The driving factors of renewable energy industry development - Based on spatial panel model

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Abstract. Enter the new era, renewable energy is constrained by regional heterogeneity, such as resource distribution, market structure and industrial environment, and its spatial heterogeneity is becoming increasingly prominent. To explore the spatial agglomeration effect of renewable energy development, this paper builds a spatial panel econometric model to explore the driving factors of renewable energy industry development on the basis of analysing the spatial correlation of renewable energy. The results show that the development of the renewable energy industry has path dependence and spatial stability, and there is an industrial agglomeration effect in spatial development. In addition, the emission of exhaust gas is negatively correlated with the development of the renewable energy industry, and the power consumption of renewable energy and the reserve of non-renewable resources will significantly promote the development of renewable energy industry. Meanwhile, government investment in environmental protection is not significantly correlated with the development of renewable energy industry. This study can provide theoretical guidance and practical support for promoting the development of China’s renewable energy industry.

1. Introduction

In response to the reform of the ecological environment and energy resources, the report of the 19th National Congress clearly pointed out the need to deepen the concept of green development and accelerate the reform of the ecological civilisation system. As China's economic development enters a new stage, the question of how to promote the clean and low-carbon development of the energy system and to base on the national conditions and regional conditions, in order to promote the high-quality development of the economy, this research is currently the focus of political and academic circles. By the end of 2018, the total installed capacity of renewable energy in China had reached approximately 730 million kilowatts, an increase of approximately 12% over the previous year. Of the total, hydropower generating units generated approximately 350 million kilowatts, wind generating units generated approximately 185 million kilowatts, and photovoltaic units generated approximately 172 million kilowatts, representing increases of 2.5%, 12.3%, and 33%, respectively, over the previous year.

At present, the incentive policies for renewable energy development in academia are focused on economic incentives and price incentives. (1) Economic incentive mechanism. Economic incentive policy plays a key role in the early development of the energy system. Its functions are embodied mainly in encouraging research and development, promoting basic technology development, project investment, and so on [1-3]. (2) Price incentive mechanism. There are many studies at this level in
academic circles, including the formulation of standards for the development and operation of energy systems and the design of operation mechanisms and regional distribution. The beneficiary of energy policy is also a game process with many players [4-6]. Some scholars have proposed that ‘FIT’ policy is more effective than ‘RPS’ in increasing the proportion of renewable energy to national energy consumption [7,8], but RPS policy is more effective in reducing carbon emissions and improving consumer surplus [5,9].

Research on the characteristics of the renewable energy market: (1) Ji and Li [10] used spatial temporal panel data to study the relationship among renewable energy subsidies, energy consumption intensity and per capita GDP; (2) policy researches of renewable energy supply enterprises from the perspective of supply. Foreign research systems are relatively perfect. Favard [11] points out that, under the circumstances of high cost of exploitation of exhaustible resources, it is better to give priority to the development of renewable energy systems with relative advantages. Shuai et al [12] pointed out that China’s renewable energy development system started relatively late, relative to the development of the country on the international competitiveness is not enough, the relative basic technology of renewable energy, circular distribution and exports all showed the deficiencies of development. Other scholars, such as Li et al [13] and Kong et al [14], have come to similar conclusions in their research and put have forward corresponding countermeasures and suggestions from the perspectives of government policy and market system.

The development of the energy system is a long and complicated process, aimed at meeting the needs of economic growth and social green development, going from polluting to clean and from high emissions to low emissions. Generally speaking, the world energy system is changing from the old development model left over by traditional industrialisation to the new energy development system developed in the post-industrialisation era. Although it is in the exploratory period, all countries and regional organisations have begun to attach importance to the development of the energy system, and a corresponding policy support system has formed gradually [15,16]. From the current situation of China’s energy market, the development of renewable energy has significant spatial heterogeneity, and the regional policy systems are also very different. This is due to different basic conditions, such as resource endowment, market structure, and location advantages; for example, the “Three North” region is rich in basic resources. China can also draw lessons from the energy system design model of other developed countries to form a multi-dimensional development path from basic technology, market system, and policy support. In summary, this paper constructs a spatial panel econometric model to study the driving factors of renewable energy industry development.

