

# Forecast and analysis of the ratio of electric energy to terminal energy consumption for global energy internet

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**Abstract.** In the background of building global energy internet, it has both theoretical and realistic significance for forecasting and analysing the ratio of electric energy to terminal energy consumption. This paper firstly analysed the influencing factors of the ratio of electric energy to terminal energy and then used combination method to forecast and analyse the global proportion of electric energy. And then, construct the cointegration model for the proportion of electric energy by using influence factor such as electricity price index, GDP, economic structure, energy use efficiency and total population level. At last, this paper got prediction map of the proportion of electric energy by using the combination-forecasting model based on multiple linear regression method, trend analysis method, and variance-covariance method. This map describes the development trend of the proportion of electric energy in 2017-2050 and the proportion of electric energy in 2050 was analysed in detail using scenario analysis.

## 1. Introduction

At present, the global energy development is facing the three major challenges of resource shortage, environmental pollution and climate change. The fundamental way is to change the way of development which relies on fossil energy, accelerate the implementation of clean alternative and energy alternative, and build a clean and efficient global energy distribution platform——global energy internet[1]. Using electric energy to replace fossil fuels and improving the proportion of electric energy in the terminal energy consumption can achieve the energy using mode which regards electricity as the centre and then drives green, low-carbon energy power transformation. Energy alternative uses electricity to replace coal and oil in the energy consumption to improve the ratio of electric energy to terminal energy consumption, that is, the proportion of electric energy. This method can reduce environment pollution and greenhouse gas emissions. The proportion of electric energy is not only an important indicator of the terminal energy consumption structure, but also an important measure of the degree of electrification of a country.

Although foreign countries did not put forward the concept of energy alternative, they have done a lot of research about the heat pump, port shore and other electrification applications. Sakamoto et al. estimated the CO<sub>2</sub> emission reduction potential in the food and beverage industry in 11 countries using heat pump technology[2]. Itoh et al. used heat pump and heat storage technology to achieve low-carbon building design, effectively reducing building energy consumption[3]. IEC/ISO/IEEE has



compiled some standards for port shore. China has done a lot of research about energy alternative in recent years. In [4], it is proposed to improve the global comprehensive energy efficiency by increasing the proportion of global power generation and the proportion of electric energy. In [5], the feasibility of energy alternative to coal and oil was analysed from the aspects of economy and environmental impact and the strategy of energy alternative. In [6], several forms of energy alternative and typical cases were given. In [7], the author consummated the calculation method of the proportion of electric energy and put forward its forecasting method. In [8], the paper analysed the power consumption of terminal energy consumption in Shaanxi Province, and provides the theoretical basis for the optimization and sustainable development of energy structure. In [9], the paper analysed the potential of electric energy in the terminal energy in Beijing based on the evaluation of competitiveness, and puts forward the suggestion about energy alternative. There are many researches on energy alternative at home and abroad, but the research literature on the forecast of the proportion of electric energy is rare.

Based on the quantitative economics method, this paper firstly analysed the influencing factors of the proportion of electric energy. On the basis of influencing factors and prediction models, this paper analysed and predicted the proportion electric energy in 2018-2050. And using the scenario analysis method to further analyse the proportion of electric energy in 2050.

## **2. Analysis of influencing factors of the proportion of electric energy**

Compared with the classical regression model and ARIMA, cointegration analysis can study the non-equilibrium time series, and the sequence disposed by the cointegration model has direct economic significance. Therefore, this paper used the cointegration theory to analyse the influencing factors of the proportion of electric energy [10].

The proportion of electricity and its influencing factors have their own long-term fluctuations, but if they are cointegrated, there is a long-term stable relationship between them. Because of the existence of this cointegration relationship, when the influencing factors change, the proportion of electricity also changes[11].

### *2.1. Samples and variables selection*

The proportion of electric energy is affected by a variety of factors such as GDP, economic structure, total population level, energy efficiency, electricity price, national policy, and residents' living standards and so on. Although there is no uniform measurement method for global electricity prices and national policies, living standards can't be measured with data; all factors are affected by other factors. Therefore, this paper mainly chose the representative factors to do cointegration analysis, which includes the GDP, the economic structure, the total population level and the energy efficiency factor[12][13].

