Analysis of the relationship between my country's electrification level and energy intensity

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Abstract. Electrification is an important indicator to measure the modernization of the country and the living standards of residents. The continuous improvement of the level of electrification is a general trend of world development. The article studies the relationship between my country's electrification rate and energy intensity, and the topic selection has practical significance in the context of "carbon peak and carbon neutrality". Through time series model analysis, it is verified that the increase of electrification level is conducive to the decline of energy intensity, but as the level of electrification increases, the effect of electrification on the reduction of energy intensity is weakened; the effect of electrification in the central and western provinces, high energy consumption or fast-increasing electrification industries The reduction in energy intensity is even more significant.

Keywords: Electrification, Energy intensity, Relationship, Time series analysis

1 Introduction

Electrification is the process by which various sectors of the national economy and residential life increasingly utilize electrical energy. With the development of the economy and society, the level of electrification continues to improve, which is a general trend in global development. Accelerating the development and utilization of renewable energy, promoting end-use electrification, and accelerating the construction of a new power system dominated by new energy sources are the main measures to achieve carbon peak and carbon neutrality. In the future, the electrification rate in our country will significantly increase, and electricity will play a more important role in the production and daily life sectors, contributing to the reduction of energy intensity.

In existing studies, there are relatively few direct investigations on the relationship between electrification and energy intensity. Reference [1] analyses the relationship between electrification and energy efficiency from two perspectives: the proportion of electricity generation and consumption and the proportion of electricity in the final energy mix, pointing out that an increase in the proportion of electricity in the final energy mix has a greater impact on energy efficiency. Reference [2] provides statisti-

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cal analysis of the reverse changing trends between electrification and energy intensity in developed countries. In addition, there are numerous empirical studies on the factors influencing energy intensity. For example, references [3-5] employ econometric methods to study the effects of variables such as energy prices, technological progress, industry structure, and FDI on energy intensity. Reference [6] utilizes factor decomposition and production theory decomposition methods to decompose energy intensity in China into five driving factors: potential energy intensity effect, industry structure effect, regional structure effect, energy use efficiency effect, and energy-saving technology effect. Overall, there is currently a lack of in-depth comparative analysis of electrification and energy intensity at the provincial and sectoral levels, and the explanation of the relationship between the two is not sufficiently comprehensive.

The main focus of the following sections includes: describing the basic trends and relationship between electrification and energy intensity in China; introducing the methodology and steps for studying the relationship between electrification and energy intensity; analyzing empirical results of electrification and energy intensity at the national, provincial, and sectoral levels; summarizing the findings and providing research prospects for future studies.

2 Electrification and Changes in Energy Intensity in China

The level of electrification is generally represented by two indicators: the proportion of electricity generation and consumption in primary energy and the proportion of electricity in the final energy consumption. This study primarily uses the latter indicator for analysis. Energy intensity refers to the amount of energy consumed per unit of output, typically represented by the ratio of GDP (value added) to energy consumption.

Since 1980, the level of electrification in China has shown an overall upward trend. From 1980 to 2000, the electrification level increased from 6.5% to 14.5%, an increase of 8.0 percentage points. From 2001 to 2020, the electrification level further rose to 25.8%, an increase of 11.3 percentage points. However, there was a temporary decline in electrification from 2002 to 2005, mainly due to the accelerated development of heavy industry during this period, with other forms of energy consumption growing faster than electricity consumption.

In contrast, energy intensity has shown an overall downward trend. From 1980 to 2000, energy intensity (measured in terms of energy consumption per unit of GDP, using 2010 prices for conversion) decreased from 2.54 tons of standard coal per 10,000 yuan to 0.95 tons of standard coal per 10,000 yuan, a decrease of 62.5%. From 2001 to 2020, energy intensity further decreased to 0.62 tons of standard coal per 10,000 yuan, a decrease of 34.5% (See Figure 1).

Historical data indicates a strong negative correlation between electrification level and energy intensity, with a correlation coefficient of -0.92. The negative correlation coefficient between electrification level and energy intensity for individual provinces and industries from 2000 to 2019 is consistently below-0.7. Even during the period of reversed changes from 2002 to 2005, the two variables exhibited inverse variations (See Figure 2 and Figure 3).

