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Original Research Paper

Factors Influencing PM2.5 and the Governance Strategies in Jiangsu, China

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ABSTRACT

Haze has impaired the order of public health as well as normal social and economic development. To analyse the factors influencing PM2.5 in Jiangsu province and propose specific governance strategies based on time-series data in Jiangsu from 2000 to 2014, this study identified five factors that cause haze pollution in Jiangsu. A multiple linear regression model was adopted to quantitatively measure the degrees of the effect of these factors and their significance levels. Specific measures that govern haze from the perspective of factors with significant influence were proposed. Findings show that the extensive economic growth mode, the sustainable growth of car ownership, heavy consumption of coal, the large amount of exhaust emissions in industrial production, and the large amount of dusts generated by urbanization construction are the five major factors that influence the frequency of haze PM2.5 weather in Jiangsu. Car ownership, generation of dust by housing construction, and emission of industrial exhaust significantly influence the frequency of PM2.5 weather. The regression coefficients of the three independent variables were positive and effective at the 5% significance level, and the growths of the three independent variables per unit increase haze weather by 0.457, 0.248, and 0.114, respectively. The findings of this study provide effective policy suggestions for analysing the factors that influence haze weather, adopting specific governance measures for the haze problem, and implementing environmental protection measures in Jiangsu.

INTRODUCTION

The eastern part of China has experienced serious haze weather in recent years. Haze usually appears under an atmospheric circulation state with weak and cold air as well as strong water vapour. Low-altitude and near-earth calm wind or breeze is influenced by surface-level static and stable weather. The movements of air in both horizontal and vertical directions are small, which lowers the diffusibility of the atmosphere. Under this condition, the pollutant emission of energies needed in transportation, life, and production continuously accumulates in the lower part of the sky.

As an economically developed province along the eastern coast of China, Jiangsu's economy, society, and culture have significantly developed through economic development at the national level. The GDP of Jiangsu increased from RMB 858,500,000,000 in 2000 to RMB 6,508,800,000,000 in 2014 (Fig. 1) With the GDP increasing by 7.5 times, significant economic benefits and social welfare were achieved, and the modernization of Jiangsu progressed. However, the problem of haze pollution was generated because of the mode of energy consumption, economic growth, and accelerated urbanization progress. Haze threatens the ecological environment and sustainable development in Jiangsu. The possibility of solving the haze problem and the ways in which it can be solved are critical problems that must be faced with the further development in Jiangsu. The haze problem is not only related to regional economic development but is also associated with the implementation of its ecological construction. Thus, this study investigated the factors that influence haze pollution and the degrees of their effect, and corresponding governance strategies to solve the haze problem faced by Jiangsu were proposed.

EARLIER STUDIES AND COMBING

With the rapid economic development, the problem in atmospheric pollution has become prominent. Haze weather, which is frequently observed in global areas, has drawn public and governmental attention. Many international and domestic scholars have conducted in-depth research on the factors that influence haze pollution and proposed strategies to solve such problem. Houthuijs conducted relevant studies on PM10 and PM2.5 and found that PM2.5 composed a significant portion in PM10 composition (Houthuijs et al. 2001). Zhang studied the chemical composition and source of PM2.5 in Qinghai Lake (Zhang et al. 2014). Dai studied the source of haze in Shenzhen, China and identified a seasonal particle matter, which the lungs could absorb, as the main source of haze pollution (Dai et al. 2013). Vega employed relevant data in Mexico from 2000 to 2002, pointed out that the PM2.5 concentration in industrial ar-