2. The current situation of renewable energy development in China

2.1. The current situation of renewable energy consumption

Figure 1 shows that China’s renewable energy consumption is increasing gradually. In 1990, China’s renewable energy consumption was 28.68 million tons of oil equivalent (MTOE); this increased to 368.30 MTOE in 2017, 12.84 times the amount in 1990. Hydropower accounts for a large proportion of China’s renewable energy consumption, with 28.68 MTOE in 1990 and 261.52 MTOE in 2017, which is 9.12 times the amount in 1990. Solar energy consumption has grown slowly, at only 24.48 MTOE in 2017. Since the implementation of the Renewable Energy Law in 2005, wind power consumption has entered a period of rapid development, and it increased to 64.73 MTOE in 2017. Because of the late development of geothermal energy and biomass energy, the consumption of geothermal energy and biomass energy has been at a low level.
2.2. Autocorrelation study on renewable energy development

To determine the spatial correlation of China's renewable energy development, this paper uses the Global Moran's I to test the spatial autocorrelation of current data. Generally speaking, the P value is less than 0.05 (passes the 95% confidence test), and the Z score exceeds the critical value of 1.65 (rejects the threshold set by the null hypothesis), indicating that the significance test has been passed.

Table 1. Global Moran’s I index of renewable energy development.

|       | 2015  | 2016  | 2017  | mean value |
|-------|-------|-------|-------|------------|
| Moran’I | 0.188 | 0.137 | 0.131 | 0.152      |
| Z-value | 2.110 | 1.639 | 1.600 |            |
| P-value | 0.017 | 0.051 | 0.055 |            |

From table 1, we can see that the Moran index in 2015, 2016, and 2017 passed the 10% significance level test and was positive. This shows that the output of renewable energy in 31 provinces and cities in China has significant positive correlation in spatial distribution (i.e., spatial dependence). That is to say, the distribution of renewable energy development in China is not random but is a spatial agglomeration. The Moran index scatter plot can divide the cluster of 31 provinces and cities in China into four quadrants: the first quadrant represents the spatial connection form of the regional unit with high observation value surrounded by the region with high value; the second quadrant represents the spatial connection form of the regional unit with low observation value surrounded by the region with high value; the third quadrant represents the regional unit with low observation value surrounded by the region with high value; and the fourth quadrant represents the spatial connection form of the region unit with high observation value surrounded by the region with low value. That is, the first and third quadrants reflect positive spatial autocorrelation, whereas the second and fourth quadrants reflect negative spatial autocorrelation.

3. Model

3.1. Analysis of the development of the renewable energy industry and its influencing factors

According to the energy economy theory and the availability of data, this paper selects the renewable

![Renewable energy consumption in China](image_url)
energy generation capacity as the measurement index of the development of the renewable energy industry. According to Zhang Liyan’s (2019) research, the influencing factors of renewable energy development are divided into six main aspects: resource utilisation, social support, technological innovation, environmental ecotype, policy support, and market cultivation. In view of the availability of data, this paper analyses the following four main aspects (See Table 2).

| Variable | Explanation                        |
|----------|------------------------------------|
| X1       | Policy support                     |
| X2       | The availability of resources      |
| X3       | Social support                     |
| X4       | Ecology of the environment         |

(1) Policy support. This paper chooses the regional environmental protection accounts (X1). The development of renewable energy requires the government’s attention and investment. At present, government guidance is still the dominant force in the development of renewable energy in China. The government’s attention to renewable energy can generally be influenced by the proportion of the government’s final accounts in the field of environmental protection. (2) The availability of resources. This paper chooses non-renewable energy reserves (X2) to measure this index, because cities in different geographical locations have different reserves of non-renewable energy due to environmental, topographic, and other factors. (3) Social support. This paper uses the renewable energy power absorption ratio (X3) to measure the proportion of energy consumption. The energy absorption ratio, in general, ‘is the efficient use of energy. High energy efficiency partly proves that the regional government attaches great importance to this aspect. (4) Ecology of the environment. This paper uses exhaust gas emissions (X4), Developing renewable energy is aimed not only at solving the problem of energy shortage in China but also at improving the current ecological environment.

