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Original Research Paper

A Study on the Relationship Among Fossil Energy Consumption, Air Pollution, and Economic Development in Hebei Province

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ABSTRACT

Fossil energy supports the normal operation of economic life and has become increasingly important in the development of the national economy. Along with the rapid development of the economy of Hebei Province, problems related to air pollution have become increasingly prominent. Fossil energy consumption accounts for 90% of the total energy consumption of Hebei province, the major driver of which is the combustion of fossil energy. This study collects the time series data of fossil energy consumption and air pollution in Hebei province from 2000 to 2013 and investigates their short- and long-term relationships through co-integration testing and causality testing. A panel model for fossil energy consumption and the economic development of 11 cities in Hebei province is then established, and empirical analysis is conducted using varying-coefficient regression models. Results show that the consumption of fossil energy causes more serious air pollution and constitutes the Granger causality of the aggravation of air pollution. Fossil energy consumption and air pollution are characterized by at least three relationships: a long-term balanced co-integration relationship, a short-term dynamic adjustment mechanism, and a one-way causation. Fossil energy consumption and economic growth are characterized by a long-term co-integration relationship, with regional differences across the 11 cities of Hebei province. Finally, this study proposes relevant suggestions to rationalize the coordinated development between environment and economy, which can ensure the economic growth rate and at the same time reduce the air pollution caused by fossil energy consumption.

INTRODUCTION

Energy is the basic factor of economic growth and a constitutive element of human welfare. Economic growth is related to the welfare of human activities, but such welfare depends on a huge investment on resources, which is not sustainable and can easily exert pressure on the environment. Global warming is an indisputable phenomenon and has serious effects on the welfare of human activities. Beside natural factors, human activities cause climate warming to a greater degree, especially man-made greenhouse gas emissions resulting from the use of fossil energy, which accounts for 60% of the total greenhouse gas emissions. Given the increasing pressure caused by global climate changes and worldwide concerns on climate issues, low-carbon economy has become the goal of the future economic development of all countries. China was the second largest energy consumer in the world until 2006, when its carbon emissions exceeded those of the USA and the country subsequently leaped to the first rank. Hebei province is a large industrial province characterized by a rapidly developing economy and constantly improving living standards. As a result, it currently faces the significant problems of high energy consumption, heavy environmental pollution, and serious ecological damages. These problems tend to increase annually, as shown in Fig.1.

Fossil energy is disposable, non-renewable, and can therefore be easily exhaustible through excessive development and utilization. Fossil energy consumption accounts for more than 90% of the total energy consumption (Table 1). At the same time, the environmental pollution and ecological damage caused by the production and consumption of fossil energy are becoming increasingly serious. Energy and environment related constraints on the economic development are becoming more obvious and are increasingly likely to affect the long-term development of the economy. Despite its development, the overall consumption of clean and renewable energy in Hebei Province remains very low because of limitations in technology and scale. Fossil energy consumption has an overwhelming dominant place in the energy consumption of the province and is therefore likely to worsen the problem of air pollution continuously. Thus, investigating the relationship among fossil energy consumption, environmental pollution, and economic growth is a very urgent and necessary task.

Among the studies on energy consumption and air pollution, Sinton et al. (2000) proposed that energy utilization is closely related to air quality and believed that energy consumption activities are closely related to pollutant emissions and atmospheric environment. Moreover, energy structure