eas is higher than that in non-industrial areas, and posited that industrial waste gas emission is the main factor influencing haze formation (Vega et al. 2004). Tran examined PM2.5 and meteorological conditions over the last 10 years in Fairbanks, Alaska and found that different meteorological conditions generate different influences on PM2.5 concentration (Tran et al. 2011). Landis et al. studied the components of PM2.5 and found that sulphur compound is the main component of PM2.5; sulphur compound is significantly determined by the concentration of SO_2 gas (Landis et al. 2001). Cheng concluded that the sources of PM2.5 include the exhaust emissions of automobiles, fuel combustion, industrial emission, pavement dust (Cheng et al. 1998). Ramanathan found that 75% of human factors cause haze in the air of the Indian Ocean and that these particle matter of haze pollution diffused from the mainland to the Indian Ocean (Ramanathan et al. 2002). Zhuang believed that PM10 in haze is mainly derived from industrial activities and that the main factors influencing this condition are the quality of gasoline, exhaust emission of engines, tail gas treatment, and the emissions of gas stations (Zhuang et al. 2014). On governance measures for haze pollution, Stuart proposed that effective supervision measures of air should be established in the suburbs (Stuart et al. 2009). Mohareb stated that cleaner production and cyclic utilization should be adopted and that trash burning and burying are methods that should not be adopted (Mohareb et al. 2011). Liu believed that to effectively implement energy conservation and emission reduction and to reduce haze pollution, construction, product energy consumption, and production must be standardized, and industry access threshold needs to be established (Liu et al. 2002). Chen believed that the government should reinforce legal governance, advocate clean production and cyclic utilization, and avoid burying trash (Chen et al. 2008). Mushkat believed that the trans-regional cooperative legal mechanism of the ASEAN could relive urban haze (Mushkat 2014).

The factors influencing PM2.5 and the corresponding governance strategies have been extensively studied. However, international and domestic studies on these factors focused on the chemical composition of PM2.5, the influence of visibility and climate, and the explanation of the source of the weather. A complete mechanism for strategies in the governance of haze has not been developed. Instead, scholars analysed and studied only from single aspects and did not consider multiple measures. Moreover, a systematic solution to haze pollution has not been established. Therefore, based on existing literature that studies PM2.5, this study analysed the factors that mainly influenced haze weather from 2000 to 2014. The Eviews7.0 software was used to measure the degrees of the effects of the key factors influencing haze pollution. Measures for the governance of haze pollution were proposed to provide theoretical basis and reference for haze governance in Jiangsu.

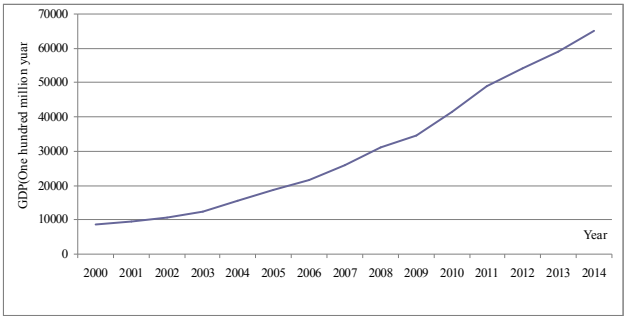

Fig. 1: GDP from 2000 to 2014 in Jiangsu province.

FACTORS INFLUENCING HAZE POLLUTION IN JIANGSU PROVINCE

The problem of haze pollution is rooted in natural and socio-economic aspects. Severe meteorological conditions result in the continuous accumulation and uneasy diffusion of pollutants in the atmosphere. Original pollutants that remain in the atmosphere do not smoothly fall onto the ground but are dispersed in air, which results in sustained and large-scale haze weather. This condition is especially true during autumn and winter in Jiangsu, when cold air movement are weak and are characterized by low wind speed. Aside from natural causes of haze formation, the main and most significant factors that influence the generation of haze in Jiangsu are:

Extensive economic growth mode purely intended for GDP growth: For a long period, Jiangsu has been guided by developmental strategies that "pursue economic growth" and "modernized industrialization." The mode of regional economic growth has always focused on extensive economic development and GDP growth. High GDP growth is achieved by increasing output through industrial input, factory construction, and expansion of labor input. The economic growth of Jiangsu has relied heavily on the industry, which resulted in excessive and blind investment on industries during the developmental process, especially the investment on heavy industries. Moreover, the proportion of heavy industries is high. Jiangsu is a major industrial province in East China, and the value of its industrial output is about 50% of its GDP (Fig. 2). Although the overall proportion of secondary industries in the GDP is decreasing, it still reached 46% in 2014. However, heavy industries were restricted by slow technological improvement and backward