- GDP. The world is in an important stage of development of industrialization and urbanization. The rapid growth of economy will inevitably lead to the rapid growth of electricity consumption.
- Economic structure. Changes in the economic structure, especially the large power consumption of industrial structure changes will have a greater impact on power demand. This paper used the ratio of industrial output to gross domestic product to account for the changes in economic structure.
- Total population level. Population growth will stimulate people's demand for electricity, and changes in population will also promote technological changes, which provide a steady stream of technical support for energy alternative.
- Energy efficiency. Energy efficiency is the energy consumed per unit of GDP. The higher the efficiency, the smaller the value. Increasing the proportion of electric energy is an important way to improve the energy efficiency.

## 2.2. Establishment of cointegration model of the proportion of electric energy

**2.2.1. Stability test.** The cointegration analysis of the sequence is based on the fact that the sequence is stationary. In this paper, the ADF unit root test was used to test the stability of the energy ratio (R), GDP (G), total population level (P), energy efficiency (SE) and economic structure (SU) in 1990-2016. The test results are as follows in table 1 (L represents the logarithm of the sequence).

**Table 1.** The ADF test results of each sequence.

Sequence	Test Value	Critical value	Conclusion	Sequence	Test Value	Critical value	Conclusion
$LR$	0.3367	-3.012	No	$LSE$	-1.107	-2.991	No
$\Delta LR$	-3.198	-3.0810	Yes	$\Delta LSE$	-4.127	-2.998	Yes
$LG$	0.1324	-2.986	No	$LSU$	-0.593	-2.986	No
$\Delta LG$	-6.479	-3.004	Yes	$\Delta LSU$	-4.770	-3.012	Yes
$LP$	2.4087	-2.998	No	$\Delta LP$	-9.286	-2.998	Yes

The ADF test results showed that the original values of all variables can't reject the zero hypothesis of the unit root, that is, the data satisfies the conditions for cointegration test, and there may be cointegration relationship between the variables.

**2.2.2. The covariance test of variables.** There are two commonly used cointegration tests which are the Engle-Granger test and the Johansen-Juselius test. In this paper, we analyse the covariance relationship between a variable and four variables, which is a multivariate analysis. Therefore, we use the Johansen-Juselius cointegration test to test the cointegration relationship between variables. It is a method which verifies regression coefficient based on vector autoregressive (VAR) model and it is a better method for covariance test of multivariate[14]. Before the cointegration analysis, a VAR model was established to determine the lag order which consisting of five variables, GDP, total population level, energy efficiency, economic structure and electricity ratio from 1990 to 2016. The model is as follows.

$$LR = 2.173642 \times LR(-1) - 1.553021 \times LR(-2) - 0.0015 \times LG(-1) - 0.00465 \times LG(-2) - 9.68411 \times LP(-1) - 10.57532 \times LP(-2) + 0.638886 \times LSE(-1) - 0.496187 \times LSE(-2) - 0.005715 \times LSU(-1) - 0.002749 \times LSU(-2) + 0.775677$$

It can be seen that the lag order of the VAR model is 2, so the lag order of the cointegration test should be 1. The cointegration test between the variables was tested using the Johansen-juselius cointegration test. The results are as follows in table 2.

**Table 2.** Johansen cointegration test results.

Number of Cointegration Equations	Eigenvalues	Likelihood Statistics	5% Critical Value	Probability
None *	0.967489	136.0051	69.81889	0.0000
At most 1*	0.588420	53.77720	47.85613	0.0126
At most 2*	0.510735	32.47118	29.79707	0.0240
At most 3	0.468095	15.31478	15.49471	0.0532
At most 4	0.006802	0.164794	3.841466	0.6857

As can be seen from Table 2, the likelihood statistics of the first three eigenvalues are greater than the critical values at the 5% level, so there are three covariance equations. The conclusion is that there is a cointegration relationship between the variables, that is, there is a long-term equilibrium relationship. Considering the covariance coefficient under the assumption of cointegration, the coefficient of the variables in the cointegration equation is the elasticity of the proportion of electric energy to different influencing factors, which can reflect the influence degree and mechanism of the different influencing factors on the energy demand. Extract a cointegration equation as follows.

$$LR = 0.031389 \times LG + 0.19886 \times LP - 0.646344 \times LSE + 0.058981 \times LSU \quad (2)$$

From the above formula can be concluded that when the GDP, the total population level, the proportion of the secondary industry increase by 1% respectively, the proportion of electric energy increases by 0.031389%, 0.19886%, 0.058981% respectively. And when energy efficiency decreases by 1%, the proportion of electric energy will increase by 0.646344%. This conclusion is consistent with the actual situation of the change in the proportion of electric energy in the world at present.