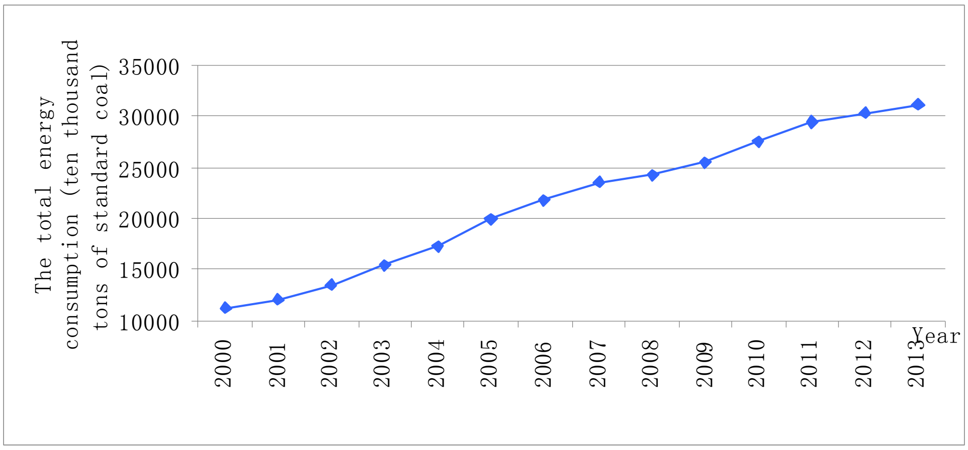

Fig. 1: Total fossil energy consumption in Hebei province.

Table 1: The proportion of total energy consumption in Hebei province.

Year	Coal (%)	Fossil oil (%)	Natural gas (%)	Hydro-electricity (%)
2000	90.94	8.17	0.84	0.05
2001	91.84	7.42	0.70	0.04
2002	91.12	8.15	0.70	0.03
2003	92.78	6.49	0.66	0.07
2004	91.14	8.01	0.75	0.10
2005	91.82	7.45	0.61	0.12
2006	91.59	7.64	0.67	0.10
2007	92.36	6.87	0.68	0.09
2008	92.31	6.67	0.94	0.08
2009	92.51	6.21	1.21	0.07
2010	90.45	7.37	1.44	0.74
2011	89.61	7.73	1.58	1.08
2012	88.8	7.7	1.94	1.56
2013	88.67	7.36	2.19	1.78

Table 2: Correlation coefficients of total energy consumption and carbon emission.

	EN	TP
EN	1	0.941*
TP	0.941*	1

(*is the threshold when the significance level is 5%.)

and motor vehicle pollution are the main causes for urban air pollution. Yong Geng (2008) believed that energy consumption has a great effect on air pollution in the development of China. Xu Ruilin et al. (2004) conducted an empirical study on the relationship between coal consumption and environmental protection in Jiangsu province. Coal has an important role in the economic development of Jiangsu; at the same time, coal consumption produces many pollutants that have significant effects on the environment. Zheng Bofu et al. (2005) established three programs for the prediction and analysis of energy consumption and corresponding environmental problems in the next 50 years in China.

Focusing on the aspect of environmental pollution and economic growth, Selden & Song (1994) investigated four important problems of air pollutant emissions, found an "inverted U" relationship between these four problems and income, and revealed a series of possible evolutionary paths for pollution and environmental quality. Soytas & Sari (2014) tested the relationship between energy consumption and economic growth in G7 and 16 emerging market economy countries through experiments and found a co-integration relationship between these two variables in G7. Chien-Chiang Lee (2004) studied the relationship between energy consumption and long-term GDP growth from 1975 to 2001 in 18 developing countries using a panel data model and found a co-integration relationship between energy consumption and GDP. Huang et al. (2008) investigated the causality between energy consumption and economic growth in 82 countries using panel co-integration. Peng Jiawen et al. (2011) found a long-term co-integration relationship among the three variables of energy consumption, carbon emissions, and economic growth.

