REGIONAL DIFFERENTIATION IN INFLUENCING FACTORS OF CLEAN RENEWABLE ENERGY CONSUMPTION FROM THE PERSPECTIVE OF AIR POLLUTION PREVENTION AND CONTROL

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Reception: 30/04/2023 **Acceptance**: 23/06/2023 **Publication**: 14/07/2023

Suggested citation:

Zhan, J. (2023). **Regional differentiation in influencing factors of clean renewable energy consumption from the perspective of air pollution prevention and control**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 331-345. https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

ABSTRACT

Global economic growth is now increasingly conflicting with the sustainable development strategy. In the context of ecological environmental preservation and air pollution prevention and control, this paper probes into the regional differentiation in the influencing factors of clean renewable energy consumption. First and foremost, a brief analysis of the status quo of clean renewable consumption in China was outputted, grounded on data on the input and output of 30 provinces and cities nationwide from 2010 to 2020. Then, national and regional models are built respectively in virtue of differential GMM, systematic GMM, and bias-corrected LSDV methods. Furthermore, efforts were invested in dissecting the working mechanism of the influencing factors and verifying the previous prediction resulting in applying the Tobit regression method. For every 1% increase in the green finance index, the clean renewable energy consumption rises by 0.882 accordingly, said the regression analysis results. Last but not least, it was concluded that the development level of green finance, internet advance, and technological progress significantly positively affected clean renewable energy consumption. While the industrial structure, the degree of openness, and the level of urbanization represented by the proportion of the secondary industry play hardly-seen impact.

KEYWORDS

Offset correction; Influencing factors; Regression method; Clean renewable energy consumption; Regional differentiation.

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https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

1. INTRODUCTION

The construction of ecological civilization is an important aspect of the long-term development of the Chinese nation and has always been a hot spot of concern for all countries. The report of the 19th National Congress states that we should continuously promote green development, strengthen environmental governance, and increase the protection of ecosystems [1]. However, the current air pollution problem faced by human society is a serious constraint to the construction of ecological civilization [2]. Atmospheric pollution can have catastrophic effects on human economic and social development, such as climate anomalies, extreme weather such as dust storms, sea level rise, and global warming [3]. Ecological and environmental issues are related to the health of the people, the harmony and stability of society, and the healthy and orderly development of the economy [4]. The management of atmospheric pollution has become a hot issue of close concern to all sectors of society [5]. And the use of clean renewable energy has a positive effect on air pollution control as well as ecological environmental protection [6].

Energy consumption is not only an important aspect of national implementation but also, it is related to the strategic overall situation of national energy sustainable development [7]. In the context of sustainable development theory and ecological modernization, people's requirements for living environment and quality of life are increasing with the increase in income level [8]. The type of energy consumption in China is shifting from high pollution to cleanliness [9]. In recent years, the rise of a low-carbon economy has increased under the premise of the sustainable development concept [10]. To deeply strengthen the management of the atmospheric environment, improve the quality of urban and rural air environment, and improve the ecological environment, China has continuously increased the development and use of clean energy [11]. The state has also introduced relevant laws and regulations, and clear requirements for the use of high-pollution fuels in some areas of the province designating a no-burn zone that requires the use of high-pollution fuels in the no-burn zone [12]. They should be removed or switched to natural gas, LPG, electricity, or other clean energy sources promptly. Clean renewable energy resources in China vary from region to region and within regions due to differences in the economic development of each region leading to their consumption [13].

The eastern region of China accounts for 41.56% of the total national consumption in 2020, while western regions account for 38.87% and 19.57%, respectively. The regional differences are large [14]. In terms of energy use consumption, the five provinces with the lowest energy consumption accounted for 16.54% of the country's energy consumption but their combined GDP only accounted for 8.28% of the country's GDP. The five provinces with the highest energy use consumption account for 15.22% of the country's energy consumption but their combined GDP accounts for 26.47% of the country's GDP. There are significant regional differences in energy consumption in China [15]. Therefore, while improving energy use consumption, a correct understanding of the structural characteristics and regional disparities in energy use consumption is significant to effectively promote the work of air pollution prevention and control in China as well as to continuously promote sustainable development strategies [16-17].

