



Study on the Relationship Between Carbon Emission and Economic Development in the Yangtze River Economic Belt – Based on the Elastic Decoupling Theory

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Abstract. Coping with global climate change and reducing greenhouse gas emissions dominated by carbon dioxide is the focus of sustainable development. Under the “carbon peaking and carbon neutrality” goal, how to reduce carbon emissions while maintaining stable economic growth is a severe challenge facing China. Scientifically measuring the decoupling effect and mechanism between carbon emission and economic development is the key to realizing regional green, low-carbon, and coordinated development. This paper takes 11 provinces of the Yangtze River Economic Belt: Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan, and Guizhou as the research object. Through the decoupling analysis of the relationship between economic growth and carbon emission, this paper discusses the correlation between economic growth and carbon emission change in 11 provinces from 2008 to 2019. The results show that the decoupling relationship between economic growth and carbon emissions in the Yangtze River Economic Belt shows three states: weak decoupling, strong decoupling and expansion negative decoupling, mainly weak decoupling, and strong decoupling.

Keywords: Carbon Emissions · Yangtze River Economic Belt · Economic Growth · Decoupling Effect

1 Introduction

Green and low-carbon development is a distinctive feature of today’s technological and industrial transformation and is an inherent requirement to promote high-quality economic and social development in China. At the 75th United Nations General Assembly, China put forward the “carbon peaking and carbon neutrality” goal, which makes the country face the severe challenge of maintaining stable economic growth while reducing carbon emissions. Therefore, using scientific methods to clarify the decoupling effect and mechanism between carbon emission levels and economic development is the key to realizing the regional economy green, low-carbon, and coordinated development.

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How to analyze the relationship between economy and energy can be divided into two levels: method and perspective.

In terms of method, decoupling theory is a popular theory used by domestic and foreign scholars to analyze the relationship between two things in recent years, which is mostly applied to study economic development and energy emissions. From the perspective of its development, the OECD introduced the concept of decoupling into agricultural policy research at the end of the 20th century, then it has been gradually expanded to fields such as environment, defined as breaking the relationship between environmental hazards and economic performance, and making the consumption of resources and the environment gradually deviate from the trend of economic growth. Later, De Bruyn et al. (1997) [2] analyzed that there was an uncoupled relationship between economic growth and environmental pressure and proposed that the relationship trend was n-shaped; Vehmas et al. (2003) [12] considered economic recession and classified decoupling into six categories: strong, weak, expansionary recoupling, strong, weak and recessionary decoupling. Tapio et al. (2005) [11] proposed the framework theory of decoupling, and defined decoupling, coupling, and negative decoupling and further divided into weak decoupling, strong decoupling, and expansive decoupling; Andrew et al. (2012) [6] rejected the assumption that the strong relationship between environmental harm and economic development would remain unchanged or might increase with time in the study of economic and environmental decoupling, believing that the relationship between the two would be different at different stages of national development. Domestic studies on decoupling theory started late. Wang (2010) [13] used decoupling theory to analyze the decoupling effect between energy consumption and economic growth in China from 1990 to 2007; Peng et al. (2011) [9] systematically studied the decoupling relationship between China's economic growth and energy carbon emissions from 1980 to 2008 by constructing an analysis model of decoupling between economy and energy carbon emissions; Sun et al. (2011) [10] measured the decoupling relationship between carbon emissions and economic growth in China's provinces from 1999 to 2008 based on Tapio decoupling index; Hu et al. (2019) [5] systematically analyzed the relationship between tourism carbon emissions and economic growth in Tibet by constructing the Tapio decoupling index model of "two-stage rolling" and using co-integration and Granger causality test. The above literature has laid a rich theoretical foundation for the study of the relationship between economy and energy.

