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Gray Correlation Analysis of Energy Consumption, Environmental Pollution, and Economic Growth in Subtropical Regions of China: Guangxi and Zhejiang as Examples

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Abstract

Energy usage strongly supports economic growth while also resulting in serious environmental problems. How to effectively use energy to achieve economic growth on the premise of environmental friendliness is an important topic on which to focus in the new century. China is the largest developing country in the world in terms of population. Its subtropical population is close to one half of its total population. The subtropical region is representative of China's regions with delayed economic development. However, the region has a small share of energy resources, including coal, oil, and gas. At the same time, the rapid economic growth of the region in the past three decades has deviated from the theory of resource endowment. Therefore, it is necessary to study the relationship among energy consumption, environmental pollution, and economic growth in China's subtropical regions. The study should be conducive to healthy economic development in China and in the world as a whole. This article calculates the degree of correlation among energy consumption, environmental pollution, and economic growth by means of a gray correlation analysis. The results show that energy consumption drives the development of the economy and causes environmental pollution. Environmental pollution also has negative effects on economic development. With regard to reconciling energy consumption, environmental pollution, and economic growth, technology can be used to improve energy use efficiency and reduce pollutant emissions. Energy consumption structure should be optimized to achieve clean, high-quality energy consumption. Policies should be established to encourage green production, and laws should be enacted to support these policies.

Keywords
energy consumption, environmental pollution, economic growth, gray relational analysis, association analysis

Introduction

Energy has always been an important strategic resource. Human survival, economic development, and social progress cannot be regarded independent of energy. With the industrial revolution, economic development around the world has been accompanied by a massive consumption of energy, at least from the viewpoint of the theory of resource endowment. However, in addition to energy consumption, economic development inevitably brings about various environmental problems. Energy consumption promotes economic development, bringing about environmental pollution. At the same time, environmental pollution hinders economic development, and these factors, feeding one another, lead to an endless circular loop. How to reconcile environment, energy, and economic development has become an important and challenging task in today's world. At present, the economic goal of most major world economies has shifted from rapid growth to higher quality of life.

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Having relied on resource elements in the past, they are now relying more on scientific and technological innovation and human capital reconstruction. More emphasis has been placed on the restriction of resources and on the effects of economic development on the environment. People no longer merely pursue the scale of gross domestic product (GDP) and instead pay more attention to environmental protection and sustainable economic development. The concept of "pollution prevention and control" has been raised frequently on many occasions. Nordhaus and Romer, who were jointly awarded the Nobel Prize in Economics in 2018, are credited with developing award-winning themes related to long-term sustainable economic development. Therefore, it is meaningful to study energy consumption, environmental pollution, and economic growth in a country or region.

China has become the second largest economy and the largest energy consumer in the world, second only to the United States. Geographically, China is divided into northern and southern regions by the Huaihe River and the Qinling Mountains. This boundary line also serves as the dividing line between two different types of climates. The region south of the Huaihe River and the Qinling Mountains has a subtropical monsoon climate. Over the years, China's economic center of gravity has shifted significantly southward, and the population of this region makes up almost half of China's population. This region is a typical example of China's delayed economic growth. Studying the relationship between energy consumption, environmental pollution, and economic growth in China's subtropical regions contributes to the understanding of how the economy develops sustainably in China and in the rest of the world.

Using data for 1947 to 1974 in the United States, a previous study found a one-way causal relationship between economic growth and energy consumption in the United States (Kraft & Kraft, 1978). Domestic and foreign scholars have studied the relationship between energy consumption and economic growth from multiple angles. In 1991, an "inverted U" type of relationship between environmental problems and economic development was proposed, and this view gradually evolved into the Environmental Kuznets Curve hypothesis (Grossman & Krueger, 1991). A series of comprehensive reviews of studies has since been launched (Dinda, 2004; Dinda & Coondoo, 2006; Managi & Jena, 2008; Selden & Song, 1994). One study (Bilen et al., 2008) focuses on Turkey's energy production, energy consumption, and environmental pollution. It is concluded that Turkey has been excessively dependent on imported energy for a long time in its economic development. This not only imposes a serious economic burden on Turkey but also causes serious environmental pollution. An endogenous economic growth model (Schurr, 1972) integrates energy consumption, environmental pollution, and economic growth into the same analysis framework. The research shows that there is a close relationship between energy consumption and environmental pollution, and that environmental pollution is caused by energy consumption and economic growth. The cointegration and ECM simultaneous model (Vahid, Alireza, & Jalil, 2016) are used to study the interaction between the environment and the economy in Iran. It is concluded that in the long run, per capita carbon dioxide emissions, GDP, and energy consumption show the strongest interaction (relation and elasticity) with one another in the model system. Many articles demonstrate that a country's economic growth is closely related to energy consumption and conclude that rapid economic development requires higher energy consumption (Ang, 2007; Bowden & Payne, 2009; Chang, 2010; Ho & Siu, 2007; Lee & Chang, 2005; Li, Liu, Wang, & Liu, 2016; Li, Zheng, Ji, & Li, 2018; Narayan & Smyth, 2008; Sun, Wang, & Li, 2018; Wolde-Rufael, 2004). Others conclude that a country can adopt energy-saving policies to reduce environmental pollution (Halicioglu, 2009; Jobert & Karanfil, 2007; Lee, 2006; Payne, 2009).

Regarding energy consumption demand, energy consumption and economic growth, other authors have continued the analysis (Liu, 2008; Mu, Wang, Ning, & Li, 2011). Using time series data on energy consumption, the environment and economic growth in China from 1985 to 2007, one study adopts the unit root test, cointegration analysis, the error correction model, and the Granger causality test to empirically analyze the relationship between economic growth, energy consumption, and the environment in China (Liu, Cheng, & Ma, 2011). The relationship between China's economic growth and environmental pollution and energy consumption is investigated using a vector error correction model. The Johansen cointegration test and the Granger causality test method are also applied (Yang et al., 2012). The dynamic econometric analysis method based on the VAR model is used in an empirical study of the relationship among the economy, energy, and the environment in Guangxi (Zhang, 2014). The panel cointegration equation, the Panel-data Vector Error Correction Model (PVECM) model, and the Panel-data Vector Autore-gression (PVAR) model are used to explore the interactions among China's environment, energy, R&D, and economic growth (Wu & Ye, 2016).

Although research on energy consumption and environmental pollution has drawn sufficient attention, studies of the relationships among energy consumption, environmental pollution, and economic growth are not frequently found. In many cases, only the bilateral relationship is studied. Furthermore, very little research on the subtropical region has been conducted. Most previous studies revolve around qualitative analysis. A small number of quantitative research studies, most of which are based on the input-output model; regression, clustering, factor, and principal component analysis; and other mathematical statistical analysis methods, have been reported. However, the model requirements are strict, and the models have some inherent weaknesses. For example, they require a large amount of sample data and a reasonable hypothesis of distribution, and a linear correlation between variables is assumed. It is not surprising that the results of these quantitative analyses are inconsistent with the results of qualitative analyses. Therefore, most of the models used are only suitable for situations in which there are few variables and in which the data show a linear relationship. It is difficult for traditional quantitative models to deal with multiple variables and nonlinear variables. The available data on the subtropical environment in China are usually limited, and their completeness is poor. Energy consumption, environmental pollution, and economic growth interact in a multilevel and multifactorial complex system for which only incomplete information is available. Hence, a new method is needed to study how energy consumption, environmental pollution, and economic growth are related.

Methods

Gray Relational Analysis Model

Gray relational analysis is a systematic analysis method based on the gray system theory proposed by Professor Deng Julong, a well-known Chinese scholar. Basically, gray relational analysis judges the closeness of a relationship based on the degree of similarity of the sequence geometry. The closer the curve is to the linear equation, the greater is the correlation between the sequences, and vice versa.

Gray correlation analysis is simple in calculation, clear in order, and requires no particular assumptions about data distribution. As an analytical method of gray system theory, gray correlation analysis is suitable for systems for which information is only partially known. The mathematical model of the gray correlation is presented here.

1. Determine the study sequences

The dependent variable reference sequence, also referred to as the mother sequence, is

$$\text{recorded as } X_0^{(k)} : X_0^{(k)} = [x_0^{(1)}, x_0^{(2)}, \ldots, x_0^{(k)}]$$

An argument comparison sequence, also called a subsequence, is recorded as

$$X_1^{(k)} \colon X_i^{(k)} = [x_i^{(1)}, x_i^{(2)}, \ldots, x_i^{(k)}] \ (i = 1, 2, \ldots, n)$$

2. The original sequence is subjected to dimensionless treatment processing using the initial value method and the mean value method to facilitate calculation and comparative analysis:

$$x_i^{(k')} = x_1^{(k)} / x_0^{(k)} \text{或} x_i^{(k')} = x_i^{(k')} / X_i$$

3. The difference sequence is then calculated:

$$\Delta_i(k) = |x_0^{(k')} - x_i^{(k')}| (i = 1, 2, \ldots, n)$$

Then, the difference sequence is:

$$\Delta_i = \left(\Delta_i(1),\ \Delta_i(2), \ldots, \Delta_i(k)\right)$$

Maximum difference:

$$\Delta_{\max} = |x_0^{k'} - \ x_0^{(k')}|$$

Minimum difference:

$$\Delta_{\min} = |x_0^{k'} - \ x_i^{k'}|$$

4. Calculation of gray correlation coefficient $L_{0i}^{(k)} = \frac{\Delta_{\min} + \lambda \Delta_{\max}}{\Delta + \lambda \max}$

$L_{0i}^{(k)}$ is the relative difference between the child factor and the parent factor of the kth point. The greater the absolute difference Δ is, the smaller b $L_{0i}^{(k)}$ is. In contrast, $L_{0i}^{(k)}$ is bigger. Therefore, the magnitude of $L_{0i}^{(k)}$ describes the degree of influence of X_i on X_0; this is called the "point correlation degree between X_i and X_0 at k." In the formula, λ is the resolution coefficient; it is generally set at a value between 0 and 1, often taking $\lambda = 0.5$.

