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Wind Energy Potential of Yozgat Province Based on the Hub Height and Wind Speed

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Abstract: The amount of potential wind energy to be generated in Yozgat province was calculated depending on the hub height (m) and wind speed (m/sec) in this study. The data of 85 wind power plants installed and operating in Turkey were utilized. The data of the amount of produced energy (kWh) in these wind power plants belonged to the year 2018. The Multi-factor Anova method was employed in order to statistically analyze the significance levels of the data set. For the methodology part of the study, tower height and wind speed were determined as input factors and the amount of energy produced selected as the output factor. As a result of the statistical analysis, it was observed that both input factors were effective on the output variable. In line with these results, the potential energy amounts to be produced by the wind power plants to be established in Yozgat province have been calculated. According to the results, it was understood that Yozgat is a suitable region for wind power plants depending on the parameters and variables considered in this study.
Keywords: Wind Energy, ANOVA, Hub Height, Wind Speed

Kule Yüksekliğine ve Rüzgâr Hızına Göre Yozgat İli Rüzgâr Enerjisi Potansiyeli

Özet: Bu çalışmada Yozgat iline ait rüzgâr enerjisinden elde edilecek potansiyel enerji miktarı kule yüksekliğine (m) ve rüzgâr hızına (m/sn) bağlı olarak hesaplanmıştır. Türkiye'de kurulu ve çalışan 85 adet rüzgâr enerji santrallerine ait veriler kullanılmıştır. Bu santrallerde üretilen enerji miktarları 2018 yılına aittir. Bu çalışmada veri setinin istatistiksel olarak önemlilik derecelerini belirlemek için çok faktörlü anova yöntemi kullanılmıştır. Çalışma metodolojisi için kule yüksekliği ve rüzgâr hızı girdi faktör ve üretilen enerji miktarı ise çıktı faktör olarak belirlenmiştir. Yapılan istatistiksel analiz sonucunda her iki girdi faktörünün de çıktı faktörü üzerinde etkili olduğu gözlemlenmiştir. Bu sonuçlar doğrultusunda Yozgat ilinde kurulacak olan rüzgâr enerji santrallerinin üreteceği potansiyel enerji miktarları hesaplanmıştır. Sonuçlara göre bu çalışma için dikkate alınan parametreler ve değişkenlere bağlı olarak Yozgat ilinin rüzgâr enerji santralleri için uygun bir bölge olduğu anlaşılmaktadır.
Anahtar Kelimeler: Rüzgâr Enerjisi, ANOVA, Kule Yüksekliği, Rüzgâr Hızı

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1. Introduction

Energy, which is a necessary input for production activities, is an indicator of the economic and social development of the countries [1], [2]. Energy demand is directly proportional to the population growth and industrialization level of developing countries. The energy consumption escalates with economic development and increases in welfare [3].

The inability of limited energy resources to meet the energy need causes the gap between energy production and consumption to grow gradually. Global energy consumption is anticipated to be twice the amount of energy consumed in 1998 by 2035 and three times by 2055. In addition, there is an undeniable threat of traditional energy sources, namely oil, natural gas, coal and nuclear energy, to the environment and human health. The extensive utilization of these conventional and non-renewable resources, especially in the transportation and in the residential and industrial sectors, induces the risk to grow even more [4]

Interest in renewable energy sources is increasing day by day as these resources have a promising potential with respect to the increasing energy need, unlike fossil fuels [5]. Renewable energy is a type of energy that does not end with its conversion to secondary energy, continues to flow by renewal, and has continuity [6]. They have a sustainable nature as they are obtained from an endless source without harming the environment or consuming a resource. The cost of renewable energy originates only from the initial capital invested, not impacted by the inconsistency in coal, oil, and natural gas prices, which help stabilize electricity payments. The other advantage of the alternative energy field is its potential to offer different job opportunities that can contribute to national economies, particularly in developing countries [7].

Wind energy is an accessible, available and sustainable renewable energy resource that is utilized worldwide to produce electricity in a cost-effective way with emitting zero or almost zero pollutions [8]. Wind power technology does not require any initial source for operation, and the area near wind power plants may be employed for other purposes [9].