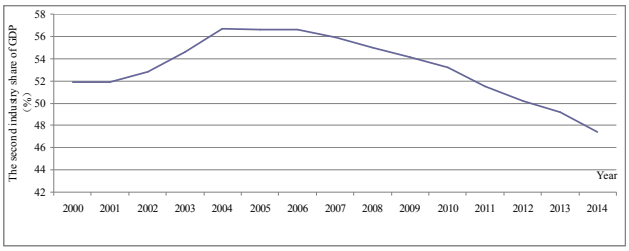

Fig. 2: Proportion of secondary industries in the GDP in Jiangsu from 2000 to 2014.

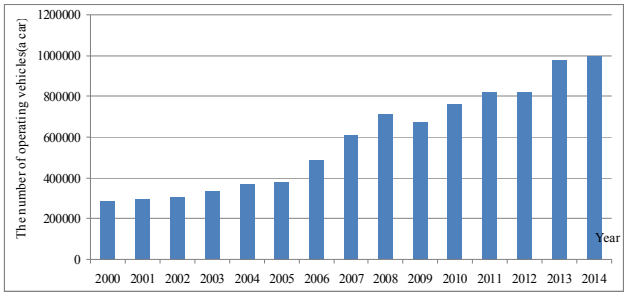

Fig. 3: Commercial car ownership in Jiangsu from 2000 to 2014.

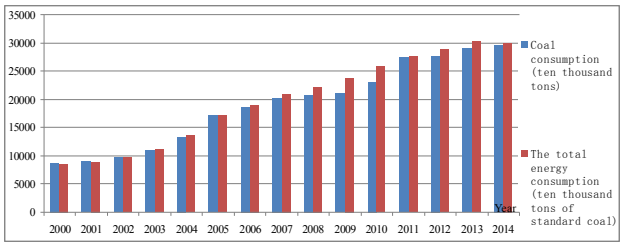

Fig. 4: Amount of coal consumption and total energy consumption in Jiangsu from 2000 to 2014.

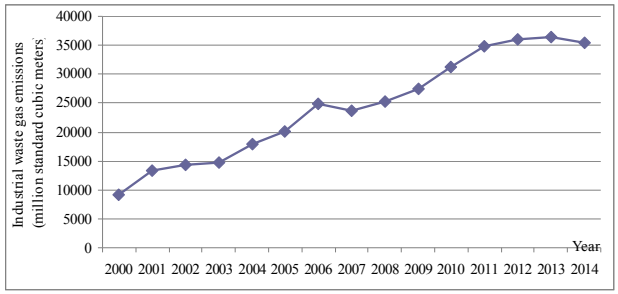

Fig. 5. Emission of industrial fuel gases in Jiangsu province from 2000 to 2014.

management. Thus, heavy industries that developed in Jiangsu have brought about serious problems in terms of environmental pollution. Therefore, extensive economic growth is the main cause for the generation of haze in Jiangsu.

Increasing car ownership gives rise to soaring tail gas emission: The quantity of car consumption increased sharply with the propulsion of the industrialization and modernization of Jiangsu (Fig. 3). From 2000 to 2014, given the economic development of Jiangsu, commercial car ownership presented an annual increase. It significantly increased from about 200,000 cars in 2000 to 1,000,000 cars in 2014. Regional car ownership increased with the significant increase in car tail gas emission. A large quantity of fine particles that obtain nitrogen is found in the polluted air in Jiangsu. These particles were generated through a joint reaction among chemical substances, such as sulphur dioxide, oxynitride, and volatile organic matters. One of the sources of these particles is car tail gas, especially fuel oil. Thus, tail gas contains harmful components that cause haze weather in Jiangsu, and tail gas emission directly influences the generation of haze weather. Therefore, increasing car ownership within the region will abruptly increase tail gas emission, and a large quantity of matter that causes haze in tail gas will enter the air and gradually accumulate, which finally results in hazy weather in Jiangsu.

