**THE RELATIONSHIP BETWEEN INNOVATION, ENVIRONMENT (CO2 EMISSION) AND RENEWABLE ENERGY: THE CASE OF 1990-2019 TURKEY**

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**ABSTRACT**

Due to rapid technological development and increase in economic activities, environmental problems such as global warming and climate change, CO2 emission, environmental pollution are among the issues of importance in the world. In recent years, Eco-innovations, which are intended to benefit the environment and contribute to environmental sustainability, bring energy saving technology, adding a new dimension to the concept of innovation and bringing its environmentalist face to the fore. In this study, the relationship between innovation, CO2 emissions and renewable energy for the 1990-2019 period for Turkey was examined and analyzed with Bayer-Hanck (2012) cointegration test, Toda-Yamamoto (1995) and Hacker-Hatemi-J (2006) causality tests. According to Bayer-Hanck (2012) cointegration test, it was concluded that the variables are cointegrated in the long run. In line with the overlapping findings of the causality analyses of Toda Yamamoto (1995) and Hacker-Hatemi-J (2006), it was concluded that there is a one-way causality relationship from Co2 emissions to renewable energy consumption.

**Keywords:** Innovation, Co2 emissions, Renewable Energy, Causality Test.

**INTRODUCTION**

Excessive energy use creates pressure on environmental quality and CO2 emissions (Apergis and Öztürk, 2015). Although the use of energy resources is a factor that accelerates the economic growth of countries, CO2 emissions increase depending on energy consumption (Canbay, 2019: 141). Compared to other pollutants, CO2 emissions are one of the leading indicators of global and environmental degradation, accounting for more than 70% of global emissions (Khattak et al., 2020: 13869). While meeting the increasing energy demand, in order to meet sustainable standards in CO2 emission increase, in addition to applications that require high technology in terms of supply and demand, the widespread use of alternative-renewable energy sources in terms of energy supply comes to the fore.

Depending on the increase in environmental awareness, the tendency to renewable energy sources has been increasing since the 1990s. Renewable energy sources that do not emit greenhouse gas emissions into the atmosphere are defined as 'clean energy' (Çağlar and Mert, 2017: 22). Increasing R&D activities (carbon capture and storage, clean coal technologies, etc.) to reduce the environmental damage of energy consumption due to the increase in carbon emissions are carried out with the aim of reducing the increased CO2 emissions due to the use of fossil energy sources (Çoban and Şahbaz Kılınç, 2015: 196).

The current equivalent of the concept of innovation with 'commercial innovation' and 'value-creating innovation' brings the green/ecological/environmental/sustainability dimensions of innovation to the fore. According to Chen et al. (2006), green innovation is defined as energy saving, prevention of environmental pollution and waste recycling (Yigit, 2014: 254).

When it comes to energy and technology, renewable energy technologies should be remembered. Renewable energy types depend on the economic, social and political developments and positions of the countries. R&D activities of countries are a concrete indicator of this. The perspectives of countries on technology development and energy security can be understood by looking at their R&D budgets for energy. With R&D activities, it is aimed to reduce the increasing energy costs due to the use of new technologies. While renewable energy has advantages such as minimizing the damage to the environment, reducing the greenhouse gas effect, reducing erosion, ensuring energy supply security, creating employment opportunities, there are also disadvantages such as low financing opportunities, high investment costs and insufficient infrastructure for production. (Bayramoglu, 2018).

Renewable energy is affected by many internal and external factors. While the international economic situation, fossil fuel prices and development using low carbon are listed as external factors, technological innovations are also decisive as internal factors for the development of renewable energy and for it to become a global energy model (Geng and Ji, 2016: 218).

 In this study, the relationship between innovation, environment (Co2 emmission) and renewable energy in Turkey is emprically analyzed for 1990-2019 period.