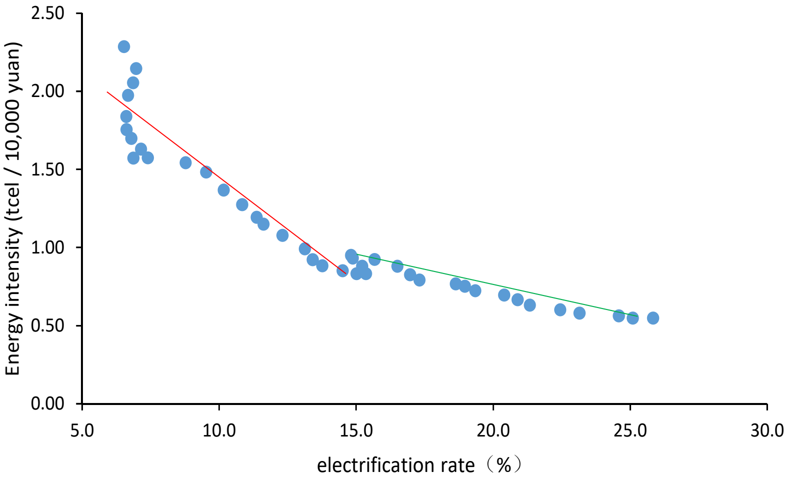

Fig. 1. Scatter chart of energy intensity and electrification rate in China from 1980 to 2020.

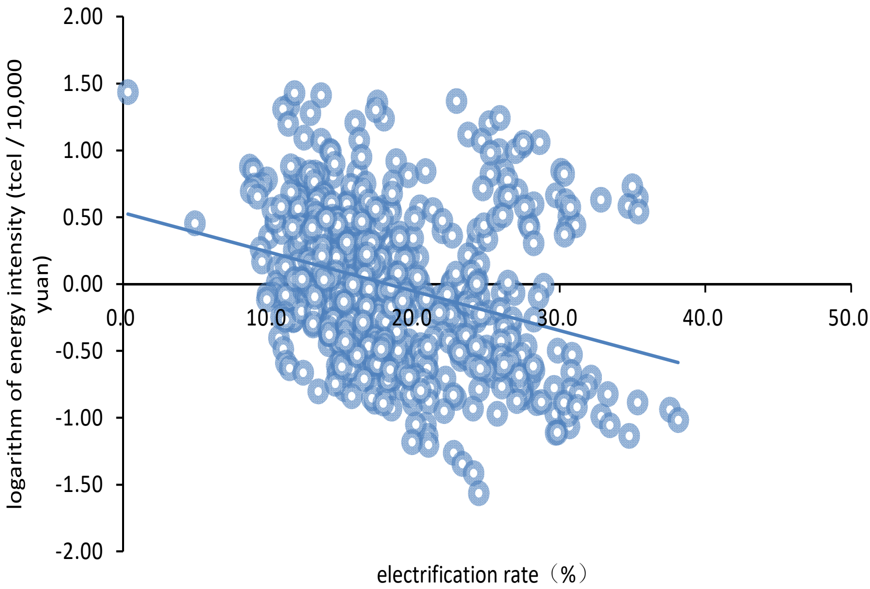

Fig. 2. Scatter chart of energy intensity and electrification rate of each province from 2000 to 2019.

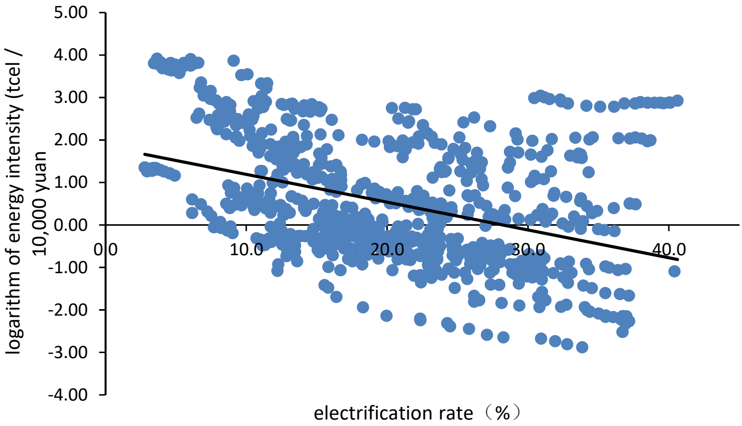

Fig. 3. Scatter chart of energy intensity and electrification rate by industry from 2000 to 2019.