Coal consumption generates a large quantity of air pollutants: The variety and reserve of energy resources in Jiangsu determine the coal-leading energy consumption structure. Even with the exploitation and utilization of oil and gas as well as the development and utilization of solar energy in a large quantity, the proportion of coal that is utilized slightly decreases. The status of coal as a main energy source has not changed because the overall amount used continuously increased and the new type of clean energy is limited. Moreover, coal is an important source of raw material and a raw material for making plastic, chemical fertilizer, and other kinds of basic chemicals. Fig. 4 shows that the amount of coal used in Jiangsu in 2014 exceeded 300,000,000 t, which is about 3.4 times of that in 2000. The total amount of energy consumption in Jiangsu in 2014 was about 3.5 times of that in 2000. Energy consumption is influenced by the increasing amount of coal consumption in Jiangsu and has always been increasing. Using coal generates a large quantity of air pollutants, which directly results in the generation of hazy weather, such as sulphur dioxide, oxynitride, and dust. Thus, the excessive use of coal will bring about serious air pollution problems.

Industrial production discharges a large quantity of exhaust gases (Fig. 5): Industry is the main pillar of economic development in Jiangsu. It centres on heavy industries with high industrial concentration ratio and a large degree of pollution. Industrial types in Jiangsu concentrate on steelmaking, petroleum refining, coking, nuclear fuel

Table 1: Housing construction area in Jiangsu province from 2000 to 2014.

Year	Housing construction area (10,000 square meters)
2000	21,287
2001	24,319
2002	27,753
2003	33,950
2004	43,171
2005	35,713
2006	63,140
2007	79,902
2008	90,145
2009	62,189
2010	119,036
2011	83,720
2012	93,685
2013	192,982
2014	112,434

processing, material production, and chemical manufacturing. These industries have high pollution discharge and high emission. The sources of industrial waste gases include industrial waste gases that are generated during fuel use and industrial waste gases generated during production. The total discharge volume of industrial waste gases in Jiangsu is rising. Industrial emission increased to about 3,600 billion cubic meters of high-amount emission in 2014, which is about 3.9 times of that in 2000. The chemical components of fuel gases generated during industrial production include soot (dust), sulphur dioxide, and nitrogen dioxide, and the increasing emission of industrial waste gases increases hazy weather.

Large quantity of dust generated by expanded urbanization construction area: Urbanization construction is important for the economic development of Jiangsu, and elevated social productive forces within the region during economic development will propel the continuous expansion in the urban scale. During the urbanization development in Jiangsu, building area is continuously expanded, which includes the building area of municipal engineering as the infrastructure of the whole region as well as the building area of ordinary civil architecture that is closely related to the daily lives of Jiangsu residents (Table 1). During the urbanization of Jiangsu, architecture in the construction process generates a large quantity of architectural dust, and these matters float in the air and increase microparticle content in the air, thereby generating problems in the atmospheric environment. From 2000 to 2014, the building construction area in Jiangsu continuously expanded, and the total housing construction area in Jiangsu in 2014 reached 1,124,340,000 square meters. However, given that construction enterprises lack awareness of environmental protection during construction, they focus on economic benefits and use cheap building materials, which generate a large quantity of dust. Moreover, they lack necessary dust-proof measures on construction sites. Thus, dust generated during construction process drifts away in the air in a large area, which results in serious air pollution. Therefore, construction makes a large quantity of building dust enter the environment, which becomes significantly causes haze pollution in Jiangsu. Given the continuous increase in housing construction area for the urbanization of Jiangsu, the construction behaviours of construction enterprises threatens the atmospheric environment, which build dust and aggravate the haze problems in Jiangsu.

