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# Statistical Measurement and Economic Effect Research on Green New Energy Industry in Yangtze River Delta

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## ABSTRACT

With the rapid development of economy, human activities have caused great impact on the ecological environment. Achieving peak carbon dioxide emissions, carbon neutrality has become the goal to be completed. Taking the new energy industry in the Yangtze River Delta region as the research subject, this paper explores the relationship between the development of new energy and social economy, scientifically accounts for and evaluates the emission reduction potential of the new energy industry, conducts coupling and coordinated development research on the new energy industry and the regional low-carbon economic integration development, and provides scientific suggestions for the realization of "peak carbon dioxide emissions, carbon neutrality". Focusing on the above purpose, this paper firstly synthesizes the literature, clarifies the relevant concepts of low-carbon economy and the evaluation indicators of the development level of new energy industry, and combs the interaction between the two, providing theoretical support for the subsequent analysis. Secondly, it constructs a multi-dimensional measurement index to explore the green new energy industry, selects the relevant data of three provinces and one city in the Yangtze River Delta region from 2011 to 2019, and uses the TOPSIS entropy method to quantify various indicators of the new energy industry. Then, the unit root test is carried out on the data of different indicators of the new energy industry to judge whether these variable data have stationarity, and then the strength and direction of the relationship between the variables of different indicators are judged through the co-integration test. At last, the PSTR model is applied to take economic growth as the conversion variable, to examine the nonlinear effect of explanatory variables such as economic growth on the development of new energy, to conduct empirical analysis and draw conclusions.

## KEYWORDS

Green new energy industry; TOPSIS entropy method; Regional economic development; Green and friendly society; PSTR model

## 1. THE RESEARCH BACKGROUND AND SIGNIFICANCE

### 1.1. Research Background

China's rapid economic growth is accompanied by an increase in energy consumption. The use of fossil fuels leads to an increase in carbon emissions. Industrialization and energy consumption will inevitably produce a large number of toxic and harmful substances. These problems are posing more and more challenges and threats to our social and economic system. In this case, low-carbon economy arises at the historic moment.

The Yangtze River Delta region is one of the most dynamic and potential economic regions in China, mainly including Jiangsu Province, Zhejiang Province, Shanghai City and several cities in Anhui Province. The Yangtze River Delta region is also a region with rapid development of new energy industry in the country. The data released by the Yangtze River Delta and Yangtze River Economic Belt Research Center show that the new energy industry plays an important role in the economic development of the Yangtze River Delta region, and its role in promoting economic development is gradually increasing. New energy industry plays an indispensable role in the realization of low-carbon economy. They are an important support for the development of low-carbon economy and a way to achieve win-win environment and economy. Therefore, this paper provides a theoretical basis for the development of new energy industry and pays attention to the transformation of energy consumption structure.

### 1.2. The Significance of the Study

Seeking new energy and sustainable energy supply is the inevitable choice of mankind. Under the current background of the times, China must explore new strategic opportunities in the field of low-carbon economy with a serious attitude, seize a new high ground and reshape a brand-new economic structure. The implementation of low-carbon economy meets the urgent needs of the current social sustainable development and transformation, and also meets the strategic needs of the country to strengthen economic construction and actively develop a green economy.

## 2. RESEARCH FRAMEWORK

### 2.1. Research Ideas and Methods

This paper will explore how to establish a green new energy industry index system, which will take into account the GDP carbon dioxide emissions, new energy power generation, new energy installed capacity, the size and growth rate of the new energy consumption market and the proportion of the secondary industry in the Yangtze River Delta region. We will use entropy method to measure the performance of this industry, and explore the interactive relationship between green new energy industry and low-carbon economic effect by constructing panel vector autoregressive model. In addition, on this basis, we also put forward a series of effective measures to promote harmonious coexistence among society, new energy and economy.

Finally, this paper will also put forward the follow-up suggestions on the coordinated development of society, new energy and economy. The technical route of this paper is as follows:

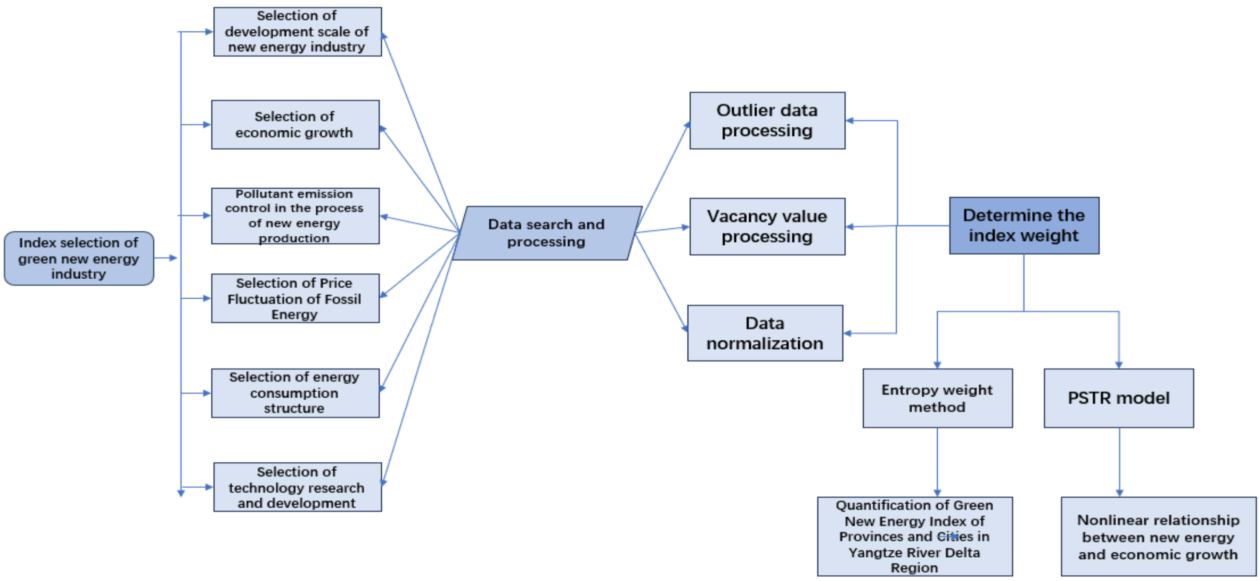


**Figure 1.** flow chart of thinking

## 2.2. Innovation and Advantages

Innovation in indicator selection: scientific selection of influencing factors based on dual carbon perspective. The evaluation index system of the development level of green new energy industry in this paper contains 4 dimensions and 10 indicators, comprehensively evaluates the development of green new energy industry, and the selection of these indicators is reasonable and scientific, which provides us with an objective and accurate reference for the evaluation of green new energy industry.

## 2.3. Method Application Innovation

(1) Evaluating the Green New Energy Industry Based on Entropy Method

The relative change of each index is taken as a measurement standard by applying the entropy weight method to determine the weight of each index in the system. We can organically combine the entropy method with the sorting method, so as to make the evaluation result more objective and accurate.

(2) Evaluating the Green New Energy Industry Based on the PSTR Model

The PSTR model uses the smooth transition function in the panel data, which can adaptively adjust the fitting curve in the smooth transition area between independent variables to better fit the data. We can assess the green new energy industry in a more comprehensive way and better assess the impact of economic growth on the development of the new energy industry. So as to improve the reliability and objectivity of the evaluation system.

(3) green new energy industry development level evaluation index data preprocessing

Abnormal value data processing: Based on the principle, this paper judges whether the data is beyond the reasonable range, and eliminates abnormally large or abnormally small data values to improve the accuracy and reliability of the data $3\sigma$ .Vacancy value processing: A missing value is a value that is missing from the dataset. Vacancy values may affect the accuracy and reliability of data analysis and therefore need to be addressed. In this paper, the missing values are predicted and filled by the linear regression model. Data normalization: Data normalization is a process of converting data of different scales into the same scale. Through normalization, comparability among different indicators can be achieved, and the influence of weights among indicators can be avoided. The specific formula is as follows:

$$x'_{\theta ij} = \frac{x_{\theta ij} - m_{\theta j}}{M_{\theta j} - m_{\theta j}} \tag{1}$$

Where, I am a city in the Yangtze River Delta region, and j is a year, which is an indicator. $M_{\theta j} = max_{1 \le i \le n}\{x_{\theta ij}\} m_{\theta j} = min_{1 \le i \le n}\{x_{\theta ij}\} \theta$

# 3. MEASUREMENT OF REGIONAL ECONOMIC LEVEL AND HIGH-QUALITY DEVELOPMENT LEVEL OF NEW ENERGY INDUSTRY

## 3.1. TOPSIS Entropy Weight Method

Entropy weight method is an objective distribution method based on data entropy, which uses the relative change of each index as a measure to determine the weight of each index in the system. By adopting the TOPSIS entropy weight method, we can organically combine the entropy method with the sorting method, thus making the evaluation result more objective and accurate. The steps are as follows:

Adopt the forward technology and use the range method to calibrate aijk to reduce the deviation between indicators. The standardized data are, where and represent year, province and indicator respectively. $a_{ijk} i,\ jk$

Construct the evaluation matrix: $A = \left(a_{ij_k}\right)_{m*n*h}$

Calculate the proportion of indicators: $P_{ijk} = \frac{a_{ijk}}{\Sigma_{\text{i}=1}^{m}\Sigma_{-j=1}^{n} a_{ijk}}$

Entropy value of indicator K: $H_k = -\frac{1}{\ln(m+n)}\left(\Sigma_{\text{i}=1}^{m}\Sigma_{-j=1}^{n} a_{ijk} \ln Pijk\right)$

Entropy weight of indicator K: $w_k = \frac{1-H_k}{n-\Sigma_{k=1}^{h} H_k}$

Normalize the matrix A to obtain a matrix B: $b_{ijk} = \frac{a_{ijk}}{\sqrt{\Sigma_{\text{i}=1}^{m}\Sigma_{-j=1}^{n}} a_{ijk}^2}$

