International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

A Comparative Study on the Coordination Degree about Economy-Energy-Environment of Different Regions in China

Hui Tiao-yan[1], Liang Jia-hui[2]

[1, 2]Xidian University, School of Economics and Management, Xifeng road, Xinglong section 266, China

Abstract: ***Coordinated development of economy-energy-environment has become more and more important for China's sustainable development. This paper measures the spatial-temporal evolution of coordination degree about economy- energy-environment for different regions in China during the period of 2005-2017. The results show that: Jiangsu Province in Eastern China, is in a good state of coordinated development with the highest degree, followed by Hubei in Central China, and Inner Mongolia in West China. Finally, it put forward some suggestions: Transforming the economic development mode, optimizing and upgrading the industrial structure. It's need to adopt a combination measures of energy consumption, reduce the share of coal in energy consumption, and develop new sources of energy; Strengthening environmental protection, control the discharge of Industrial wastes, and increase the efficiency of environmental protection.***

Keywords: economy-energy-environment; Coordinated development; Coordination degree**.**

1. Introduction

It is of great significance to coordinated development. Coordinated development refers to the harmonious and consistent development of its subsystems (Yang and Yang 2007). The coordinated development of economy- energy-environment(3E) referred to multi-aspect relationship in economy, energy, ecology and environment, emphasizing on their mutual adaptation, coordination, collaboration and promotion, not just one single area growth. China's geography is amplitude, it has a great difference in the east, the central and the west, with the eastern region having the highest level of economic development, followed by the central and western regions. With the rapid development of economy in China, the problem of heavy consumption of resources and emissions of environmental pollution has become more and more serious, which in turn mainly restricts the economic development in the further. This paper aims to distinguish the coordinated development degree of different regions in the eastern, central and western regions in China, based on the three representative provinces of Jiangsu, Hubei and Inner Mongolia, to explore the coordination status and main problems faced in spatial variation and its future trends, then provide some suggestions for sustainable development in China.

2. Literature Review

Scholars have conducted extensive research on coordinated development of between economy, energy and environment. Muhammad Shahbaz et al. [1] used the ARDL boundary test method of co-integration and the innovative accounting method (IAA) to verify the existence of EKC between economic growth, energy consumption, trade liberalization and carbon dioxide emissions. Hsiao-tienpao et al. [2] (2015) applied lotka-volterra model to study the competitive interaction between energy, environment and economy (3E) in the United States. Vahid Mohamad Taghavee et al [3] calculated the long-term and short-term energy, environmental and economic elasticity of Iran from 1974 to 2012 using co-integration and EMC synchronization models. Lingling Deng [4] built 3E coordination degree indicator system framework, establishes a coordination evaluation model for 3E system, analyze the 3E coordination situation of 30 provinces of China and find out that environmental policy and energy construction are positive factors, consumption level, population size and urbanization are negative factors for 3E system coordination. JIA Jia et al [5] constructed a model of system dynamics (SD) for river-basin which comprised of several sub-system, designed three different scenarios of socio-economic development, found it should optimization of industrial structure and pollution industrial. XIONG Jianxin et al [6] used capacity coupling to analyzes the coupling coordinative degree and temporal and spatial difference in the Dongting Lake region, found the coupling strength was greater than the internal coordination. HUANG Xinhuan et al [7] constructed a system coordination degree model based on bull's-eye distance, and extended the application of grey theory in the evaluation of system coordination state. Xu Ni-ya et al [8] analyzes the advantages and disadvantages of the resource utilization in Wuhan's economic development, to found the core problems is that coordinate "Economy-Resources-Environment". DUAN Haiyan et al [9] (2017) takes Jilin province as an example, setting baseline scenario, stable scenario, and coordinate scenario with coupling coordinated development degree prediction model that to forecast the population-economy-energy-environment coupling coordinated development degree. GAO Ya [10] (2018) built a system dynamics model based on urban agglomeration in Fujian rive deltas resource and environmental carrying capacity, set four scenarios, found Technology Garden scenario is an ideal model for city development. WANG Yu [11] (2018) combined the coupling coordination evaluation model, autocorrelation analysis and Radial Basis Function Neural Network(RBF)model, , unit root test - cointegration test - Granger causality test and three