The wind energy potential of Turkey was estimated to be 48,000 MW that corresponds to 1.30% of the country’s surface area. As of the end of December 2020, the installed capacity based on wind energy was 8,832 MW constituting an 8.09% share in total electricity production [10]. The wind energy generation was 19.9 Terawatt-hours in 2018, which was increased to 21.7 Terawatt-hours in 2019, indicating an 8.8% growth rate in Turkey [11].

In the literature, several methods were applied to determine the wind power potential for different parts of the world. Shu et al. investigated wind characteristics to calculate wind energy potential in Hong Kong with the help of statistical analysis [12]. Chang examined various probability density functions in order to predict the energy potential by wind [13]. Jung and Kwon used artificial neural network (ANN) application on the basis of weighted error functions so as to forecast wind speeds of a selected location in the long-term, which in turn help determine wind energy generation annually [14]. Gross and Magar employed a global climate simulation to get accurate climatic data and so to figure out the offshore potential of wind energy in Mexico [15]. Höfer et al. have aimed to reduce the cost of renewable energy resources using the Heckit sample selection statistical model [16]. Wang et al. suggested a polynominal regression model to precisely estimate the distributions of wind speed occurrence rate, which in turn help compute wind energy generation correctly. They claimed to produce more energy by wind at less cost with the proposed method [17]. In order to predict wind speed in the short term, a support vector machine (Jaya-SVM) model based on Jaya algorithm was offered by Liu et al. The presented regression model was checked against the real datasets to confirm its performance [18].

The objective of this particular work was to estimate the probable amount of wind power based on the real data of two parameters, namely hub height and wind speed. Within this context, a regression model for multiple factors was implemented to evaluate the wind energy potential of Yozgat Province, considering only hub height and wind speed as variables. In addition, the impact of changes in these input parameters on the amount of wind energy production was discussed. The remaining of the research is organized as follows. Section 2 forms the methodology of the study, explaining the regression model with multiple factors, input factors and response variable. Section 3 expresses the statistical computation and results of the analysis. Section 4 provides the conclusion of this work.

2. Methodology

2.1. Regression Model for Multiple Factors

Regression analysis is an easy technique that is applied to examine the possible correlations between variables. The connection of the response or output variable with one or more input factors is represented as an equation or a model. Regression analysis is employed in a wide range of fields, such as business, economics, medicine, chemistry, engineering, biology, education, history, meteorology, etc. [19].

The basic regression equation with one input factor is formulated as follows [20], [21]:

$$y = \beta_0 + \beta_1 x_1 + \in \quad (1)$$

where y represents the output factor, x_1 denotes the input factor, β_0 is the regression's constant value, and β_1 is the coefficient of the input factor in the regression equation—the value of $\in$ means, the margin of error of the regression equation [20].

The multi-factor regression equation is used since there is more than one input factor in this study. The multi-factor regression equation is shown as follows [19], [22]:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \in \quad (2)$$

where $x_1, x_2, \ldots, x_n$ stand for the input factors and $\beta_1, \beta_2, \ldots, \beta_n$ symbolize the coefficients of the input factors in the regression equations.

2.2. Input Factors

This study aimed to forecast the wind energy potential of Yozgat Province depending on the real data of only two variables. Hub height (m) and wind speed (m/sec) were used as the input factors to create a regression equation for this research. The hub height values obtained from 85 installed wind power plants operating in Turkey were shown in **Figure 1**. According to these data, the maximum hub height was observed as 117 meters, while the minimum hub height was 64 meters. The average hub height for these 85 operational wind power plants was calculated as 86.045 meters.