Construct the weighting matrix: $R = B * W$

Determine the best plan and the worst plan: $Q^+ Q^-$

$$Q^+ = (q_1^+, q_2^+, \dots \dots q_n^+)$$

$$Q^- = (q_1^-, q_2^-, \dots \dots q_n^-)$$

Optimal and worst distance:

$$S_{ij}^+ = \sqrt{\Sigma_{k=1}^{h}\left(r_{ijk-q_k^+}\right)2}$$

$$S_{ij}^- = \sqrt{\Sigma_{k=1}^{h}\left(r_{ijk-q_k^-}\right)2}$$

Structure relative proximity (i.e. evaluation index): $C_{ij} = \frac{S_{ij}^-}{S_{ij}^+ + S_{ij}^-}$

The larger the formula, the better the evaluation object. $C_{ij} \in [0,1], C_{ij}$

### 3.2. The Green New Energy Industry Development Level Evaluation Index System

In this paper, through reading a large number of domestic and foreign literature, comprehensive rationality, scientific and data availability factors, select new energy consumption structure, new energy supply industry structure, new energy industry environmental protection level, energy consumption structure, a total of 4 dimensions, a total of 10 indicators to build a green new energy industry development level evaluation index system.

**Table 1.** Indicator System Table

| Level 1 indicators | Secondary indicators | explain | attribute | weight |
|---|---|---|---|---|
| New energy consumption structure | Number of new energy installations | Total installed capacity of wind power, photovoltaic power and solar power (units) | forward direction | 10.47% |
| | New energy generating capacity | Wind power, photovoltaic and solar power generation/total power generation (%) | forward direction | 5.46% |
| | New energy coverage | New Energy Vehicles/Total Vehicles (%) | forward direction | 2.69% |
| Industrial Structure of New Energy Supply | Investment in research and development of new energy technologies | GDP of New Energy Industry/gross industrial output value (%) | forward direction | 37.51% |
| | Transformation of New Energy Technology Achievements | Number of Patent Licenses/Total (Pieces/10,000) | forward direction | 16.58% |
| Environmental Protection Level of New Energy Industry | Comprehensive utilization rate of industrial solid waste | Solid waste utilization/total industrial solid waste (%) | forward direction | 0.21% |
| | Output value of comprehensive utilization of three wastes | Three Wastes Utilization/Total Amount of Three Wastes (%) | forward direction | 5.99% |
| Energy consumption structure | Consumption of coal and oil | Coal and oil consumption/total energy consumption (%) | negative direction | 14.11% |
| | Natural gas consumption | Natural gas consumption/total energy consumption (%) | forward direction | 6.98% |

### 3.3. Data Sources

After consulting the papers and literatures of Fu Weizhong and other scholars, and referring to their practices, this paper selects the data of Pan-Yangtze River Delta states, namely Anhui, Zhejiang, Jiangsu and Shanghai from 2011 to 2019 as the research object.

### 3.4. Analysis of Measurement Results

The data of three provinces and one city from 2011 to 2019 in the yangtze river delta region are substituted into the TOPSIS entropy weight method model to obtain the green new energy industry development index of each province and city respectively. And according to the relevant data draw the Yangtze River Delta region green new energy industry development trend chart.

**Table 2.** Development Index of Green New Energy Industry in Yangtze River Delta Region

| province | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|
| Shanghai | 0.198 | 0.215 | 0.294 | 0.360 | 0.459 | 0.509 | 0.747 | 0.870 | 0.946 |
| Zhejiang (Province) | 0.155 | 0.159 | 0.251 | 0.258 | 0.296 | 0.343 | 0.391 | 0.835 | 0.998 |
| Jiangsu (Province) | 0.087 | 0.092 | 0.107 | 0.122 | 0.266 | 0.328 | 0.336 | 0.477 | 0.717 |
| Anhui (Province) | 0.039 | 0.004 | 0.069 | 0.081 | 0.247 | 0.277 | 0.360 | 0.376 | 0.512 |

As can be seen from Table 2, the development of new energy industry in the Yangtze River Delta region as a whole showed an upward trend from 2011 to 2019. Shanghai's overall development index ranks first in the Yangtze River Delta. This was followed by Zhejiang, Jiangsu and Anhui. The development index of new energy industry in Zhejiang and Jiangsu is very close and keeps a high growth rate. The average value of high-quality development of new energy industry in Anhui is the lowest, but the gap with other provinces and cities is gradually narrowing.

# 4. EMPIRICAL ANALYSIS ON NONLINEAR EFFECTS OF NEW ENERGY INDUSTRY DEVELOPMENT AND ECONOMIC GROWTH

## 4.1. Variable Selection

### 4.1.1. Selection of development scale of new energy industry

New energy sources commonly used in the Yangtze River Delta region mainly include solar energy, wind energy and photovoltaic power generation. Compared with traditional energy, new energy is characterized by high utilization efficiency, strong renewability and good economy, which is one of the main directions of energy development in the future. In this paper, the Yangtze River Delta region of solar, wind and photovoltaic power generation as a measure of the development of new energy industry indicators.

### 4.1.2. Selection of economic growth

In the early stage of economic development, the government and enterprises have limited financial and technological resources. At the same time, the suppliers of traditional energy have a stronger market position, which inhibits the widespread promotion of new energy technologies. When the level of economic growth is high, demand such as strict carbon emission requirements will promote the promotion of new energy applications. At the same time, economic development will expand the demand for new energy and increase the market capacity of new energy. Economic growth is an important economic indicator. In this paper, GDP per capita is taken as the economic growth indicator of each province and city in the Yangtze River Delta.