preset scenarios, study the coordinated development to reveal the function principals and mechanism of driving factors, coupling time and path and realization mechanism of the coordinated development.. GAI Mei et al [12] (2018) used coordinated development model measures the carrying capacity's coordinated development, and used gray relational analysis to measure the main factors of carrying capacity. YU Yang et al [13] (2019) calculated the coordinated degree and development degree of the economy-environment-science-technology systems of 10 eastern province from 2007 to 2015, found quaternionic systems's development degree are different with coordinated degree. It can be seen that there is a mutual influence between economy, energy and environment, and the problem of incoordination caused by economic development is widespread, but an effective way to achieve coordinated development has not been found at present. Based on this, the evaluation index system of coordinated development of economy, energy and environment was established. With the three provinces of Jiangsu, Hubei and Inner Mongolia as the research background, the calculation of coordination degree of different regions and the comparative analysis of spatial and temporal evolution were conducted.

3. Comparative analysis of 3E coordination degrees for different regions

3.1 3E Development of Jiangsu, Hubei and Inner Mongolia

Jiangsu is located in the east of China, with rapid economic development. Its per capita GDP ranks the first level among all provinces in China, and has reached the standard of developed countries. Hubei, located in central China, is a fast-developing province. Its GDP rose to the seventh place of all the provinces of China in 2017.Inner Mongolia is located in the west of China. It is rich in mineral resources. It plays an important role in energy supply. Depending on their own endowment, the three provinces of Jiangsu, Hubei and Inner Mongolia have formed their own development paths with typical characteristics, which can well represent the eastern, central and western regions of China.

(1) Economic development

From 2005 to 2017, the GDP of Jiangsu and Hubei increased steadily, while that of Inner Mongolia slowed down and showed a downward trend of economic growth rate (figure 1). In 2017, the GDP of Jiangsu was 8.6 trillion yuan, with a growth rate of 7.2% and the per capita GDP was 107,000 yuan, and the proportion of primary, secondary and tertiary industries output was 4.7:45.0:50.3. The GDP of Hubei is 3.5 trillion yuan, with a growth rate of 7.8% and the per capita GDP is 6.0 ten thousand yuan. The proportion of primary, secondary and tertiary industries is 10.0:43.5:46.5. The GDP of Inner Mongolia is 1.6 trillion yuan, with a growth rate of 4.0% and the per capita GDP is 64,000 yuan. The proportion of primary, secondary and tertiary industries is 10.2:39.8:50.0. Under the downward pressure of the global economy, Jiangsu, Hubei and Inner Mongolia have all transformed of industrial structure from "231" to "321", but the economic growth of Inner Mongolia is restricted by the industrial structure, resulting in a decline of GDP.

For industrial structure, all industries are divided into three types, such as heavy industry, light textile industry and high-end manufacturing industry. For Jiangsu Province, although the pharmaceutical and electronic information manufacturing are the main parts, the proportion of heavy industry is about 35%.The proportion of heavy chemical industry of Hubei has been decreasing, and realized the balanced of heavy chemical industry, light textile industry and high-end manufacturing industry. For Inner Mongolia, the industrial structure is mainly heavy chemical industry, accounting for about 70%, while high-end manufacturing industry is weak, accounting for less than 10%.

