4$. In this phase, circular economy development is beyond the requirements, with the environmental impact declining annually and obviously. Decoupling has been formed for economic growth and environment consumption, eventually to the negative growth period, which is the highest return available for circular economy development. This phase is deemed to be the super phase of circular economy.

In view of a different Benchmark Year, the annual GDP growth rate varies and the general mode can be summarized (Table 2) according to the formula (11):

I_0 is the environmental impact of the Benchmark Year, g stands for the annual GDP growth rate from the Benchmark Year to the Year n and t represents the annual declining rate of the environmental impact per unit of the GDP from the Benchmark Year to the Year n.

The four phases of circular economy development are illustrated according to Table 2, as presented in Figure 1:

As illustrated by Figure 1, with the different values of the environmental impact declining rate t per unit of the GDP, the respective development phase will be determined. As long as the t value falls within

Table 2 The circular economy development model

IPAT Equation	t Value ranges	Phases
$I_n = I_0 \times (1+g)^n \times (1-t)^n$	t_1 much smaller than $t_k = g/(1+g)$, close to 0, or even < 0	Initial
	$t_1 < t_2 \leq t_k = g/(1+g)$	Intermediate
	$t_3 = t_k = g/(1+g)$	Advanced
	$t_4 > t_k = g/(1+g)$	Super

Source: Authors

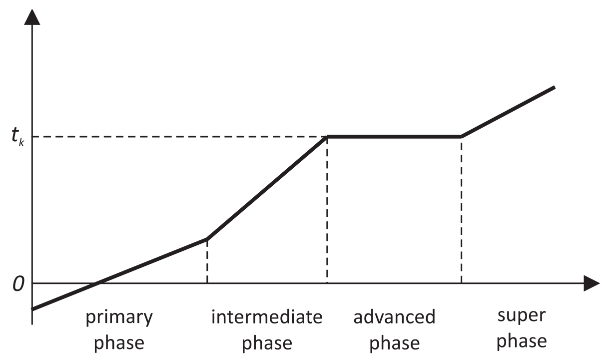

Figure 1 The circular economy development phases

Source: Authors

the range of the advanced phase in decades to come, sustainable economic growth will be realized with the better control between economic development and the resource environment. If *t* falls below the advanced phase, it is indicative of circular economy development failing to achieve anticipated results. Measures should be taken for improvement and moving the *t* value upward till it fits within the advanced phase or even in the zone of the super phase.

THE EVALUATION OF THE CIRCULAR ECONOMY DEVELOPMENT PHASE IN SHAANXI

The Status Quo of Circular Economy Development in Shaanxi

In recent years, under the correct leadership of the Shaanxi Provincial Party's Committee and the Provincial Government, the Circular Economy Promotion Law of the People's Republic of China has earnestly been implemented throughout the province and all decisions and arrangements by the Central Committee and the State Council in relation to circular economy are actively carried out. Local laws and regulations supportive of circular economy, such as the Regulations on the Promotion of Circular Economy in Shaanxi, the Circular Economy Development Plan of Shaanxi Province During „the Twelfth Five-Year Plan", the Regulation on Energy Conservation in Civil Buildings in Shaanxi Province. The pilot demonstration of circular economy is organized from cities, industrial zones and enterprises. The Yangling demonstration zone in Yulin City has been identified as the national circular economy pilot city. Xi'an Goods & Materials Recycling Company Sino-steel Xi'an Machinery Co., Ltd. and Shaanxi fast auto drive Refco Group Ltd. are awarded to be the national circular economy pilot companies. Some circular economy pilot units at the provincial level are also designated in the key industries and industrial zones with Xi'an's economic and technological development zone, Shaanxi Shenhua Power Co., Ltd. and the Hancheng Longmen national ecological demonstration zones having been selected from within the total of the 23 candidates. Energy conservation, the reduction of emissions, clean production and the comprehensive utilization of resource activities are organized in order to promote innovative technology in circular economy in the fields of power, coal, steel, nonferrous metal, chemicals, building materials and automobile, which is a high energy consuming and resource dependant.

The key projects in circular economy, such as the comprehensive utilization of coal, oil gas and salt, the semi-coke comprehensive treatment, the comprehensive utilization of coal ash, tail slag comprehensive utilization in Southern Shaanxi and the gangue generating electricity technology are all implemented so as to promote the development of circular economy in production, circulation and consumption.

The foregoing only introduces the circular economy development work in terms of a macroscopic view. It only displays that the circular economy work has been conducted but does not actually mean that it boosts economic development. Now, based on the t value calculation of the IPAT equation, to determine the circular economy development phase model, the development phase of Shaanxi Province will be analyzed in figures.

