Energy consumption forecast of different industries under the social and economic transformation

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Abstract. With the development of Shanghai’s social economy and the continuous transformation of the three major industries, Shanghai’s energy structure will also undergo corresponding changes. In order to study the proportion of electricity in energy consumption in the future, this paper predicts the consumption of electric energy and non-electric energy in Shanghai based on the Vector Error Correction Model (VECM), and analyses impulse response analysis and variance. The result of the experiment shows that development of Shanghai’s energy consumption structure will still keep in low carbon and electrification trend. From the perspective of the terminal energy consumption structure, the growth rate of power consumption will exceed the non-electric energy consumption one, and the proportion of electrification will be further increased.

1. Introduction
Energy structure is defined as the composition and proportional relationship of various primary energy and secondary energy in the total energy production or consumption of the energy. And the structure will directly affect the development of the national economy[1-2]. Energy Development Strategy Action Plan 2014-2020 released by State Council pointed out that the path to optimize the energy structure of country is to reduce the proportion of coal consumption, increase the proportion of natural gas consumption, vigorously develop renewable energy such as wind power, solar energy, and geothermal energy, and safely develop nuclear power[3]. Energy structure can be further divided into production structure and consumption structure. Shanghai’s energy consumption is highly dependent on foreign input. In 2017, Shanghai’s coal, oil, and electricity consumption were 45.778 million tons, 37.745 million tons, and 152.677 billion kWh, respectively. And among them, the proportions of transfers and imports from other provinces and cities reached 99.35%, 97.39%, and 43.31%, respectively[4]. Therefore, the analysis and prediction of development trend in energy consumption structure during Shanghai’s transformation and development period is of great significance to Shanghai’s economic development and energy security. Based on Shanghai's energy, economy, and population data, this paper predicts and analyses the trend of Shanghai's total energy demand and structural characteristics in the future. Furtherly, based on the research on the characteristics of energy consumption structure under the transformation and development of Shanghai and forecast and analysis of electricity and non-electric energy consumption trends from the perspective of terminal energy consumption. Based on these works, suggestions on energy structure optimization strategies will finally be proposed.
2. Energy structure prediction model

2.1. Shanghai Energy Consumption Structure
This paper categorizes Shanghai’s energy consumption according to electricity and non-electric energy types and analyses the impact of economic growth, economic structure changes, and demographic factors on Shanghai’s electricity and other energy consumption demand. It also forecasts the consumption levels of electricity and other energy sources in Shanghai. According to the Energy Statistics Yearbook: Reference Coefficient of Various Energy Converted into Standard Coal[5], convert energy consumption into standard coal and calculate the proportion of electricity consumption. The result is shown in Figure 1. Shanghai’s electricity consumption as a proportion of total energy consumption maintains an upward trend, from 8.78% in 1980 to 16.83% in 2017. The absolute amount of electricity consumption rises from 13.995 billion kWh to 152.677 billion kWh.

2.2. Energy consumption forecast based on VECM
Based on the time series of Shanghai’s total energy consumption, economic total, economic structure, population and other data from 1980 to 2017, we forecast the trend of changes in the total consumption of electric energy and non-electric energy in Shanghai. This research adopts the idea of co-integration, combining unit root sequences with common random trends to eliminate random items. Using Vector Error Correction Model (VECM)[6-7], to predict Shanghai’s total energy consumption. The model is expressed as:

\[ \Delta Y_t = \alpha Y_{t-1} + \sum_{i=1}^{p-1} B_i \Delta Y_{t-i} + \varepsilon_t \]  

(1)

where \( Y_t \) is a vector composed of the five endogenous variable time series contained in the model, and \( Y_t = (Electricity_t, Primary_t, Secondary_t, Tertiary_t, Pop_t) \). In vector \( Y_t \), \( Electricity_t \) denotes Shanghai’s total electricity consumption, if using \( nonElectricity_t \) to replace representing energy consumption other than electricity in Shanghai; \( Primary_t \) denotes the industrial added value of Shanghai’s primary industry; \( Secondary_t \) denotes the industrial added value of Shanghai’s secondary industry; \( Tertiary_t \) denotes the industrial added value of Shanghai’s tertiary industry; \( Pop_t \) denotes the permanent population of Shanghai. The \( \Delta Y_t \) denotes the difference of the variable between the \( t^{th} \) and the \( (t-1)^{th} \) period. \( \alpha \) and \( B_i \) denote the parameter matrix to be estimated. \( \varepsilon_t \) denotes errors. The data time span is from 1980 to 2017. The added value of the three major industries and Shanghai’s permanent population data are mainly derived from Shanghai Statistical Yearbook. Shanghai’s electricity consumption data comes from the WIND database.

