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Influencing Factors and Emission-Reducing Potential on Carbon Emission in the Industrial Sectors of Economic Underdeveloped Areas - A Case Study

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This study selected Shanxi province as one typical study object, and investigated the influencing factor of carbon emission and its emission-reducing potential of Shanxi industrial sectors in the past ten years, in order to understand the main emission-reducing factors and provide related policy recommendations. The result showed that the industrial output was the main positive influencing factor on industrial carbon emission growth, while the effect of energy intensity was the main negative influencing factor; in the non-energy exploitation and raw material processing industries, the carbon emission displayed the decreasing trend with the lower degree, while the output effect in Chemical Fibre Manufacturing industry presented the negative trend. The increases of carbon emission ranked top three in the energy exploitation, raw material processing, and manufacturing industries in Shanxi.

1. Introduction

Global climate change has brought a serious challenge for the sustainable development of economic society in the world, and also in China. As the largest developing country, China has played one more important role in promoting the environment issues in terms of energy conservation and emission reduction (Chen, 2009). In 1980, the Energy Conservation Law was issued, and then in September, 2012, the pilot carbon emission permit trading was kicked off in China. Also, on Jan, 13rd, 2014, the Notice regarding the greenhouse gas emission report in key enterprises and public institutions was issued by National Development and Reform Commission to improve the basic statistics and accounting work system of greenhouse gas emission at three levels of country, locality and enterprise, and intensify the control of greenhouse gas emission in key unit. This research investigated the influencing factor of carbon emission and its emission-reducing potential of industrial sectors. Then related policy recommendations were provided in Shanxi province as one typical study object.

2. Method

2.1 Factor decomposition model of CO_2 emission

Factor decomposition is one commonly applied method to analyse the influencing factors of carbon emission. Compared with input-output method, the main advantages of factor decomposition is the acquisition of more sufficient data for easier comparison in the same assumed condition for object of study (Torvanger,1991). Besides, from the technological perspective, the factor composition analyses avoid the unavailability of results from the multicollinearity between different factors in the multivariate statistical analysis (Shrestha, 1996). Sun (1998) proposed a refined Laspeyres index decomposition method which it evenly apportioned the undecomposed residual terms onto the effect of various factors by following the principle “Common creation and fair distribution” in order to realize complete decomposition. To make a contrastive study of different industry sub-sectors in this paper, the refined Laspeyres index decomposition mode (Ang et al., 2000) was adopted. The decomposition model is given as:

$$C_t = E_t * f = \sum_{i=1} Y_{it} * a_{it} * e_{it} * f \quad (1)$$

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Where, C_t is the CO_2 emission by energy consumption in the t year, E_t is the total of energy consumption in the t year, and f is energy emission coefficient; then suppose that the energy emission coefficient in this period is unchanged. The total energy consumed is calculated as the product of output values of all sectors Y_i and the energy intensity e_t of different sectors and output portion a_t. So, relative to the C_t variation a_t the base period t=0, the CO_2 emission in the t year is given as:

$$DC_t = \sum_{i=1} Y_{it} * a_{it} * e_{it} * f - Y_0 \sum_{i=1} Y_{i0} * a_{i0} * e_{i0} * f \quad (2)$$

Therefore, DY means output effect, Da the industrial structure effect, and De energy intensity effect. To understand the influences of different effects on carbon emission, the change of one effect factor in the t year is considered by comparison with base period, with other factors invariant:

$$DC_t = DY_t + Da_t + De_t \quad (3)$$

These three effect factors include effects of single factor change (with other factor unchanged), and also the common influence of these factors. Taking Y as example, it is calculated as:

$$DY_t = \sum_{i=1} (Y_{it} - Y_{i0}) * a_{i0} * e_{i0} * f + \frac{1}{2}\sum_{i=1} R_{Y,S} + \frac{1}{3}\sum_{i=1} R_{Y,S,t} \quad (4)$$