Therefore, this paper will select the GDP, the total population level, energy efficiency, economic structure as four influencing factors to forecast the proportion of electric energy.

### 3. Prediction of the proportion of electric energy based on MV combination method

The traditional energy demand forecasting methods include multiple linear regression analysis, trend analysis method, elastic coefficient method, time series prediction method, grey prediction method and so on. Multiple linear regression analysis is a kind of method which establishes a forecasting model based on the correlation analysis of two or more independent variables. It can take into account the effects of various influencing factors. Trend analysis can be a good method to analyse the inherent characteristics of data changes. And its calculation speed is fast. Therefore, this paper chose the multiple linear regression analysis and trend analysis method which are effective in medium and long term energy demand forecasting, and constructs the combined forecasting model based on the variance covariance (MV) method to predict the global proportion of electric energy[15].

#### 3.1. Multiple linear regression analysis

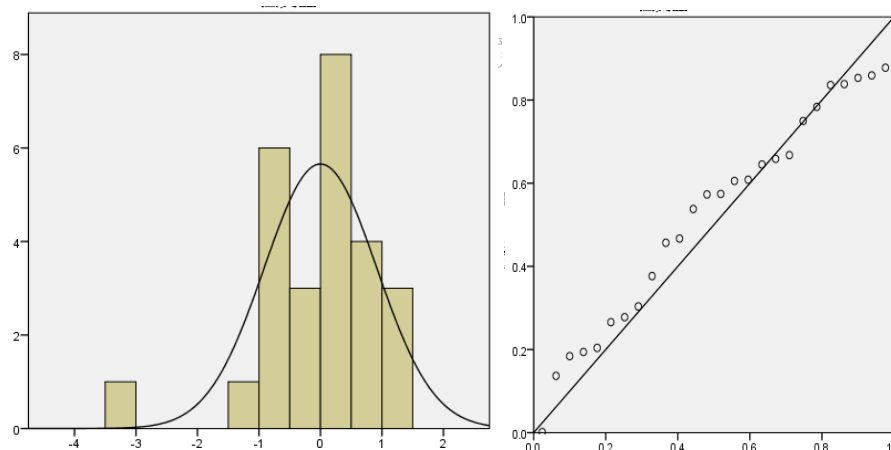
The above four influencing factors were used as the independent variables and the proportion of electric energy as the dependent variable. The data from 1990 to 2016 were used as the training set. Use the software SPSS to analyse the correlation between the independent variables and the dependent variables and construct the multiple regression model. Confidence interval width was set to 95%. Multiple linear regression equation is as follows.

$$LR = 8.599 + 0.022 \times G + 1.629 \times P - 0.763 \times SE - 0.037 \times SU \quad (3)$$

The fitting degree of the model is shown in the following table 3. And residual analysis is shown in the following figure 1.

**Table 3.** Multiple Linear Regression Prediction Model.

$R$	$R^2$	Adjustment $R^2$	Standard estimation error
0.999	0.999	0.999	0.06048



**Figure 1.** Residual analysis.

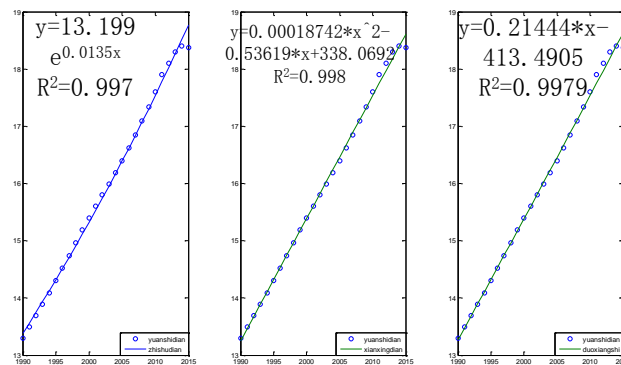
The  $\bar{R}^2$  of the multiple linear regression equation was 0.999, which showed that the fitting effect of regression variance was very good. The probability  $P$  of the  $F$  statistic was 0, which was less than

the significance level 0.05, so the significance test of the equation was passed. Residual test showed that the residuals in line with the normal distribution, that was, the regression equation was reliable.