Empirical studies show that, given the differences in the selection of research objects, interception of research stages, and method of measurement, the obtained conclusions significantly vary. Thus, if we want to develop a scientifically rigorous and objective national or regional energy environment policy, we must incorporate both the relationship between energy consumption and economic development and that between environmental pollution and economic development in an analytical framework under existing conditions. Based on research methods and related theories of energy, economy, and air pollution at home and abroad, the present study collects the time series data of fossil energy consumption and air pollution in Hebei province from 2000 to 2012 and investigates their long and short term relationship using co-integration testing and causality testing. A panel model is then established for the fossil energy consumption and economic development of 11 cities of Hebei province. An empirical analysis with model regression is also conducted. Finally, the relationship and interaction among the energy consumption, economic growth, and air pollution in Hebei province is discussed, and a theoretical basis is provided for the formulation of sustainable development policies in the province.

METHODOLOGY

Co-integration Theories and Methods

Test of correlation coefficient: The correlation coefficient between fossil energy consumption and air pollution is first calculated using SPSS. A significant correlation between the variables indicates that a strong dependency relation exists between them, which lays the foundation for the ensuing regression analysis.

$$r = \frac{1}{n-1}\sum_{i=1}^{n}(\frac{x_i - \bar{x}}{s_x})(\frac{y_i - \bar{y}}{s_y}) \quad ...(1)$$

Where, r represents the Pearson correlation coefficient between fossil energy consumption and air pollution, x_i and y_i the annual values of fossil fuel consumption and air pollution, respectively, s_x and s_y the standard deviations of fossil energy consumption and air pollution, respectively, $\bar{x}$ and $\bar{y}$ the average values of fossil energy consumption and air pollution, respectively, and n the time length of these two variables.

Unit root test: First, the stability of the variables is tested using the unit root test. The methods usually include Dickey-Fuller test (DF), PP test, and Augmented Dickey-Fuller (ADF) tests. In practice, the ADF test is typically used, whose model is

$$\Delta X_t = \sigma X_{t-1} + \sum_{i=1}^{m} \beta \Delta X_{t-i} + \varepsilon_t \quad ...(2)$$

$$\Delta X_t = \alpha + \sigma X_{t-1} + \sum_{i=1}^{m} \beta \Delta X_{t-i} + \varepsilon_t \quad ...(3)$$

$$\Delta X_t = \alpha + \beta t + \sigma X_{t-1} + \sum_{i=1}^{m} \beta \Delta X_{t-i} + \varepsilon_t \quad ...(4)$$

Where, $\{\varepsilon_t\}$ is the white noise, X_t represents the time series index tested, and Δ stands for the first-order difference of the variable. The null hypothesis is $H_0 : \rho = 1$, that is, $\{x_t\}$ has a unit root (non-stationary), and *t* is the time trend factor. If the value of ADF is less than the Mackinnon threshold, then the series is stationary.

Granger test: Although the co-integration test can determine whether or not a long-term equilibrium relationship exists between *X* and *Y*, further investigation is still needed on whether or not it constitutes a causal relationship. Conducting the regression of *Y* with the past values of *X* and *Y* is better and more persuasive than that with only the past values of *Y*. In the former case, *X* is the Granger cause of *Y*, or it is the non-Granger cause of *Y*. The form of the Granger test is as follows:

$$y_t = c + \sum_{i=1}^{p} \alpha_i y_{t-i} + \sum_{j=1}^{q} \beta_j x_{t-j} + \varepsilon_{t1} \quad ...(5)$$

Where, $\{\varepsilon_t\}$ is the white noise, y_t is the dependent variable, stands for the independent variable, and *t* is the time trend factor. The null hypothesis tested is as follows: *x* is not the Granger cause of y, that is, $H_0 : \beta_1 = \beta_2 = ... = \beta_q = 0$ is usually tested with the *F*-test. If it is greater than the threshold, then the null hypothesis is rejected, and *x* is not the Granger cause of *y*.