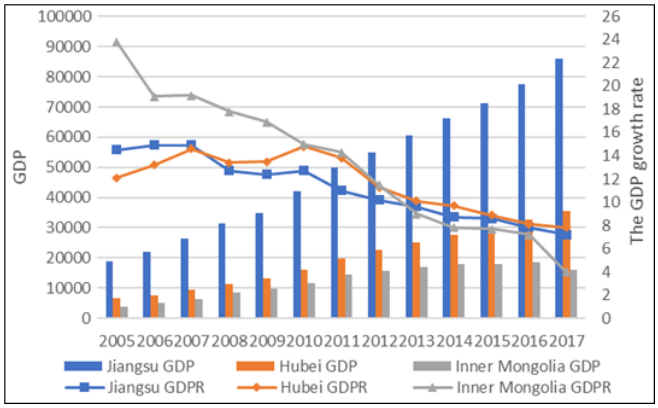

Figure 1: GDP and growth rate of the three provinces from 2005 to 2017

(2) Energy production and consumption

Jiangsu is a major provinces of energy consumption, facing the shortage of energy. More than 90% of the coal, oil and natural gas relies on external regions. Hubei province has intensified energy reform to develop the energy industry continuously. However, the external dependence is still high. It is difficult to develop clean energy and change the coal-dominated energy based industrial structure. Inner Mongolia has a more prominent position in energy. In 2017, it ranked first Province in raw coal production in China, and its energy supply capacity has been constantly improved. However, it lacks innovation in energy development, which lead to low energy efficiency, and low utilization rate of new energy. From the perspective of total energy production, Jiangsu is the lowest, accounting for only about 10% of all, with a large energy supply and demand gap, mainly relying on energy import. Energy production in Hubei accounts for about 30%-40% of consumption, and no need energy import, which is mainly transferred across provinces. Inner Mongolia energy production is about three times of energy consumption, is an important energy base in China. In terms of total energy consumption, Jiangsu, Hubei, Inner Mongolia reached 31,430, 17,150 and 199,915 tons of standard coal respectively in 2017. For energy consumption structure, coal consumption has been reduced generally. In 2017, coal consumption accounted for about 60% in Jiangsu, less than 50% in Hubei, and about 80% in Inner Mongolia (figure 2). This indicates that China's energy structure adjustment has achieved some good results, but for resource-based provinces still faces many challenges.

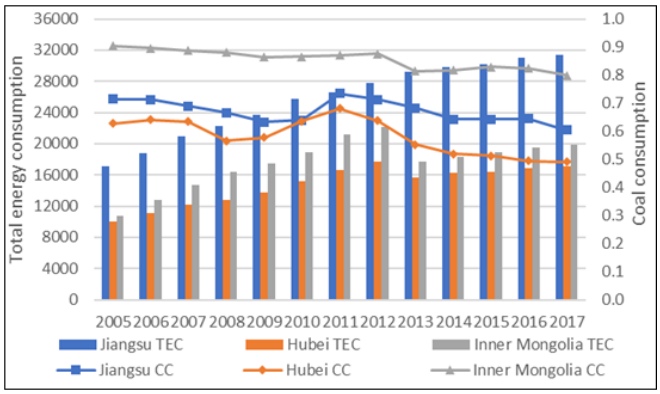

Figure 2: Total energy consumption and coal consumption of the three provinces from 2005 to 2017

(3) Environmental pollution and treatment

Environmental pollution is mainly caused by industrial waste emissions. "Pollution first, treatment later" has made China's environmental problems more serious. From 2005 to 2017, industrial sulfur dioxide emissions and waste water production are both in a downward trend, while industrial solid waste production keeps increasing (figure 3).It can be seen that industrial sulfur dioxide emissions decreased significantly in 2016, with the decline rates of 34%, 61% and 59%, respectively for Jiangsu, Hubei, Inner Mongolia Province, indicating that China has achieved a certain good results in waste gas control. Inner Mongolia's industrial sulfur dioxide emissions and solid waste production are highest, mainly due to the high proportion of heavy chemical industry, belonging to the high pollution industry, indicating that the industrial structure affects environmental pollution. From the perspective of environmental protection, Jiangsu's investment in environmental protection keeps increasing, and the environmental protection investment coefficient is between 0.8% and 1.8%. Environmental protection investment in Hubei increased to 43.5 billion yuan in 2016, with the coefficient fluctuating between 0.6% and 1.4%. Environmental protection investment in Inner Mongolia has grown rapidly, from less than 10 billion yuan in 2005 to nearly 100 billion yuan in 2017, with the investment coefficient exceeding 6%. In general, the intensity of environmental pollution coefficient in Inner Mongolia > Hubei > Jiangsu is the result of pollution discharge and treatment. Emphasizing development and paying more attention to pollution treatment can effectively reduce pollution intensity and save investment in environmental protection afterwards.

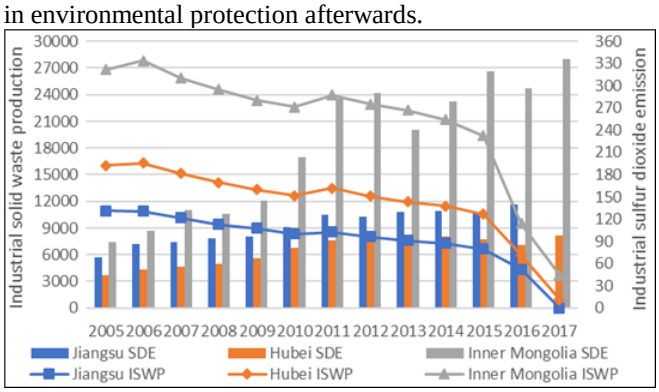

Figure 3: Industrial solid waste and sulfur dioxide production in the three provinces of from 2005 to 2017