5. Calculation of the gray correlation degree

In this article, the mean value method is used to calculate the total correlation degree:

$$R_{0i} = \frac{1}{n} \sum_{k=1}^{n} L_{0i}^{(k)}$$

The closer the correlation degree is to 1, the greater the correlation degree is. According to the previous example, when $\lambda = 0.5$, the correlation degree of the two factors is greater than 0.6, indicating an obvious correlation.

Study Area

Although southern China generally has a subtropical monsoon climate, such a climate only exists in some areas of certain provinces such as southern Henan, south-central Jiangsu, and southeastern Sichuan. In most subtropical regions, the proportion of fossil energy sources such as coal and petroleum is relatively small. Guangxi Province is the most typical of these areas. Compared with the coal, oil, and gas resources in Sichuan Province, those in Guizhou Province, Guangxi Province, and Zhejiang Province are smaller. The output is far less than the demand, and most of the demand is met by other provinces. Natural resources are the feedback of nature. Most of the subtropical regions in the world do not possess abundant resources. Moreover, compared with other provinces such as Guangdong Province, the policy support from the government is relatively insufficient. Zhejiang Province is located in the south wing of the Yangtze River Delta along the southeastern coast of China and accounts for approximately 1.10% of China's total land area. It is one of the smallest and most economically active provinces in China. Its GDP is ranked fourth among all provinces, and its disposable per capita income was ranked first for 21 consecutive years until 2013. Guangxi Province is the only coastal autonomous region in China and provides the most convenient passage to the sea in southwestern China. Its area accounts for approximately 2.5% of China's total land area. Its GDP is ranked 19th, while its GDP per capita is ranked 30th. Guangxi's GDP is approximately 40% of Zhejiang's, and its GDP per capita is less than half of Zhejiang's. Taking Guangxi and Zhejiang provinces as examples, this article studies the relationships among energy consumption, environmental pollution, and economic development in subtropical areas that lack great resource advantages and sufficient policy support.

Data Collection

This article collects the annual data on energy consumption (including coal, oil, hydropower, and other resources), total energy consumption, GDP, and emissions in Guangxi Province from 2004 to 2017 and in Zhejiang Province from 2007 to 2017. The data are mainly acquired from the statistical yearbooks of the two provinces. Standard coal is used as the unit of measurement of energy consumption.

Current situation of development in Guangxi Province. First, we study the growth of energy consumption and GDP. As shown in Figure 1, the growth rate of energy consumption in Guangxi Province has been higher than the growth rate of national energy consumption since 2006, while the growth rate of its GDP was not substantially different from that of the nation as a whole. In 2007, the growth rate of Guangxi energy consumption was even slightly lower than that of the national GDP. To protect the environment in the early 21st century, Guangxi

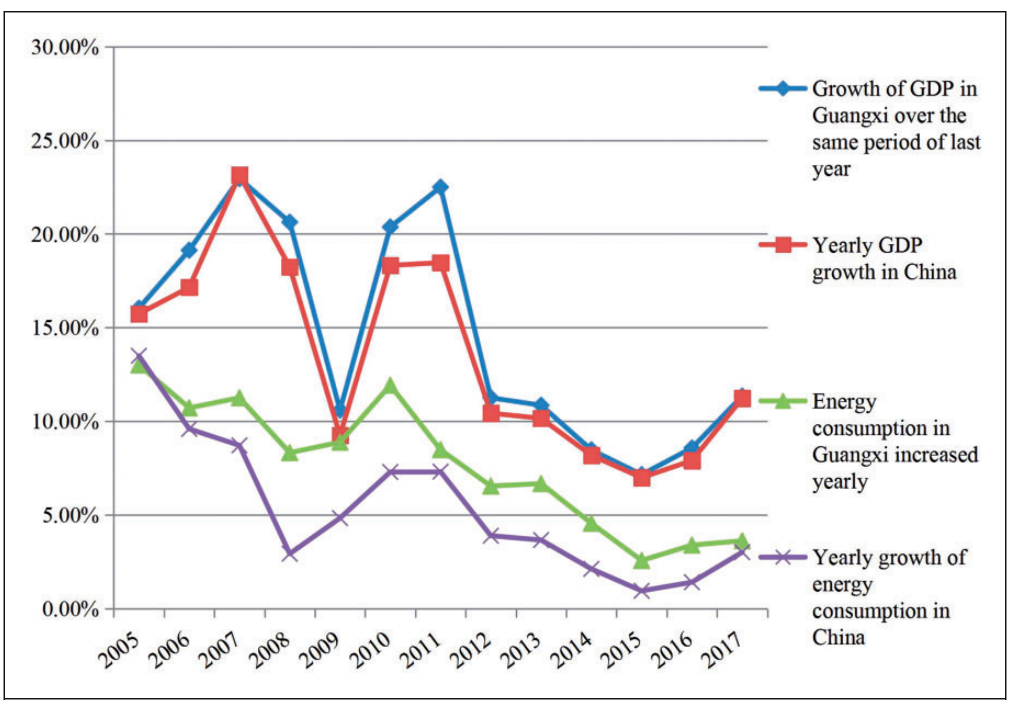

Figure 1. Energy consumption growth and GDP growth in Guangxi Province. GDP: gross domestic product.

Province began to curb the development of industrial enterprises and reduce the negative effects of industry on the environment. As a result, industrial development in Guangxi was less rapid than industrial development in Guangdong, Hunan, and other southern provinces. Prior to 2011, there was no obvious relationship between total energy consumption and GDP in Guangxi Province, and GDP growth showed little dependence on energy consumption. From 2011 to 2016, GDP and energy consumption in Guangxi Province appeared almost synchronized. Although GDP increased with energy consumption, the growth rate of GDP was significantly higher than that of energy consumption.

Second, we study the energy consumption. The energy consumption of Guangxi Province mainly consists of three parts: coal, petroleum, hydropower, and other resources (hereinafter collectively referred to as hydropower resources). As shown in Figure 2, the consumption of coal in Guangxi Province increased from 2004 to 2013, decreased from 2013 to 2015, and then increased. The proportion of coal consumption was always lower than 60%, and coal consumption reached its lowest level in 2017, in which coal provided only 45.38% of the total energy consumed. The proportion of oil consumed was modest in the last decade, hovering between 15.9% and 18.4%. The proportion of water and electricity consumption fluctuated greatly, reaching 36.23% in 2017. Since 2015, the proportion of water and electricity consumption has remained at approximately 36.0%.

Third, we study the environmental problems. In this article, the environmental quality of Guangxi province is proxied by the discharge of industrial wastewater, the production of industrial solid waste, the discharge of industrial sulfur dioxide, and the discharge of industrial smoke (dust). As seen in Figure 3, during the period from 2004 to 2008, the discharge of industrial wastewater increased (with the exception of a decrease in 2006), and industrial wastewater discharge reached its highest level of 1.94958 billion tons in 2008. The overall trend showed a decline from 2008 to 2017, slight rebounds in 2010 and 2012, and a fall to 312.87 million tons in 2017; this suggests that Guangxi has made great progress in environmental protection and pollution control. Industrial solid waste production, which is much smaller than industrial waste emissions, continued to increase slowly until 2014 and has declined since.

Figure 4 shows that industrial smoke and dust emissions began to decline in 2005 and that they rose in 2009, 2012, and 2014; overall, they decreased from 945,217 tons in 2005 to 151,414.4 tons in 2017. Industrial sulfur dioxide emissions have been declining since 2007, reaching a level of 101,495.3 tons in 2017. From 2006 to 2015, industrial sulfur dioxide emissions have been higher than industrial smoke (powder) dust emissions, indicating that industrial sulfur dioxide pollution is worse than industrial smoke (powder) dust among the exhaust gas indicators affecting Guangxi's environment.

Current Situation of Development in Zhejiang Province

First, we study the energy consumption growth and GDP growth. Zhejiang Province is one of the smallest but also one of the most active provinces in China.