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Clean renewable energy has been studied by many scholars. The literature [18] presents a model used to describe the development. The literature [19] simulates the consumption of natural gas by randomly combining several influences including GDP, population, natural gas imports and exports, and employment while predicting natural gas consumption by selecting the most realistic equation from all simulated equations. Literature [20] and literature [21] investigate the impact of the national economic growth rate through the ARDL method [22-24]. Literature [25] and literature [26] studied the impact of various factors on renewable energy consumption based on a multivariate framework. Literature [27] conducted research using panel data from nearly 35 years and obtained that, from a long-term perspective, natural gas energy consumption has an impact on the GDP growth of GCC countries. Literature [28] proposes a parameter estimation method that eliminates omitted variable bias due to unobserved cross-sectional individual effects by differencing. In addition, the literature [29] used the Granger causality test to obtain the relationship between natural gas consumption and GDP. Literature [30] argues that marketization facilitates the formation of a virtuous response between renewable energy and consumption, guiding the consumption of clean renewable energy through price signals.

The aforementioned studies include the search for clean and renewable alternatives to fossil energy through data models. The relationship between consumption has been explored and the factors influencing have been studied. This study further extends the study of natural gas energy to clean renewable energy based on the previous study. We analyze the factors influencing the consumption of clean renewable energy in the context of ecological environmental protection and air pollution prevention. We also combine the panel data of 30 Chinese provinces to build a mathematical model and estimate the model using differential GMM, systematic GMM, and bias-corrected LSDV methods for the national and regional levels, respectively. Based on this, the Tobit regression method is applied to validate the results. Based on the data model, the influencing factors of energy consumption were analyzed, to provide some theoretical references for ecological environmental protection and air pollution control.

2. RESEARCH BASIS

2.1. CURRENT SITUATION OF CLEAN RENEWABLE ENERGY CONSUMPTION

To examine the regional differences in energy consumption, the specifics of each region in 2020 were investigated and plotted in Figure 1.

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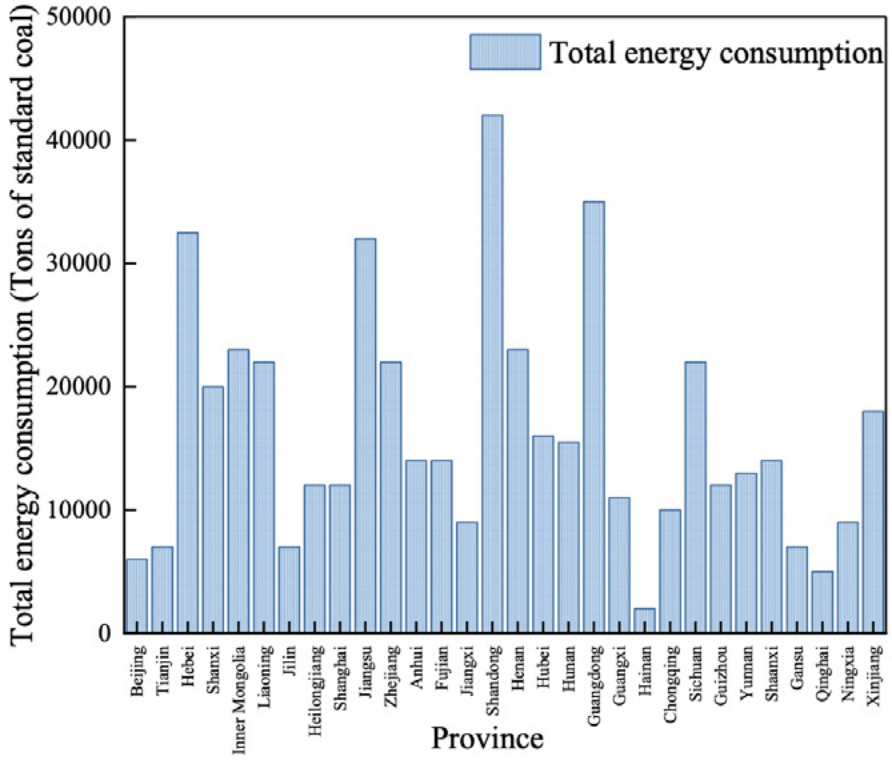

Figure 1. Clean Renewable energy consumption by Provinces in 2020

From Figure 1, we can see that the top three clean renewable energy consumption in 2020 are Shandong Province, Guangdong Province, and Hebei Province respectively. The highest consumption of clean renewable energy is over 40,000 million tons [31] in Shandong province, while the lowest consumption is only about 20 million tons of standard coal in Hainan, so we can easily see through the above chart that there are big differences in the consumption data of clean renewable energy in different regions at the same point of time.