EMPIRICAL STUDY ON THE FACTORS THAT MAINLY INFLUENCE HAZE POLLUTION

Variable Selection and Data Source

Factor analysis of variable selection: This study identified several factors related to haze generation in Jiangsu: unreasonable economic development, tail gas emission due to increasing car ownership, heavy consumption of coal, large amount of industrial waste gas emission, and building dust caused by the increase in building construction area. Based on the factors identified in the literature review, the consideration of data availability, and the principles of quantification and availability, this study identified five independent variables: unit GDP energy consumption, car ownership, coal consumption, gas emission from industrial waste gas emission, and building construction area (Table 2). This study also used the days of PM2.5 haze weather in Jiangsu as dependent variables.

Data source: The data on the five independent variables-unit GDP energy consumption, car ownership, coal consumption, industrial waste gas emission, and housing construction area, were derived from the Jiangsu Statistical Yearbook (2001-2015). The days of PM2.5 haze weather were derived from the Statistical Yearbook of Jiangsu Environment (2001-2015), and the investigation period was 2000-2014.

Empirical Study

Based on variable selection, this study examined the influencing degrees of the days of haze weather and the key influencing factors in Jiangsu. An econometric model was also developed, as shown in Formula (1).

$$\ln y = \alpha_0 + \alpha_1 \ln x_1 + \alpha_2 \ln x_2 + \alpha_3 \ln x_3 + \alpha_4 \ln x_4 + \alpha_5 \ln x_5 + \mu \quad ...(1)$$

Table 2: Index selection and description.

Index selection	Index descriptions
Unit GDP energy consumption	It is an important index that determines the reasonability of economic development and industrial structures. It provides the degree to which existing economic industrial structures influence haze pollution in Jiangsu.
Car ownership	It has a positive correlation with tail gas emission. Tail gas is a constituent part of haze pollutants. Using car ownership data shows the influence of car quantity on the haze pollution in Jiangsu.
Housing construction area	It reflects building dust emission, degree of pollution, and the difficulty of construction manage ment. Building dust is component of haze pollutants. Using data on building construction area can reflect the degree to which housing construction behaviors influence haze pollution in Jiangsu.
Coal consumption	It can effectively determine the effect of coal to the haze problem in Jiangsu.
Industrial waste gas emission	Industrial waste gases contain pollutants that result in haze, and industrial waste gas emission directly influences air pollution. This index can reflect the degree to which industrial waste gas emission influences haze pollution in Jiangsu.
Days of PM2.5 haze weather	Haze is a normal atmospheric phenomenon but not air pollution. However, when the size and content of particles in haze reach a certain degree, haze will generate major adverse effects on the society, economy, life, and human health as well as hazardous air pollution. The days of PM2.5 haze weather is an important index that measures whether haze reaches hazardous air pollution.

Table 3: Correlation coefficients among the independent variables.

	In x_1	In x_2	In x_3	In x_4	In x_5
In x_1	1	0.124	0.247	0.302	0.164
In x_2	0.124	1	0.097	0.312	0.101
In x_3	0.247	0.097	1	0.054	0.165
In x_4	0.302	0.312	0.054	1	0.123
In x_5	0.164	0.101	0.165	0.123	1

Where y is the dependent variable, namely, the days of PM2.5 haze weather in Jiangsu; x_1, x_2, x_3, x_4, x_5 are the five independent variables, namely, unit GDP energy consumption, civic car ownership, housing construction area, coal consumption, and industrial waste gas emission, respectively; a_0 is the regressive intercept item, and μ is the random error. Before multiple regression, correlation coefficients between independent variables should be checked. The calculation results obtained using the SPSS20.0 software are shown in Table 3.