**THE RELATIONSHIP BETWEEN INNOVATION, ENVIRONMENT (CO2 EMISSION) AND RENEWABLE ENERGY**

Energy is a necessary component for an economy to make long-term progress. Population growth, lifestyle, advances in production and economic competitive environment also affect the increasing energy demand. With the effect of the increase in global energy consumption, the increase in the use of fossil fuels causes intense CO2 emissions, causing climate change and environmental degradation. This situation compelled governments to take precautions and the Kyoto Protocol was put into effect in 2005 in order to reduce the total greenhouse gas emissions of industrialized countries. In addition, the European Union (EU) commission provides financing with the aim of reducing the use of fossil fuels, increasing energy efficiency and providing new technological developments, especially for renewable energy. In addition to environmental problems, the dependence of economies with import-based growth, which depends on fossil fuel consumption, on fossil fuel consumption also causes energy supply uncertainty. Disruptions in the energy supply and demand balance also have economic effects. (Qayyum et al., 2021: 1, 2).

The use of traditional energy sources such as Oil, Natural Gas, Coal has environmental effects by causing energy crises, global warming (CO2 - greenhouse gas effect) and acid rain as a result of fluctuations in oil prices. CO2 emissions, as the main source of global warming (Stern, 2006), can also be the main source of environmental problems such as climate change (Wuebbles et al., 2002). Because the increase in CO2 emission causes global warming and plays a negative role in the deterioration of climate balances. Since the use of renewable energy sources (wood, hydro energy, solar, marine, wind energy, geothermal energy, biomass energy and hydrogen energy) does not cause CO2 emission or causes less CO2 emission (Chiu and Chang, 2009), it causes a decrease in the negative effects on the environment. In addition, it causes a decrease in foreign dependency in terms of fuel and energy and the high import expenses arising from energy imports (Kumbur et al., 2015) and allows the balance of payments deficits to be reduced.

**Figure 1. Innovation and Energy Consumption Diagram**



Source: Assi et al., 2021: 692.

In addition to economic growth, energy consumption, financial development and urbanization also affect CO2 emissions. Especially in developing countries, CO2 emissions are increasing due to the consumption of petroleum and fossil fuels, depending on the increasing industrialization. The increasing demand for traditional energy sources compels us to turn to alternative energy sources. Dependence on fossil energy sources causes environmental problems such as global warming, climate change and air pollution (Lau et al., 2012). It is also thought that renewable (biomass, geothermal, hydro, solar and wind) and nuclear energy sources, which are used as energy alternatives to fossil fuels due to global warming, provide solutions to energy security and climate change problems (Menyah and Wolde-Rufael, 2010). Many countries are turning to renewable energy sources in order to prevent them from being affected by variable oil prices and to reduce their energy dependence and environmental pollution (Boluk and Mert, 2014). The production and consumption of renewable energy sources is accepted as one of the most important methods of reducing CO2 emissions (Pata, 2018: 770, 771).

**Figure 2. Relationships Between CO2 Emission and Six Factors impacts CO2 Emission**



Source: Cheng et al., 2019: 23.

According to Sadorsky (2009), energy consumption as an indicator of economic development in the energy economy literature (Bulut, 2017: 15416) is a method of providing energy technological innovation, energy saving and reducing CO2 emissions. Lee and Min (2015) argue that environmental technological innovations will significantly reduce carbon emissions. In addition to the low-carbon and efficient use of traditional fossil energy, the use of renewable energy at low cost is possible with technological innovation. Technological innovation for traditional fossil energy can increase energy efficiency and reduce energy consumption and CO2 emissions in the production process, resulting in energy savings and emission reductions. Technological innovations in renewable energy can increase the development of renewable energy. High renewable energy technological innovation enables countries to meet renewable energy demand at a lower cost (Chen and Lei, 2018). Renewable energy is considered as the energy of the future because it does not contain CO2 emissions (Sadorsky, 2014). Therefore, the use of renewable energies can increase energy security and reduce climate change (Irandoust, 2016). In this respect, it is accepted as a cost-effective method to become a country with low carbon emissions (Lin and Zhu, 2019: 1506).

**LITERATURE REVİEW**

Concerns are increasing day by day in order to minimize the threat of carbon dioxide emission, which has become a global threat with increasing environmental pollution (Godil et al., 2021: 4). When compared with the existing studies on CO2 emissions of developed countries in the literature, it is seen that the results of renewable energy consumption reducing CO2 emissions are similar.