From this perspective, most scholars analyze the relationship between economic growth and energy utilization, resource pollution, etc. from a macro perspective. Wang et al. (2019) [14] adopted the decoupling model and log-average Dee's Index (LMDI) decomposition analysis model to conclude and suggest that emission reduction in Beijing-Tianjin-Hebei can be carried out by strictly controlling energy-consuming industries, increasing technological input, making use of economic leverage and improving environmental compensation, etc. Huang et al. (2019) [4] analyzed the decoupling effect of economic growth and environmental pollution by Tapio decoupling elasticity index and concluded that the economy of the Yangtze River presents a cyclical feature of absolute decoupling - expansion - negative decoupling - absolute decoupling and has a good development trend of absolute decoupling. Zhao et al. (2021) [19] obtained the dynamic relationship among energy consumption, economic growth, and CO₂ emission

through the Granger causality test, impulse response analysis, and variance decomposition; Gao et al. (2021) [3] used the decoupling model to analyze the decoupling trend of water resources in the Yellow River Basin and concluded that the scale economy factor of the Yellow River Basin was a positive decoupling factor. With the proposal of “carbon neutrality” and “carbon peak” strategies, more and more scholars have shifted their perspective to a micro perspective, choosing CO₂ in energy to study the decoupling relationship between economic growth and carbon emissions. In terms of the selection of research objects and spatial scope, they are mainly divided into two categories: region and industry. Wu et al. (2019) [17] studied the decoupling relationship between economic growth and carbon emissions in the Shanxi-Shaanxi-Mongolia region and found that there was a dynamic decoupling relationship that is mainly weak between economic growth and carbon emissions; Zheng et al. (2021) [20] estimated the tourism carbon emissions in the provinces along the “Belt and Road”, and tested the cointegration and mutual prediction ability between the tourism economy and carbon emissions; Li et al. (2021) [8] adopted the “bottom-up” method for tourism, combined with Tapio decoupling model and exploratory spatial analysis, and found that the decoupling index of China’s overall tourism carbon emissions was in constant fluctuation, and there were significant differences in the carbon emissions of tourism in different provinces. Shengtao, Chen et al. (2021) [1] started with agriculture and found that the main traditional agricultural production areas have great emission reduction potential, and there is a strong decoupling effect between CO₂ emissions and agricultural economic development in most regions; Wang et al. (2021) [15] took China’s equipment manufacturing industry as the perspective and found that the decoupling relationship with carbon emissions changed from weak decoupling and negative decoupling to strong decoupling.

To sum up, although the existing literature has a rich theoretical basis, there is still insufficient research on the relationship between regional economic growth and carbon emissions from a relatively micro perspective. In the context of the country’s overall “carbon peaking and carbon neutrality”, further theoretical and methodological research is urgently needed. The Yangtze River Economic Belt is of great strategic significance as a pacesetter for China’s high-quality economic development in the new era and a demonstration belt for the country to implement green and ecological development. Decoupling analysis of the relationship between economic growth and carbon emissions in the Yangtze River Economic Belt is conducive to exploring a new win-win model of emission reduction and economic development for the country. Based on the above background, this paper selects the Yangtze River Economic Belt 11 provinces as the research object, by constructing a decoupling model analysis of carbon emissions and the intrinsic relationships between economic development and to find the key to energy conservation and emissions reduction factors in the economic development and key mechanisms, provide policy advice to control carbon emissions at the same time guarantee economic stability growth and better promote high-quality economic development. Organic combination and research analysis of the important internal links between carbon emissions and economic development can avoid the defect of separating the two studies in the existing literature.

2 Research Object Profile

The Yangtze River Economic Belt, which spans East, West, and Central China, is one of the “three major strategies” and it covers 11 provinces and cities such as Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan, and Guizhou, covering an area of about 2052300 square kilometers, accounting for 21.4% of the country, and its population and GDP exceed 40% of the country. Promoting the development of the Yangtze River Economic Belt is a major strategy related to the overall situation of national development. It is of great significance to realize the goals of the “two centenaries” and the Chinese Dream of the great rejuvenation of the Chinese nation.