### 4.1.3. Pollution discharge control in the process of new energy production

With the rapid development of solar photovoltaic power generation, the smelting, purification and treatment of silicon in photovoltaic panels bring a large amount of silicon tetrachloride and toxic waste gas, which lead to environmental pollution and imbalance of surface energy. Through the development of new energy industry, the pollutant emission system can be improved to effectively solve the negative impact of new energy emissions. Therefore, nitrogen oxides and sulfur dioxide in air pollution are included in the analysis framework.

### 4.1.4. Selection of price fluctuation of fossil energy

There is a mutual substitution and complementary relationship between fossil energy and new energy. The unstable price of fossil energy and the difference of energy reserves between different regions are the main factors that cause the price fluctuation. This kind of fluctuation has a negative impact on the production of enterprises and the whole economy, thus hindering economic growth. The continuous development of new energy technologies helps to reduce the dependence on fossil energy and mitigate the adverse effects brought by the fluctuation of fossil energy prices. Therefore, the price fluctuation of fossil energy is regarded as an important factor.

### 4.1.5. Selection of energy consumption structure

Coal is one of the major energy sources in the Yangtze River Delta region. Large industrial enterprises need a large amount of coal to supply their production and operation. The combustion of oil will produce pollutants, and oil leakage accidents are easy to occur in the process of mining and transportation. In order to improve the pollution, the provincial and municipal governments in the Yangtze River Delta actively promote the development of new energy industry. Therefore, the energy consumption structure is regarded as an important factor in the analysis framework.

### 4.1.6. Selection of technology research and development

The research and development and application of new energy technologies can promote the transformation and upgrading of the energy structure in the Yangtze River Delta region. It can also help the Yangtze River Delta region to achieve a national and even global leading position in the research and development and application of new energy technologies and further improve the core competitiveness of the economy. Therefore, this paper studies how technological progress promotes the development of new energy industry.

## 4.2. Unit Root Test

The purpose of unit root test is mainly to determine whether the time series is stationary. If the time series is non-stationary, additional processing is required to smooth it. Because the panel data is adopted in this paper, we will use the homogeneity and heterogeneity unit root test to test the variables. The following table is a summary of inspection results:

**Table 3.** Unit Root Test

| test method | LLC | IPS | ADF | HT | Breitung | Stationarity |
|---|---|---|---|---|---|---|
| SC | 0.3656 | 0.4294 | 0.221 | 0.1108 | 0.4575 | Not smooth |
| GDP | 0.2422 | 2.3852 | -3.834 | 0.1387 | 0.9871 | stable |
| PDS | 2.8681 | 0.5363 | -2.905 | 2.0751 | 1.5479 | Not smooth |
| PRI | 1.3315 | 2.8431 | -0.568 | 0.7845 | 0.5443 | stable |
| ENS | 2.5137 | 0.9751 | -2.423 | 3.7429 | 1.1756 | Not smooth |
| TEC | 7.5506 | 0.6465 | 0.406 | 0.2765 | 1.1912 | Not smooth |

From Table 3, it is known that the four variables of the development scale of new energy industry, pollutant emission control in the new energy production process, energy consumption structure and technology research and development level are unstable. In order to judge whether the original variables can continue to be used for empirical analysis, the next step is cointegration test.

## 4.3. Cointegration Test

Cointegration test can judge the intensity and direction of the relationship between variables and determine whether there is a long-term relationship between two or more time series to ensure that they can be effectively classified.

Kao test is a commonly used unit root test method, which adds more lag difference terms on the basis of Dickey-Fuller test, thus improving the accuracy and reliability of the test. Pedroni was also introduced to meet specific inspection requirements.

After co-integration test and analysis, we found that there was a significant correlation between the variables, as shown in Table 4.

**Table 4.** Cointegration Test Analysis Table

| test method | | null hypothesis | Statistic | Statistic-value |
|---|---|---|---|---|
| Pedroni test | Including intercept | $H_0: No\ cointegration$<br>$H_1: All\ panels\ are\ cointegrated$ | Modified Phillips-Perron t<br>Phillips-Perron t<br>Augmented Dickey-fuller t | 2.5454<br>-0.7982<br>-0.1659 |
| | Including intercept and time trend | $H_0: No\ cointegration$<br>$H_1: All\ panels\ are\ cointegrated$ | Modified Phillips-Perron t<br>Phillips-Perron t<br>Augmented Dickey-fuller t | 2.5459<br>-6.3929<br>-4.9334 |
| | Intercept and time trend not included | $H_0: No\ cointegration$<br>$H_1: All\ panels\ are\ cointegrated$ | Modified Phillips-Perron t<br>Phillips-Perron t<br>Augmented Dickey-fuller t | 2.1633<br>-0.7211<br>0.1872 |

Pedroni test rejected the original hypothesis at 1% significance level, indicating that there is a cointegration relationship between new energy and explanatory variables. Therefore, although SC, PDS, ENS and TEC do not pass the unit root test, the panel smooth transition regression model can still be used to analyze them.