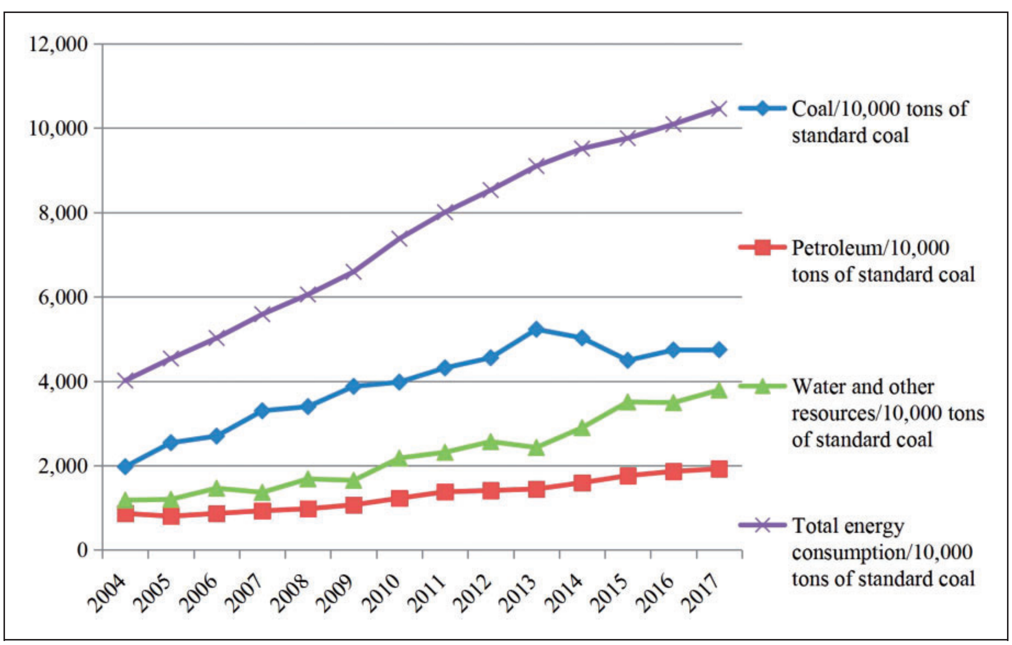

Figure 2. Energy consumption in Guangxi Province.

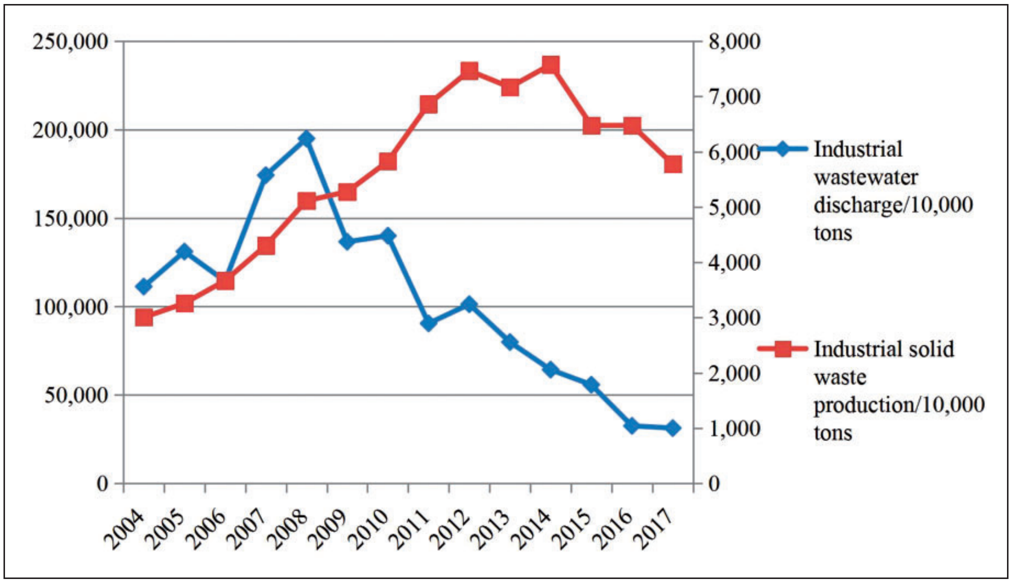

Figure 3. Discharge of industrial wastewater and production of industrial solid waste in Guangxi Province.

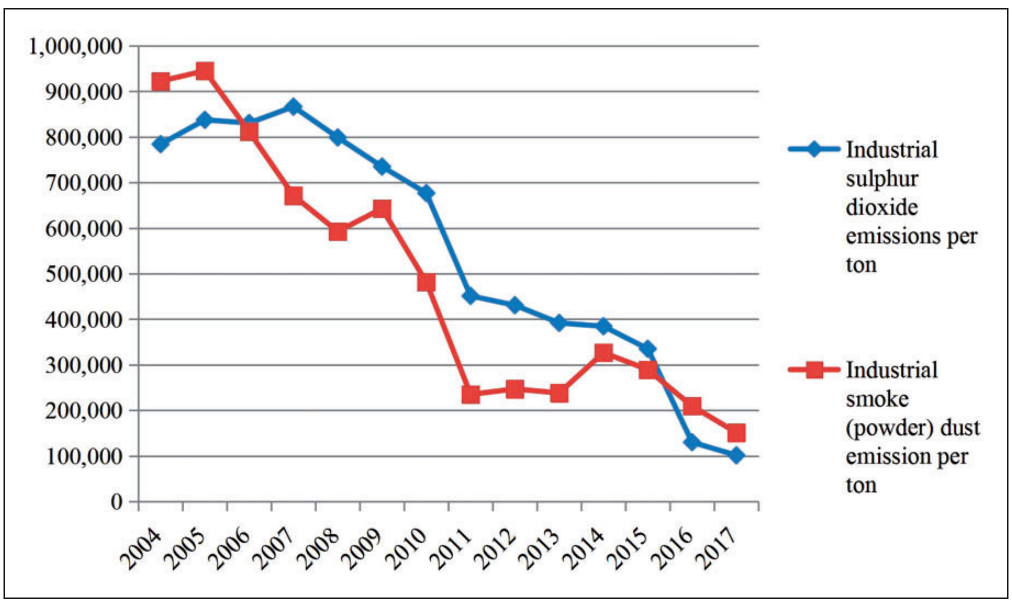

Figure 4. Industrial sulfur dioxide and smoke or dust emissions in Guangxi Province.

The rapid development of the private economy in Zhejiang has led to a take-off of the economy. The province has been widely known to have a distinctive "Zhejiang economy," with per capita disposable income ranking first in China for more than 20 consecutive years. As shown in Figure 5, the average rate of growth of the GDP in Zhejiang Province was higher than that of China in 2016 and slightly lower than that of China in 2017. The average growth rate of energy consumption was slightly lower than that of China, in contrast to that of Guangxi Province. Negative energy growth even occurred in 2013. The year-on-year growth rate decreased by 2.72%, and GDP growth rate also declined.

Second, we study the energy consumption. Compared with Guangxi Province, Zhejiang Province has more types of energy consumption. Most of the energy consumed in Zhejiang Province is produced from raw coal, electricity, crude oil, and heat. The consumption of energy from these four sources has always accounted for more than 90% of the total energy consumption in Zhejiang Province. Consumption of electricity, heat, and natural

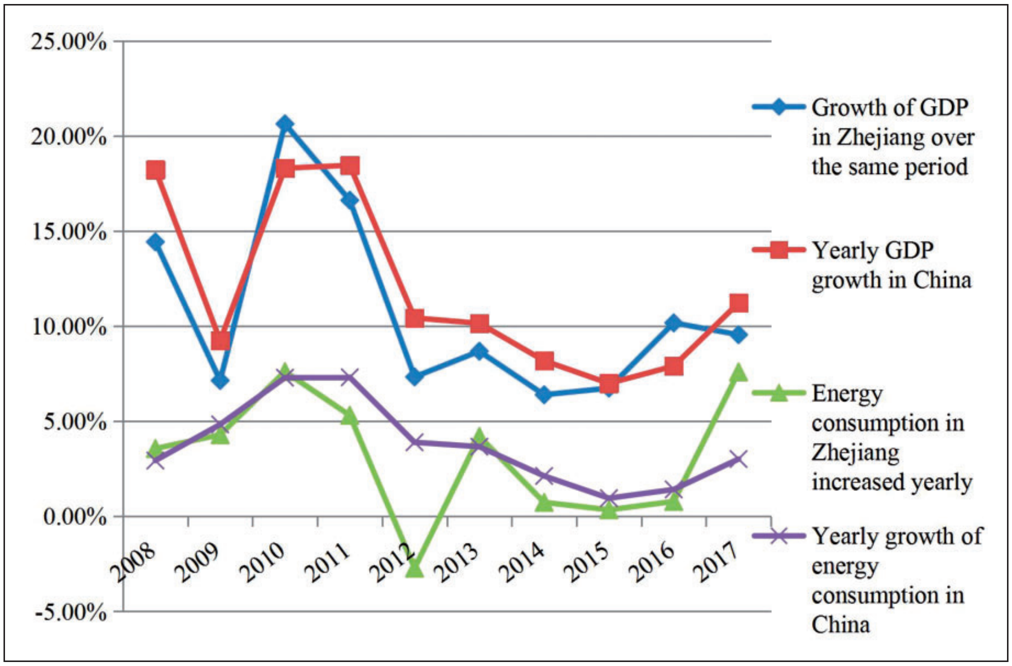

Figure 5. Energy consumption growth and GDP growth in Zhejiang Province. GDP: gross domestic product.