Panel data model: To study the influence of fossil energy on the economic growth of different regions, we must consider not only the differences in the economic base and overall geographical advantages of the different regions (cross-section data), but also the effect of national energy industry development policies and systematic factors (time series). However, using only cross-section data or time series, cannot achieve the above goal. To overcome this problem, combining panel data model with time series and cross-section data can simultaneously reflect the change rules and characteristics of research objects in these two directions. Panel data not only greatly increases the amount of observation samples and improves the freedom of samples but also reduces the effect of multiple linear explanatory variables and estimated errors (Li & Pan 2010). The general form of panel data is as follows:

$$\begin{aligned} Y_{it} &= a_{it} + X_{it}\beta_{it} + \varepsilon_{it} \\ X_{it} &= (X_{1it}, X_{2it}, \cdots X_{kit}) \\ \beta &= (\beta_{1i}, \beta_{2i} \cdots \beta_{ki}) \\ i &= 1, 2 \cdots N ; t = 1, 2 \cdots T \end{aligned} \quad ...(6)$$

Where, α_i is the intercept, β_i stands for the coefficient of the explanatory variable, ε_{it} is the white noise, and *K* is the number of explanatory variables. According to different hypotheses of α_i and β_i, the model can be divided into three forms:

Mixed data model: $\alpha_i = \alpha_j, \beta_i = \beta_j$

Variable intercept model: $\alpha_i \neq \alpha_j, \beta_i = \beta_j$ ...(7)

Variable coefficient model: $\alpha_i \neq \alpha_j, \beta_i \neq \beta_j$

The first step in establishing a panel data model is to test which model is suitable for the sample to avoid deviations in model specification and improve the validity of the parameter estimation. The analysis test of covariance is widely used and is mainly conducted with two F statistics:

$$F_1 = \frac{(S_2 - S_1)/(N-1)K}{S_1/[N(T-K-1)]} \sim F[(N-1)K, N(T-K-1)] \quad ...(8)$$

$$F_2 = \frac{(S_3 - S_1)/(N-1)(K+1)}{S_1/[N(T-K-1)]} \sim F[(N-1)(K+1), N(T-K-1)] \quad ...(9)$$

Where, S_1, S_2, and S_3 stands for the RSS of the varying coefficient model, variable intercept model, and mixed data model, respectively, *N* is the number of the cross section sample points, *T* is the time span, and *K* is the number of independent variables. In general, for a given significance level $\alpha = 0.05$, the statistic F_2 is first adopted to determine whether or not it is a mixed model. If F_2 is less than the threshold, then the model parameters are believed to be unrelated to individual changes. Hence, the mixed data model is selected; otherwise, F_1 is adopted to test again. If F_1 is less than the threshold, then the variable intercept model is selected; otherwise, the variable coefficient model is selected.

According to the differences in addressing various individual effects, both the variable coefficient model and the variable intercept model can be divided into fixed and random effect models. Hence, the second step in establishing a panel data model is to select between these two effect models. Housman believed that individual effects in the model should be considered random, although the random effect model is uncorrelated with explanatory variables in the model and some problems exist. Thus, the Housman test is generally used for this kind of selection. The hypothesis of the test is that the individual effects of the random effect model are not related to explanatory variables. The construction of the statistic W in the testing process is as follows:

$$W = [b - \hat{\beta}]\hat{\Sigma}^{-1}[b - \hat{\beta}] \quad ...(10)$$

Where, b is the estimated result of the regression coefficient in the fixed effect model, and $\hat{\beta}$ is the estimation result of the regression coefficient in the random effect model. $\hat{\Sigma}$ stands for the variance of the difference between these two results, that is, $\hat{\Sigma} = \text{var}[b - \hat{\beta}]$. When the null hypothesis is true, *W* is subject to Chi-square distribution with the freedom degree of *K*, under the given significance level. In general, $\alpha = 0.05$ if the statistic *W* is greater than the threshold. The fixed effect model is then selected; otherwise, the random effect model is selected.

Index Selection and Data Sources

Fossil energy consumption: Fossil energy consumption accounts for more than 90% of the total energy consumption; thus, it is represented by the amount of fossil energy consumption (i.e., the unit is 10000 tons of standard coal). This index reflects the total fossil energy consumed in the production and everyday life of the whole country or a certain region in a certain period. It is also the aggregate index of the energy consumption level, structure, and growth rate of a certain region.