Table 3 shows that the correlation coefficients among the five independent variables are lower than 0.7, which indicates that no multi-collinearity exists among the variables. Thus, multiple regression could be performed. The regression results obtained using the Eviews7.0 software are as shown in Table 4:

Table 4 shows the following:

1. F=274.896 indicated that the overall regression equation was significantly effective. DW=2.748 indicated that the variables have no self-correlation. The regression coefficients of variables x_2, x_3, and x_5 were positive. T statistics indicated that regression coefficients were significantly effective. The regression coefficients of variables x_1 and x_5 were insignificant.
2. x_2 represented car ownership, and its regression coefficient was 0.457, which indicated that increasing car ownership significantly influences the increase of the days of haze weather. Car ownership growth per unit could increase by 0.457 unit of the days of haze weather; car tail gas emission also increased as the number of cars continuously increased. Running cars generate carbon monoxide, oxynitride, and particles, which affect the formation of haze weather. The increasing tail gas emission significantly influences haze in Jiangsu. This problem requires urgent solution.
3. x_3 represented the housing construction area, and its regression coefficient was 0.248, which indicated that increasing housing construction area significantly influences the increasing number of days of hazy weather. The housing construction area growth per unit could increase by 0.248 unit of the days of hazy weather. The

increasing housing construction area in Jiangsu increases building dust emission. However, some construction units took advantage of policy loopholes given the lack of powerful construction management policies. The arbitrary expansion of construction area and scope, the lengthening of construction period, and rule-breaking operations during construction would generate a large quantity of dust, which increases the number of days of hazy weather and generates serious damage to the atmospheric environment.

4. x_5 represented industrial waste gas emission, and its regression coefficient was 0.114, which indicated that increasing industrial waste gas emission significantly influences the increase of the number of days of hazy weather. The increase of industrial waste gas emission per unit could drive the increase of 0.114 unit of days of hazy weather. Industrial fuel gas is one of the important constituent parts in industrial pollution. Given ineffective supervision, some factors did not have waste gas purification equipment, and waste gases were directly discharged, which results in serious haze pollution.

GOVERNANCE STRATEGIES OF THE HAZY WEATHER IN JIANGSU

Enhance the monitoring of construction site and reduce dust emission: Building dust emission tax is levied. Using the declared housing construction area, construction period, estimated dust emission, construction site, hazard degree, and other factors, the generated building dust can be quantified and the cost and danger generated by governing atmospheric environmental pollution problems can be calculated, based on which all housing construction behaviours can be levied. The supply and demand relation can be regulated by increasing the cost of construction to reduce the construction area, control dust emission, and lower the probability of haze generation. A large quantity of accumulated tax revenues can be used to govern and compensate for the adverse consequences and effects brought about by hazy weather. Moreover, finances should encourage the utilization of new type of building materials and dust-proof facilities. Some construction units lack management in the construction process given that they focus on high construction benefits and use building materials that are cheap and emit large amounts of dust, as well as dust-proof facilities with poor dustproof effect, thus resulting in increased haze. By reducing the purchase cost of these new type of materials and facilities, more construction units can be absorbed to change the construction materials, guide consumption behaviours, and use new type of materials and new facilities to control the generation and diffusion of dust during the construction process and reduce the occurrence of hazy weather. Complete construction behaviour rewards and punishments system can also be established. For construction units that establish reasonable awards and punishments systems without illegal behaviours and complete construction tasks with dust generation being lower than expected in housing construction projects, economic awards or tax reduction and exemption can be given to encourage these behaviours. For those that lack dust-proof measures, arbitrarily expand construction area and scope, and prolong the construction period, which lead to dust pollution, punitive compensation fees or double fines can be added to different degrees according to violation and degrees of influence.

Table 4: Multiple regression results.