2.2. MODEL PARAMETER SETTING

Panel data is adopted by a wide range of scholars for its advantages of large data size. Economic theory suggests that the individual's past state determines the current behavioral state due to inertia, so the lagged values can be included in the panel model, and this type of data is dynamic.

The following dynamic panel parameters are considered:

$$y_{it} = \alpha + \rho y_{i,t-1} + x_{it}\beta + Z_i\delta + \mu_i + \varepsilon_{it}, t = 2,3,\cdots,T \quad (1)$$

First-order differencing to eliminate individual effects μ_i.

$$\Delta y_{it} = \rho \Delta y_{i,t-1} + \Delta x_{it}\beta + \Delta \varepsilon_{it} \quad (2)$$

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However, the DIF-GMM method has some shortcomings, such as the elimination of non-observed section individual effects and other variables that do not change with time when differencing. Also, its estimator is often not efficient (minimum variance).

Blundell and Bond combined the difference GMM with the level GMM to perform GMM estimation of the difference and level equations as a system of equations, called System GMM (SGS).

The methods mentioned above are more suitable for short dynamic panels. Because while instrumental variable or GMM-based estimators are consistent estimators, they may be more heavily biased for smaller and larger long panels. After Monte Carlo simulations, the results show that the LSDV method is significantly better than the differential GMM or the systematic GMM for smaller long panels. The basic idea of the LSDV method is to first estimate the dynamic panel model using the LSDV method, and the estimated coefficient is β. Secondly, the bias of the LSDV method is estimated as Bias; finally, this bias is subtracted from the estimated LSDV coefficient to obtain a bias-corrected consistent estimate.

In this paper, the Dynamic Panel Model (DPM) with a first-order lag is considered because the consumption target is expressed using the previous year's renewable energy generation, so it contains first-order lagged data of the explanatory variables [32]. Since the national and regional panels are studied separately in this paper, the bias-corrected LSDV method is used considering the existence of bias in the differential GMM and the systematic GMM.

The variables are selected according to the validity of the data, and the model is as follows:

$$RE_{it} = \alpha + \beta_1 \times RE_{i,t-1} + \sum_{k=1}^{K} \gamma_k \times X_{kit} + \sum_{m=1}^{M} \delta_m \times Y_{mit} + \sum_{n=1}^{N} \omega_n \times Z_{nit} + \sum_{s=1}^{S} \rho_s \times V_{sit} + \varepsilon_{it} \quad (3)$$

Where RE_{it} denotes renewable energy generation in year t of region i; V_{sit} is a random disturbance term.

3. DATA, VARIABLES, AND DESCRIPTIVE STATISTICS

The factors influencing the production of renewable energy generation include the green financial development index (Gfi), government intervention (Gov), openness to the outside world (Trade), R&D investment intensity (RD), tertiary industry share (TI), energy consumption structure (ES), urbanization rate (Urban), and Internet penetration rate (Ipr).

To make a more accurate and comprehensive measurement, this paper quantifies the green financial development level by constructing a more reasonable index. The composition of the index system is shown in Table 1. The degree of government intervention is expressed as the ratio of general budget expenditures to GDP. The intensity of R&D investment by provinces and municipalities is used to express the indicator of technological progress. The development level of the tertiary industry can well represent the development trend. The level of urbanization is represented by the

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urbanization rate of each province and city. The indicator of Internet penetration rate is used to measure the degree of Internet development.

Each influencing factor is quantified on the premise that the possible influencing factors are clarified. The explanatory variables used for the specific quantified influencing factors are shown in Table 1.