### 3.2. Trend analysis

This paper constructed the forecasting model based on the global data of 1990-2016.

Three kinds of prediction models with good fitting precision were obtained by fitting and analysing the data of the proportion of electric energy which were index trend forecasting model, linear trend forecasting model and polynomial trend forecasting model. The fitting curve is shown in the following figure 2.



**Figure 2.** The index, linear and polynomial trend fitting curve of proportion of electric energy.

The fitting precision of the three trend forecasting models was further analysed, and the fitting precision is as follows.

$$R^2(\text{index}) = 0.997, \quad R^2(\text{linear}) = 0.997, \quad R^2(\text{polynomial}) = 0.998$$

$$RMSE(\text{index}) = 0.097, \quad RMSE(\text{linear}) = 0.073, \quad RMSE(\text{polynomial}) = 0.072$$

Therefore, this paper chose the polynomial trend forecasting with better fit and fitting precision to forecast the proportion of electric energy. The polynomial trend fitting forecasting model is as follows.

$$y = 0.00018742x^2 - 0.53619x + 338.0692 \quad (4)$$

Where  $y$  represents the proportion of electric energy and  $x$  represents the year number.

### 3.3. Combined forecast analysis

The MV combination method is based on the forecasting accuracy of different models, and the weights of different forecasting models are determined according to the idea of giving higher weight to the forecasting model with higher accuracy. The basic principles are as follows.

Let  $f_1, f_2$  be two unbiased predictions of  $f$ ,  $f_c$  is the weighted average of the combined prediction,  $\omega_1$  and  $\omega_2$  are corresponding weights. And  $\omega_2 = 1 - \omega_1$ ,  $Var(e_1) = \sigma_{11}$ ,  $Var(e_2) = \sigma_{22}$ ,  $cov(e_1, e_2) = \sigma_{12}$ . Since  $e_1, e_2$  are independent of each other,  $\sigma_{12} = 0$ . The combined forecasting weights of the two forecasting methods are as follows.

$$\omega_1 = \frac{\sigma_{22}}{\sigma_{11} + \sigma_{22}} \quad (5)$$

$$\omega_2 = \frac{\sigma_{11}}{\sigma_{11} + \sigma_{22}} \quad (6)$$

The weight values of the two forecasting models are as follows.

$$\omega(\text{multiple linear regression}) = 0.509824, \quad \omega(\text{polynomial trend}) = 0.490176$$

The results of the above three methods show that the MAPE values of the multiple linear regression forecasting model, the polynomial trend forecasting model and the combined forecasting model are 0.2522%, 0.2624%, 0.2124%. In the three models, the forecasting accuracy of the combined forecasting model is the highest. Therefore, the following will use the combined forecasting model to forecast the proportion of electric energy.

#### 4. Forecasting results and analysis

##### 4.1. Forecasting result

It can be seen from the above chapter that the forecasting accuracy of the combined forecasting model is the highest among the three forecasting models. The combined forecasting model is as follows.

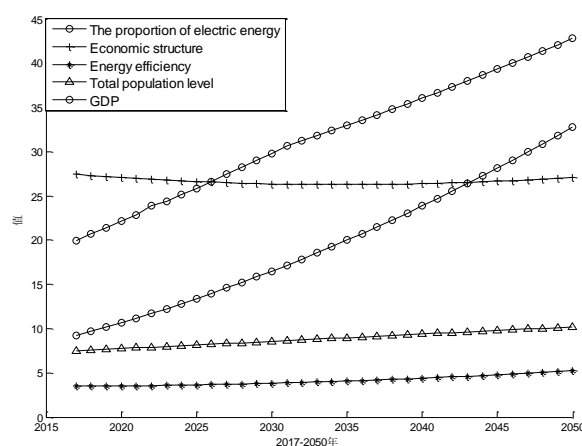
$$f(\text{combined model}) = f(\text{multiple linear regression}) \times 0.509824 + f(\text{polynomial trend}) \times 0.490176$$

Where  $f$  represents forecasting value.