Yii and Geetha (2017) examined the period 1971-2013 for Malaysia and concluded that there is a causal relationship between technological innovations, growth, energy consumption and energy prices and CO2 emissions, and that technological innovation causes a decrease in CO2 in the short run.

Coban and Şahbaz Kılınç (2015) discussed the period of 1990-2012 for Turkey with Granger causality analysis in the context of the relationship between renewable energy consumption and carbon emission. In line with the analysis findings, it has been determined that there is a one-way causality relationship between renewable energy consumption per capita and carbon emissions per capita.

Baek (2016) and Cheng et al. (2018), although inconsistent in studies in developed countries, it is concluded that renewable energy significantly reduces CO2 emissions in the US and 28 EU countries, respectively. Two important factors seem to be effective in this. The first factor is that innovation is crucial for reducing CO2 emissions in 28 OECD countries (Mensah et al., 2018), while the second factor is related to environmental patents and GDP has negative effects on CO2 emissions in 28 EU countries (Cheng et al., 2018). sThe result is not consistent with the results regarding GDP.

Godil et al. (2020), is examined the period 1990-2018, it was found that economic growth, technological innovation and renewable energy played an active role in reducing CO2 emissions in the transportation sector in China, and that the increase in renewable energy and innovation caused a decrease in CO2 emissions in the transportation sector, but GDP. It was concluded that the increase in the transportation sector increased the level of CO2 emissions.

Khattak et al. (2020) is examined the period 1980-2016 for the BRICS countries. He examined the relationship between innovation, renewable energy consumption and CO2 emissions (CO2e) within the framework of the Kuznets curve with the CCEMG method. Analysis findings show that innovation activities do not increase CO2 emissions in China, India, Russia and South Africa except Brazil, and renewable energy consumption reduces CO2 emissions in BRICS countries Russia, India and China (excluding South Africa). It is concluded that the EKC hypothesis is valid for other BRICS country economies except India and South Africa. In addition, in line with the causality analysis findings, there is a bidirectional causality relationship between innovation and CO2 emissions, innovation and GDP per capita, innovation and renewable energy consumption, and CO2 emission and income variables, thus in BRICS economies income-led emission hypothesis concluded that it is valid (vice versa).

**DATA AND METHODOLOGY**

In this study, it is aimed to examine the relationship between innovation, environment (Co2) and renewable energy for Turkey's 1990-2019 period. In the study, the logarithmic function of innovation (the share of R&D expenditures in GDP) and CO2 emissions (lnCO2) data is taken. While these two variables were obtained from the TUIK (Turkish Statistical Institute) database, the renewable energy consumption (total energy consumption %) variable was obtained from the 'data.worldbank.com' databases. For econometric analyzes of the study, ADF (1970) unit root test, Bayer-Hanck (2012) cointegration test and Toda-Yamamoto (1995) and Hacker-Hatemi-J. (2006) causality tests were used and econometric analyzes of the study were tested using Eviews 10.0, Stata 12.0 and Gauss 10.0 programs.

ANALYSIS FINDINGS

In time series analysis, it is important whether the series has a unit root or not. Unit root tests are applied to test the stationarity. It is also important to determine the lag length in the Extended Dickey Fuller (ADF) test. Since the ADF unit root test is sensitive to the number of lags, it is also important to determine the appropriate lag length. It is also important to include error terms in the model to eliminate autocorrelation. Lag-length criteria, consisting of Akaike Information Criteria (AIC), Schwart Information Criteria (SIC), Hannan Quin (HQ) and the corrected forms of these three criteria, are among the lag criteria included in the literature (Akyüz, 2018).

ADF (1979, 1981) generalized unit root test will be applied. The regressions for the ADF unit root test are as expressed in equations 1 and 2 (Yavuz, 2006: 164):

(1)

(2)

With Equations 1 and 2, the existence of unit root is determined for the variable. Lagged difference terms are included in the model so that the error term is free from autocorrelation. In Equation 1, the basic hypothesis, which states that the variable has a unit root, is tested against the alternative that the trend is stationary. In Equation 2, on the other hand, the basic hypothesis that the variable is stationary around the mean is tested, as opposed to the alternative that it has a unit root (Yavuz, 2006: 164): Accordingly,

, The series is not stationary, the series has a unit root.