3 Analysis of the Relationship between Electrification Level and Energy Intensity

From an international perspective, the level of electrification in a country is adapted to its level of economic development. As the economy advances, the level of electrification continues to increase while energy intensity decreases [1]. Existing literature [3-6] demonstrate that the variation in energy intensity is influenced by multiple factors, with electrification level being one of the significant factors.

The impact of electrification level on energy intensity can be observed through direct and indirect effects. In terms of direct effects, electricity is a clean and high-quality secondary energy source, with higher utilization efficiency compared to coal, oil, and other energy sources. The substitution of coal and oil with electricity can improve energy system efficiency, and electricity creates an economic value in end-use sectors that is 3.2 times higher than oil and 17.3 times higher than coal [7]. In terms of indirect effects, electrification level is closely related to technological advancements, industrialization, urbanization, digitalization, and other factors. These factors indirectly influence energy intensity through electrification [8]. Electrification originated from the Second Industrial Revolution, with each technological revolution driving high levels of productivity. As new technologies continue to develop and be applied (such as the rapid replacement of fuel-powered vehicles with electric vehicles), the electrification process in China continues to experience rapid growth. Industrialization and urbanization promote the scaling and specialization of production processes, favoring the centralized use of electricity. Digitalization enables precise localization of energy supply, transportation, and usage in the energy system, effectively enhancing energy efficiency. Sectors such as data centres and communication base stations exhibit strong growth in electricity demand, further promoting the advancement of electrification level.

4 Analytical Methods and Data

The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table 2 should be used.

4.1 Analytical Methods

This study will analyze the time series data of electrification rate and energy intensity using established econometric models for bivariate time series analysis. The main steps of the analysis are as follows:

4.1.1 Unit root tests on the series. This test is a prerequisite for time series analysis. For bivariate analysis, it is necessary for the variable series to have unit roots of the same order, which is a requirement for building time series models.

4.1.2 Model regression. Considering the data characteristics of electrification rate and energy intensity, the basic model is semilog model: $\ln y = c_0 + c_1 x + \mu$, Where c_0 is the constant term, and c_1 is the coefficient to be estimated, The coefficient means that changes by 1 unit and y changes by $100 * c_1$ percentage points; μ is a random error term.

For time series regression models, it is crucial to ensure that the regression coefficients are statistically significant and economically meaningful, the model has a high goodness of fit, and there is no serial correlation. If there is evidence of serial correlation in the regression model, it can be addressed by incorporating autoregressive terms and conducting stability tests to ensure the reliability of the results.

4.1.3 Cointegration test. To avoid spurious regression in time series analysis, it is necessary to conduct a cointegration test. For two variable time series, the Engle-Granger two-step method can be applied to test for cointegration. This involves testing the stationarity (lack of unit roots) of the residual series from the regression model. If the residual series is stationary, it indicates the presence of a long-term stable relationship between the two variables, making the regression results more reliable.

4.1.4Calculation of contribution rate. Based on the regression results, the changes in the electrification rate over different time periods are reverse-calculated to determine the corresponding decrease in energy intensity. Subsequently, the contribution rate of the electrification rate to the decrease in energy intensity is calculated.

4.2 Data Compilation

National energy consumption, final energy consumption, GDP, and its growth rate data are obtained from the National Bureau of Statistics and the annual China Energy Statistical Yearbook. Taking the year 2010 as the base year, national GDP is converted into comparable-price GDP, and then energy intensity is calculated.

Provincial energy consumption, GDP, and its growth rate data are obtained from the National Bureau of Statistics. The data on end-use energy consumption by industry are obtained from the annual China Energy Statistical Yearbook, specifically the physical energy balance sheets of each province. The consumption of various energy types is standardized using conversion factors for standard coal consumption. The electrification rate is then calculated. Due to significant data gaps in Tibet, it has been excluded from the analysis. Ningxia lacks energy consumption data for the years 2000-2002, Beijing lacks energy consumption data for 2001, Hunan and Hainan lack energy consumption data for 2002, and Hubei lacks energy consumption data for 2019. For the other provinces, the data cover the continuous period from 2000 to 2019. Missing data for intermediate years have been interpolated.