Use the combined forecasting model to forecast the global proportion of electric energy from 2017 to 2050, the forecast results are shown in the following table 4 and figure 3.

**Table 4.** The combined forecast results of proportion of electric energy in 2017-2050.

Year	The Proportion of Electric Energy	Year	The Proportion of Electric Energy	Year	The Proportion of Electric Energy	Year	The Proportion of Electric Energy
2017	19.98335	2026	26.64585	2035	32.16821	2044	41.66551
2018	20.69106	2027	27.42684	2036	33.09756	2045	42.98814
2019	21.40692	2028	28.21597	2037	34.21506	2046	43.83891
2020	22.13091	2029	26.16324	2038	35.1407	2047	45.03783
2021	22.86305	2030	26.81866	2039	35.39448	2048	46.24489
2022	23.85823	2031	27.63221	2040	36.0264	2049	47.46009
2023	24.35174	2032	28.909	2041	38.46646	2050	48.28343
2024	25.15929	2033	30.09393	2042	39.52467		
2025	25.87301	2034	31.187	2043	40.79102		



**Figure 3.** The forecast curve of proportion of electric energy in 2017-2050.

From the forecasting table and the forecasting trend chart can be seen, the proportion of electric energy from 2017 to 2050 increases year by year. In 2030, the proportion of electric energy is 26.82%.



And this year have a turning point, whose growth rate accelerate. In 2050, the proportion of electric energy reaches 48.28%.

#### 4.2. Result analysis

From 1990 to 2016, China, Brazil and other developing countries rise, and their upward trend are obvious. But the outbreak of third financial crises has brought serious impact on the local economy. In general, the world economy is in good shape.

- No mutation scenario. The overall growth trend of world economic development between 2015 and 2050 will be similar to that of 1990 and 2015. While the world's total population growth slows, energy efficiency continues to rise. In this scenario, it is expected that the proportion of electric energy will be 26.82% in 2030. And this year will have a turning point, whose growth rate will accelerate. In 2050, the proportion of electric energy will reach about 48%.
- Pessimistic scenario. After the outbreak of the US subprime mortgage crisis, the world economy is sluggish and has not yet recovered. Conflict is intensified in some areas, and there is the probability of a large-scale conflict. In this scenario, it is expected that the proportion of electric energy in 2050 will be less than 20%.
- Optimistic scenario. After the US subprime mortgage crisis, the world economy fully recovered. Conflicts in local areas is controlled in a certain range. The cost of clean energy power generation dropped significantly. The electricity is the main alternative energy in the world. In this scenario, it is expected that there will have a turning point in 2025, and the proportion of electric energy in 2050 will be more than 55%.

#### 5. Conclusions

This paper studied the inevitable trend of global development of energy alternative from different angles and forecast the proportion of electric energy. The obtained conclusions are as follows.

- Through the cointegration analysis, GDP, economic structure, the total population level, energy efficiency was four main important factors to the proportion of electric energy.
- The accuracy of MV combined forecasting method based on multiple linear regression and trend analysis was higher than that of two kinds of individual forecasting methods.
- In the case of no mutation scenario, the global proportion of electric energy from 2017 to 2050 was forecast. The results were analysed further using the scenario analysis. It is expected that the proportion of electric energy will be 48%, less than 20%, more than 55% respectively in no mutation scenario, pessimistic scenario and optimistic scenario.

Energy alternative is the inevitable trend of global energy development in the future. The implementation of energy alternative has great significance on promoting the energy consumption revolution, implementing the global energy strategy, and promoting the development of energy clean. The steady progress of energy alternative is beneficial to enhancing the added value of some industrial products, promoting industrial upgrading, enhancing the level of global electrification and improving people's quality of life. People can enjoy more comfortable, convenient and intelligent energy services

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