Air pollution: Total carbon emission is used to represent air pollution. This index reflects the average greenhouse gas emission from the production, transportation, use and recycling of this product, which can reflect the degree of environmental pollution to a certain extent.

Economic growth: GDP is used to represent the economic growth (i.e., the unit is 100 million Yuan, RMB). To eliminate the effect of price changes, this study considers the GDP index in 2000 as the basis for the calculation of the GDP series of the constant price.

ANALYSIS OF RESULTS

Relationship Between Fossil Energy Consumption and Air Pollution in Hebei Province

Correlation analysis: The analysis of the total energy consumption and carbon emission shows a long-term increasing trend. The correlation analysis table (Table 2) of the total energy consumption and carbon emission shows that the Pearson correlation coefficient of these two variables reaches 0.941, which indicates a significant dependency relation between them. For the sake of convenience, the total amount of energy consumption is represented by EN, and the total amount of carbon emission by TP.

Unit root test: According to Formulas (2)-(4), the extract natural logarithms of the total energy consumption and carbon emission, and *Ln* represent the extracting natural logarithms. DLNEN and DLNTP stands for conducting first-order difference. The specific results of the ADF test are given in Table 3.

Table 4 shows that the ADF values of DLNEN and DLNTP are less than the threshold and that DW is close to 2. Hence, the time series LNEN and LNTP become stationary after the first-order difference, which belongs to the first-order integration.

Co-integration test: The important idea of co-integration is that, even if two or more variables are not stationary, some of their linear combinations may offset the effect of the trend terms, thereby making their combination a stationary vari-

Table 3: Unit root test of total energy consumption and carbon emission.

Variables	ADF Test	Thresholds	AIC	SC	DW	Conclusions
LNEN	2.148	-3.845*	-3.415	-3.315	1.757	No stationary
LNTP	-1.193	-3.056*	-3.656	-3.425	2.052	No stationary
DLNEN	-3.427	-3.277**	-3.334	-3.264	1.989	Stationary
DLNTP	-4.549	-3.089*	-4.505	-4.3723	2.785	Stationary

(*is the threshold when the significance level is 5%, and ** is the threshold when the significance level is10%)

Table 4: ADF test results of the residual regression equation.

Variables	ADF	Threshold	AIC	SC	DW	Conclusions
Resid1	–3.686	–2.973*	–3.521	–3.281	1.917	Stationary

(* is the threshold when the significance level is 5% and ** is the threshold when the significance level is 10%)

able. The important significance of co-integration theory lies in avoiding a long-term equilibrium relationship and the short-term dynamic relationship between the false regression and distinctive variables. This study adopts the Engle-Granger test of two variables, with the following specific steps:

Step 1: The ordinary least squares method is used to estimate the equation between LNRR and LNGDP and calculate non-uniform errors. The estimation equation is

$$LnTP = \underset{(2.06)}{8.452} + \underset{(1.93)}{0.357} LnEN \quad (R^2=0.986) \qquad ...(11)$$

Table 4 shows that the co-integration relationship between LNEN and LNTP reflected in the regression model is true, which shows a long-term and stable relationship between them. The total energy consumption per unit promotes the increase of carbon emission by 0.357 units, indicating that the total energy consumption still has a huge effect on air pollution.

Causality test: Causality refers to the dependency between variables; the variable for the result is determined by the variable for the cause; and changes in the variable for the cause lead to changes in the variable for the result. According to formula (5), the results are depicted in Table 5.

Table 5 shows that, when the significance level is a = 0.05, the hypothesis, EN is not the Granger cause of TP, is rejected during lag phases 2, 3, and 4, which means that energy consumption is the Granger cause of air pollution. This in turn indicates that energy consumption causes serious pollution in the atmospheric environment and that only a one-way Granger causality exists between them.