In terms of economic development, the Yangtze River Economic Belt has gradually become the main force leading the high-quality economic development. Its GDP rose from 43.1% in 2016 to 46.7% in the first three quarters of 2021, and its per capita disposable income was higher than the national average, with rural per capita disposable income 23.82% higher than the national average in 2020. In addition, in the first three quarters of 2021, seven of the country’s top 10 cities in terms of GDP are located in the Yangtze River Economic Belt, namely Shanghai, Chongqing, Suzhou, Chengdu, Hangzhou, Wuhan, and Nanjing. In terms of green ecology, fishing has been banned for 10 years along the Yangtze River. According to the Ministry of Agriculture and Rural Affairs, a total of 111,000 fishing boats and 231,000 fishermen were returned to shore by 2021. In addition, the treatment of Yangtze River disease is being steadily resolved. According to the websites of provinces and municipalities along the Yangtze River Economic Belt, Jiangsu will close down 995 chemical enterprises and cancel the positioning of 11 chemical parks by 2021. 134 chemical enterprises along the Yangtze River in Yichang have been transformed from customs clearance to relocation. Jiujiang dismantled 87 illegal wharves along the river and cleared 38 chemical enterprises...

The development of the Yangtze River Economic Belt is inseparable from a path of ecological priority and green development. It is of great immediate and far-reaching historical significance to the realization of the “Two Centenary Goals” and the Chinese Dream of national rejuvenation.

3 Materials and Methods

3.1 Data Sources

The data used in this study mainly come from the “China Energy Statistical Yearbook”, the EPS database, and the National Bureau of Statistics. The research period is from 2008 to 2019, and the Yangtze River Economic Belt: Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan, and Guizhou. The 11 provinces are the research objects, and the GDP and energy consumption (10,000 standard tons of coal) of each province are studied. According to the “China Statistical Yearbook” and “China Energy Statistical Yearbook”, it is divided into four types of energy: coal, oil, natural gas, hydropower, wind power, and nuclear power, and the consumption is uniformly converted into standard coal. Among them, the carbon emission coefficient of new energy (secondary energy such as hydropower and wind energy) is 0, and we do not need to include it in the calculation.

3.2 Research Method

3.2.1 Decoupling Effect Model of Carbon Emissions and Economic Growth

The decoupling theory was first applied to physics. Later, with the prevalence of the EKC curve, more and more scholars combined it with decoupling and applied it to the study of the relationship between economic development, environmental pollution, and resource consumption [7]. This paper uses the Tapio decoupling model with elastic growth characteristics to explore the relationship between carbon emission levels and economic development in the Yangtze River Economic Belt. The growth rate of emissions continues to decrease, eventually achieving zero or even negative growth. The Tapio indicator uses the time-scale elasticity analysis method, combines the carbon emission data of the Yangtze River Economic Belt from 2008 to 2019, integrates the two types of indicators, the total change, and the relative change, and finally explores the effect of changes in different factors on the changes in the decoupling index, avoiding. The calculation error caused by the high sensitivity of the selection data of the base period and the end period, and the amount of data required is small, which is more convenient for calculation [16], which provides the basis for my country to formulate relevant policies and regulations on carbon reduction and emission reduction. Following.

Therefore, this paper cites the method of Wu Yang et al. [18], which introduced energy consumption as an intermediate variable based on the decoupling index model to decompose the causal chain and decomposed the decoupling elasticity index of economic growth and carbon emission into two sets of intermediate variable elasticity. The elasticities of these two groups of intermediate variables are the emission reduction decoupling index and the energy efficiency decoupling index, respectively. The elasticity between carbon emissions and energy consumption is:

$$e(C, E) = \frac{VC}{C} / \frac{VE}{E} = \frac{\%VC}{\%VE} \quad (1)$$

Among them, “C” represents the carbon emissions of the provinces and cities in the study area this year; “VC” represents the change in carbon emissions in this year compared with the previous year; “E” represents the energy consumption of the provinces and cities in the study area this year; “VE” represents the change of energy consumption in this year compared with the previous year.

This formula expresses the percentage change in carbon emissions when energy consumption changes by one percentage point in a specific period. The elasticity between energy consumption and GDP is:

$$e(E, GDP) = \frac{VE}{E} / \frac{VGDP}{GDP} = \frac{\%VE}{\%VGDP} \quad (2)$$

Among them, “GDP” refers to the gross domestic product of the provinces and cities in the study area this year; “VGDP” refers to the change in GDP of this year compared with the previous year; “%VGDP” refers to a percentage point change in GDP this year.