As the environmental impact can specifically refer to energy consumption or waste residue discharge, the energy consumption index will be researched into for the convenience of the analysis. By collecting data from the China Statistical Yearbook and the Shaanxi

Statistical Yearbook, the GDP growth rate and the annual declining rate of energy consumption per unit of the GDP of Shaanxi Province from 2007 to 2011 are listed as accounted for in Table 3. The GDP growth data are from the China Statistical Yearbook.

Table 3 The relevant Shaanxi province data from 2007 to 2011

	2007	2008	2009	2010	2011
GDP annual growth rate g	13.9%	15.8%	16.4%	14.6%	14.9%
t-annual declining rate of energy consumption per unit of the GDP	3.41%	4.55%	5.94%	4.56%	4.64%
t_k	12.20%	13.64%	14.08%	11.97%	12.73%
t_k-t	8.79 %	9.09%	8.14%	7.41%	9.09%

Source: Authors

According to Table 3, t is much smaller than t_k, The development of the circular economy of Shaanxi Province can be deemed to be below the intermediate phase. During the five-year period from 2007 to 2011, $t_k - t$ remains at 7.41% - 9.09%, which indicates that Shaanxi did not make any strides in its circular economy development and the development is still at a low level. It is obvious that Shaanxi was promoting the development of circular economy but the effects have not proved to be quite satisfying. A regulation will be addressed to move the phase up to the advanced level.

The Analysis of Circular Economy in Different Phases in Shaanxi

The Prediction of the Environmental Impact in the Advanced Phase

During the eleventh five-year period, the average annual growth rate was 14.9%. If the growth rate continues, the environmental impact critical value of Shaanxi Province will be t_k = 12.97%. Now, assuming that Shaanxi has already entered into the advanced phase, taking 2011 as the benchmark, from the year 2011 to the Year n, the t value (the annual declining rate of the environmental impact per unit of the GDP) is set to be equivalent to the decoupling value of 12.97%. With the intention of an easy calculation, the value of the annual GDP growth rate and decoupling is rounded up to the nearest number, 15% and 13%, respectively. In this sense, the environmental impact on the Year n derived from the equation (10) is:

$$I_n = I_{2010}(1+15\%)^n(1-13\%)^n = 1{,}005^n I_{2010} \tag{14}$$

The analysis is conducted for several specific environmental impact value indexes based on the equation (14).

A. Energy consuming indexes

$$\text{Energy consumption} = P \times \frac{GDP}{P} \times \frac{\text{Energy consumption}}{GDP} \tag{15}$$

The energy consumption of Shaanxi Province in the Year n, $E_n = E_{2010}(1 + 15\%)^n (1 - 13\%)^n = 1.005^n E_{2010}$. The predictions for the Years 2015, 2030 and 2050 are listed below:

$E_{2015} = 1.005^5 E_{2010} = 1.0253 E_{2015}$

$E_{2030} = 1.005^{20} E_{2010} = 1.1048 E_{2015}$

$E_{2050} = 1.005^{40} E_{2010} = 1.2207 E_{2015}$

Given the fact that the energy consumption of Shaanxi in 2011 was 92.38 million tons, the total energy consumption in 2015, 2030 and 2050 will be 94.72 million tons equivalent of coal, 102.06 million tons equivalent of coal and 112.77 million tons equivalent of coal.

B. Solid waste production

$$\text{Solid waste production} = P \times \frac{GDP}{P} \times \frac{P}{\text{Solid waste production}} \tag{16}$$

The solid waste production of Shaanxi Province in the Year n, $S_n = S_{2010}(1 + 15\%)^n(1 - 13\%)^n = 1.005^n S_{2010}$. The predictions for the Years 2015, 2030 and 2050 are listed below:

$S_{2015} = 1.005^5 \, S_{2010} = 1.0253 \, S_{2015}$

$S_{2030} = 1.005^{20} \, S_{2010} = 1.1048 \, S_{2015}$

$S_{2050} = 1.005^{40} \, S_{2010} = 1.2207 \, S_{2015}$

Given the fact that the solid waste production of Shaanxi in 2011 was 69.86 million tons, solid waste production in 2015, 2030 and 2050 will be 71.63 million tons, 77.18 million tons and 85.27 million tons, respectively.