, ADF test is applied with the hypotheses that the series is stationary and the series does not contain unit roots.

**Table 1: ADF (1981) Unit Root Test**

|  |  |
| --- | --- |
| **Variables** | **ADF Unit Root Test Results** |
| **Level I(0)** | **Differenced I(1)**  |
| **Innovation** | 1.0908 (0.996) | -7.822\*\* (0.000) |
| **Co2**  | -0.661 (0.841) | -5.292\*\* (0.000) |
| **Renewable**  | -0.678 (0.836) | -5.024\*\* (0.000) |

 Note: \*\*\*, \*\*, \* denote significance at 1%, 5% and 10% significance levels, respectively.

As seen in Table 1, while innovation (R&D), CO2 and renewable energy variables are not stationary at the level, when the unit root test is applied by taking the first-order differences of all three series and the difference of the series is taken, it is seen that the series become stationary at the 5% significance level.

**Table 2. Selection of Lag-Length**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Lag  | LogL | LR | FPE | AIC | SC | HQ |
| 0 | 54.179 | NA | 5.19e-06 | -3.655 | -3.512 | -3.612 |
| **1** | **112.268** | **99.581\*** | **1.57e-07\*** | **-7.162\*** | **-6.591\*** | **-6.987\*** |
| 2 | 120.268 | 11.999 | 1.73e-07 | -7.090 | -6.091 | -6.785 |

\* : Appropriate lag-length

As seen in Table 2, LR, FPE, AIC, SC and HQ information criteria statistics were in the same direction and the appropriate lag length was determined as 1 according to the information criteria.

Bayer and Hanck (2012) cointegration test is available in the literature Engle-Granger (1987), Johansen (1991), Boswijk (1994) and Banerjee et al. (1998) tests, a new test statistic is obtained by combining it with the Fisher type chi-square formula given in equation 3, since it is a cointegration test that gives new and stronger results.

If the calculated test statistic is greater than the critical values, it is decided that there is a cointegration relationship between the variables (Topal, 2018: 187):

EG – JOH – BO – BDM = -2 (3)

**Table 3: Bayer-Hanck (2012) Cointegration Tests Result**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|

|  |
| --- |
| **Model 1: Renewable = f(Co2, Innovation)** |
| Fisher Type Test Statistics, Bayer Hanck Test |
|  | **Engle-Granger** | **Johansen** | **Banerjee** | **Boswijk** |
| **p-values** | 0.6401 | 0.002 | 0.038 | 0.0000 |
| **Test Statistics** | -2.1895 | 30.283 | -3.600 | 40.470 |
| **EG-J:** 13.1308 10% critical value: 8.479 |
| **EG-J-Ba-Bo:** 74.8864 10% critical value: 16.444  |

|  |
| --- |
| **Model 2: Co2 = f(Renewable, Innovation)** |
|  | **Engle-Granger** | **Johansen** | **Banerjee** | **Boswijk** |
| **p-values** | 0.7019 | 0.0022 | 0.4059 | 0.0083 |
| **Test Statistics** | -2.0597 | 30.283 | -2.2796 | 19.103 |
| Fisher Type Test Statistics, Bayer Hanck Test |  |  |
| **EG-J:** 12.9465 10% ciritical value: 8.479  |
| **EG-J-Ba-Bo:** 24.3328 10% ciritical value: 16.444 |

|  |
| --- |
| **Model 3: Innovation = f(Co2, Renewable)** |
| Fisher Type Test Statistics, Bayer Hanck Test  |
|  | **Engle-Granger** | **Johansen** | **Banerjee** | **Boswijk** |
| **p-values** | 0.9345 | 0.0022 | 1.0000 | 0.0022 |
| **Test Statistics** | -1.269 | 30.283 | 3.649 | 22.543 |
| **EG-J:** 12.372 10% ciritical value: 8.479 |
| **EG-J-Ba-Bo:** 24.610 10% ciritical value: 16.444 |

 |

\*\*\*, \*\*, \* indicate that the variables are stationary at 1%, 5% and 10% significance levels, respectively.

