Research on Intervention Analysis Model of Medium-to-long-term Electric Power Substitution Policy

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Abstract. In order to study the quantitative impact of electric power substitution policy, a medium-to-long-term electric power substitution policy intervention analysis model is established. Based on the time series analysis model and the intervention function, the model considers the persistence of the impact time, and uses the proportion of China's electric power consumption as an example for quantitative analysis. The results show that the medium-to-long-term electric power substitution policy intervention analysis model can quantitatively measure the impact of electric power substitution policies.

Key words: Electric power substitution; Time-series analysis model; Intervention analysis model.

1. Introduction
The electric power substitution is the energy consumption mode of using the electric energy instead of the bulk coal and fuel in the terminal energy consumption. Such as electric heating, geothermal heat pump, industrial electric boiler, agricultural electric irrigation and drainage, electric vehicles, shore use of shore power, airport bridge equipment, electric storage peaking. Electrical energy has the advantages of being clean, safe and convenient.[1] The implementation of the electric power substitution is of great significance for promoting the energy consumption revolution, implementing the national energy strategy, and promoting the clean development of energy, which is an important measure to increase the proportion of coal, control the total consumption of coal, and reduce air pollution.[2] The effects of electric power substitution are influenced by many factors, such as planning policies, environmental policies, technological advances, and so on. In order to evaluate the impact of these medium-to-long-term electric power substitution policies on the energy replacement process, a time series intervention analysis model is needed for quantitative analysis.

In this paper, the medium-to-long-term electric power substitution is regarded as an intervention event of electric power substitution, and an electric energy replacement time series intervention analysis model is established. It analyzes the proportion of electricity consumption in 1990–2016, quantitatively
calculating the impact of medium-to-long-term policies, and predicts the proportion of electricity consumption by 2030, which will help energy decision-making departments make better decisions, which helps energy decision-making departments make better decisions in grid planning and operation optimization.

2. Establishment of medium-to-long-term intervention model for electric power substitution

2.1. Modeling time series
In an intervention analysis where electrical energy replaces long-term policy influences, it is assumed that the intervention exerts an influence on the process by changing the mean function or trend of the time series.[3-4] Considering the situation in which a long-term policy affects the intervention, and then by appropriate transformation, the general model of the time series \( \{Y_t\} \) can be expressed as:

\[
Y_t = \begin{cases} 
N_t, & t < T \\
 m_t + N_t, & t \geq T 
\end{cases}
\]  

(1)

Among them, \( m_t \) represents the influence of external intervention, which contains other influencing factors. \( N_t \) represents basic time data that is not affected by policy intervention. In the intervention analysis model applied to the impact of the electric power substitution policy on the electric power substitution index, \( m_t \) represents the impact of the electric power substitution policy on the electric power substitution indicator, and \( N_t \) represents the electric power substitution indicator that is not affected by the electric power substitution policy. Assuming that the policy is implemented at time \( T \), that is, the time series of the electric power substitution indicator is intervened at time \( T \), then before time \( T \), \( \{Y_t\} \) is the uninterrupted power replacement time series, which can be used to identify the energy replacement model before the implementation of the electric power substitution policy.[5]

2.2. Modeling medium-to-long-term policy intervention variables
The basic variable of the intervention analysis model of electric power substitution policy is the intervention variable of electric power substitution policy. The policy intervention variable is assumed to be a virtual variable with a value of 0 or 1. The intervention variable is 1 when the intervention occurs and 0 when the intervention does not occur. For the medium-to-long-term policy intervention variables, the intervention events have a continuous impact after the \( T \)-moment. For example, the long-term planning of electric power substitution policy or environmental protection policy. This intervention variable can be expressed by a ladder function:

\[
S^{(T)}_t = \begin{cases} 
0, & t < T \\
1, & t \geq T 
\end{cases}
\]  

(2)

For medium-to-long-term policies, in practice, intervention cannot have a complete impact immediately at the beginning, and its full impact will take a long time to fully reflect.[6] This form of policy suggests that in the early stages of long-term policy implementation, its energy substitution policy cannot be fully implemented immediately, possibly due to uncertainty about the specific method of implementation. However, due to various aspects of advancement, it was able to gradually show its strength and has a stronger influence in the specific promotion policy. Therefore, such long-term policies have a tendency to increase the effect. The simplest intervention model of this form is:

\[
Y_t = \frac{\omega B}{1 - \delta B} S^{(T)}_t, \quad 0 < \delta < 1
\]  