Table 1. Description of explanatory variables

Variable Name	Variable	Definition
Green Finance Index	GIF	The entropy method is calculated from the exponent
Government Intervention	Gov	General budget expenditure of government finance as a percentage of GDP
Degree Of Openness	Trade	The ratio of total imports and exports to GDP
R&D investment intensity	RD	Proportion of R&D investment in GDP by province and city
Industrial Structure	TI	The ratio of the output value of the tertiary industry to GDP
Energy Consumption Structure	ES	Coal consumption as a percentage of total energy consumption
Urbanization Rate	Urban	The proportion of urban population to total population
Internet Penetration	Ipr	Proportion of Internet users and population

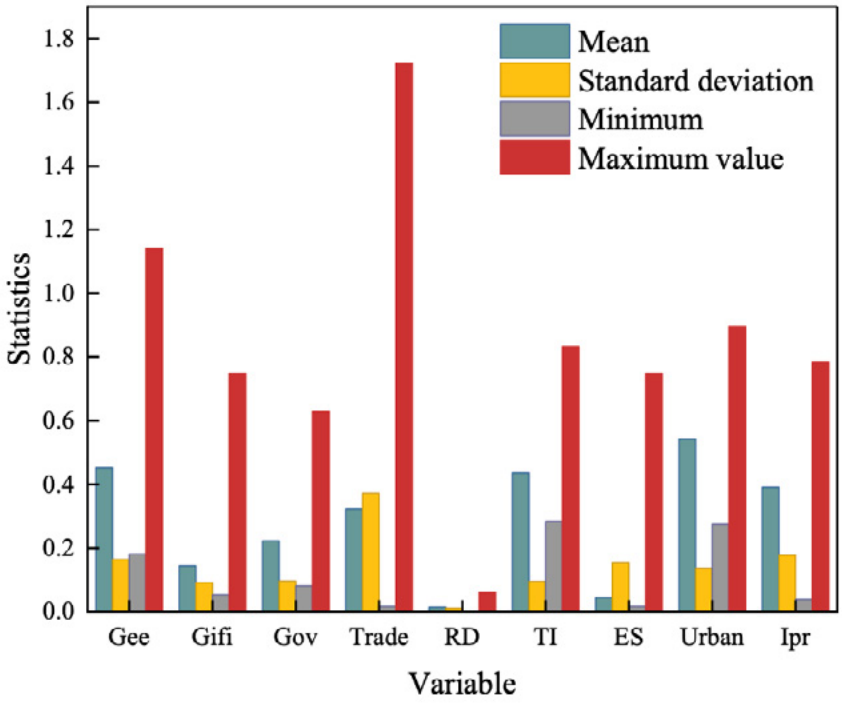

Figure 2. Descriptive statistics of the explanatory variables

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The results of the descriptive statistics of the explanatory variables for the whole country show that the maximum value is 1.15 and the minimum value is 0.17, which proves that the selected observations have a wide range. The selected observations are somewhat representative. The mean value of the explanatory variables for the nation as well as for each province and city is 0.47, and since the mean value is susceptible to extreme values, we use the standard deviation to indicate the degree of aggregation of the data. From the above figure, it can be seen that all the interpretive variables for the country as well as for each province and city are less than 0.18, which proves that the data are more aggregated and less volatile4

4. RESULTS AND ANALYSIS

First of all, to avoid the problem of biased regression results brought about by the problem of multicollinearity [33], the corresponding test must first be performed on the collated sample data. The most direct and effective method is to use the variance inflation factor (VIF) method for the test [34]. The following information can be found: none of the selected explanatory variables has a VIF above 10 and their mean does not exceed 5. Therefore, Table 2 indicates that there is no serious multicollinearity among the eight explanatory variables we have selected and a panel Tobit regression can be performed.

Table 2. Multicollinearity test for each explanatory variable

Variable	VIF	1/VIF
Gif	9.15	0.1355
Urban	8.65	0.1438
RD	7.92	0.1578
TI	5.30	0.2496
Ipr	5.04	0.2654
Trade	4.72	0.2878
ES	3.74	0.3919
Gov	2.02	0.5350

In this study, the quantitative value of clean renewable energy is used as the dependent variable. The independent variables are eight variables: green financial development index (Gfi), government intervention (Gov), openness to the outside world (Trade), R&D investment intensity (RD), tertiary industry share (TI), energy consumption structure (ES), urbanization rate (Urban), and Internet penetration rate (Ipr). In this regard, we constructed panel data and used Tobit regression models to conduct sub-sample regressions for the whole country and the eight economic regions, and obtained two regression analysis results of positive and negative effects, respectively, as shown in Figure 3 and Figure 4.