## 4.4. Panel Data Fixed Effect Test

The alternative hypothesis of the fixed effect model is compared with the original hypothesis of the mixed regression model and the random effect model by using two methods of F test and Hausman test. Through the model test, determine the most suitable model type and solve the problem of model selection . The detailed model test results of the above can be obtained in Table 5.

**Table 5.** Fixed Effect Test Table

| | Fixed effect test | | |
|---|---|---|---|
| Original assumption: mixed regression model | F test | P value | Test result |
| Alternative assumptions: fixed effect model | 19.80 | 0.0000 | Reject the original hypothesis |
| Original assumption: random effect model | Hausman test | P value | Test result |
| Alternative assumptions: fixed effect model | 20.62 | 0.0000 | Reject the original hypothesis |

According to the data in Table 5, when the confidence reaches 1%, our hypothesis is rejected whether using F test or Hausman test. This indicates that our sample meets the assumptions of the fixed effect model.

# 5. THE PROVINCIAL ASYMMETRIC EFFECT OF EMPIRICAL ANALYSIS

## 5.1. Panel Smooth Transition Model is Introduced

Panel smooth transition model is a nonlinear regression model for panel data, which is used to describe the nonlinear relationship between independent variables and dependent variables. The PSTR model uses the smooth transition function in the panel data, which can adaptively adjust the fitting curve in the smooth transition area between independent variables to better fit the data.

A typical two-mechanism panel smooth transition model (PSTR) expression is as follows:

$$y_{it} = \mu_{it} + a'X_{it} + \beta' X_{it} * c + \varepsilon_{it} \tag{2}$$

$$i = 1, \dots, N; t = 1, \dots, T$$

Where, $\alpha = (\alpha_1,\ \alpha_2,\ \dots,\ \alpha_k)$; $\beta = (\beta_1,\ \beta_2,\ \dots,\ \beta_k)$ are coefficient vector, K is the number of explanatory variables, $x_{it} = \left(x_{it,1},\ x_{it,2},\ \dots,\ x_{it,k}\right)$ representing explanatory variables, and $g(q_{it};\ \gamma, c)$ is a conversion function with a value range between 0 and 1. The specific form of the conversion function is shown in the following formula:

$$g(q_{it}; \gamma, c) = \frac{1}{1+\exp\left(-\gamma \prod_{j=1}^{m}(q_{it}-c)\right)}, \gamma > 0 \tag{3}$$

When the model size is 1, the model is quickly converted from 0 to 1. The transformation threshold of the model is determined by the position parameter C, whose value can be expressed as $(c_1, c_2, c_m)$. Through the logical function $g(q_{it}; \gamma, c)$ the process of achieving a continuous smooth transition, the coefficients of the explanatory variable xit will be smoothly converted between $x_{it}$ and $(\alpha + \beta)$

According to the different values of m in the formula, the panel smooth transition model is divided into different types: the LSTR1 model is a nonlinear regression model, which takes m=1 as a reference value and describes the effects of variables in two different regions of $\alpha$ and $(\alpha + \beta)$. When m=2, it is called the LSTR2 model, and the coefficients of the model change with the change of variables $q_{it}$.

The smooth conversion model of two mechanism panels is generalized into a model with r+1 mechanisms, the general form of which is as follows:

$$y_{it} = \mu_{it} + a'X_{it} + \sum_{J=1}^{r} \beta X_{it} g_j(q_{it}; \gamma, c)' + \varepsilon_{it} \tag{4}$$

When r is greater than or equal to 1, such as when r=2, three different regions will appear, forming a smooth panel conversion model:

$$y_{it} = \mu_{it} + a'X_{it} + \beta_1 X_{it} g_j(q_{it}^1; \gamma, c) + \beta_2 X_{it} g_j(q_{it}^2; \gamma, c) + \varepsilon_{it} \tag{5}$$

## 5.2. Model Inspection and Results

### 5.2.1. Heterogeneity test and residual nonlinear test

Firstly, the relationship between the explained variable and the explained variable is checked whether it is linear or non-linear, and then the homogeneity of the model is checked. If the relationship between the explained variable and the explained variable is linear and the model is homogeneous, then there is no need to establish a PSTR model.

In this paper, the heterogeneity test is mainly performed by approximating the transformation function $g(GDP_{it}; \gamma, c)$ .At $\gamma = 0$ point, the following auxiliary regression is obtained from the M-order Taylor expansion of the transformation function:

$$y_{it} = a'X_{it} + \sum_{j=1}^{m} \beta X_{it} q_{it}^{j} + \varepsilon_{it} \tag{6}$$

The original assumption $H_0: \beta_1 = \beta_2 = \cdots = \beta_m = 0$ (equivalent to H0: = 0) that there is no nonlinear relationship;

The alternative assumption $H_1: \beta_1,\ \beta_2, \cdots,\ \beta_m$ is different from 0 (equivalent to $H_1$: 0), i.e. the model is heterogeneous and has a nonlinear relationship.

For this assumption, this paper gives the statistical tests of LMW, LMF and LR, as follows:

First, the Wald LM test statistics are shown as follows:

$$LM_F = \frac{NT(SSR_0 - SSR_1)}{SSR_0} \tag{7}$$

Where N represents the number of sections of the panel data, T represents the time series length of the panel data, $SSR_0$ represents the sum of squares of all residuals under the invalid model, and $SSR_1$ represents the sum of squares of all residuals under the valid model.