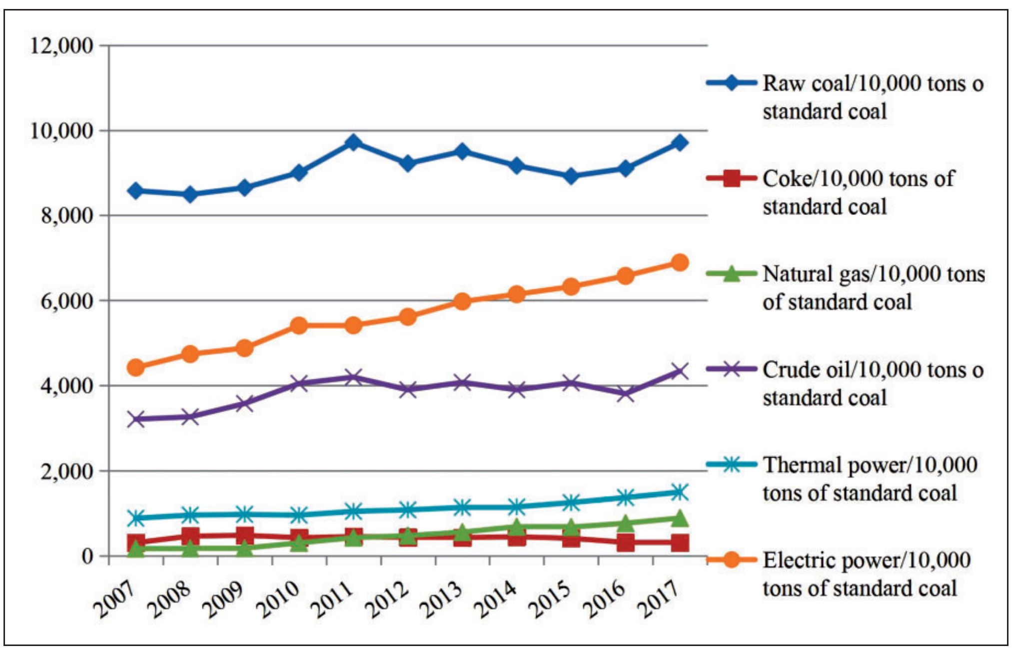

Figure 6. Energy consumption in Zhejiang Province (raw coal/coke/natural gas/crude oil/thermal power/electric power).

gas continued to rise, and electricity consumption increased by an average of 24.674 million tons per year from 2007 to 2017. The consumption of raw coal, crude oil, and coke fluctuated within a certain range. The consumption of diesel, oil, and gasoline showed a downward trend in general. The fluctuation in the amounts of washed coal, fuel oil, and blast furnace gas used was relatively large, but the total consumption of energy from these sources was small, accounting for a maximum of 4.15% and a minimum of 2.3% of the total energy consumption in Zhejiang Province. Energy consumption in Zhejiang Province is shown in Figures 6 and 7.

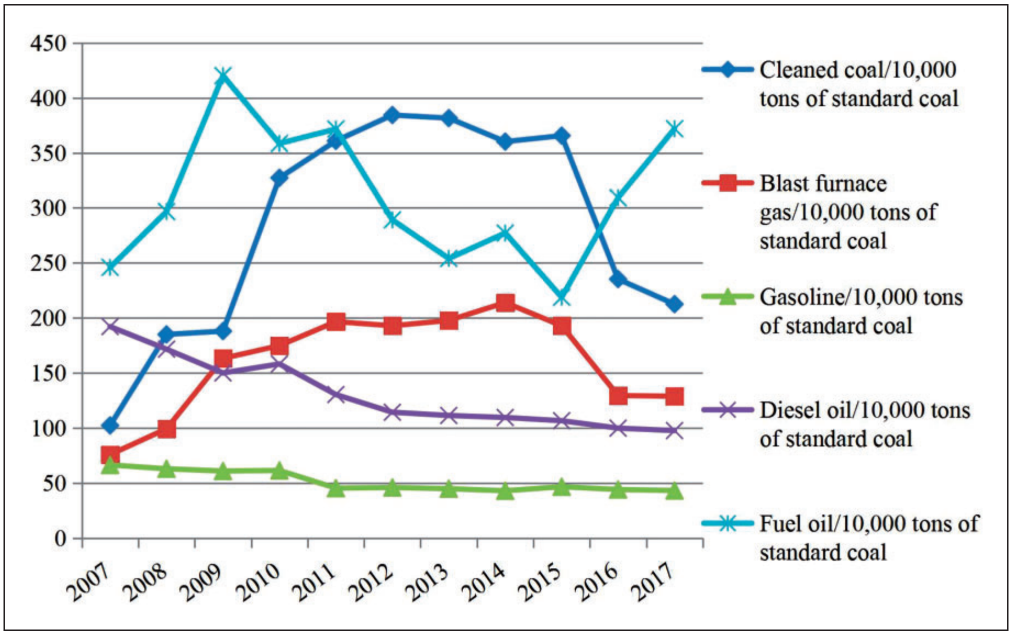

Figure 7. Energy consumption in Zhejiang Province (cleaned coal/blast furnace gas/gasoline/diesel oil/fuel oil).

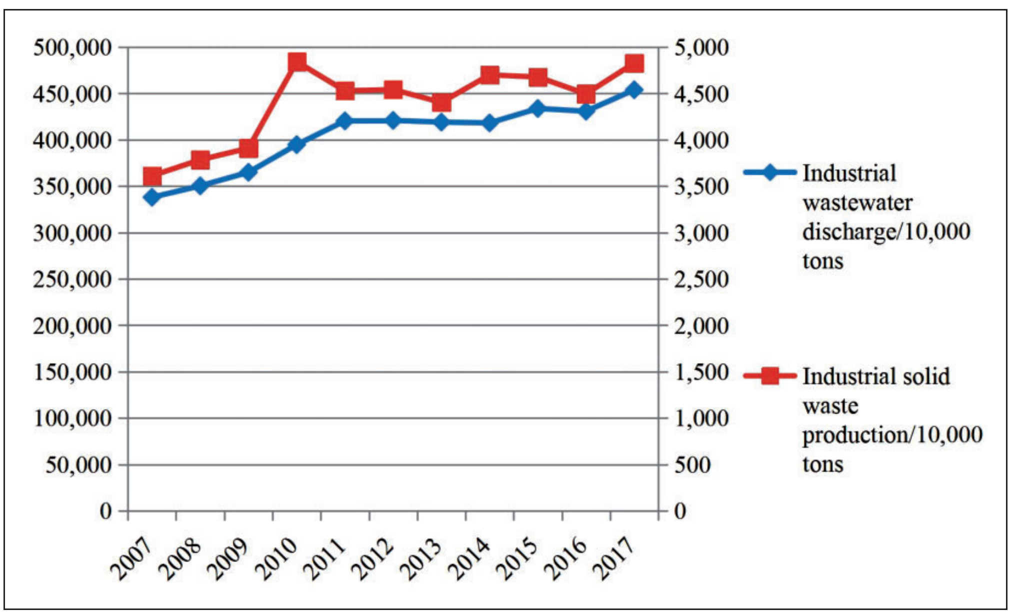

Figure 8. Discharge of industrial wastewater and production of industrial solid waste.

Third, we study the environmental problems. The criteria used to evaluate the environmental quality in Zhejiang Province are the same as those used previously. Industrial wastewater discharge, industrial solid waste production, industrial sulfur dioxide discharge, and industrial smoke (powder) dust discharge are used to illustrate the environmental quality problems in Zhejiang Province. As seen from Figure 8, the discharge of industrial wastewater in Zhejiang Province has been on the rise. The production of industrial solid wastes has fluctuated within a certain range since 2010, but on the whole it remains unchanged. Unlike the environmental situation in Guangxi Province, Zhejiang Province has not yet made any significant achievements in environmental protection and pollution control. The results are also related to the degree of local economic development. The monitoring mechanism is not perfect, and regulation of the emissions caused by many enterprises is not up to the standard.

As shown in Figure 9, industrial sulfur dioxide emissions showed a downward trend from 775,900 tons to 181,000 tons during the 10-year period from 2007 to 2017, with an average annual rate of decline of 7.67%. Although it showed a downward trend, the emission of industrial smoke (powder) dust displayed significant recovery in 2010, 2013, and 2014. This suggests that Zhejiang Province paid more attention to the control of industrial sulfur dioxide emissions during the studied period. Since 2007, the amount of sulfur dioxide emissions has been higher than the amount of industrial smoke (powder) dust. Among the waste gas indicators affecting the environment of Zhejiang Province, industrial sulfur dioxide pollution of the environment is worse than industrial smoke (powder) dust pollution, similar to the situation in Guangxi Province.