In line with the Bayer-Hanck (2012) cointegration test findings obtained from table 3, because the Fisher EG-J-Ba-Bo test statistic is greater than the critical value of Bayer and Hanck (2012). The basic hypothesis stating that there is no cointegration relationship is rejected, the alternative hypothesis stating that there is a cointegration relationship is accepted. It was concluded that the series are cointegrated in the long run in line with the cointegration analysis findings for three different models, where each of the renewable energy, CO2 emissions and Innovation variables are taken as dependent variables, respectively.

In Toda Yamamoto (1995) causality analysis, it is possible to apply causality analyzes without the need for the existence of a cointegration relationship of cointegrating series of the same or different degrees. The modified Wald test (MWALD) test developed by Toda-Yamamoto can be applied without the need for any pre-test as it is based on the standard asymptotic distribution. In the Toda-Yamamoto causality test (the maximum degree of integration of the d series), the VAR (p+d) model is estimated. It is not necessary to test the existence of a cointegration relationship between non-stationary series and to estimate the VEC model (Çalışkan, Karabacak and Meçik, 2017: 50):

In Equation 4, , k is the vector consisting of the variable k, v is a vector of constants, μ is the vector of error terms, and A is the parameters matrix. The obtained MWALD statistic has an asymptotic chi-square distribution with p degrees of freedom. The MWALD statistics based on the Hacker-Hatemi-J (2006) bootstrap distribution are taken into account in the analysis of small samples of the MWALD statistic with a standard chi-square distribution (Çalışkan, Karabacak and Meçik, 2017: 50).

**Tablo 4. Toda Yamamoto Causality Results**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Causality Direction**  |  test statistic | df | Prob | **Decision** |
| Innovation Co2 | 2.836 | 2 | 0.242 | No causal relationship from innovation to CO2 emissions |
| Renewable Energy Co2 | 8.178 | 2 | 0.610 | There is no causal relationship from renewable energy consumption to CO2 emissions. |
| Co2 Innovation | 0.468 | 2 | 0.791 | There is no causality from CO2 emissions to innovation |
| Co2 Renewable Energy | 5.742 | 2 | 0.056\*\* | There is a causal relationship from CO2 emission to renewable energy consumption at the 5% significance level. |
| Innovation Renewable Energy  | 2.828 | 2 | 0.243 | There is no causal relationship from innovation to renewable energy |
| Renewable Energy Innovation | 0.249 | 2 | 0.882 | There is no causal relationship from renewable energy to innovation |

Note: \*\*\*, \*\*, \* indicate that the variables are stationary at 1%, 5% and 10% significance levels, respectively.

In order to apply the Toda-Yamamoto (1995) analysis expressed in Table 4, the appropriate lag length must first be determined. According to the AIC, SBC, HQ information criteria, the appropriate lag length is determined as 1. In line with the causality findings formed by the estimated VAR (2) model, it was found that CO2 emission at the 5% significance level was the cause of renewable energy consumption.

In the Hacker-Hatemi (2006) causality test, which was developed based on the Toda-Yamamoto (1995) causality test, the bootstrap distribution is taken into account. The use of bootstrap simulation techniques developed by Efron (1979) in obtaining critical values allows to obtain more reliable critical values. It is an advantageous causality test in that it is not sensitive to the assumption of normality and time-varying volatility (Hacker-Hatemi-J, 2006: 1490-1492; Arı, 2016: 61, 62). Hatemi-J (HJC) information criterion was obtained from the average of Hatemi-J (2003), SIC and Hannan-Quinn (HQ) information criteria (Pata, 2018: 104):

HJC = ln(+j (), j=0.......,k (5)

In Equation 5, |Ω ̂ | While j gives the variance-covariance matrix of the error terms of the estimated VAR model depending on the lag length, n represents the number of equations in the VAR model. T gives the number of observations. In the Hacker-Hatemi-J test, HJC is important for determining the appropriate lag length (Pata, 2018: 104). Hacker-Hatemi-J (2006) causality test analysis findings are given in Table 5.