Formula (2) shows the absolute change of carbon emission, while dc=DC/C_0 means the relative changes (%), so the dy, da, and de were obtained in this way, where dy, da, de and dc is the relative quantity of output effect, structure effect, energy intensity effect, and total emission effect respectively.
The carbon emission intensity is calculated according to the CO_2 emission of domestic industrial output in Shanxi. It is given as:

$$T = Q * NCV * CEF * 44/12 \quad (5)$$

Where, T: CO_2 emission, Q: energy consumed, NCV: net calorific value of energy, CEF: carbon emission coefficient by IPCC, and the number 44 and 12: CO_2 and carbon molecular weight; the CO_2 emission factor of standard coal is calculated to obtain the 2.7725 tons CO_2 per one ton of standard coal (t CO_2/tce) (IPCC, 2011).

2.2 Decoupling analysis model construction based on factor decomposition

Generally, the evaluation standard for low carbon economy is negative growth degree of the greenhouse gas emission with the economic growth (Guo et al., 2007).The transformation to low carbon economy is the process of continuous decoupling between economic growth and greenhouse gas emission, i.e. the carbon emission intensity increases at the lower speed than economic growth (Robert et al., 2002). The decoupling index D is applied to measure the decoupling, D=E/F. Where, D: decoupling index, E: environment index, and F: dynamic factor. The index is mainly used to make comparison in the different regions or periods for judging pressure intensity and trend. With reference to the factor decomposition mode of CO_2 emission (Diakoulaki et al., 2007), the emission-reducing contribution by Shanxi in certain period can be expressed in the following two effect factors: industrial structure effect and energy intensity effect. The energy-reducing contribution is expressed by absolute amount (Liu et al., 2015) (DF_t):

$$DF_t = DC_t - DY_t = Da_t + De_t \quad (6)$$

In the process of effective emission reduction, considering the overall function of industrial structure effect and energy intensity effect, the decoupling index by Guo, et al. (2011) was applied in Formula (7), in order to evaluate the effectiveness degree of emission reduction contribution in the separated form between economic growth and CO_2 emission.If DY_i>0, then D_t=- DF_t/ DY_i; if DY_i>0, then:

$$D_t = \frac{(DF_i - DY_i)}{DY_i} \quad (7)$$

At $D_t \geq 1$, it means strong decoupling effect; at $0<D_t<1$, it means weak coupling effect; at $D_t \leq 0$, no decoupling effect.

2.3 Data

In this paper, the value-added of industrial (sectoral) output and energy consumed were cited from Shanxi Statistical Yearbook in 2004-2015, where the industrial sectors were classified into No. X1-X38 according to the sequence in the yearbook, and the value-added of industrial sectoral output was deflated by the producer price index, ignoring the influence of price factor.

3. Results

3.1 Influencing factors on CO_2 emission in Shanxi industrial sectors

3.1.1 Analysis for influencing factors in every period

In Figure1, it can be seen that the overall industrial CO_2 emission has changed greatly, where the output effect dy and energy effect de have the highest impact on the CO_2 emission. The output effect dy has a positive impact on carbon emission growth at a greater variation: in 2004-2008 it increased slowly, in 2008 started to decline rapidly, between 2009-2012 it grew quickly, in 2013 began to take negative effect, and in 2012-2015 it continued to drop. For energy effect, it showed negative effect in 2004-2008, rapidly rose to be positive effect in 2008, then turned back to be negative effect in 2009-2012, finally in 2012-2015 it took positive effects in the increasing trend. But the industrial effect da has varied less, with slight fluctuation in 2009-2012. At last, in terms of total emission effect dc, two fluctuations occur: in 2004-2008, it increased slightly, started to rapidly rise in the following three years since it declined in 2008, then in 2013 it lowered dramatically, finally in 2014-2015 negative value appeared, with the absolute amount of emission similar to de.
To better analyse the periodic characteristics of CO_2 emission by industrial sectors and the related influencing factors, the sample period in 2004-2015 was divided into three stages: 2004-2008, 2008-2012, and 2012-2015. The results are shown in Figure 2.
In 2004-2015, the industrial CO_2 emission has increased by 49.99 % relatively. The economic structure effect and industrial structure effect play a positive role for CO_2 emission, to be 82.27 % and 11.73 % respectively, where it in the periods 2004-2008 and 2008-2012 is similar; but the energy intensity effect has an obvious negative impact on CO_2 emission, to be -44.01 %, where it in the periods of 2004-2008 and 2008-2012 is similar, but contrary to that in the period 2012-2015, which was related to the implementation of industrial structure adjustment policy in industrial sectors in Shanxi recently.