3.2. Construction of spatial error model

- Testing the Relevance of the Spatial Panel

To determine whether the spatial econometric model is better than the traditional model without spatial correlation, we need to test the Lagrange Multiplier (LM) and the robustness LM of the model. LM Error is used to test the original assumption that there is no spatial autocorrelation for errors; alternatively, the model should be a spatial error model. The LM Lag test is based on the assumption that the spatial lag variables do not have spatial autocorrelation, and the alternative assumption is that the model is a spatial lag model.

|                           | Value   | P       |
|---------------------------|---------|---------|
| Moran MI Error, Test      | 1.0859  | 0.2775  |
| LM Error (Burridge)       | 3.8670  | 0.0492  |
| LM Error (Robust)         | 4.1226  | 0.0423  |
| LM Lag (Anselin)          | 0.0065  | 0.9357  |
| LM Lag (Robust)           | 0.2621  | 0.6087  |

From the results of Table 3, we can see that the value of the spatial error model is 3.8670, and it is 4.1226 after optimisation, which is much higher than is that of the spatial lag model. It has passed the test at the 5% significance level. Although the P value of the Moran index is 0.2775, the statistical value is 1.0859, which still shows that it is reasonable to introduce spatial factors to some extent. So, the result of LM is that the spatial error model is more suitable for this study. Therefore, this paper should establish a spatial error model (SEM).
4. Results and discussions
In the empirical analysis of spatial econometric models, the commonly used estimation methods are the two-stage least squares method and maximum likelihood estimation method. The method adopted in this paper is maximum likelihood estimation, which assumes that the error obeys normal distribution, and the dependent variables obey multivariate normal distribution. In this model, the significance test of the regression coefficient is the Z test and the confidence level is P.

Table 4. Regression results of double fixed spatial error model.

| Explanatory variable | Spatial Error Model (SEM) | Traditional Stochastic Model |
|----------------------|---------------------------|-----------------------------|
| X1                   | -1.4e+03                  | -1.7e+03                    | (-1.213) |
| X2                   | 807.185***                | 1127.457***                 | (4.501)  |
| X3                   | 3.413***                  | 0.491                       | (0.681)  |
| X4                   | -0.814                    | -0.151                      | (-0.249) |
| Constant term        | 88.618                    | 1.4e+03                     | (0.705)  |
| Spatial lambda       | 0.078                     | 0.262                       | (1.587)  |
| Sigma2_e             | 1173.436***               | 1922.321***                 | (5.427)  |
| Ln_phi               | 4.930***                  | 1173.436***                 | (14.773) |

* P < 0.10, ** P < 0.05, *** P < 0.01

The geospatial matrix used in this regression model is a 0-1 matrix, that is, when two provinces are adjacent, the geospatial matrix coefficient is 1 and the non-adjacent matrix coefficient is 0. In table 4, the SEM of the 0-1 matrix is on the left, and the traditional panel model is on the right. From the above table, we can see that, under the traditional panel model, only the variable X2, non-renewable energy reserves, has a significant impact on the size of renewable energy generation, whereas the other three variables have no significant impact. We can see also that the overall fitting effect of the traditional panel model is lower than that of the SEM, which proves that it is more suitable to establish the SEM in this paper.

Under the 0-1 weight matrix, the spatial correlation coefficient (Spatial Lambda) of the SEM is positive, which means that there is a positive spatial effect in the development of renewable energy in China. But the only deficiency is that it is not significant enough to meet the saliency conditions. According to the data analysis, it can be concluded that there are some special cases in the development of bioenergy among different provinces in China, which means that the spatial significance level is not high. To take Beijing as an example; although Hebei province is a big energy province, Beijing does not dominate the development of the energy industry due to its unique regional location and economic status. In the model results, we can also see that individual specific errors are very significant, which is caused partly by political and economic factors. However, on the whole, renewable energy has had a certain diffusion, which has tended to make the development of this industry clustered. The energy industry would develop similarly among provinces because of the unique nature of renewable energy, and the development of the industry in provinces would promote its development in other provinces.

5. Conclusions
In the new era, China’s renewable energy is constrained by regional heterogeneity, such as resource distribution, market structure, and industrial environment, and its spatial heterogeneity is highlighted constantly. To explore the spatial agglomeration effect of renewable energy development, based on analysis of the spatial correlation of renewable energy, this paper chooses four factors – resource utilisation, social support, environmental ecotype, and policy support – to build a spatial econometric model to study the driving factors of renewable energy development. Based on the research results, the regional exhaust emissions and renewable energy power generation show a negative correlation trend, and the output of renewable energy power decreases by 0.8 kWh for each additional ton of exhaust emissions. Non-renewable energy reserves have a significant correlation with the development of the renewable energy industry. The correlation between the government’s final accounts’ expenditure on environmental protection and the development of the renewable energy industry is not significant.
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