**Table 5: Hacker- Hatemi-J (2006) Causality Analysis for Turkey**

|  |  |  |
| --- | --- | --- |
| **Causality Direction** | **w-stat (MWald).** | **Critical Value** |
| **%1 (\*\*\*)** | **%5 (\*\*)** | **%10 (\*)** |
| Renewable Energy Innovation | 0.870 | 9.427 | 5.109 | 3.424 |
| Innovation Renewable Energy | 0.376 | 8.161 | 4.292 | 2.962 |
| Co2 Innovation | 0.098 | 9.242 | 4.896 | 3.338 |
| Innovation Co2 | 0.000  | 8.380 | 4.551 | 3.020 |
| Renewable Energy Co2 | 0.016 | 8.463 | 4.518 | 3.023 |
| Co2 Renewable Energy | 10.218\*\*\* | 7.987 | 4.129 | 2.877 |

Note: Bootstrap critical values are achieved in 10,000 cycles. The appropriate lag length was determined according to the AIC (Akaike Information Criterion). \*\*\*, \*\*, \* indicate that the variables are stationary at 1%, 5% and 10% significance levels, respectively. In the HH causality test, the bootstrap critical values were obtained with 1000 iterations, the lag length was determined by the Hatemi-J information criterion.

According to the results of the Hacker-Hatemi-J (2006) bootstrap causality analysis expressed in Table 5, it was found that CO2 emission at the 1% significance level was the cause of renewable energy consumption. This result is supported by the results of the Toda-Yamamoto (1995) test. By applying both causality tests, it was concluded that there is a one-way causality relationship from Co2 emissions to renewable energy consumption in Turkey for the period examined according to the common result. This finding also coincides with the analysis findings of Coban and Sahbaz Kılınc (2017)'s studies on Turkey.

**CONCLUSION**

With the effect of factors such as globalization, increasing industrialization, urbanization and population growth, there is an increase in energy consumption due to the increase in the welfare level.The dependence on the increasing demand for primary energy source also has effects on environmental pollution (due to the increase in CO2 emissions).Due to the increase in carbon emissions, problems such as global warming and climate change are also observed.Countries are turning to renewable energy sources in order to reduce the level of carbon dioxide emissions to the minimum level.In addition, energy R&D expenditures also play a role within the scope of innovation activities.

In this study, the period of 1990-2019 in the context of the relationship between innovation, environment (CO2) and renewable energy relation for Turkey is examined with Bayer-Hanck (2012) cointegration test and Toda-Yamamoto (1995) and Hacker-Hatemi-J. (2006) causality tests. In line with the Bayer-Hanck (2012) cointegration test findings, three different models were established in which each of the renewable energy, CO2 emission and innovation variables were taken as dependent variables, respectively, and according to the examined cointegration analysis findings is concluded that the series are cointegrated in the long run. Toda-Yamamoto (1995) and Hacker-Hatemi-J. (2006) in line with the causality test findings, it was found that there is a unidirectional causality relationship from CO2 emission to renewable energy consumption in Turkey. According to the findings of this analysis, it can be stated that the necessity of orientation towards renewable energy sources due to the increasing carbon dioxide emissions because of the increase in fossil fuel consumption in Turkey.

While carbon storage-capture techniques can be used to reduce carbon emissions, economic tools such as carbon tax and carbon trade, and renewable energy resources developed through R&D and innovation activities carried out in the field of energy also play a significant role. In addition, although it is not a sufficient measure on its own within the scope of combating environmental pollution and global warming, there is an international consensus on carbon tax rates, which expresses the internalization of economic externalities through the price mechanism of negative externalities arising from greenhouse gas emissions, in line with the 'polluter pays' principle, and Pigouvian tax approach, must also be required.

As a policy recommendation in line with the analysis findings, it is seen that it is necessary to develop renewable energy sources with low carbon emissions and prioritize innovative activities in the field of energy R&D, support them economically and allocate resources. Thus, environmental factors are also taken into account in energy production and distribution. Fossil fuel consumption, which causes increased carbon emissions, should be abandoned and the orientation towards renewable energy sources that cause the least harm to the environment should be increased.

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