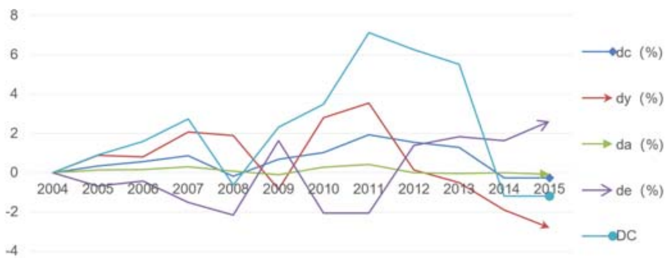

Figure 1: CO_2 emission variation and its decomposition effects in Shanxi industrial sectors in 2004-2015 (Note: DC means the absolute amount of CO_2 change (Million t))

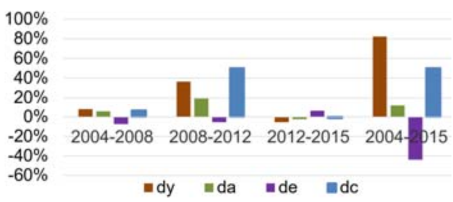

Figure 2: Emission decomposition effect by industrial sectors at different stages

3.1.2 Analysis for influencing factors by all sub-industries

In order to deeply exploit the energy-reducing potential in specific industry sector, the industry is classified into 38 relatively important sub-industries and then numbered in the sequence according to investigation and classification in the national and Shanxi statistical yearbooks rather than dividing the whole industry into 9 major sections by the previous scholars; this classification can help to understand the key industrial points and further analyse the effect in every period on the carbon emission of all industries.
It is shown in Table 1 that in 2004-2015, the total emission effect dc=50.00 %, output effect dy=82.77 % and industrial effect da=11.73 % are both positive influencing factors, and energy effect de=-44.01 % is negative influencing factor.

Table 1: Calculation results of output effect, emission-reducing contribution and decoupling index in Shanxi industrial sectors