This formula expresses the percentage change in energy consumption when GDP changes by one percentage point in a specific period.

Multiplying formula (1) and formula (2) can get:

$$e(C, GDP) = e(C, E) \times e(E, GDP) \quad (3)$$

Among them, “ $e(C, GDP)$ ” represents the elasticity between carbon emissions and GDP; “ $e(C, E)$ ” represents the elasticity between carbon emissions and energy consumption; “ (E, GDP) ” represents the relationship between energy consumption and GDP elasticity.

According to Tapio’s division of decoupling elasticity index, this paper divides the index into 6 types, namely expansion negative decoupling, strong negative decoupling, weak negative decoupling, weak decoupling, strong decoupling, and recession decoupling. The best state of low-carbon development, strong and negative decoupling is the most unfavorable state. The various decoupling states and their meanings are shown in Table 1.

Among them, when the development trend of carbon emission is opposite to that of the economic state, that is, economic recession, an increase of carbon emission (strong negative decoupling) or economic growth, a decrease of carbon emission (strong decoupling), the elasticity e is less than 0.

Table 1. Various decoupling states and their meanings

Decoupled state	$\Delta C\%$	$\Delta GDP\%$	elasticity: e	The characteristics of the decoupling state of carbon emissions and economic growth
Expansion Negative Decoupling	>0	>0	$e > 0.8$	Economic growth, carbon emissions increase, carbon emissions increase more than economic growth
Strong negative decoupling	>0	<0	$e < 0$	Economic recession, carbon emissions increase
Weak negative decoupling	<0	<0	$0 < e < 0.8$	Economic recession, carbon emissions decline, carbon emissions decline less than economic growth
weak decoupling	>0	>0	$0 < e < 0.8$	Economic growth, carbon emissions increase, carbon emissions increase less than economic growth
Strong decoupling	<0	>0	$e < 0$	Economic growth, carbon emissions fall
recession decoupling	<0	<0	$e > 0.8$	Economic recession, carbon emissions decline, carbon emissions decline more than economic growth

4 Results and Discussion

According to the decoupling effect model, the decoupling indicators of China's carbon emissions and economic growth from 2008 to 2019 are calculated, and the decoupling indicators are decomposed into causal chains. The results are shown in Table 2.

It can be seen from the table that from 2008 to 2019, the economy of the Yangtze River Economic Belt has been in a state of growth, with more carbon emissions. That is to say, the decoupling relationship between economic growth and carbon emissions in the Yangtze River Economic Belt during the study period shows three states: weak decoupling, strong decoupling, and expansion negative decoupling, mainly weak decoupling and strong decoupling. Among them, weak decoupling means that the economy and carbon emissions are in a growth trend, and the increase of carbon emissions is less than that of economic growth; If the increase of carbon emissions is greater than that of economic growth, it is expansion negative decoupling; strong decoupling is the most ideal state of economic growth.

(1) From 2008 to 2011, the economic growth of provinces in the Yangtze River Economic Belt was still the main factor for the increase of China's carbon emissions. Although the growth rate of carbon emissions was lower than that of economic growth, and the decoupling state was dominated by weak decoupling, the demand for energy by economic growth increased, and the carbon emissions also increased, and there was still a great pressure relationship between the two. From 2012 to 2019, with the promotion

Table 2. Decoupling elasticity between carbon emissions and economic development in the Yangtze River Economic Belt from 2008 to 2019