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From the Tobit regression results, all the explanatory variables are significant except for the urbanization rate, the degree of openness to the outside world, and the share of tertiary industry, which are not significant in the model. The specific analysis is as follows:

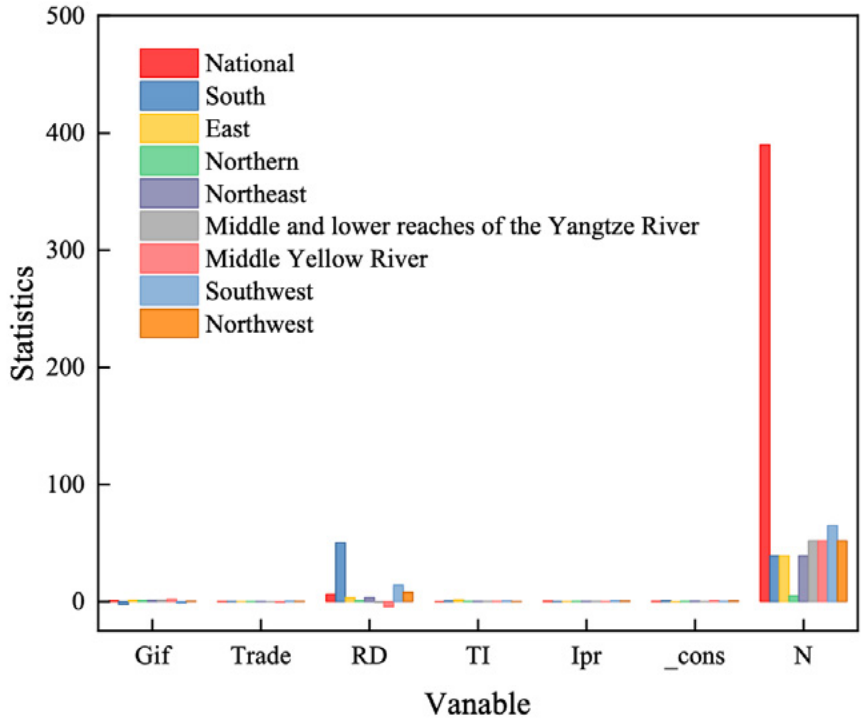

Figure 3. Results of regression analysis of the positive influence of inter-provincial clean renewable energy in China

Figure 3 shows that the level of green financial development has a significant contribution to clean renewable energy efficiency. Overall, for every 1% increase in the green finance index, the consumption of clean renewable energy increases by 0.882. The level of green finance development provides green credit specifically to the relevant transition enterprises through banks. Financial instruments such as green bonds offered in the market by the government and other market players can give financing support to environmental protection companies and green transformation companies, and policy incentives to motivate them to improve their production processes. Reduce factor inputs, and thus increase the consumption of clean and renewable energy. At the same time, the relevant policies introduced together with green finance have formed financing constraints for the "three high" enterprises, restraining the continuation of the crude development approach and forcing the "three high" enterprises to transform and upgrade their energy structures to increase the consumption of clean renewable energy. By economic zone, the most obvious role of green financial development level for the promotion of clean renewable energy consumption is the Yellow River Middle River Economic Zone. Many of the provinces in the Middle Yellow River Economic Zone have an industrial system that was previously dominated by secondary industries and is now undergoing an important journey of industrialization and transformation. A deep policy dividend has been given to these regions through credits and bonds under the green finance policy. The region

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where the effect is not obvious is the Northwest Economic Zone. Possible reasons for this are, on the one hand, that there is a lag in the use of more practical green financial instruments tools because the pilot scope of green finance has not yet been fully spread. On the other hand, the northwestern region has not been very effective in bringing the advantages of the financial system into play at this stage due to the limitations of its own economic and financial development level [35].

R&D investment intensity has an impact on consumption. At the national level, each unit increase in R&D investment intensity increases clean renewable energy consumption by 6.425 units. The coefficient value is the largest of all explanatory variables and has the strongest effect, indicating that technological progress is particularly critical to the increase in clean renewable energy consumption. This proves that technological progress is the most powerful and sustainable means to increase the consumption of clean renewable energy. Further, it can be found that the southern economic zone has the most significant release of dividends from technological progress due to the strong technological strength of the provinces and the high degree of integration between industry, academia, and research. RD has the greatest impact on consumption, while the eastern, northern and middle, and lower reaches of the Yangtze River economic zones are not significant [36].