The Prediction of the Environmental Impact in the Current Phase

Based on the analysis of the foregoing, the circular economy development of Shaanxi is in its intermediate phase. Judging from the declining rate of energy consumption per unit of the GDP, the annual declining rate of the environmental impact is 3.7% on average, rounded up to 4%. Similarly, through analyzing the energy consumption and solid waste production by means of the GDP growth rate of 15% during the eleventh five-year period, if the current status continues, the following equation is derived from the equation (10) for the environmental impact in 2015, 2030 and 2050.

$$I_n = I_0 \, (1+15\%)^n \, (1-4\%)^n \tag{17}$$

A. Energy consuming indexes

$$\begin{matrix} \textit{Energy} \\ \textit{consumption} \end{matrix} = P \times \frac{GDP}{P} \times \frac{\textit{Energy consumption}}{GDP} \tag{18}$$

The energy consumption of Shaanxi Province in the Year n, $E_n = E_{2010} \, (1+15\%)^n \, (1 - 4\%)^n = 1.104^n \, E_{2010}$. The predictions for the Years 2015, 2030 and 2050 are listed below:

$E_{2015} = 1.104^5 \, E_{2010} = 1.6400 \, E_{2015}$

$E_{2030} = 1.104^{20} \, E_{2010} = 7.2340 \, E_{2015}$

$E_{2050} = 1.104^{40} \, \mathrm{E}_{2010} = 188.8835 \, E_{2015}$

Given the fact that the energy consumption of Shaanxi in 2011 was 92.38 million tons in the Year n, the total energy consumption in 2015, 2030 and 2050 will be 151.51 million tons equivalent of coal, 668.28 million tons equivalent of coal and 17449.05 million tons equivalent of coal.

B. Solid waste production

$$\begin{matrix} \textit{Solid waste} \\ \textit{production} \end{matrix} = P \times \frac{GDP}{P} \times \frac{P}{\textit{Solid waste production}} \tag{19}$$

The solid waste production of Shaanxi province in the Year n, $S_n = S_{2010}(1 + 15\%)^n(1 - 4\%)^n = 1.104^n \, S_{2010}$. The predictions for the Years 2015, 2030 and 2050 are listed below:

$S_{2015} = 1.104^5 \, S_{2010} = 1.6400 \, S_{2015}$

$S_{2030} = 1.104^{20} \, S_{2010} = 7.2340 \, S_{2015}$

$S_{2050} = 1.104^{40} \, S_{2010} = 188.8835 \, S_{2015}$

Given the fact that the solid waste production of Shaanxi in 2011 was 68.9 million tons, solid waste production in 2015, 2030 and 2050 will be 114.57 million tons, 505.36 million tons and 13195.86 million tons, respectively.

The Comparison of the Environmental Impact between the Advanced and Intermediate Phases

Sorting the results of the analysis of The Prediction of the Environmental Impact in the Advanced Phase and The Prediction of the Environmental Impact in the Current Phase, we obtain Table 4:

Table 4 The comparison of the environmental impact between the advanced and intermediate phases

		Advanced phase	Intermediate phase
Energy consumption (10,000 tons equivalent of coal)	Year 2015	9472	15151
	Year 2030	10206	66828
	Year 2050	11277	1744905
Solid waste production (10,000 tons)	Year 2015	7163	11457
	Year 2030	7718	50536
	Year 2050	8527	1319586

Source: Authors

The data comparison is made with Table 3; it is obvious that the environmental impact in the advanced phase goes up gradually year by year, with a small increasing amount, whereas the amount of an increase in the intermediate phase is substantial with the passage of time. In the year 2015, the comparison is not apparent for the two phases; in the year 2050, however, the indexes values in the intermediate phase are huge, but the gap with the advanced phase widens more and more. The advantages of the advanced phase are increasingly obvious in the long run. Certainly, this is a prediction not taking the other factors into account. Judging from the prediction, if the extensive economic development of Shaanxi Province fails to improve circular economy, the loot of the resources will be increasingly severer with devastating environment destruction. The limitation of the resources will not tolerate the continuously growing economy. Therefore, a regulation must be taken with respect to Shaanxi's economic development moving up to the advanced phase. Only in this way can a sustainable development of the economy be promoted and the entire society continue to develop sustainably as well.

CONCLUSION

Based on the analysis of the IPAT equation, we put forward the concept of the development phase of circular economy and set up the model for it. By our carrying out the analysis of Shaanxi's circular development and by doing research into its development data, an evaluation of Shaanxi's circular economy development is conducted in order to make a conclusion that Shaanxi is still in the intermediate phase of the development of its circular economy. By means of analyzing the IPAT equation and by comparing energy consumption and solid pollutants, which are the two indexes in the intermediate and advanced phases of the development of circular economy, the analysis shows that the advantages of the advanced phase are obvious and a conclusion is drawn that moving from the intermediate phase to the advanced phase is indispensable.

However, this paper does not consider the dynamic of environment pollution and the influence of the surrounding area; because of the complexity of China's economic development and the Chinese Government's emphasis on environmental pollution control, a constant GDP growth and the environmental load drop speed may be open to question. It is necessary that the research scope should be expanded in the country and that a space measurement method should be introduced in order to examine the regional influence. We should make sure that he dynamic changes of economic development and environmental protection are also considered.

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