Prefecture	Shanghai	Jiangsu	Zhejiang	Anhui	Jiangxi	Hubei	Hunan	Chongqing	Sichuan	Guizhou	Yunnan
2008–2009	Weak decoupling	Weak decoupling	Weak decoupling	Expansion negative decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Expansion negative decoupling	Weak decoupling	Expansion negative decoupling
2009–2010	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Strong decoupling	Weak decoupling	Weak decoupling
2010–2011	Weak decoupling	Expansion negative decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling
2011–2012	Strong decoupling	Weak decoupling	Strong decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Strong decoupling	Strong decoupling	Weak decoupling	Weak decoupling	Weak decoupling
2012–2013	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Strong decoupling	Strong decoupling	Strong decoupling	Weak decoupling	Weak decoupling	Strong decoupling
2013–2014	Strong decoupling	Strong decoupling	Weak decoupling	Expansion negative decoupling	Expansion negative decoupling	Strong decoupling	Strong decoupling	Expansion negative decoupling	Strong decoupling	Strong decoupling	Strong decoupling
2014–2015	Weak decoupling	Weak decoupling	Strong decoupling	Weak decoupling	Expansion negative decoupling	Strong decoupling	Strong decoupling	Strong decoupling	Strong decoupling	Strong decoupling	Strong decoupling
2015–2016	Weak decoupling	Weak decoupling	Strong decoupling	Weak decoupling	Expansion negative decoupling	Strong decoupling	Weak decoupling	Weak decoupling	Strong decoupling	Weak decoupling	Strong decoupling
2016–2017	Strong decoupling	Strong decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Strong decoupling	Weak decoupling	Weak decoupling	Strong decoupling	Weak decoupling	Weak decoupling
2017–2018	Weak decoupling	Strong decoupling	Strong decoupling	Weak decoupling	Expansion negative decoupling	Weak decoupling	Expansion negative decoupling	Strong decoupling	Strong decoupling	Strong decoupling	Weak decoupling
2018–2019	Weak decoupling	Weak decoupling	Strong decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Strong decoupling	Weak decoupling	Weak decoupling	Weak decoupling	Weak decoupling

of energy conservation and emission reduction in various regions, energy consumption has shown a downward trend and the upward trend of carbon emission slowed down. Therefore, the strong decoupling state increased, that is, economic growth and carbon emission decreased. Except for Jiangxi Province, the growth rate of carbon emissions accelerated from 2013 to 2018, and the growth rate of carbon emissions was greater than that of economic growth, resulting in negative decoupling of expansion.

(2) Among the provinces in the Yangtze River Economic Belt, Zhejiang, Hubei, Hunan and Sichuan experienced economic growth and carbon emissions decreased in nearly half of the years from 2008 to 2019, that is, the two were in a state of strong decoupling. From 2012 to 2019, the energy utilization rate of Zhejiang, Hubei, Hunan, and Sichuan has been further improved. The improvement of energy efficiency has a certain inhibitory effect on carbon emission, and the fluctuation of energy consumption is small, the trend is flat and at a low consumption level, which is the main factor to realize the strong decoupling between carbon emission and economic growth.

(3) Among the provinces in the Yangtze River Economic Belt, Jiangsu, Anhui, Jiangxi, Hunan, Chongqing, Sichuan, and Yunnan are in the state of negative decoupling of expansion. During the period of negative decoupling of expansion, energy consumption and carbon emissions have increased, and the growth rate of carbon emissions is large, exceeding the range of economic growth.

5 Conclusions and Recommendations

5.1 Conclusion of the Study

This paper selects 11 provinces in the Yangtze River Economic Belt as the research objects and analyzes the internal relationship between carbon emissions and economic development by constructing the decoupling effect model. It is concluded that the Yangtze River Economic Belt has only three states of weak decoupling, strong decoupling, and expansion negative decoupling from 2008 to 2019. During the study period, the economy of the Yangtze River Economic Belt has been in a growth trend, but carbon emissions are mainly growth. In this way, we can find the key factors and key mechanisms of energy conservation and emission reduction in economic development and better promote high-quality economic development. The study found that:

(1) The carbon emissions of economic development in the Yangtze River Economic Zone are generally in a shrinking trend, but the growth rate is slow and the increase is small. The economic development of the basin is based on a high intensity of energy consumption and carbon emissions, and the development model is extensive. At the same time, the carbon emissions of economic development in most provinces and municipalities in the Yangtze River Economic Zone are significantly aggregated.