Results

Analysis of Gray Relevance Degree in Guangxi Province

Between energy consumption and environmental pollution. The gray correlation degree between the energy consumption and the environmental pollution is calculated using each pollutant discharge sequence as the mother sequence and the energy consumption sequence as the subsequence. The results are shown in Tables 1 to 4.

The correlation degree between energy consumption and pollutant emission is greater than 0.5, indicating that all types of energy consumption have a great impact on environmental quality. The correlation degree between industrial wastewater and three types of energy source is the lowest, 0.5952; since the

Table 1. Gray Correlation Between Energy Consumption and Wastewater (Guangxi).

	Wastewater		
Year	Coal	Petroleum	Hydroelectric resource
2004	1.0000	1.0000	1.0000
2005	0.9054	0.7939	0.8998
2006	0.7573	0.9734	0.8742
2007	0.9085	0.6648	0.7812
2008	0.9737	0.6099	0.8180
2009	0.5900	0.9900	0.8966
2010	0.5833	0.8579	0.7141
2011	0.4358	0.5543	0.5607
2012	0.4315	0.5744	0.5366
2013	0.3546	0.5050	0.5226
2014	0.3504	0.4343	0.4384
2015	0.3743	0.3876	0.3722
2016	0.3349	0.3431	0.3545
2017	0.3333	0.3333	0.3333
λ	0.5952	0.6444	0.6502

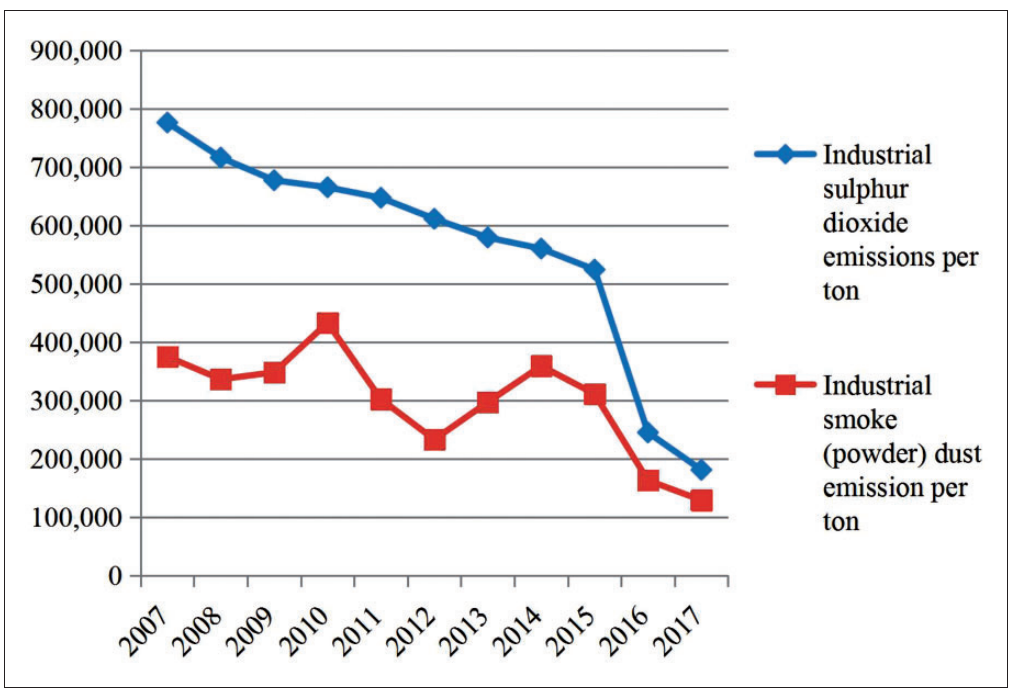

Figure 9. Industrial sulfur dioxide and smoke or dust emissions in Zhejiang Province.

Table 2. Gray Correlation Between Energy Consumption and Solid Waste (Guangxi).

	Solid waste		
Year	Coal	Petroleum	Hydroelectric resource
2004	1.0000	1.0000	1.0000
2005	0.5424	0.7283	0.9027
2006	0.6219	0.6598	0.9735
2007	0.5020	0.5441	0.6994
2008	0.9187	0.4270	0.7003
2009	0.5350	0.4513	0.6419
2010	0.7554	0.4506	0.8716
2011	0.7199	0.3826	0.6658
2012	0.5833	0.3333	0.6755
2013	0.4753	0.3742	0.6618
2014	0.8952	0.3871	0.9064
2015	0.6617	0.7864	0.4409
2016	0.4938	0.9990	0.4447
2017	0.3333	0.5828	0.3333
λ	0.6456	0.5790	0.7084

Table 3. Gray Correlation Between Energy Consumption and Sulfur Dioxide (Guangxi).

	Sulfur dioxide		
Year	Coal	Petroleum	Hydroelectric resource
2004	1.0000	1.0000	1.0000
2005	0.8376	0.8801	0.9665
2006	0.7865	0.9474	0.8958
2007	0.6674	0.9721	0.9684
2008	0.6180	0.9048	0.7910
2009	0.5253	0.7776	0.7704
2010	0.4966	0.6535	0.6109
2011	0.4138	0.5071	0.5266
2012	0.3927	0.4923	0.4866
2013	0.3460	0.4723	0.4974
2014	0.3562	0.4364	0.4396
2015	0.3809	0.3943	0.3771
2016	0.3373	0.3453	0.3555
2017	0.3333	0.3333	0.3333
λ	0.5351	0.6512	0.6442

relationship is generally considered to be significant when the correlation degree is greater than 0.6, this indicates that there is a significant correlation between industrial wastewater and energy consumption. The impact of energy consumption on industrial wastewater, industrial solid waste production, industrial sulfur dioxide, and industrial fume (dust) dust is, respectively, ranked by gray correlation as follows:

1. Industrial wastewater: λ (hydropower) > λ (petroleum) > λ (coal)

Table 4. Gray Correlation Between Energy Consumption and Smoke or Dust (Guangxi).

	Smoke or dust		
Year	Coal	Petroleum	Hydroelectric resource
2004	1.0000	1.0000	1.0000
2005	0.8192	0.9121	0.9936
2006	0.7102	0.8949	0.8094
2007	0.5589	0.7483	0.7808
2008	0.5257	0.6795	0.6604
2009	0.4853	0.6562	0.6853
2010	0.4458	0.5368	0.5366
2011	0.3824	0.4350	0.4718
2012	0.3695	0.4307	0.4440
2013	0.3333	0.4219	0.4586
2014	0.3530	0.4089	0.4204
2015	0.3786	0.3742	0.3643
2016	0.3549	0.3485	0.3579
2017	0.3480	0.3333	0.3333
λ	0.5046	0.5843	0.5940

2. Industrial solid waste: λ (hydropower) > λ (coal) > λ (petroleum)
3. Industrial sulfur dioxide: λ (hydropower) > λ (petroleum) > λ (coal)
4. Industrial smoke/dust: λ (petroleum) > λ (hydropower) > λ (coal)

It can be seen from the aforementioned rankings that the correlation between coal and environmental quality is lower than the correlation of other energy sources with environmental quality, indicating that the degree of pollution of the environment caused by coal consumption is relatively small. Among the three types of energy consumed, oil has the greatest impact on industrial smoke (dust) emissions, while hydropower and other resources have the greatest impact on industrial solid waste production, industrial wastewater, and industrial sulfur dioxide emissions. Overall, the consumption of hydropower resources has the greatest impact on environmental pollution in Guangxi Province, with the exception of the correlation degree of 0.5940 with smoke (dust) and the correlation of more than 0.64 with other pollutants. It is noteworthy that the consumption of coal, a traditional energy source, has the least impact on air pollution in Guangxi Province.

Between energy consumption and GDP growth. To analyze the relationship between GDP growth and energy consumption in Guangxi Province, this article adopts GDP as the mother sequence and uses coal consumption, oil consumption, and hydropower resources consumption as subsequences to calculate the gray correlation degree. The method of mean value is used to deal with each series in a dimensionless manner, and the gray correlation degree of each year is obtained.

It can be seen from Table 5 that the gray correlation degree between coal, petroleum, hydropower resources, and GDP is greater than 0.5; this indicates that all types of energy consumption have a great influence on GDP and that energy consumption has driven the development of the economy. The correlation degree is the highest for coal ($\lambda = 0.6810$). This shows that there is a significant correlation between coal consumption and GDP, whereas the gray correlation between hydropower resources and oil and GDP is 0.5881. The average range of hydropower resources is 1.27, which is less than the average range of oil, 1.83. This also reflects the fact that current energy consumption in Guangxi Province relies mainly on coal.

Table 5. Gray Correlation between GDP and Energy Consumption (Guangxi).

	GDP		
Year	Coal	Petroleum	Hydroelectric resource
2004	1.0000	1.0000	1.0000
2005	0.9322	0.8875	0.9036
2006	0.9922	0.8296	0.9046
2007	0.9851	0.7482	0.7149
2008	0.8438	0.6684	0.6862
2009	0.8545	0.6431	0.6105
2010	0.6938	0.5739	0.5889
2011	0.5880	0.5034	0.4821
2012	0.5405	0.4598	0.4546
2013	0.5289	0.4209	0.3861
2014	0.4646	0.4039	0.3905
2015	0.4014	0.3924	0.4128
2016	0.3760	0.3686	0.3649
2017	0.3333	0.3333	0.3333
λ	0.6810	0.5881	0.5881

Note. GDP = gross domestic product.