Variable	Coefficient	T value
In x_1	0.159	0.269
In x_2	0.457	4.568
In x_3	0.248	3.687
In x_4	-0.147	0.791
In x_5	0.114	4.987
α_0	14.748	0.124
R^2 = 0.917	DW = 2.748	F = 274.896

Enhance the governance of tail gas emission and guide the utilization of new energies: Tail gas emission tax is levied. Directing the continuous expansion of the number of civic cars, the policy of levying tail gas emission tax can be adopted. A levy standard and force taxation can be established when automobiles are registered according to the newness degree of vehicles, durable years, varieties of used energies, vehicle displacement, and different pollution classes. Levying tail gas emission tax directly increases the usage cost of vehicle users. Cost regulation demand is used to control vehicle growth, reduce emission, and control the occurrence of haze weather. Finance and tax can be used to subsidize new-energy motor vehicles and clean energies for cars given that most civic automobiles that are used nowadays use ordinary fuel oil ones with high carbon-emission energies, such as diesel and gasoline, which result in air pollution and hazy weather. The government can use fiscal subsidies for car purchasing behaviours. These can directly provide policy subsidy or the reduction and exemption of consumption tax when the new-type energy-motor cars are purchased. The government can also provide subsidy and tax refund for the accelerated scrapping of old fuel oil cars. Financing should be encouraged to support the development of urban public transportation. While limiting automobile growth speed, financial support must be used to develop urban public transport and expand its coverage area

to meet the requirements of people for means of transportation. During the construction of urban public transportation, financial input in the public transportation industry must be expanded and attention must be given to the development of urban mass transit systems, such as subways and new mixed-energy buses. We should elevate the comfort degree of public transportation tools, reduce people's reliance on private cars, lessen the quantity of cars and utilization frequency, decrease tail gas emission, and cut the generation of haze weather while adding the quantity of the means of transportation and operating frequency and expanding coverage area.

Establish regional haze joint defence mechanism and develop a regional mechanism for haze ecological compensation: The haze problem is a kind of air pollution problem. PM2.5 diffuses along the wind direction toward adjacent areas, which is insufficient to solve the haze problem in local practical situations. Starting from the regional macroscopic whole, we can establish a perfect mechanism for haze ecological compensation within a regional scope, find special atmospheric control department, set up atmospheric ecological compensation fund, and implement classified collection by province and city. We can guide enterprises to establish sustainable development capital reserves to cope with personnel placement problems by eliminating backward productivity. While establishing and perfecting the regional mechanism for haze ecological compensation, we should consider the long-term economic development of the whole region, realize the transition of regional sustainable economic development, and pursue energy conservation and low carbon emission. We should reform the industrial structure, reduce the proportion of a secondary industry in the region, vigorously develop a tertiary industry, and transform the original production pattern into a sustainable production pattern. We should utilize governmental and market means to guide the consumption behaviours of regional consumers, lead the consumers into sustainable lifestyles that conserve energy and emit less carbon, and develop self-conscious low-carbon consumption habits. We should continue to facilitate the popularization of clean energies and the promotion of new energies. We can finally realize benign, low-carbon, and sustainable operating status through the influence of production and consumption on energy utilization.

CONCLUSION

To further analyse the factors that mainly influence the increase in the number of days of haze weather in Jiangsu and propose specific governance measures, this study used time-series data from 2000 to 2014. A multiple regression model was adopted to quantitatively measure the effect degrees and significance levels of these factors. Strategies for governing haze were proposed from perspective of factors with significant influences. Findings show that extensive economic growth, sustainable car ownership growth, heavy consumption of coal, a large amount of exhaust emission in industrial production, and a large amount of dust generated by urbanization construction are the five major factors that influence the increasing days of PM2.5 haze weather in Jiangsu. Car ownership, generation of dust from housing construction, and industrial exhaust emission significantly influence the days of PM2.5 haze weather. The regression coefficients of the three independent variables were positive and effective at the 5% significance level. The growths of the three independent variables per unit could result in increasing haze weather by 0.457, 0.248, and 0.114. However, this study emphasized the analysis of the main factors that induce the increasing days of PM2.5 weather in Jiangsu. This study only performed time-series analysis at the provincial level. Thus, it could not effectively analyse the regional spatial distribution of haze pollution among various cities in Jiangsu. Future research should adopt panel data models to quantitatively measure and analyse multiple factors that influence haze pollution, such as meteorology, human factors, and socio-economic factors.

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