Relationship Between Fossil Energy Consumption and Economic Growth in Cities of Hebei Province

A panel regression analysis is conducted on the panel data constituted with these two indicators: fossil energy consumption and the economic growth of 11 cities of Hebei province from 2000 to 2013.

Selection and verification of models: According to formulas (8) and (9), the edge value of the F distribution inverse operation is obtained using Stata12.0 and the order of display, inv F. When $F_1 = 3.268 > F_{0.01}(10,132) \approx 2.458$ is obtained, the mixed data model is not selected. When $F_2 = 2.673 > F_{0.01}(20,132) \approx 2.021$, the variable coefficient model should be selected. On this basis, the Housman test is conducted, and the probability of obtaining a random cross-section is 0. Thus, the null hypothesis is rejected, and the variable coefficient model of the fixed effect model should be selected.

The regression equation shows that the estimated values of all the regression coefficients are significant at 1% and that the fitting degree of the equation is very high when R^2 =0.948. F =18.265 indicates that the regression equation is significant on the whole, and $D.W$ = 1.963 indicates that the effect of the regression equation is less significant.

The regression coefficients (Table 6) show that the regression coefficients of Langfang, Qinhuangdao and Handan are very high, indicating that less fossil energy consumption can promote greater economic growth. This observation may be related to the positioning of the three cities, which are still in the early stage of industrialization and need energy consumption to drive their economic growth. Shijiazhuang has the lowest regression coefficient, which means that its economic basis is relatively high, and ordinary energy consumption cannot quickly promote economic growth. Thus, Shijiazhuang should focus on industrial restructuring, strive to develop the tertiary industry, and avoid practices that depend merely on energy consumption to boost its economic development.

Table 5: Granger causality test for total energy consumption and carbon emission.

Null hypothesis	Lagged orders	Values of P	Conclusions
TP is not the Granger cause of EN	2	0.785	Accepted
EN is not the Granger cause of TP	2	0.016	Rejected
TP is not the Granger cause of EN	3	0.554	Accepted
EN is not the Granger cause of TP	3	0.012	Rejected
TP is not the Granger cause of EN	4	0.453	Accepted
EN is not the Granger cause of TP	4	0.004	Rejected

Table 6: Regression coefficients of various cities.

Explanatory variables of all cities	Regression coefficients	Values of *T*
The constant C	154.56	20.45
Shijiazhuang	0.668	2.36
Tangshan	0.965	45.21
Handan	1.987	1.96
Qinhuangdao	2.694	2.35
Baoding	0.765	15.68
Zhangjiakou	0.458	2.68
Chengde	1.023	10.24
Langfang	2.368	4.69
Cangzhou	1.973	2.39
Hengshui	0.846	3.56
R^2 = 0.948, F = 18.265, D.W. = 1.963		

POLICY SUGGESTIONS

Promoting Industrial Structure Optimization and Reducing the Proportion of High-energy Consumption Industries

Adjusting and optimizing the industrial structure is an important way to develop a low-carbon economy and reduce air pollution in Hebei province. In the process of adjusting and optimizing the industrial structure, the development of low-energy consumption industries should be actively promoted and supported, whereas that of high-energy consumption industries should be controlled and restricted. Steel, cement, and other similar industries should be reorganized and restructured in accordance with environmental protection requirements and be guided to gradually achieve a reasonable and healthy development. At the same time, the optimization of industrial structure should focus on the optimization of the irrational structures in the second industry and the traditional enterprises with high energy consumption. High emission and pollution should be phased out, and the tertiary industry with low energy consumption, especially the modern service industry, should be promoted vigorously. The proportion of the service industry in the industry structure should be enlarged and inherent advantages of the service industry, such as low energy consumption, less environmental pollution, and more employment opportunities, should be brought into full play.