Between environmental pollution and GDP. With GDP as mother sequence and pollutant discharge as subsequence, the gray correlation degree between economic growth and environmental pollution is calculated to analyze their relationship. It can be seen from Table 6 that the gray correlation degree between industrial smoke or dust emission and GDP is 0.59. The gray correlation degrees between the emissions of the other three pollutant emissions and GDP are all greater than 0.6, indicating that the rapid economic growth of this area has resulted in emission of a large number of industrial pollutants at the same time. This conclusion is also true for the entire nation of China, especially with respect to industrial solid waste, industrial wastewater, and industrial sulfur dioxide.

Analysis of Gray Relevance Degree in Zhejiang Province

Between energy consumption and environmental pollution. The gray correlation degree between energy consumption and environmental pollution is calculated using

Table 6. Gray Correlation Between GDP and Environmental Pollution (Guangxi).

	GDP			
Year	Industrial wastewater discharge	Industrial solid waste production	Industrial sulfur dioxide emissions	Industrial smoke or dust emission
2004	1.0000	1.0000	1.0000	1.0000
2005	0.9939	0.9635	0.9692	0.9551
2006	0.8886	0.9256	0.8999	0.8518
2007	0.9548	0.8825	0.8301	0.7482
2008	0.9046	0.8522	0.7381	0.6723
2009	0.7313	0.7970	0.6860	0.6478
2010	0.6477	0.7007	0.6004	0.5601
2011	0.5198	0.6374	0.5047	0.4766
2012	0.4937	0.6020	0.4710	0.4490
2013	0.4465	0.5218	0.4381	0.4212
2014	0.4139	0.4932	0.4151	0.4057
2015	0.3907	0.4214	0.3931	0.3857
2016	0.3595	0.3872	0.3598	0.3612
2017	0.3333	0.3333	0.3333	0.3333
λ	0.6484	0.6798	0.6171	0.5906

Note. GDP = gross domestic product.

each pollutant emission sequence as the parent sequence and each energy consumption sequence as the subsequence. The results of the calculations are shown in Tables 7 to 10.

The impact of energy consumption on industrial wastewater, industrial solid waste production, industrial sulfur dioxide, and industrial smoke (dust) is ranked based on the outcome obtained using the gray correlation method.

1. Industrial wastewater: λ (thermal power) > λ(fuel oil) > λ (natural gas) > λ (electric power) > λ (crude oil) > λ (coke) > λ (raw coal) > λ (blast furnace gas) > λ (petrol) > λ (cleaned coal) > λ (diesel oil)
2. Industrial solid waste: λ (thermal power) > λ (fuel oil) > λ (electric power electric power) > λ (natural gas) > λ (coke) > λ (crude oil) > λ (raw coal) > λ (blast furnace gas) > λ (cleaned coal) > λ (petrol) > λ (diesel oil)
3. Industrial sulfur dioxide: λ (petrol) > λ (thermal power) > λ (raw coal) > λ (natural gas) > λ (electric power) > λ (fuel oil) > λ (crude oil) > λ (diesel oil) > λ (blast furnace gas) > λ (cleaned coal) > λ (coke)
4. Industrial smoke/dust: λ (raw coal) > λ (thermal power) > λ (natural gas) > λ (diesel oil) > λ (fuel oil)- > λ (electric power) > λ (crude oil) > λ (petrol) > λ (cleaned coal) > λ (coke) > λ (blast furnace gas)

From the aforementioned ranking of correlation degree, we can see that the most serious environmental pollution is caused by thermal power. The degree of

Table 7. Gray Correlation Between Energy Consumption and Wastewater (Zhejiang).

	Waste water										
Year	Raw coal	Cleaned Coal	Coke	Blast furnace gas	Natural gas	Crude oil	Petrol	Diesel oil	Fuel oil	Thermal power	Electric power
2007	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2008	0.7234	0.6194	0.3404	0.7439	0.9990	0.7087	0.7969	0.7446	0.6487	0.7882	0.7531
2009	0.6301	0.6236	0.3333	0.4248	0.9864	0.5729	0.6804	0.5828	0.3333	0.8883	0.8191
2010	0.5069	0.3821	0.5295	0.4104	0.7568	0.3333	0.5878	0.5478	0.5199	0.6671	0.6607
2011	0.5229	0.3548	0.5202	0.3700	0.6045	0.4217	0.3819	0.4248	0.5397	0.7404	0.8478
2012	0.4163	0.3333	0.5981	0.3789	0.5563	0.6089	0.3849	0.3909	0.8197	0.8786	0.8160
2013	0.4798	0.3353	0.6149	0.3667	0.4873	0.6131	0.3802	0.3873	0.6036	0.7889	0.4922
2014	0.4193	0.3548	0.5306	0.3333	0.4100	0.6767	0.3699	0.3848	0.7412	0.7390	0.4140
2015	0.3333	0.3541	0.8339	0.3858	0.4192	0.7313	0.3737	0.3642	0.4444	0.5730	0.4234
2016	0.3630	0.5505	0.4877	0.6462	0.3750	0.3456	0.3620	0.3560	0.9496	0.3895	0.3364
2017	0.3658	0.6309	0.4065	0.6895	0.3333	0.8430	0.3333	0.3333	0.6389	0.3333	0.3333
λ	0.5237	0.5035	0.5632	0.5227	0.6298	0.6232	0.5137	0.5015	0.6590	0.7078	0.6269

Table 8. Gray Correlation Between Energy Consumption and Solid Waste (Zhejiang).

	Solid waste										
Year	Raw coal	Cleaned coal	Coke	Blast furnace gas	Natural gas	Crude oil	Petrol	Diesel oil	Fuel oil	Thermal power	Electric power
2007	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2008	0.7157	0.6227	0.3448	0.7441	0.9951	0.5856	0.7751	0.7284	0.6632	0.8331	0.8348
2009	0.6629	0.6243	0.3333	0.4153	0.9851	0.5725	0.6749	0.5788	0.3333	0.9018	0.8512
2010	0.3333	0.4031	0.8608	0.4405	0.8130	0.3509	0.4525	0.4447	0.7266	0.4064	0.5075
2011	0.5459	0.3557	0.5306	0.3622	0.6068	0.4444	0.3755	0.4187	0.5482	0.7138	0.8048
2012	0.4435	0.3343	0.6155	0.3715	0.5587	0.5062	0.3777	0.3847	0.7941	0.8309	0.9085
2013	0.5669	0.3333	0.5823	0.3538	0.4851	0.4620	0.3869	0.3930	0.6267	0.7251	0.4790
2014	0.3852	0.3612	0.6176	0.3333	0.4161	0.3333	0.3442	0.3617	0.6435	0.9886	0.5779
2015	0.3634	0.3552	0.8689	0.3783	0.4207	0.5993	0.3669	0.3588	0.4362	0.6001	0.4731
2016	0.4422	0.5432	0.5189	0.6212	0.3731	0.4248	0.3715	0.3636	0.9594	0.3693	0.3333
2017	0.4156	0.6228	0.4096	0.6768	0.3333	0.7416	0.3333	0.3333	0.6396	0.3333	0.3535
λ	0.5341	0.5056	0.6074	0.5179	0.6352	0.5473	0.4962	0.4878	0.6702	0.7002	0.6476

Table 9. Gray Correlation Between Energy Consumption and Sulfur Dioxide (Zhejiang).

	Sulfur dioxide										
Year	Raw coal	Cleaned coal	Coke	Blast furnace gas	Natural gas	Crude oil	Petrol	Diesel oil	Fuel oil	Thermal power	Electric power
2007	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2008	0.8700	0.6275	0.3995	0.7310	0.9550	0.8554	0.8917	0.8233	0.6925	0.8196	0.8164
2009	0.7680	0.6072	0.3588	0.4506	0.9313	0.6981	0.8248	0.5998	0.4334	0.7610	0.7415
2010	0.7001	0.3891	0.4224	0.4202	0.7271	0.5806	0.7548	0.8027	0.5155	0.7655	0.6441
2011	0.6007	0.3564	0.3777	0.3738	0.5976	0.5414	0.5780	0.4692	0.4855	0.6768	0.6292
2012	0.6101	0.3344	0.3820	0.3742	0.5544	0.5665	0.6828	0.4161	0.6223	0.6273	0.5788
2013	0.5541	0.3333	0.3727	0.3606	0.4962	0.5167	0.7432	0.4515	0.6905	0.5745	0.5228
2014	0.5643	0.3476	0.3447	0.3333	0.4303	0.5313	0.7337	0.4749	0.6121	0.5583	0.4980
2015	0.5520	0.3398	0.3680	0.3597	0.4311	0.4862	0.8870	0.5322	0.7490	0.4971	0.4675
2016	0.3761	0.4292	0.3497	0.4300	0.3730	0.3911	0.3745	0.4027	0.4045	0.3718	0.3613
2017	0.3333	0.4473	0.3333	0.4175	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
λ	0.6299	0.4738	0.4281	0.4774	0.6208	0.5910	0.7094	0.5732	0.5944	0.6350	0.5994

Table 10. Gray Correlation Between Energy Consumption and Smoke or Dust (Zhejiang).