No.	Decomposition effect of carbon emission	2004-2015			
		dy	da	de	dc
X_1	Coal Mining and Dressing	625.7	63.34	-326.36	362.68
X_2	Petroleum and Natural Gas Extraction	0.35	0.04	1.11	1.5
X_3	Ferrous Metals Mining and Dressing	33.06	21.86	-51.99	2.94
X_4	Nonferrous Metals Mining and Dressing	0.09	0.12	-0.05	0.16
X_5	Nonmetal Minerals Mining and Dressing	0.04	-0.1	0	-0.07
X_6	Farm Products Processing	31.31	43.81	-45.1	30.02
X_7	Food Manufacturing	25.57	0.73	-17.3	9
X_8	Wine, Beverages and Refined Tea Manufacturing	0.68	0.67	-0.65	0.69
X_9	Tobacoo Products Manfacturing	0.49	0.28	-0.58	0.19
X_{10}	Textile Industry	0.02	0.04	-0.07	-0.01
X_{11}	Textile, Wearing Apparel and Accessories	0.48	0.15	-0.5	0.12
X_{12}	Leather, Fur, Feather and Related Products and Footwear	0.78	0.29	-1.07	0
X_{13}	Timber Processing, Bamboo, Cane, Palm Fiber and Straw Products	0.31	0.33	-0.55	0.09
X_{14}	Furniture Manufacturing	0.05	0.05	-0.09	0.01
X_{15}	Paper Making and Paper Products	0.03	0.06	-0.03	0.05
X_{16}	Printing and Record Medium Reproduction	0.08	0.07	-0.1	0.06
X_{17}	Culture, Education, Art and Crafts, Sport and Entertainment Products	0.02	0.02	-0.02	0.02
X_{18}	Petroleum Processing, Coking and Nuclear Fuel Processing	0.4	1.77	-0.23	1.94
X_{19}	Raw Chemical Materials and Chemical Products	4.26	2.37	-1.54	5.09
X_{20}	Medical and Pharmaceutical Products	6.71	2.7	3.62	13.03
X_{21}	Chemical Fiber Manufacturing	-1.1	-0.04	1.03	-0.11
X_{22}	Rubber and Plastic Products	0.15	0.28	-0.16	0.27
X_{23}	Nonmetal Mineral Products	1.01	1.69	-1.02	1.69
X_{24}	Smelting and Pressing of Ferrous Metals	2.19	5.48	-2.28	5.39
X_{25}	Smelting and Pressing of Non-ferrous Metals	8.96	3.13	-5.42	6.67
X_{26}	Metal Prodcuts	3.03	0.86	-1.8	2.09
X_{27}	Ordinary Machinery Manufacturing	0.03	0.1	-0.21	-0.08
X_{28}	Special Purpose Equipment Manufacturing	1.01	0.9	-0.61	1.3
X_{29}	Automobile Manufacturing	0.25	0.16	-0.56	-0.14
X_{30}	Railroad, Marine, Aviation and Other Transport Equipments Manufacturing	0.13	0.25	0.27	0.65
X_{31}	Electrical Machinery and Equipment Manufacturing	2.08	1.05	-3.09	0.05
X_{32}	Computers, Telecommunication and Other Electronic Equipments Manufacturing	45.02	41.4	-64.8	21.62
X_{33}	Equipments and Instruments Manufacturing	0.22	0.15	-0.27	0.1
X_{34}	Other Manufacturing	0.02	0.01	0	0.03
X_{35}	Comprehensive Utilization of Waste Resources	0.68	0.13	-0.76	0.05
X_{36}	Production and Supply of Electricity, Heat, Gas and Water	5.34	9.54	-5.1	9.79
X_{37}	Production and Supply of Gas	61.14	7.17	-67.37	0.95
X_{38}	Production and Supply of Water	0.06	0.1	0.02	0.18

For total effect of carbon emission, the industry sector X_1 ranks the first, for dc=362.68 %. In Shanxi, with the coal mine as the pillar industry, this industry is the main influencing factor on the carbon emission increasing in Shanxi. Besides, among 38 sub-industries, it has the maximum positive output effect (dy=625.70 %) and max negative energy effect (de=-326.36 %). In terms of dc, only in the industries X_5, X_{10}, X_{21}, X_{27} and X_{29}, it is negative, and these industries have the relatively smaller scale.
For output affect dy, the first 6 sub-industries are X_1, X_{37}, X_{32}, X_3, X_6 and X_7 successively in ranking. In the industry X_{37}, the industrial structure changes have a greater impact on carbon emission, then followed by the

downstream industries of coal mining industry such as X_3 and X_{32}, and finally X_7 and X_6, as one of the eight traditional 8 industries in Shanxi, the industrial adjustment and planning have always been made in Shanxi.
For industrial effect da, the ranking comes to X_1, X_6, X_{32} and X_3 in all industrial structures in Shanxi. Generally, the output effect should keep consistent with it, but there exist some exceptions in the X_7 and X_{37} with the industrial structure effect relatively lower and output effect higher then.
For energy effect de, it is related to the carbon emission intensity. Among all sub-industries, the energy effect and carbon emission effect of X_1, X_6 and X_{32} are both higher, and the energy effect influences carbon emission negatively; besides, in the industries such as X_3, X_7 and X_{37}, the total emission effect is rather lower, although their energy effect has a greater negative impact on carbon emission. Finally, there exist some industries such as X_{20}, X_2, X_{21}, X_{30} and X_{38} where the energy effect influences the carbon emission positively with lower output effect, because of the limited industrial size/scale, indicating that the efficiency can be improved continuously in these industries.