Adjusting the Energy Consumption Structure and Exploring the Energy-saving Potential

The energy consumption structure of Hebei province is mainly based on fossil energy consumption, and the resource endowment “rich in coal, lacking in oil and gas” also determines the dominant position of coal consumption. Such energy consumption structure has confronted Hebei Province with not only the contradiction between supply and demand of fossil energy, but also the fact that carbon-based energy is a major form of energy consumption and leads to the problem of high carbon emission. To change the coal-based energy consumption structure, we should vigorously develop clean and renewable energy (e.g., hydropower, wind power, solar energy, and geothermal energy) to achieve diversification of energy consumption. In terms of optimizing the energy consumption structure, we should make full use of the advantages of regional energy, exploit and utilize new energies according to circumstances, develop advanced and efficient energy equipment with low emission, and continuously improve their efficiency and advancement.

Improving the Environmental Protection System and Promoting Energy Conservation and Emission Reduction

We should strengthen the construction of an environmental legal system and protect and promote the healthy development of environmental protection according to laws. Strengthening the construction of an environmental legal system guarantees the protection of the environment and resources. We should reinforce publicity and education in environmental protection knowledge and improve awareness of social environmental responsibility in enterprises and awareness of environmental protection of the public. We should also increase investment in environmental protection, strengthen environmental supervision, improve the investment mechanism of environmental protection, and further clarify the corresponding environmental management fees and protection fees for resource exploitation to achieve the rational allocation of resources in the market and price leverage. The government should give full play to macro readjustment and control, increase financial support to advanced enterprises with energy conservation and emission reduction, and establish special funds for scientific studies to achieve substantial breakthroughs in technology.

Improving the Efficiency of Fossil Energy and Perfecting the Market of Carbon Emission

A high level of technology can improve the utilization efficiency of energy resources and reduce resource consumption and pollutant emission. Hence, we should eliminate outdated technologies, equipment, and production capacity, and accelerate the promotion of new technologies, new processes, and new energy-saving equipment to reduce the energy consumption of the added value and output of wastes. We should develop large enterprises with high scientific and technological content, good economic benefits, low-resource consumption, and less environmental pollution, and release market space and environmental capacity. We should also formulate a reasonable price for carbon emission, make enterprises transform the social cost of their carbon emission into their internal cost, innovate their low-carbon technology, and also shows development directions for their future investment. Only by achieving all this we can build a “low-carbon” Hebei.

CONCLUSIONS

Compared with coastal developed provinces, Hebei province has higher energy consumption. However, to maintain the primary goal of economic growth, it faces tremendous energy consumption with rapid economic development, which also leads to many serious air pollution problems, such as haze. This study collects the time series data of the fossil energy consumption and air pollution of Hebei province from 2000 to 2013 and investigates their short and long term relationships based on co-integration testing and causality testing. A panel model for the fossil energy consumption and economic development of 11 cities of Hebei province is established, and empirical analysis is conducted through the panel unit root test and panel regression. The results show that the consumption of fossil energy causes more serious air pollution and is the Granger causality of the aggravation of air pollution. Fossil energy consumption and air pollution are characterized by at least three relationships: a long-term balanced co-integration relationship, a short-term dynamic adjustment mechanism, and a one-way causation. Fossil energy consumption and economic growth are characterized by a long-term co-integration relationship, with regional differences across the 11 cities of the province. Finally, this paper proposes some suggestions to rationalize the coordinated development between the environment and economy in terms of the following four aspects: (1) promotion of the optimal industrial structure and reduction of the proportion of high-energy consumption industries, (2) adjustment of the energy consumption structure and mining of energy-saving potential, (3) improvement of the environmental protection system and promotion of energy conservation and emission reduction, and (4) improvement of the efficiency of fossil energy and perfecting the market of carbon emission. All these measures can ensure the economic growth rate and at the same time reduce the air pollution caused by fossil energy consumption.

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