Second, Fisher LM test statistics are shown as follows:

$$M_F = \frac{NT(SSR_0 - SSR_1)/mk}{SSR_0/[NT - N - m(k+1)]} \tag{8}$$

In this formula, m represents the order of Taylor expansion, k represents the total number of descriptive variables, and n and t represent the number of sections of panel data and the length of time series, respectively.

Third, the likelihood ratio test statistic is shown as follows:

$$LRT = -2[log(SSR_1) - log(SSR_0)] \tag{9}$$

After testing, if the original hypothesis is rejected, indicating the existence of complex nonlinear interaction, the panel smooth transition model is required for modeling; If the zero hypothesis cannot be rejected, the model cannot be used.

In this paper, the PSTR model is used to test the data. The heterogeneity test and the residual nonlinearity test are needed to determine the specific form of the model. We use LMwv, LMF and LRT to test the linearity and residual nonlinearity. Under the original hypothesis H0, we assume g =0, and the alternative hypothesis H1 is g =1 (linear test) or g =2 (residual nonlinear test). See Table 6 for inspection results.

**Table 6.** Non-linear Test

| Original and alternative assumptions | Statistic | m=1 | m=2 |
|---|---|---|---|
| null hypothesis $H_0: \gamma = 0$ Alternative assumptions $H_1: \gamma = 1$ | $LM_w$ | 10.798 | 22.104 |
| | $LM_F$ | 2.071 | 3.049 |
| | LRT | 12.837 | 34.268 |
| null hypothesis $H_0: \gamma = 1$ Alternative assumptions $H_1: \gamma \geq 2$ | $LM_w$ | 1.896 | 10.106 |
| | $LM_F$ | 0.158 | 0.358 |
| | LRT | 1.948 | 11.863 |
| Optimal number of transfer functions ()$\gamma = 1$ | AIC | -6.028 | -5.924 |
| | BIC | -5.413 | -5.264 |

According to the results in Table 6, it can be known that at the level of 1% significance, all three statistics reject the original assumption, indicating that there is a nonlinear relationship between the variables. After checking the number of conversion functions in the model, all three statistics reject the possibility of having two or more conversion functions. Therefore, the PSTR model with only one conversion function is adopted in this paper. In the case of γ*=1, the selected position parameter is 1(m=1), at which time both AIC value and BIC value are relatively small. Therefore, m*=1 in the PSTR model.

### 5.2.2. Model estimation

The set of transformation functions and position parameters is (γ*=1, m*=1), and the preliminary form of the model is obtained as follows:

$$NEW_{it} = \mu_i + \alpha_1 GDP_{it} + \alpha_2 SC_{it} + \alpha_3 PDS_{it} + \alpha_4 PRI_{it} + \alpha_5 ENS_{it} + \alpha_6 TEC_{it} + (\beta_1 GDP_{it} + \beta_2 SC_{it} + \beta_3 PDS_{it} + \beta_4 PRI_{it} + \beta_5 ENS_{it} + \beta_6 TEC_{it}) \times \mathrm{g}(\mathrm{GDP}_{\mathrm{it}}; \gamma, \mathrm{c}) + \varepsilon_{\mathrm{it}} \quad (10)$$

The PSTR model is constructed by lattice search method and nonlinear least square method and the variables are estimated. The following results are obtained:

**Table 7.** Variable estimation table

| variable | Coefficient estimate | Standard error | T statistics | P value |
|---|---|---|---|---|
| economic growth | -0.7253 | 0.8634 | 1.8206 | <0.0001 |
| Proportion of new energy | -0.0785 | 0.0981 | 2.2310 | <0.0001 |
| Total energy consumption | -0.3701 | 0.0291 | 2.8647 | <0.0001 |
| Adjustment of energy consumption structure | 0.0238 | 0.0067 | -0.2599 | <0.0001 |

It can be seen that economic growth and energy consumption structure adjustment have a negative non-linear impact on the development of new energy, while the Adjustment of energy consumption structure has a negative non-linear impact on the development of new energy. The total energy consumption has no significant impact on the development of new energy.

**Table 8.** Model Estimation Results

| variable | parameter | estimated value | parameter | estimated value |
|---|---|---|---|---|
| GDP | $a_1$ | -0.7035 | $b_1$ | 1.5720 |
| SC | $a_2$ | -0.0678 | $b_2$ | 0.2190 |
| PDS | $a_3$ | -0.0194 | $b_3$ | -0.0605 |
| PRI | $a_4$ | -0.2700 | $b_4$ | 0.1460 |
| ENS | $a_5$ | 0.0194 | $b_5$ | -0.0223 |
| TEC | $a_6$ | 0.0189 | $b_6$ | -0.0040 |
| | Slope parameter γ | 4.5800e+03 | Position parameter c | -5.3073 |

The result of that PSTR model is obtained:

$$NEW_{it} = \mu_i - 0.7035GDP_{it} - 0.0678SC_{it} - 0.0194PDS_{it} - 0.2700PRI_{it} - 0.0194ENS_{it} + 0.0189TEC_{it} + (1.5720GDP_{it} + 0.2190SC_{it} - 0.0605PDS_{it} + 0.1460PRI_{it} - 0.0223ENS_{it} - 0.0040TEC_{it}) \times \mathrm{g}(\mathrm{GDP_{it}}; 4.58\mathrm{e}+03, -5.3073) + \varepsilon_{\mathrm{it}} \quad (11)$$