3. Experiment

3.1. Impulse response analysis of energy consumption
After testing the VECM model based on Shanghai’s total electricity consumption, the added value of the three major industries, and the number of permanent residents from 1980 to 2017, there is 1-cointegration rank and 4-lags. Impulse response analysis results are shown in Figure 2 (a). The positive impact of the primary industry will have a weak same-directional impact on Shanghai’s total...
electricity consumption and the impact has increased to the largest in the first two periods, then tends to decline; when the secondary industry is directly impacted, it will have a positive impact on Shanghai’s total electricity consumption in the same direction and the direct impact expanded rapidly in the first 5 periods. After the 5th period, the growth rate of the impact has slowed down and eventually stabilized; when the tertiary industry has received a directly impact, it will also have a positive impact on Shanghai’s total coal consumption in the same direction and the direct impact gradually expanded in the first 6 periods, the impact range is stable after the 6th period; after Shanghai’s permanent population was directly impacted, it has a direct impact on the total power consumption immediately, and then the positive impact weakened. Then there will be a negative impact around the third period, and the impact will eventually disappear.

After testing the VECM model, when there is 1-cointegration rank and 1-lag. Impulse response analysis results are shown in Figure 2(b). The direct impact of the primary industry has only a weak positive impact on Shanghai’s total non-electric energy consumption, increasing in the first 5 periods and then stabilizing; when the secondary industry receives a direct impact, it will have a positive impact on Shanghai’s total non-electric energy consumption in the same direction, and the impact will gradually expand in the first five periods, and the growth will tend to stagnate after the 5th period; the tertiary industry receives a direct impact, it will have a weak reverse impact on Shanghai’s total non-electric energy consumption, and the negative impact will gradually expand in the first five periods, and the impact will gradually stabilize after the fifth period; after Shanghai’s permanent population receives a direct impact, it will have a gradually increasing positive impact on the total non-electric energy consumption in the first five periods, and then the impact will stabilize after the 5th period.

![Figure 2](image_url)

**Figure 2. The impact of industry and population expansion on the demand for electricity and non-electric energy consumption.**

### 3.2. Analysis of variance of energy consumption

This section analyzes the variance of the contributing factors of Shanghai’s electricity and non-electric energy consumption demand. Contribution rate of the impact of electricity and non-electric energy consumption demand infected by industry and population expansion is shown in Figure 3. As shown in the Figure 3(a), the contribution rate of Shanghai’s primary, secondary, and tertiary industries to Shanghai’s total power consumption demand varies with time. The contribution of the primary industry reaches its maximum around the 3rd period, and then drops to almost zero; the contribution of the secondary industry rose rapidly in the first five periods, and then the growth stagnated; the contribution of the tertiary industry maintains a slow and slow growth trend. The highest contribution rates of the primary, secondary, and tertiary industries are around 2%, 6%, and 1%, respectively. This shows that the output growth of industry and construction has made a greater contribution to the impact of Shanghai’s total power consumption demand. In addition, the growth of the permanent population has a small contribution to the impact of electricity consumption demand.

In addition, the figure also shows the contribution rate of Shanghai’s primary, secondary and tertiary industries and the impact of the permanent population on the total non-electric energy consumption.
consumption. The impact of the primary industry and the tertiary industry on non-electric energy consumption has a very low contribution rate, almost no impact; The influence of the secondary industry and population will reach a contribution rate of about 12% and 15% respectively after the 20th period. This result means that Shanghai’s total non-electric energy consumption is mainly affected by industry and construction, as well as demographic factors and agriculture, animal husbandry, and service industries have little impact on Shanghai’s total non-electric energy consumption. In particular, the demographic factor has the largest impact contribution rate to the total non-electric energy consumption. And the contribution rate of demographic factor rose to 10% at a faster rate in the first 10 periods and the growth rate slowed between the 10th and 20th periods; the contribution rate of the secondary industry to the total non-coal energy consumption was almost zero in the first two periods. However, it increased at a relatively rapid rate between the 3rd and 10th periods, and then the growth tended to be flat.

![Diagram](image)

**Figure 3.** Contribution rate of the impact of electricity and non-electric energy consumption demand infected by industry and population expansion.