Data on sectoral energy consumption and end-use energy consumption by energy type are obtained from the annual China Energy Statistical Yearbook. The initially published values for energy consumption in various sectors for the years 2000 and 2005 have changed significantly. Therefore, a uniform coefficient is used to estimate the values for the years 2001-2004, which is the ratio between the new and old values for the years 2000 and 2005. Industrial value-added data from 2000 to 2008 are sourced from reference [9], while industrial value-added data from 2009 to 2019 are derived by multiplying the growth rate of value-added of above-scale industries by the ratio of the annual growth rate of total industrial value-added to the growth rate of above-scale industrial value-added. Value-added data for other industries are obtained from the Wind Financial Information Database. When citing data from the years 2000 to 2008, value-added is calculated based on the comparable prices of 1990 [10]. The choice of different years for calculating comparable prices does not affect the final analysis conclusions.

Due to differences in industry classifications for energy consumption and value-added, as well as variations between years, adjustments and consolidations have been made to form a unified and continuous classification of 40 industries, as shown in Table 1.

Table 1. Unified processing industry names.

Number	Industry	Number	Industry
1	Agriculture, Forestry,	**21**	Pharmaceutical manufacturing
2	Coal mining	**22**	Chemical fibre manufacturing
3	Oil mining	**23**	Rubber and plastic products industry
4	Ferrous metal mining	**24**	Non-metal product
5	Non-ferrous metal min-	**25**	Ferrous metal processing
6	Non-metallic mining	**26**	Non-ferrous metal processing
7	Agricultural and sideline	**27**	Metal products

8	Food manufacturing	**28**	General equipment manufacturing
9	Beverage manufacturing	**29**	Special equipment manufacturing
10	Tobacco processing	**30**	Traffic equipment manufacturing
11	Textile industry	**31**	Electrical machinery manufacturing
12	Garments industry	**32**	Computer communication equipment
13	Fur products	**33**	Instrumentation
14	Wood processing	**34**	Electricity production and supply
15	Cabinet making	**35**	Gas production and supply
16	Paper industry	**36**	Water production supply
17	Printing trade	**37**	Building industry
18	Sporting goods	**38**	Transportation, warehousing and post-
19	Oil processing	**39**	Wholesale and retail trade, catering
20	Chemical raw materials	**40**	Other industries

5 Empirical Analysis Results

5.1 Analysis at the National Level

From 1980 to 2020, for every 1 percentage point increase in electrification rate in China, energy consumption intensity decreased by 2.1 percentage points. The specific regression equation is as follows:

$$lnY = -0.021 * X + [AR(1) = 1.49,\ AR(2) = -0.51] \tag{1}$$

In equation (1), AR (1)and AR (2) are the first-order and second-order autoregressive terms of the explained variable Y, indicating the inherent inertia influence of energy intensity variable (Y) itself and the influence of other important variables. This paper does not focus on the analysis, the same below.

From 1980 to 2000, for every 1 percentage point increase in electrification rate in China, energy consumption intensity decreased by 3.3 percentage points. The specific regression equation is the following formula (2):

$$lnY = -0.033 * X + \left[AR(1) = 0.95\right] \tag{2}$$

From 2000 to 2020, for every 1 percentage point increase in electrification rate in China, energy consumption intensity decreased by 1.6 percentage points. The specific regression equation is the following formula (3):

$$lnY = -0.016 * X + [AR(1) = 1.57,\ AR(2) = -0.60] \tag{3}$$

The results of the analysis show that the increase of electrification rate in the past 40 years is conducive to reducing energy intensity and improving energy efficiency, which is consistent with the theoretical analysis in Part 3. As the level of electrification has risen, the impact of changes in electrification rate on energy intensity has diminished. This is mainly due to the widespread adoption of electricity in key sectors, leading to a reduction in the marginal influence of further electrification in areas with incremental energy consumption. The summary results of the autoregressive lag model are shown in Table 2.

Table 2. National empirical analysis results summary.