3.2 Method and coordinated development degree index

Coordinated development is the best way to deal with the relationship among economic development, energy consumption and environmental protection, which is a necessary prerequisite for sustainable development. Economy, energy consumption and environment pollution interact with each other. First, energy consumption depend on economic development, industrial structure energy efficiency. Secondly, High level of economic development leads to high investment in environmental protection, and better the ecological environment. Finally, Energy consumption is the main source of pollutants. The lower the energy utilization efficiency, the greater the pressure on environmental governance. In general, economy, energy and environment are closely related, mutual support and feedback, in a continuous cycle of development. However, in the course of China's economic development, it has taken a road of "pollution first, treatment later", which has separated the relationship among economy, energy and environment, resulting in serious energy shortage and ecological degradation.

For this paper, coordinated development degree of Zhongbin Liao [14] (1999) is adopted, and the coupling coordination degree model of 3E systems is referred to by Mei Gai et al [15] :

$$D = \sqrt{C \times T} \tag{1}$$

$$C = \left\{ \frac{f(x) \cdot g(y) \cdot h(z)}{\left[\frac{f(x) + g(y) + h(z)}{3}\right]^3} \right\}^{\frac{1}{3}} \tag{2}$$

$$T = \alpha f(x) + \beta g(y) + \gamma g(z) \tag{3}$$

Where, D is the coupling coordinated development degree, $D \in (0 \sim 1)$; C is the coupling degree, reflecting the coordination level between systems; T is the comprehensive evaluation value, α、β、γ reflecting the overall synergy effect of the three-way system. As the three systems have the same importance, take $\alpha = \beta = \gamma = {}^1/_3$.

$$f(x) = \sum_{i=1}^{m} a_i x_i' \quad g(y) = \sum_{j=1}^{n} b_j y_j' \quad h(z) = \sum_{k=1}^{l} c_k z_k' \tag{4}$$

$f(x)$、$h(y)$、$g(z)$ represents the development level of economy, energy and environment. x_i'、y_j'、z_k' respectively, degree of coordinated development of the economy-energy-environment standardized data, evaluation of specific indicators by the method of extremum x_i、y_j、z_k standardizing, the specific method is:

$$x_i' = \begin{cases} \dfrac{x_i - \lambda_{min}}{\lambda_{max} - \lambda_{min}} & x_i \text{ is a positive indicator} \\ \dfrac{\lambda_{max} - x_i}{\lambda_{max} - \lambda_{min}} & x_i \text{ is a negative indicator} \end{cases} \quad (i = 1,2, \ldots m) \tag{5}$$

The standardization of y_j、z_k adopts the above methods.
The coordinated development degree was used to measure the coordinated development of Jiangsu, Hubei and Inner Mongolia from 2005 to 2017, and the criteria for coordinated development of economy, energy and environment were used (table 1). 14 main indicators were selected to construct the coordinated development evaluation index system (table 2).

Table 1: Coordination level standard

0~0.09	0.10~0.19	0.2~0.29	0.3~0.39	0.4~0.49
Extreme dysregulation recession	Severely unbalanced recession	Moderate dysplasia	Mild dysplasia	On the verge of recession
0.5~0.59	0.6~0.69	0.7~0.79	0.8~0.89	0.9~1.0
Barely balanced development	Primary coordinated development	Intermediate coordinated development	Well-coordinated development	Quality coordinated development

Table 2: Indicators for coordinated development of economy-energy-environment

	Indicator	Direction
Economic index	Regional GDP	Positive
	Proportion of output value of textile industry	Positive
	Proportion of high-end manufacturing output value	Positive
	Total capital formation	Positive
	Technical innovation level	Positive
Energy index	Total energy consumption	Negative
	Total energy production	Positive
	Proportion of coal consumption	Negative
	Proportion of oil consumption	Negative
	Energy consumption per unit of output	Negative
Environmental index	Environmental investment coefficient	Positive
	Exhaust gas emissions	Negative
	Amount of wastewater generated	Negative
	Amount of solid waste generated	Negative