### 5.3. Result Analysis

As can be seen from Table 8, the value of the location parameter C is exp (0.005)=1.005, which indicates that the threshold value of economic growth is 1.016. The slope parameter of the model is $\gamma = 4.58\mathrm{e}+03$. When the function is converted $\mathrm{g}(\mathrm{GDP_{it}}; 4.58\mathrm{e}+03, -5.3073) = 0$, the model is at a low level of economic growth, and the impact coefficient of economic growth on new energy is $\alpha_i$: When the function is converted $g(\mathrm{GDP_{it}}; 4.58\mathrm{e}+03, -5.3073) = 1$, the coefficient that affects the development of new energy industry under high economic growth level is $\alpha_i + \beta_i$. Therefore, the development of new energy industry in the Yangtze River Delta region is affected by many factors, the reaction coefficients of these factors are time-varying and regional heterogeneity.

According to the results of the model, it is known that the impact of economic growth on new energy sources is nonlinear. The economic growth factor is expressed by this formula:$\beta_{\mathrm{gdp}} = \alpha_1 + \beta_1 + \mathrm{g}(\mathrm{GDP_{it}}; 4.58\mathrm{e}+03, -5.3073)$. From the conversion function diagram, we can see that under the premise of economic growth,when $\mathrm{GDP}_{it} < 1.001$ the $\beta_{\mathrm{gdp}}$ is negative, and the new energy industry index is negatively correlated with economic growth; At $\mathrm{GDP}_{it} > 1.001$ time, $\beta_{\mathrm{gdp}}$ was positive, and the new energy industry index was positively correlated with economic growth. When the economic growth level does not reach the threshold, the impact of economic growth on the development of new energy industry is linear; When the threshold value is reached, the impact of economic growth on the new energy industry changes within the regional system, and the two are U-shaped.

In order to explore the impact of other variables on the development of new energy industry, this paper assumes that when the economic level is less than -5.3073, the value of the conversion function at this time is equal to 0, and when the economic level is more than -5.3073, the value of the conversion function at this time is equal to 1. From Table 9, we can see the impact coefficients of various variables on new energy at different economic levels.

**Table 9.** Two Interval Coefficients

| variable name | Low level of economic growth (growth function =0) $\alpha_i$ | High level of economic growth (growth function =1) $\alpha_i + \beta_i$ |
|---|---|---|
| GDP | -0.7035 | 0.8685 |
| SC | -0.0678 | 0.1512 |
| PDS | -0.0194 | -0.0799 |
| PRI | -0.2700 | -0.124 |
| ENS | 0.0194 | -0.0029 |
| TEC | 0.0189 | 0.0149 |

As can be seen from Table 9:

The impact of economic growth (GDP) on the new energy industry has changed with the improvement of economic level. The reason is that when the economy is growing at a high speed, enterprises usually adopt traditional energy resources to meet the energy demand, while the demand for new energy is relatively small. This hinders the development of new energy industry. At a time of rapid economic growth, the state is focusing on the development of low-carbon economy, while energy demand is also increasing. The new energy industry can meet the growing demand for energy, thus obtaining more market demand and business opportunities. At this time, economic growth promotes the development of new energy industry.

The impact of new energy industry development scale (SC) on the development of new energy industry has changed with the improvement of economic level. The new energy industry needs huge capital investment. When the economic level is low, social capital is limited, and the government may not have enough capital to support the development of the new energy industry, which may slow down the development speed of the new energy industry. At a high economic level, they often have more advanced technologies and facilities, which makes the research and development of new energy technologies more convenient. Researchers and institutions at a high economic level also have easier access to capital and talents, thus promoting technological innovation and development and promoting the development of new energy industry.

Pollutant Emission Control (PDS) in the process of new energy production plays a negative role in promoting the development of new energy industry. By controlling the pollutant emissions in the new energy production process, enterprises can improve their environmental performance, enhance their brand value and corporate image, and attract consumers to enter the market. In the process of controlling pollutant emissions, various advanced technologies and equipment are required for treatment. At a low economic level, there is a lack of corresponding technologies, so the promotion effect is weak. With a highly developed economy, the new energy industry continues to strengthen technological research and innovation to further promote the development of the new energy industry.

The impact of the price fluctuation of fossil energy (PRI) on the development of new energy industry has changed. Under the low economic level, due to the instability of fossil energy price and the fluctuation of traditional energy price, enterprises mostly use new energy instead of traditional energy, which provides opportunities for the development and expansion of new energy industry. Under the high economic level, the new energy industry still faces the cost challenge, which is usually high. The new energy industry is facing great competitive pressure in the market. The new energy industry needs to compete for a large number of market shares to achieve sustainable commercial development, which is easily affected by the price fluctuations in the fossil energy market.