The increase in Internet penetration significantly contributes to the increase in clean renewable energy consumption, in a homogeneous relationship. For every unit increase in Internet penetration, clean renewable energy consumption can increase by 0.34 units. This has great policy implications in the context of the strong Internet development and the emergence of the digital economy. The greatest impact has been in the Northern Economic Zone, where the Internet has led to the construction of an online platform on the one hand, which has greatly reduced the intermediate costs for the energy companies involved. On the other hand, the penetration rate has improved the quality of the workforce and optimized the consumption of clean and renewable energy. In contrast, the southwestern and northwestern economic regions are more in need of a better role in the improvement of energy consumption through the upgrading of the Internet [37].

The sign of the regression results of the degree of external openness and the share of tertiary industry is consistent with the theoretical analysis. The deepening of external openness can improve the learning effect of domestic enterprises through foreign technology spillover and trade connection, forming a virtuous cycle of "foreign spillover, domestic learning, and exchange and progress". Specifically, the positive effects are evident in the northern, southwestern, and northwestern economic regions. The increase in the share of the tertiary sector indicates that the industrial structure is in the process of upgrading, which is disadvantageous compared to the secondary sector with high energy input. The tertiary sector is more conducive to increasing consumption because it is dominated by the service sector, which has a lower energy input and a larger share of clean energy use. In particular, the effect of the eastern economic zone is the most obvious. The eastern economic zone has attracted a large number of high-quality labor forces through its advantages of high urbanization and perfect basic public services, which further optimized its industrial structure. The tertiary industry is more developed and has a higher proportion.

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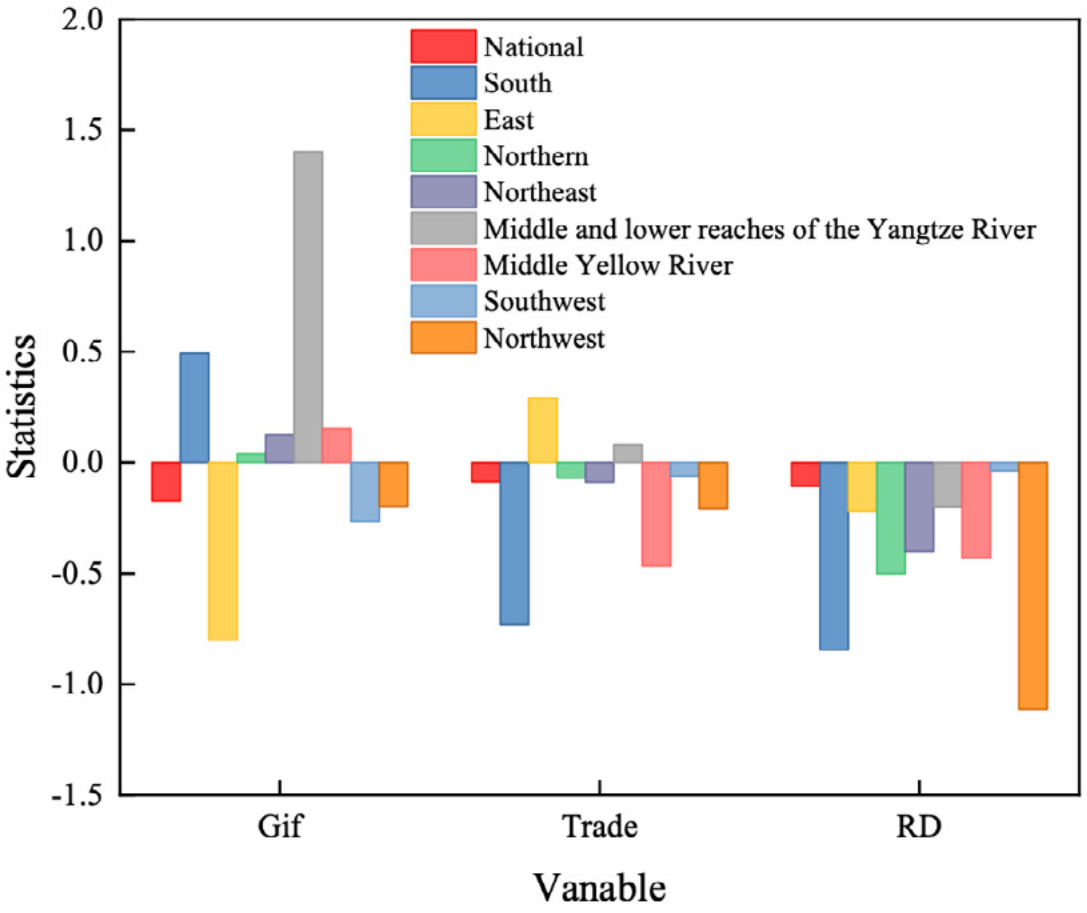