3.3 Results of coordinated development degree

3.3.1Coordinated development degree

The results of coordinated development degree (figure 4) show that the coordinated development level of Jiangsu, Hubei and Inner Mongolia's increases on the whole. From 2005 to 2007, Jiangsu's was barely balanced development; from 2008 to 2013, it was primary coordinated development; and from 2014 to 2017, it was intermediate coordinated development. This indicates that the coordinated development was improved, but improved little after 2014. For Hubei, it was on the verge of unbalanced recession In 2005; from 2006 to 2011, it was barely balanced development; from 2012 to 2015, it was primary coordinated development; and from 2016 to 2017, it was directly promoted to good coordinated development. The coordinated development level of Hubei was the highest among the three provinces, mainly due to significant decrease in pollutant emission, which led to rapid improvement in environment. From 2005 to 2007, Inner Mongolia experienced primary coordinated development; from 2008 to 2014, it fell to barely balanced development; from 2015, it experienced primary coordinated development; and from 2016 to 2017, it rose to intermediate coordinated development. The improvement of coordinated development in Inner Mongolia is due to the optimization of energy consumption.

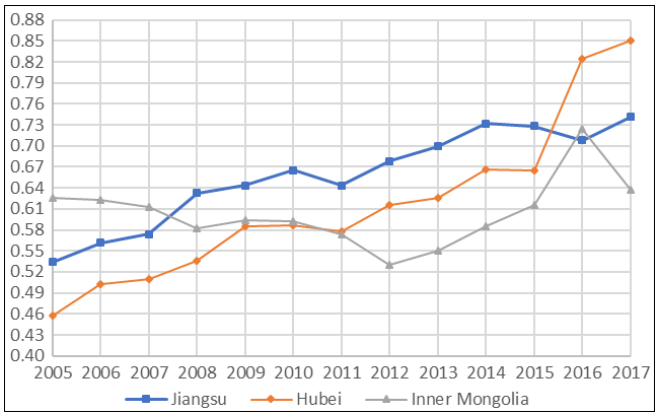

Figure 4: coordinated development of the three provinces from 2005 to 2017

3.3.2 Temporal evolution trend and spatial variation

The spatial and temporal evolution patterns of the three provinces are significantly different (figure 5,6,7). Economy of Jiangsu has been continuously improved, and the level of energy and environmental development has been spiraling upward. The economy has developed firstly, accumulated abundant resources and promote innovation to focus on high-end manufacturing and reduce the proportion of heavy and chemical industries. Due to the rapid development of economy in recent years, demand for energy is large, so as to face a certain supply and demand gap. Investment in environmental protection is large, and pollution from industrial "waste gas", "waste water" and "solid waste" remains at a high level, with the treatment rate exceeding 70 percent, 95 percent and 90 percent respectively in 2017.

For Hubei, energy development level of is leading, the economy is improving rapidly, and the environmental status is stable. With rapid economic development, the government has constantly expanded the level of opening-up. The GDP of the region is second only to that of Henan province. The energy demand and per capita energy consumption are the lowest in three provinces. The emission of industrial "three wastes" is at a relatively low level, and the emission of industrial "waste gas" and "solid waste" is the lowest. Moreover, with the higher requirements for environment, environmental protection and management acquired great achievements.

For Inner Mongolia, economic development is declining in recently, energy capability is improving, and the level of environment is slowly declining, but it has been significantly improved in 2016. Economic development heavily relies on resource, and the total volume is far different from that of Jiangsu and Hubei. Promoting the transformation and upgrading of industrial structure has become the main way for economic development. High energy consumption, especially in terms of output and per capita energy consumption, with more coal and natural gas production than consumption and less oil production than consumption in the province; The intensity of environmental pollution is the highest, mainly due to the large amount of pollution discharged. The discharge of industrial "waste gas" and "solid waste" is the highest.

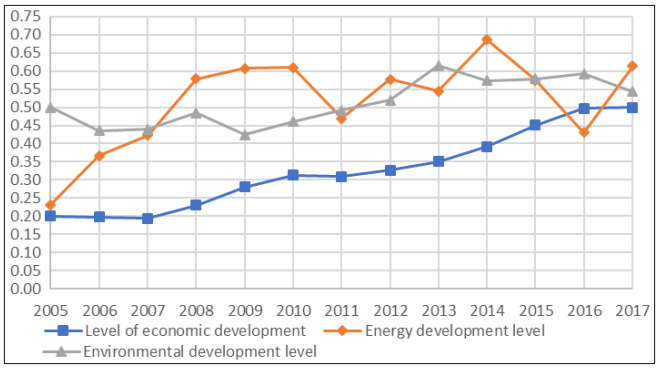

Figure 5: Coordinated development of economy, energy and environment of Jiangsu from 2005 to 2017