	Smoke or dust										
Year	Raw coal	Cleaned coal	Coke	Blast furnace gas	Natural gas	Crude oil	Petrol	Diesel oil	Fuel oil	Thermal power	Electric power
2007	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2008	0.8085	0.6323	0.3951	0.6997	0.9442	0.8068	0.7517	0.9830	0.6533	0.7831	0.7761
2009	0.8308	0.6328	0.3844	0.4397	0.9502	0.7300	0.9323	0.5684	0.4281	0.7952	0.7758
2010	0.7892	0.4340	0.6362	0.4549	0.7937	0.8258	0.4033	0.3689	0.6581	0.9009	0.8988
2011	0.5463	0.3655	0.3735	0.3497	0.5880	0.5008	0.5579	0.6943	0.4527	0.6414	0.5916
2012	0.4649	0.3333	0.3333	0.3333	0.5286	0.4589	0.6909	0.8793	0.5131	0.5292	0.4836
2013	0.5550	0.3380	0.3964	0.3461	0.4951	0.5136	0.5694	0.4768	0.7080	0.5769	0.5207
2014	0.7796	0.3795	0.4444	0.3401	0.4432	0.6617	0.3333	0.3333	0.7747	0.6637	0.5842
2015	0.6516	0.3636	0.4387	0.3591	0.4374	0.5356	0.5495	0.4135	0.9063	0.5358	0.5027
2016	0.3861	0.4567	0.3988	0.4302	0.3745	0.4013	0.4051	0.6956	0.4152	0.3771	0.3659
2017	0.3333	0.4750	0.3752	0.4150	0.3333	0.3333	0.3377	0.5416	0.3333	0.3333	0.3333
λ	0.6496	0.4928	0.4706	0.4698	0.6262	0.6152	0.5937	0.6241	0.6221	0.6488	0.6212

correlation of thermal power with each pollutant is greater than 0.63; the highest correlation is even greater than 0.7. The second most serious environmental pollution is caused by natural gas; in this case, the degree of correlation with each pollutant is greater than 0.62. The pollution caused by electric power and fuel oil ranks third; its correlations with industrial wastewater, industrial solid waste production, and industrial smoke (dust) are greater than 0.62, and its correlation with industrial sulfur dioxide is less than 0.60 but also reaches 0.59. Compared with the aforementioned four energy sources, blast furnace gas and washed coal cause the least pollution; the correlation with each pollutant is not more than 0.53, and the correlation with industrial smoke (powder) dust and sulfur dioxide is not more than 0.5. In addition, coke has little effect on the emission of smoke (powder) dust and sulfur dioxide; its correlation degree is less than 0.48. It also has little effect on the discharge of wastewater and solid waste.

Generally, the greatest impact of energy consumption on environmental pollution in Zhejiang Province is wastewater discharge. The correlation between energy and industrial wastewater is greater than 0.5. The pollution of industrial smoke (powder) dust severely impacts the environment. Seven of the energy sources have correlation degrees greater than 0.6.

Between energy consumption and GDP growth. With GDP as the parent sequence and energy consumption of raw coal and washed coal as the subsequences, the dimensionless treatment of each series is conducted. Finally, the gray correlation degree between economic growth and energy consumption in each year is obtained, as shown in Table 11.

Energy consumption in Zhejiang Province has a certain impact on GDP growth, and the correlation degree is greater than 0.5. Energy consumption promotes economic development. The consumption of coke, natural gas, crude oil, and fuel oil has a significant impact on GDP, and the correlation degree is greater than 0.6. Of the main sources of the energy consumed (raw coal, electricity, crude oil, and heat) in Zhejiang Province, only the correlation degree between crude oil and GDP ($\lambda = 0.6028$) exceeds 0.6.

It can be seen that although energy consumption plays a certain role in the economic development of Zhejiang Province, Zhejiang Province is not a province whose economic growth depends heavily on energy consumption. There are other factors that promote its rapid economic growth. For example, Zhejiang Province is located in the Yangtze River delta and relies on this geographical advantage to promote its economic development. The Yangtze River delta urban agglomeration, which is composed of Zhejiang, Jiangsu, Anhui, and Shanghai, has become one of six world-class urban agglomerations in the world.

Between environmental pollution and GDP. With GDP as the parent sequence and pollutant discharge as the subsequence, the gray correlation degree between economic growth and environmental pollution for each year is calculated as shown in Table 12 to make it possible to analyze the relationship between economic growth and environmental pollution. The gray correlation degree between GDP and SO_2 is the lowest ($\lambda = 0.5944$). Like most regions, the environment in Zhejiang Province has suffered a negative impact along the path of economic development.

Using the data on energy consumption, GDP and industrial pollutant emissions in Guangxi Province from 2004 to 2017 and in Zhejiang Province from 2007 to 2017, the gray analysis of the relationship between energy consumption, environmental pollution, and energy consumption in the two provinces is conducted, and the following conclusions are drawn.

Relationship Between Energy Consumption and Economic Growth in Guangxi and Zhejiang Provinces is Relatively Large

Coal consumption in Guangxi Province shows the highest correlation with GDP, with a correlation coefficient of 0.6810. This shows that economic growth and coal consumption in Guangxi Province are closely related. Economic growth is strongly dependent on coal. Coal shortages would have a negative impact on economic growth in Guangxi Province. However, the economic growth rate is obviously higher than the rate of increase in the use of coal, and the dependence of economic growth on coal is gradually declining, consistent with the reality of Guangxi Province. Guangxi Province has guided major energy-consuming industrial enterprises to implement cleaner production and to pay close attention to energy savings and consumption reduction, thereby ensuring that the economy grows while at the same time the environment is protected. The gray correlation degree between energy consumption and GDP in Zhejiang Province is not particularly large. The gray correlation degree between coke and GDP is the highest

Table 11. Gray Correlation Between GDP and Energy Consumption (Zhejiang).

	GDP										
Year	Raw coal	Cleaned coal	Coke	Blast furnace gas	Natural gas	Crude oil	Petrol	Diesel oil	Fuel oil	Thermal power	Electric power
2007	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2008	0.8404	0.5894	0.7150	0.7628	0.9179	0.8470	0.8431	0.8176	0.9182	0.8972	0.8919
2009	0.7888	0.6090	0.7291	0.3637	0.8730	0.8628	0.7732	0.7166	0.5914	0.8107	0.8302
2010	0.6544	0.3565	0.8973	0.3905	0.7996	0.7631	0.6554	0.6318	0.9705	0.5724	0.7009
2011	0.5786	0.3458	0.7701	0.3791	0.6102	0.6274	0.5029	0.5182	0.7655	0.4957	0.5453
2012	0.5115	0.3333	0.6633	0.4336	0.5674	0.5251	0.4761	0.4724	0.5080	0.4583	0.5077
2013	0.4735	0.3568	0.5853	0.4708	0.4929	0.4863	0.4409	0.4399	0.4161	0.4236	0.4757
2014	0.4314	0.4084	0.5593	0.4376	0.3943	0.4318	0.4137	0.4173	0.4077	0.3878	0.4441
2015	0.3951	0.4251	0.4798	0.6717	0.4225	0.4084	0.3998	0.3940	0.3333	0.3795	0.4123
2016	0.3583	0.8138	0.3712	0.3954	0.3826	0.3457	0.3625	0.3602	0.3563	0.3548	0.3679
2017	0.3333	0.5830	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3589	0.3333	0.3333
λ	0.5786	0.5292	0.6458	0.5216	0.6176	0.6028	0.5637	0.5547	0.6042	0.5557	0.5918

Note. GDP = gross domestic product.

Table 12. Gray Correlation Between GDP and Environmental Pollution (Zhejiang).

Year	GDP			
	Industrial wastewater discharge	Industrial solid waste production	Industrial sulfur dioxide emissions	Industrial smoke or dust emission
2007	1.0000	1.000	1.0000	1.000
2008	0.8676	0.8803	0.8507	0.8297
2009	0.8285	0.8317	0.7813	0.8020
2010	0.6945	0.8365	0.6699	0.7881
2011	0.5951	0.6013	0.5862	0.5676
2012	0.5386	0.5447	0.5427	0.4953
2013	0.4782	0.4727	0.4993	0.4973
2014	0.4392	0.4584	0.4708	0.5049
2015	0.4139	0.4179	0.4395	0.4532
2016	0.3628	0.3583	0.3644	0.3669
2017	0.3333	0.3333	0.3333	0.3333
λ	0.5956	0.6123	0.5944	0.6035

Note. GDP = gross domestic product.

($\lambda = 0.6458$), but coke accounts for only a small proportion of the energy consumption structure of Zhejiang Province. The correlation degree between most energy consumption sources (raw coal, electricity, crude oil and heat) and economic growth is less than 0.6, suggesting that use of those energy sources has no significant impact on the economic growth.