3.2 Influencing factors on CO_2 emission in Shanxi industrial sectors

Based on the decomposition results of influencing factors on CO_2 emission, the decoupling index of CO_2 emission and economic growth was obtained (Table 2).

Table 2: Calculation results of output effect, emission-reducing contribution and decoupling index in Shanxi

Year	Output effect DY_t	Emission-reducing contribution dF_t	Decoupling index D_t
2005	2.28	-0.54	0.61
2006	2.30	-0.25	0.31
2007	6.56	-1.21	0.58
2008	6.59	-2.08	1.09
2009	-2.86	1.54	-2.81
2010	9.52	-1.77	0.63
2011	13.14	-1.63	0.46
2012	0.58	1.40	-9.88
2013	-2.17	1.80	-4.55
2014	-8.52	1.63	-1.86
2015	-12.49	2.53	-1.90

The negative values in 2009, 2012-2015 periods means no decoupling effect. On Jan., 13rd, 2014, the Notice regarding the greenhouse gas emission report in key enterprises and public institutions was issued by National Development and Reform Commission to improve the basic statistics and accounting work system of greenhouse gas emission at three levels of country, locality and enterprise, and intensify the control of greenhouse gas emission in key unit. But the emission reduction hasn't been achieved in the short period. During the time of economic recovery, the industrial emission was still rapidly rising and environment quality deteriorates, so the environment pressure by economic growth increases continuously.
In 2008, $D_t \geq 1$ indicates the strong decoupling effect, because the financial crisis in 2008 influenced the industrial development in Shanxi; the actual emission reduction contribution by means of various emission-reducing policy, measures and implementation is over or equals to the increased emission by economic growth. At higher D_t, the more obvious emission reduction effect shall be achieved, and the industrial structure, energy consumption structure be better optimized; the significant declining of energy intensity further indicates the higher resource utilization efficiency, so that the environment pressure can be relieved greatly, validating the higher effectiveness of existing emission-reducing policy and measures.
In the periods 2005-2007 and 2010-2011, it shows the weak decoupling effect. In 2005-2017, with the rapid economic development in Shanxi, the resource utilization efficiency of scientific technology improved to decrease the CO_2 emission in some degree and improve the economic growth at high consumption. However, in terms of absolute amount, the emission reduction should be less than the increased CO_2 emission by economic growth; otherwise, the total emission keeps increasing so that the effectiveness and efficiency of emission policy and measures cannot be ensured. Thus, the emission-reducing measures and behaviour cannot well help to reach the purpose for optimizing industrial structure and reducing energy intensity. As a result, the industrial emission was still rapidly rising and environment quality deteriorates, so the environment pressure by economic growth increases continuously.

4. Conclusions

It is found above that the CO_2 emission varies greatly in the whole industry, with the output effect and energy effect influencing the CO_2 emission more greatly, and industrial structure effect influencing less. The effective measures should be taken that: more support for the energy technical changes in the public policy of government; the formulation of high-energy industrial development planning, measures and product energy efficiency standard; further implementation of the energy efficiency certification system of product; stricter control of the energy consumption and carbon emission for key products in order to improve its energy utilization efficiency; full support for the development of the industries in the decreasing trend of carbon emission; adjustment of industrial structure.

The carbon emission and economic growth remain in the fluctuation state; with economic growth, the bottleneck occurs to the resource utilization efficiency of unit output (Subash et al., 2018). Due to lower output values and higher carbon emission in such industries as raw material processing, energy exploitation, and manufacturing etc., there will be greater emission reducing potential, so it is necessary to improve the energy utilization rate as well as expand its scale by prohibiting the low-level repeated construction, eliminating the backward production capacity, encouraging technical innovation, and promoting industrial upgrading.

The industries at lower carbon emission intensity have more serious difficulties than those at higher intensity in the emission-reducing process. The emission-reducing potential of these industries should be fully exploited for the purpose of carbon emission control, which is also the key measure for emission reduction in future. To be specific, in these industries, the traditional process should be improved and updated by optimizing the product design and improving equipment manufacturing so as to booster the resource use ratio and reach the average level in the industrial sector.

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