Regression	Roots of unity	Model(a,c,T)[b]	Regression coefficient	Co-integration test
1		(0,0,2)	-0.021	√[c]
2	I(1),I(1)[a]	(0,0,1)	-0.033	√
3		(0,0,2)	-0.016	√

[a] I() in the table represents the unit root order of the electrification rate and energy intensity series.

[b] (a,c,T) indicates whether the variable of electric gas rate in the regression equation has a lag term, whether the equation has an intercept term, and the order of the autoregressive term.

[c] √ means that there is a stable cointegration relationship between the two variables, and x means that there is no cointegration relationship.

From the perspective of the contribution of the increase in electrification rate to the decrease in energy intensity, during the three time intervals of 1980-2020, 1980-2000, and 2000-2020, the contributions of the variations in electrification rate to the decrease in energy intensity were 15.2%, 11.7%, and 40.0%, respectively. This can be mainly attributed to the significant increase in electrification rate in the past two decades and the relatively smaller decrease in energy intensity compared to the previous two decades, leading to an increased contribution of electrification rate to energy intensity reduction.

5.2 Analysis at the Provincial Level

After excluding Tibet, empirical analysis was conducted on 30 provinces (including municipalities directly under the central government and autonomous regions) in China. It was found that 23 provinces exhibited stationary time series with respect to electrification rate and energy intensity, and a stable cointegration relationship existed between them. Among these provinces, 13 provinces had absolute regression coefficients for electrification rate that exceeded the national average (-0.016). The top five provinces in terms of absolute regression coefficients were Jiangsu (-0.110), Guangdong (-0.089), Anhui (-0.044), Chongqing (-0.036), and Jiangxi (-0.033). Most of these provinces are located in the central and eastern parts of China, while only Sichuan, Chongqing, and Guizhou represent the western provinces. Please refer to Table 3 for detailed information.

Based on the regression equations for each province, the contribution rate of electrification rate variations to the decline in energy intensity during the period from 2000 to 2020 can be calculated. As the regression results indicate, electrification rate serves as one of the driving forces behind the reduction in energy intensity, but it does not explain all the variations in energy intensity. Among the 30 provinces, 11 provinces have a contribution rate of electrification rate to energy intensity change exceeding 10%, and this relationship is stable. However, other provinces have relatively low contribution rates, which may be attributed to their development stage and industrial structure.

Table 3. Summary of empirical analysis results from 30 provinces.

Province	Roots of unity	Model(a,c,T)	Regression coefficient	Co-integration test
Hebei	I(0),I(0)	(0,0,1)	-0.002	√
Shanxi	I(0),I(0)	(0,0,1)	-0.021***	√
Inner Mon-	I(0),I(1)	(0,0,2)	-0.013***	√
Jilin	I(1),I(1)	(0,1,1)	0.029	√
Heilongjiang	I(0),I(0)	(0,0,1)	-0.004	√
Jiangsu	I(0),I(0)	(0,1,2)	-0.110***	√
Zhejiang	I(1),I(1)	(0,0,1)	-0.027***	√
Anhui	I(1),I(1)	(0,0,1)	-0.044***	√
Fujian	I(0),I(0)	(0,0,1)	0.004**	√
Jiangxi	I(1),I(1)	(0,0,1)	-0.033***	√
Shandong	I(1),I(1)	(0,0,1)	-0.029***	√
Henan	I(1),I(1)	(0,0,1)	-0.033***	√
Hubei	I(1),I(1)	(0,0,2)	-0.026**	√
Guangdong	I(1),I(1)	(0,1,0)	-0.089***	√
Guangxi	I(1),I(1)	(0,0,1)	-0.018***	√
Hainan	I(1),I(1)	(0,0,1)	-0.003	√
Chongqing	I(1),I(1)	(0,0,1)	-0.036***	√
Sichuan	I(1),I(1)	(0,0,2)	-0.019*	√
Guizhou	I(1),I(1)	(0,0,2)	-0.032**	√
Yunnan	I(1),I(1)	(0,0,2)	0.006	√
Shanxi	I(1),I(1)	(0,0,2)	-0.015*	√
Gansu	I(0),I(0)	(0,0,1)	-0.006	√
Qinghai	I(1),I(1)	(0,0,1)	-0.001	√
Ningxia	I(1),I(1)	(0,1,1)	-0.002	√

For the provinces where the econometric analysis results of electrification rate and energy intensity index are not significant, this result is either due to complex economic and social relations or due to sample selection problems. Therefore, further in-depth research is still needed, such as more detailed empirical research specifically for a certain province.