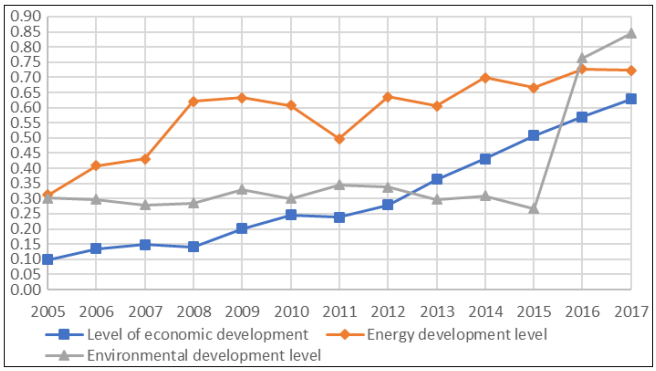

Figure 6: Coordinated development of economy, energy and environment of Hubei from 2005 to 2017

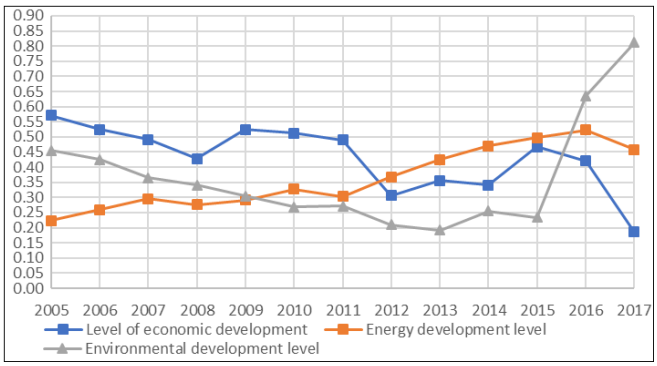

Figure 7: Coordinated development of economy, energy and environment of Inner Mongolia from 2005 to 2017

The coordinated development of Jiangsu, Hubei and Inner Mongolia can be divided into three stages: starting, differentiation and adjustment. From 2005 to 2007, less environmental problems, Inner Mongolia achieved the highest level of coordinated development with the rapid development of economy benefit from abundant energy resources. In 2008-2016, Jiangsu coordination development level, the highest and stable, this period China put forward the "12th Five-year plan" development of the equipment manufacturing industry and "13th Five-year plan" focus strategy for the development of strategic emerging industries, Jiangsu's economy has been greatly developed, followed by Hubei. While Inner Mongolia, with the worse environment, lead to economic recession. Since 2016, Hubei has achieved the highest level of coordinated development, mainly due to the serious environmental degradation in China. The government issued lots of environmental protection policies to limit pollutant emissions, and the environmental situation in Hubei province has improved significantly. On the whole, Jiangsu has the best coordinated development, which has been steadily improved, followed by Hubei, and Inner Mongolia needs to be improved.

4. Conclusion and Suggestion

Taking the representative province of Jiangsu, Hubei and Inner Mongolia in the east, middle and west of China as the research sample, the coordinated development degree of the economy-energy- environment system was calculated, and the spatio-temporal evolution was compared and analyzed. It was found that the coordinated development level of Jiangsu, Hubei and Inner Mongolia was improved and the evolution was obviously different. The development level of energy and environment in Jiangsu is higher than that of economy. The level of energy development in Hubei is the highest, then economy developed, and environment is stable, coordinated development is better. Inner Mongolia has developed from economic leading development to economy lagging behind energy and environment, and the situation of coordinated development is not good.

The following policies can be adopted to promote the coordinated development of economy, energy and environment. (1)accelerating the transformation of economic development mode, optimizing and upgrading the industrial structure; (2)adjust the energy consumption structure, reduce the proportion of coal energy consumption and develop new energy; (3) strengthen environmental protection, reduce the discharge of "three wastes" from industry, and improve the efficiency energy utilization and environmental treatment. In addition, the realization of coordination requires synchronous development of economy, energy and environment. Focusing on economy development but ignores energy and environment will cause serious uncoordinated. Measures in a single field cannot achieve satisfactory results. Measures and regulations for economic development, energy efficiency and pollution reduction should be implemented together to achieve good coordinated development of economy, energy and environment.

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Author Profile

Liang Jia-hui received bachelor's degree in management from Shijiazhuang Tiedong University in 2017. Now majoring in management science and engineering at Xidian University.