Energy consumption structure (ENS) has a negative effect on the development of new energy industry in different economic levels. Under the low economic level, the development of heavy industry uses a large amount of fossil energy, which leads to its consumption increasing. At this time, the energy consumption structure has relatively weak inhibition on new energy. Under the high economic level, the country pays more and more attention to the green development strategy, and various regions are actively adjusting their future development strategies. At the same time, with the support of the economy, the development of new energy industry is gradually mature and the cost is gradually reduced. At this time, the negative effect of relying too much on coal in the energy consumption structure on the development of new energy is becoming stronger.

Technological Progress (TEC) plays a positive role in the development of new energy industry in different economic levels. Technological progress can help enterprises reduce production costs, thus increasing competition, and help to improve the energy conversion efficiency of new energy products in the process of production and use, making them more attractive. Under the low economic level, there is less investment in scientific research of new energy industry, so the support for new energy technology is relatively weak, and the positive effect of technological progress on the development of new energy industry is relatively small. At a high economic level, technological progress has had a profound impact on the production efficiency, cost and marketization of new energy. Therefore, the positive effect of technological progress on the development of new energy industry has become stronger.

## 6. RESEARCH CONCLUSIONS AND PROSPECTS

### 6.1. Research Conclusions

This paper studies the impact of economic growth on the new energy industry to provide decision support for the government, enterprises and academic institutions, to help promote the innovation and development of new energy technologies, and to promote the application of clean energy and sustainable development. The following conclusions have been drawn from this study:

(1) Based on the data of the Yangtze River Delta region, the entropy weight model is constructed to establish an index system of green new energy industry. From the index, it can be seen that the development of new energy industry in the Yangtze River Delta region as a whole is on the rise.

(2) The impact of economic growth on the development of new energy industry in the Yangtze River Delta region is non-linear. Under different levels of economic growth, the impact of the development scale of new energy industry and the fluctuation variables of fossil energy price on the development of new energy industry has changed. The impact of pollutant emission control, energy consumption structure and technology research and development variables on the development of new energy industry has not changed but strengthened.

(3) There are periodic characteristics between the development of new energy industry and economic growth in the Yangtze River Delta region. In the first stage, the economy is at a low level. The development of the Yangtze River Delta region focuses on heavy industry. At the same time, the price of traditional energy is low, which makes it difficult for new energy to compete with it in the energy market. It lacks sufficient market demand to promote the development of new energy industry, and the overall level of technological innovation and research and development is relatively low due to limited research funding. The development of new energy industry is slow. In the second stage, the economic level is at a higher level and the energy demand increases. New energy can provide a clean and environment-friendly energy form and attract more market demand. The government usually gives strong support to the development of new energy sources and the reduction of carbon dioxide emissions, and formulates a series of policies to encourage enterprises and individuals to invest in and use new energy technologies, and to improve their market competitiveness.

### 6.2. Recommendations

Promoting the development of new energy industry in the Yangtze River Delta requires the active participation and cooperation of the government, enterprises and all sectors of society to jointly promote the sustainable development of the new energy industry. Therefore, based on the study, the following recommendations are made:

(1) The government is an important force to promote the development of new energy industry. The government can provide more financial support to enterprises in the new energy industry by means of financial subsidies and investment in scientific and technological innovation to encourage and promote technological innovation and development of enterprises. Formulate policies and measures to adapt to the development of new energy industry in the Yangtze River Delta region, guide enterprises to invest in new energy industry, and promote industrial development. Strengthen regional coordinated development. The government should strengthen the cooperation and exchange with the surrounding areas and different industries, continuously explore and innovate in the field of new energy, improve its core competitiveness, and make greater contribution to the green development of the Yangtze River Delta region. The government plays an important role in promoting the development of new energy industry, guiding and promoting the development of new energy industry to promote the sustainable and healthy development of new energy industry in the Yangtze River Delta region.

(2) Strengthen scientific and technological innovation and research and development. The Yangtze River Delta region should strengthen research and development and innovation of new energy technologies, and promote the extension of industrial chain and industrial development by expanding the industrial scale and increasing the degree of industrial agglomeration, improving efficiency and reducing costs. The new energy industry in the Yangtze River Delta region also needs to actively carry out international cooperation and exchange, strengthen the exchange and cooperation of technology and experience, promote the international development of new energy technology, and improve the international competitiveness of the new energy industry in the Yangtze River Delta region.

(3) Strengthening the training and introduction of talents. The new energy industry in the Yangtze River Delta region needs to attract and train high-quality talents, establish a talent training and introduction mechanism, improve the market recognition and professional value of technical and management talents, and promote the development of new energy talents. We will increase our support for personnel training and introduction, and attract more high-quality personnel to join the new energy industry by setting up professional courses, providing incentives and subsidies, etc.

### 6.3. Research Outlook

In this paper, a large number of empirical analysis and visualization map production and display are carried out, and each index is quantified from multiple angles and multiple model angles, which demonstrates the multiple nonlinear effects of economic development and green new energy industry. However, there are still deficiencies, which need to be improved in the future.

First of all, although this paper tries its best to measure the green new energy industry in a comprehensive and detailed way, it is subject to the economic development at the municipal level and the evaluation of the green new energy industry without a unified standard and its own knowledge level restriction, which may lead to a certain deviation in the evaluation results. Secondly, in the process of writing this paper, there are individual missing values in the data that can be consulted and collected, which will increase the deviation of the measurement results.

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