Energy Consumption Is Closely Related to Environmental Pollution

With the rapid development of the economy, improvements in the standard of living, and increasing consciousness of environmental protection, the consumption structure of energy has also changed. The contribution of traditional energy sources such as coal to energy consumption has decreased, and the proportion of clean energy consumption such as hydropower has gradually increased. From the perspective of consumption structure, energy consumption in Guangxi Province is tending toward cleanliness, but the mission of building a society based on clean energy still remains very arduous. Based on our gray correlation analysis of energy consumption and environmental pollution, coal pollution of the environment is relatively slight. This shows that Guangxi Province exerts heavy regulation of coal use. However, hydropower has a great impact on the environment; this indicates a low utilization efficiency of hydropower resources and flawed measures of treatment in Guangxi Province. Energy sources such as thermal power and electric power account for a large proportion of the consumption structure of Zhejiang Province, but their shortcomings are also prominent. With the exception of the gray correlation degree of 0.5994 for electric power and sulfur dioxide, the gray correlation degrees are greater than 0.6, and some are even greater than 0.7. Thermal and electric power sources cause serious pollution of the environment. The gray correlations between natural gas, which is regarded as a clean form of energy, and various pollutants are greater than 0.6, implying that the use of natural gas also contributes to environmental pollution.

Correlation Degree Between Economic Growth and Environmental Pollution Is Significant

The increase in GDP is one of the causes of pollution emissions. The rapid economic development of Guangxi Province and Zhejiang Province inevitably brings about environmental problems, and such problems are also common in various parts of China. China is known as the "world factory." This "world factory" development model has extracted a great price from its residents in terms of resources and environment. China's rapid economic growth is spurred by the consumption of large quantities of energy and the sacrifice of environmental quality. To minimize fossil energy consumption, the two provincial governments should improve energy clean technology, increase the utilization of hydropower resources, accelerate research on and development of new energy sources, promote transformation of the energy structure, and prevent environmental degradation.

Several differences between Zhejiang Province and Guangxi Province should be pointed out. In terms of total energy consumption and environmental pollution, Zhejiang Province consumes twice as much energy as Guangxi Province, but its impact on the environment is smaller than that of Guangxi Province. Energy consumption in Zhejiang Province has shifted to low-energy consumption, low pollution, and a multi-wheel-driven supply system of coal, oil, carbon, electricity, gas, and renewable energy. Compared with Guangxi Province, the energy supply system is relatively unified. In terms of industrial structure, Zhejiang Province has completed the initial stage of industrialization characterized by quantitative expansion and entered the mid-stage of industrialization characterized by structural adjustment and growth transformation. Economic development has changed from quantitative expansion to qualitative improvement, and the industrial structure is undergoing major changes and readjustments. The proportion of strategic emerging industries, low-energy-consumption industries and high-tech industries has gradually increased. The industry of Guangxi Province is still in the early stage of industrialization and is mainly based on quantity expansion. It still has a large gap to cross to reach the mid-stage of industrialization. The overall quality of industrial structure is low, and the upgrading of industrial structure is very slow. The proportion of high-tech industry, low-energy-consumption industry, and strategic emerging industries is very small. Compared with Zhejiang Province, Guangxi Province not only has low rationality and stability of its internal subdivision industry structure but also has not improved the unreasonable degree of industrial structure and low conversion efficiency of its resources. Moreover, its industrial products are mainly low-value-added middle and low-end products, and the supply of high-quality products is insufficient.

Discussion

Implement a Taxation or Subsidy Policy

On enterprises that cause external economy, the government should levy a tax. The amount of the tax should be equal to the losses caused by the enterprise to other members of the society so that the private cost of the enterprise is exactly equal to the social cost. In the case of residents or enterprises that cause external economy, the government should take measures to subsidize to make the private incomes of residents or enterprises equal to the social benefits.

Optimize and Adjust the Energy Consumption Structure

The process of optimizing and adjusting the energy consumption structure cannot be conducted too hastily. The construction of ecological civilization should be taken as a guide in fighting the battle against pollution. We should gradually reduce the consumption of highly polluting energy such as oil and coal, introduce high-quality energy such as natural gas, and at the same time make use of natural and abundant water resources and solar energy resources. The government should strive to lead the energy supply revolution; establish a reasonable carbon tax system; vigorously promote the clean and efficient use of coal; fully develop a noncoal energy source; form a multi-wheel-driven energy supply system of coal, oil, gas, nuclear, new, and renewable energy; and strengthen the construction of energy transmission and distribution networks and storage facilities to achieve the goal of improving the energy supply structure.

Improve Energy Efficiency and Develop Low-Energy Consumption

On one hand, clean coal, clean oil combustion, and energy-saving technology are popular. Through the development and innovation of related technologies, energy utilization efficiency and waste recovery rates are continuously improved, and pollutant emissions are reduced. On the other hand, the environmental standards should be used to promote technological progress in the field of energy and to reduce energy consumption per unit economic activity. We should take a new road of industrialization with high scientific and technological content, good economic benefits, low resource consumption, less environmental pollution, and full play of human resources.

Increase Capital Investment in Environmental Protection

The experience of environmental regulation in developed countries shows that to control the trend of environmental deterioration, environmental investment must reach 1.5% of GDP and environmental improvements should reach 2.5% of GDP. Therefore, to improve environmental quality, we must increase the funds invested in environmental protection to achieve a win–win situation between environmental protection and economic development.

Establish and Improve Relevant Laws and Regulations

We should revise laws and regulations to promote the effective use of energy, strengthen enforcement of the Energy Saving Law, and base the government's energy-saving actions on legislation. We should establish a system for statistical monitoring of the energy consumption of key energy-using groups to keep abreast of the energy-saving trends of enterprises; impose a deadline for those whose energy consumption habits need rectifying; control the number of enterprises that engage in high energy consumption and pollution; eliminate backward production capacity; encourage enterprises with high energy consumption to develop healthy industries with low-energy consumption and high efficiency; and use high-quality, clean, and efficient energy resources. The government should establish a system and mechanism of supervision and increase the level of punishment, imposing large fines and suspension of business for repeated violations of the law.

Strengthen People's Awareness of Environmental Protection and Establish a System of Public Participation and Supervision

People are often reminded of the importance of environmental protection through the Internet, television, and other forms of media. They are educated on the anniversary of Arbor Day and World Environment Day. The government should formulate incentives to encourage the public to report various forms of ultrastandard emissions.

People are encouraged to report to the government various forms of ultrastandard emissions and to formulate incentives such as small amounts of money or goods.

Increase Investment in Education

Energy consumption and environmental pollution are closely related to technological level and to environmental protection awareness, and people are the carriers of both. To solve the problem of energy consumption and environmental pollution in the long term, developing countries located in subtropical regions should increase their investment in education. Basic education helps cultivate the environmental protection consciousness of future consumers, and vocational and technical education and higher education expand the theoretical and technical knowledge levels of talented individuals. Theory and practice have proven that human capital is an important parameter of endogenous economic growth. Increasing investment in education at all levels is a guaranteed method of improving the total level of human capital and promoting sustainable development.

Advanced Technologies Will Promote the Development of the Whole Economy and Society

In a given period of time, energy consumption and environmental pollution change in the same direction. However, with economic and technological progress and enhancement of the awareness of environmental protection in the whole society, an emphasis on environmental pollution will lead to more innovative actions in this field and accordingly, more advanced energy technology; clean energy technologies with zero pollution can even be achieved. The derivative technologies of these advanced technologies affect the growth and structure of other sectors of the economy, thus promoting the development of the whole economy and society.

Implications for Conservation

The government should improve the proportion of high-quality, clean energy used and should further optimize the energy structure. Specifically, this involves achieving one of two improvements. One improvement is to reduce energy intensity and control total consumption. Industrial restructuring and elimination of the inefficient use of high-pollution energy are fundamental ways to improve environmental air quality. Two other possible improvements are to gradually increase the proportion of natural gas, water, and electricity in the energy consumption structure and reduce the consumption of coal and oil products. The development and utilization of alternative technologies for terminal energy consumption should be actively encouraged. The use of electricity instead of coal and gas in industry should be actively promoted, and research on and development of related technologies for electric vehicles and LNG vehicles and vessels for transportation should be promoted to achieve the goal of replacing oil and gas with electricity. The development and application of energy ladder utilization technology to improve energy efficiency should be encouraged.

The government should also improve the use of renewable energy such as solar, wind, biological, and tidal energy. In the development of tidal energy, favorable terrain such as bays and estuaries is used to build dikes and reservoirs to accumulate large amounts of sea water, and hydroelectric power plants are built in or near dams to generate electricity through hydroelectric generating units. The storage and conversion of solar energy should be studied. There are two ways to improve the use of wind energy: one is to deepen the study of geographical locations and choose more suitable locations for the use of wind energy; the other is to intensify research on wind energy equipment and improve the conversion rate of wind energy. With respect to bioenergy, we should not only increase support for the use of biomass energy but also encourage enterprises or individuals to use biomass energy with government subsidies. In the end, we will improve energy utilization and optimize the energy consumption structure.

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