(3)
If the intervention occurs at $T$ time, but the effect begins to appear after the delay of $b$ time units, that is, at $T+b$ time, the intervention model can be adjusted as follows:

$$Y_t = \frac{\omega B^b}{1-\delta B} S^{(T)}_t, \quad 0 < \delta < 1$$

Such a model can be used to represent and simulate the long-term planning that starts at a certain time. In the policy of electric power substitution, the model can be used to simulate and analyze the regional planning and industry planning for each electric power substitution, because the impact of long-term regional and industry planning will be affected when it starts to implement at a certain time. Presents a gradual state, long-term planning in the initial stage will not produce immediate results, will gradually influence over time. The intervention model for such electricity substitution policy is shown in Figure 1.

3. Case study
The proportion of primary electricity consumption in total energy consumption is selected in this paper for analysis. The total energy consumption and composition of 1990-2016 can be obtained according to the relevant information of the National Bureau of Statistics. According to the data, we can get the time series diagram of the proportion of primary electricity consumption, as shown in Figure 2.

By analyzing the intervention impact of the electric power substitution policy by the ratio of power consumption, firstly, the corresponding time series model is established. A time series analysis model is established for the year data before the implementation of the electric power substitution policy (1990-2011), and the data is simulated and predicted by the time series ARMA model. The result is shown in Fig 3.
Through the above model, we simulated the electricity consumption in 2012-2016. The result is shown below:

| Year | 2012 | 2013 | 2014 | 2015 | 2016 |
|------|------|------|------|------|------|
| Actual value (%) | 9.70 | 10.20 | 11.30 | 12.10 | 13.30 |
| Predicted value (%) | 8.74 | 10.10 | 10.92 | 11.96 | 13.29 |
| Difference value (%) | -0.96 | -0.10 | -0.38 | -0.14 | -0.01 |

Considering the impact of the electric energy replacement policy starting in 2012, a model for the intervention of electric power substitution policies was established. Since the electric energy replacement policy is a medium- and long-term industry regional plan, it is also analyzed based on its difference. Through the difference, we can get the influence of the electric power substitution policy on the proportion of primary energy consumption, the predicted value gradually approaches the actual value and the difference gradually decreases. This shows that the adoption of the electric power substitution policy has accelerated the increase in the proportion of electric energy consumption, and its impact will gradually decrease from a long-term perspective. According to the difference and the form of policy intervention, the intervention function takes the following form:
\[ Y_t = \frac{\omega B}{1 - \delta B} S_t^{(T)}, 0 < \delta < 1 \]  

\[ S_t^{(T)} = \begin{cases} 0, & t < T \\ 1, & t \geq T \end{cases} \]  

It shows that the effect of the formula on the proportion of primary power consumption is also a decreasing form of long-term impact. Through this formula, we simulate the proportion of primary power consumption based on the intervention model of the electric power substitution policy, as shown in Fig 4.

![Fig 4](image)

**Fig. 4** Fitting chart of the ratio of power consumption in the policy intervention model in 1990-2016

After the policy intervention is added to the policy simulation intervention model, the simulation effect is more closely attached to the actual value. Therefore, the model can be used to study the energy substitution policy and predict the future power consumption ratio. By using the policy intervention model to predict the ratio of electricity consumption in 2017-2030, the following results can be obtained:

![Fig 5](image)

**Fig. 5** Forecast of primary electricity consumption by electric power substitution policy

It can be seen from the above figure that due to the adjustment and reform of energy structure and the intervention effect of the electric power substitution policy, the proportion of power consumption in
2017-2030 has continued to rise. And the proportion of increase is greater than the increase in the past 20 years, mainly due to the development of advanced energy technologies and related policies. According to the prediction of the electric power substitution policy intervention model, the proportion of electricity consumption will rise to about 22% by 2030.

4. Conclusion
In this paper, the medium-to-long-term electric power substitution policy is regarded as an intervention event of electric power substitution process, electric power substitution and an electric power substitution time series intervening analysis model is established to simulate and analyze the proportion of primary electricity consumption. This paper analyses the proportion of primary electricity consumption from 1990 to 2016, quantitatively calculates the impact of medium and long-term policy of electric power substitution on the proportion of primary electricity consumption, and predicts the proportion of primary electricity consumption by 2030. By simulating and analyzing the proportion of primary electricity consumption, we can quantitatively describe the structural changes of the growth trend of electric power substitution, which helps energy decision-making departments to make better grid planning, operation optimization and other decisions.

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