Figure 4. Results of regression analysis of negative influencing factors of inter-provincial clean renewable energy in China

As seen in Figure 4, the degree of government intervention has a dampening effect on clean renewable energy consumption in the Tobit regression results. Overall, each unit increase in the degree of government intervention. Instead of increasing, the consumption of clean renewable energy decreases by 0.173 units, which has a significant counter effect. This reflects that the government's intervention in energy-related aspects will, to a certain extent, restrict the increase of clean renewable energy consumption and fail to give full play to the regulation and allocation function of the market for the relevant factors. Further subsampling reveals that the overall governance capacity of the government in the northwest economic zone is limited by historical development factors compared to the developed economic zones. Therefore, government intervention in energy is not conducive to the allocation of factors. The improved governance capacity of local governments promotes market circulation and rational allocation of energy and other factors. The results demonstrate that government intervention is effective in not hindering the progress of energy consumption.

Each unit increase will lead to a 0.0876 unit decrease. And the absolute value of the coefficient impact is high compared to the rest of the explanatory variables, indicating that the energy consumption structure with the share of coal can

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significantly and negatively affect the energy consumption enhancement. The results of the sub-sample regression also corroborate the national regression results.

The increase in the urbanization rate inhibits the increase in the consumption of clean renewable energy. Specifically, each unit increase in the urbanization rate decreases clean renewable energy consumption by 0.107 units. A possible explanation for the insignificant regression is that the income effect created by the urbanization process leads to an increase in the demand for residential energy consumption. At the same time, the negative externalities of urban pollutant emissions inhibit the improvement of energy consumption. The significant negative regressions in the northern, northeastern, and middle reaches of the Yellow River and northwestern economic zones also support the analysis of the previous theoretical mechanism.

5. DISCUSSION

Given the above research deficiencies, it is necessary to investigate, understand and grasp the situation, characteristics, and patterns of Chinese household energy consumption from multiple levels and in-depth in the future research process. In addition, the structure is changing dramatically with the intensive development of clean and renewable energy sources. Therefore, further research on the factors influencing the consumption of clean renewable energy is of great significance and has important reference value for China's future inquiry on the formulation of related policies.

6. CONCLUSION

This paper adopts the input-output-related data of 30 provinces and cities nationwide from 2010 to 2020 to establish a mathematical model. The different influencing factors of clean renewable energy consumption are sorted out. The trends and characteristics of spatial differences in clean renewable energy consumption in China are revealed. The spatial effects of the influencing factors are quantitatively analyzed, which can provide some reference for energy policy formulation and energy planning in China. It provides some references for developing energy structure optimization strategies and energy saving and emission reduction measures with regional characteristics.

1. In this paper, differential GMM, systematic GMM, and bias-corrected LSDV methods are used to build the national and regional models. The highest consumption of clean renewable energy is over 40,000 million tons, while the lowest consumption is only about 20 million tons. The evolution and spatial differences in its development are fully recognized and understood.

2. The absolute values of the results analyzed by the Tobit regression method, except for the urbanization rate, the degree of openness to the outside world, and the share of tertiary industry, which are less than 0.15, all the explanatory variables are greater than 0.15. This result fully demonstrates that all the

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relevant variables have significant effects on the results, except for the insignificant effects of urbanization rate, degree of openness to the outside world, and tertiary industry.

3. The results of the regression analysis are obtained by the Tobit regression method, such as every 1% increase in the green finance index increases the consumption of clean renewable energy by 0.796. The level of green financial development, the degree of Internet development, and technological advances are analyzed to have a significant positive effect on the consumption of clean renewable energy. The results that the industrial structure represented by the share of secondary industry, the degree of openness to the outside world, and the level of urbanization do not have a significant effect on the consumption of clean renewable energy are also derived.

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https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345