5.3 Analysis by Industry

Empirical analysis of 40 industries nationwide revealed that 23 industries exhibit unit root characteristics in both electrification rate and energy intensity indicators, indicating the presence of a stable cointegration relationship. Among these industries, 17 industries have absolute regression coefficients for electrification rate greater than the national average (-0.016). The top three industries with the highest absolute coefficients are non-metallic manufacturing (-0.117), chemical fiber manufacturing (-0.115), and ferrous metal processing (-0.104). These industries with larger absolute coefficients are primarily characterized by high energy consumption or rapid improvement in electrification levels. Please refer to Table 4 for details.

Table 4. Summary of empirical analysis results from 40 industries.

Industry	Roots of unity	Model (a,c,T)	Regression coefficient	Co-integration test
Non-ferrous metal min-	I(1),I(1)	(0,1,1)	-0.065***	√
Tobacco processing	I(1),I(1)	(1,0,1)	-0.047***	√
Fur products	I(1),I(1)	(0,0,1)	-0.021**	√
Wood processing	I(1),I(1)	(1,0,1)	-0.004***	√
Cabinet making	I(1),I(1)	(0,0,1)	-0.028***	√
Printing trade	I(1),I(1)	(1,0,1)	-0.004**	√
Sporting goods	I(1),I(1)	(1,0,1)	-0.005**	√
Pharmaceutical manu-	I(1),I(1)	(1,0,0)	-0.008***	√
Chemical fiber manu-	I(1),I(1)	(1,1,1)	-0.115***	√
Rubber and plastic	I(1),I(1)	(0,1,1)	-0.051***	√
Non-metal product	I(1),I(1)	(1,1,1)	-0.117***	√
Ferrous metal pro-	I(1),I(1)	(1,1,1)	-0.104***	√
Non-ferrous metal pro-	I(1),I(1)	(1,0,0)	0.005*	√
Metal products	I(1),I(1)	(1,1,0)	-0.023**	√
Traffic equipment man-	I(1),I(1)	(1,1,0)	-0.034**	√
Electrical machinery	I(1),I(1)	(1,0,0)	-0.057**	√
Computer communica-	I(1),I(1)	(0,1,1)	-0.057***	√
Instrumentation	I(1),I(1)	(1,0,1)	-0.009**	√
Electricity production	I(1),I(1)	(1,1,1)	-0.025**	√
Building industry	I(1),I(1)	(1,1,1)	-0.044**	√
Transportation, ware-	I(1),I(1)	(1,1,0)	-0.039**	√
Wholesale and retail	I(1),I(1)	(0,1,1)	-0.035***	√
Other industries	I(1),I(1)	(0,1,1)	-0.014***	√

Based on the regression equations for each industry, the contribution rate of electrification rate variations to the decline in energy intensity during the period from 2000 to 2020 can be calculated. Similar to the provincial regression results, electrification rate serves as one of the driving forces behind the reduction in energy intensity at the industry level, but it does not explain all the variations in energy intensity. Among the 40 industries, 16 industries have a contribution rate of electrification rate to energy intensity change exceeding 10%, and this relationship is stable and statistically significant. However, other industries have relatively low contribution rates, which may be attributed to their specific attributes such as energy utilization methods and structural characteristics within the industry.

6 Conclusion

Through the analysis of time series econometrics model, this paper verifies the view that electrification is conducive to the decline of energy intensity. Continuous promotion of electrification level will help improve energy efficiency and promote high-quality development of energy consumption side, which has important practical significance for China to achieve the vision goal of "carbon peak and carbon neutrality". Of course, with economic and social development, the role of electrification in promoting energy intensity decline has weakened, and this role has significant differences between different provinces and different industries. The main contribution of this study is to verify that electrification in China is beneficial to reducing energy intensity through econometric methods, and to solve people's doubts about the correlation between electrification and energy intensity.

In addition, in the follow-up study, the author believes that the detailed analysis of differences between provinces and industries and their causes will have direct practical significance for accelerating the process of electrification and reducing energy intensity, and we will continue to promote research in this area.

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