(2) The decoupling index of carbon emissions in the economic development of the Yangtze River Economic Zone has been changing dramatically for a long time, and the decoupling type has changed from growth connection to weak decoupling for a long time, and the relevant policy efforts to develop the economy in a green carpet way in the basin have achieved some results. Most of them are still far from the strong decoupling of the core indicators of green and low-carbon economic development.

(3) The global spatial correlation between the decoupling index of economic development and carbon emissions in the Yangtze River Economic Zone is weak, but at the same time, the decoupling effect of carbon emissions in the whole basin from the lower reaches to the middle reaches and then to the upper reaches shows an alternating spatial change of “high-low-high-low”.

5.2 Countermeasures and Suggestions

Carbon emissions in the Yangtze River Economic Zone have not yet reached a turning point, and the decoupling type of carbon emissions in the whole economic zone has not crossed to the strong decoupling stage, and the decoupling types of provinces and municipalities in the economic zone are stratified. Therefore, the Yangtze River Economic Zone should be based on the production, ecology, and living space of different provinces and regions. To formulate a win-win path of economic development and ecological protection to reduce carbon emissions according to local conditions.

(1) Summarize the existing situation and learn from the advanced experience. As a region with the advantage of decoupling effect of carbon emissions in economic development, on the one hand, we should learn from the experience of advanced countries in formulating low-carbon standards for economic development and innovating green low-carbon development models based on summing up the existing practices of energy saving and emission reduction in economic development. On the other hand, we should give full play to the policy support of the new and old kinetic energy conversion comprehensive pilot zones and free trade zones, introduce, digest, absorb and test, innovate low-carbon or zero-carbon supporting technologies, develop low-carbon products or services in all links, reduce carbon emissions from the source as far as possible, and then promote the adjustment of the established carbon emission ceiling for economic development.

(2) Improve the driving structure of economic development and innovate new low-carbon environmental protection technologies. Provinces and regions with better decoupling effect of carbon emissions in economic development should further coordinate the relationship between economic development and carbon emissions, especially focusing on the introduction of energy-saving and emission-reduction technologies, the adjustment of energy structure, and the strengthening of the carbon sink mechanism.

(3) Strengthen top-level design and promote regional green and coordinated development. Based on determining the ecological environment capacity, provinces and regions with the poor decoupling effect of carbon emission in economic development should determine the carbon emission threshold of economic development as soon as possible instead of flood irrigation, to rationally plan the scale and speed of economic development. The decoupling effect of carbon emission in the Yangtze River Economic Zone is quite different in space, and the lack of interaction between provinces and regions has become an obstacle to the low-carbon, green, coordinated, and healthy development of the basin's economic development, while the coordinated development has become an important dependent path to break the above obstacles. So, The Yangtze River Economic Zone should bridge the spatial polarization pattern of carbon emission decoupling effect of economic development in the Yangtze River Economic Zone using top-level planning and design, growth pole promotion, and regional multi-field cooperation.

5.3 Research Deficiency and Prospect

In this paper, the Tapio model is used to measure the decoupling index of carbon emissions of economic development in the Yangtze River Economic Zone, and the carbon emissions of economic development and the economic development level of provinces in the Yangtze River Economic Zone are two key core variables in the Tapio model. This study measures the decoupling relationship between carbon emissions and economic development of provinces and municipalities in the Yangtze River Economic Zone based on the combination of top-down methods. Based on the existing literature, this study directly uses official statistical data as the basis for demonstration, and only makes a macro-level analysis of the actual situation. Therefore, the limitations of the above two aspects may lead to some deviations in the measurement of the decoupling effect of carbon emissions in economic development. In addition, due to space constraints, The paper does not analyze the weighted influence of each factor in the decoupling effect of carbon emissions in the economic development of the Yangtze River Economic Zone and then does not clarify the influence degree of different factors on the decoupling effect of carbon emissions in the economic development of the Yangtze River Economic Zone. Therefore, based on the literature screening, the factors that may affect the decoupling effect between economic development and carbon emissions are selected. The geographically weighted regression model is used to detect the factors affecting the decoupling effect between economic development and carbon emissions in the basin, which will become an important direction for future research.

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