### 3.3. Energy consumption prediction

This article further predicts Shanghai’s total energy consumption from 2018 to 2027 based on VECM, which includes data on Shanghai’s total energy consumption demand, the added value of the three major industries, and the total number of permanent residents from 1980 to 2017. The vertical axis in Figure 3 shows the log value of electricity (non-electric energy) consumption. According to the prediction results of the VECM model, showing in the following Figure, in the ten years from 2017 to 2027, Shanghai’s total electricity consumption demand will grow at an average annual rate of 6.31%. According to historical data, the average annual growth rate of electricity demand from 2007 to 2017 was 3.60%. And from 1997 to 2007, the average annual growth rate of electricity demand was 8.97%. It is obvious that the growth rate of Shanghai’s electricity consumption demand has slowed down during the period from 2007 to 2017. However, according to the results estimated by the VECM model, the growth rate of Shanghai’s total electricity consumption from 2017 to 2027 will increase compared to the period from 2007 to 2017. Combining the estimation of the added value of the primary, secondary and tertiary industries in the model, the increase in total power consumption is mainly affected by the expansion of the secondary industry in Shanghai. In addition, as shown in table 1, in the three time periods from 2017 to 2027, Shanghai’s power consumption elasticity (that is, the absolute value of the power consumption growth rate and the economic growth rate) has increased relative to the period from 2007 to 2017. It shows that the model does not fully predict the factors that increase energy consumption intensity. This shows that if under the current economic system, mainly due to the development of the secondary industry, Shanghai’s electricity consumption will continue to increase. But if the decline in energy intensity is fully considered, the average growth rate of power demand may be lower than the model estimated.
Figure 4(b) shows the total consumption of non-electric energy in Shanghai from 2018 to 2027, which is predicted based on the VECM model including the total demand for non-electric energy consumption in Shanghai from 1980 to 2017, the added value of the three major industries, and the total number of permanent residents. According to model estimates, Shanghai’s non-electric energy consumption growth rate will be approximately 4.44% from 2017 to 2027. Compared with the 2.49% between 2007 and 2017, it has increased; however, compared with the 6.49% between 1997 and 2007, there has been a decrease. Based on the development trend of the current economic system model, the demand for non-electric energy in Shanghai will continue to maintain a relatively high growth rate. From the perspective of non-electric energy consumption elasticity: Every 1% increase in GDP from 2007 to 2017 requires a 0.27% increase in non-electric energy consumption to support. Compared with the 0.47% from 1997 to 2007, there is a significant decrease. This means that Shanghai's economic growth has reduced its dependence on non-electric energy input. According to the results estimated by the VECM model, the elasticity of non-electric energy consumption in Shanghai from 2017 to 2027 is 28.46%, which is similar to the consumption elasticity between 2007 and 2017. It shows that the future economic growth of Shanghai will still bring about a steady increase in demand for non-electric energy consumption. In addition, according to the results of the analysis of variance, the expansion of the scale of the secondary industry and the expansion of the population will make a greater contribution to the increase in demand for non-electric energy. From 2017 to 2027, why Shanghai's non-electric energy demand can maintain a relatively high growth rate mainly from the VECM model's estimation of the expansion of the secondary industry. However, from the comparison of the growth rate and consumption elasticity of electricity demand and non-electric energy demand, Shanghai's economic growth in the future will depend more on electricity consumption.

| Year Range | Electricity Growth Rate | Non-Electricity Growth Rate | Electricity Consumption Elasticity | Non-Electricity Consumption Elasticity |
|------------|-------------------------|----------------------------|-----------------------------------|----------------------------------------|
| 1997-2007  | 8.97%                   | 6.49%                      | 65.14%                            | 47.11%                                 |
| 2007-2017  | 3.60%                   | 2.49%                      | 38.34%                            | 26.56%                                 |
| 2017-2027  | 6.31%                   | 4.44%                      | 52.02%                            | 28.46%                                 |

The historical change trend of Shanghai's electricity, non-electric energy consumption, and the proportion of electricity consumption and the forecast results in the past ten years is shown in Figure 5. From the perspective of total electricity and non-electric energy consumption, Shanghai's electricity and non-electric energy consumption will maintain a steady growth trend from 2018 to 2027; From a structural point of view, the share of electricity consumption in Shanghai's total energy consumption has also maintained a steady upward trend, rising from 16% in 2018 to 18.19% in 2027.
Figure 5. Prediction of the proportion of electricity and non-electric energy consumption.

4. Conclusion
This paper incorporates historical data on Shanghai’s historical energy demand, economy, and population and predicts Shanghai’s total energy consumption demand and structural changes in the next ten years based on VECM model. The three major industries and demographic factors all have the same impact on power consumption demand. Under this condition, the secondary industry mainly contributes to influence; the secondary industry, population, and primary industry all have the same impact on the demand for non-electric energy in Shanghai; among these factors, the secondary industry and population are the main influences, while the tertiary industry has a weak reverse impact on non-electric energy consumption. Under the influence of the development of low-carbon energy transition and urban re-electrification, Shanghai’s total power consumption demand will increase substantially and presents the clean characteristics of the primary power generation energy structure. Re-electrification of the city means that electric energy will become the lifeblood of energy for Shanghai’s economic development in the future. The power supply industry has good development prospects.

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