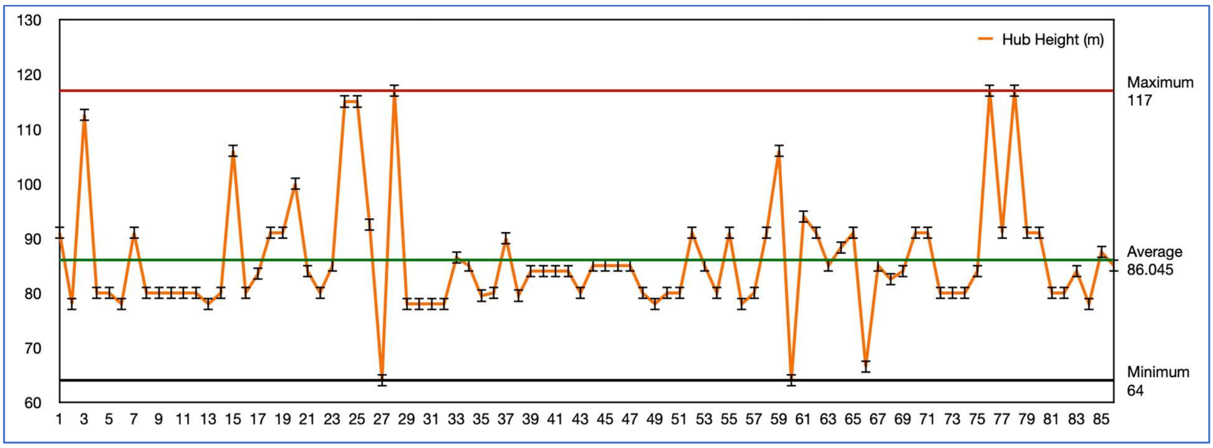

Figure 1. Hub Heights of 85 wind power plants installed in Turkey

Some wind power plants have different number of wind turbines with dissimilar hub heights. For such wind power plants, the average value was computed using the formula below:

$$Hub\ Height\ [average] = \sum_{i=1}^{n} \frac{n_i hh_i}{n_i} \tag{3}$$

where, n_i represents the number of turbines and hh_i signifies the height of the hubs. The wind speeds of the regions where the wind power plants installed in Turkey were demonstrated in **Figure 2**. Based on this figure, the maximum wind speed was 7.75 m/sec, while the minimum wind speed was 5.4 m/sec. The average wind speed of 85 installed wind power plants was calculated as 6.801 m/sec.

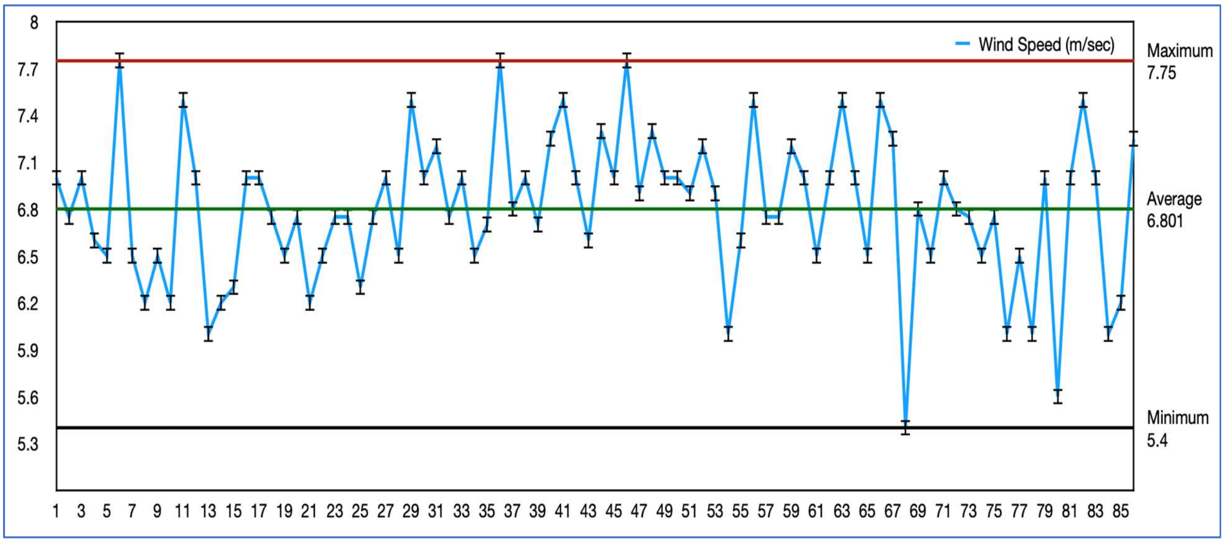

Figure 2. Wind Speed data of operating 85 wind power plants

The purpose of this work was to estimate the wind energy potential of Yozgat Province, with the consideration of both hub height and wind speed. The data of descriptive statistics belonging to wind speed parameter of Yozgat Province was illustrated in **Table 1** [23].

Table 1. The descriptive statistics of wind speed at 100 m of Yozgat Province

Parameters	Value
Minimum wind speed at 100 m (m/sec)	2.47
Maximum wind speed at 100 m (m/sec)	7.43
Average wind speed at 100 m (m/sec)	4.68
Variance	0.48
Standard deviation	0.69

2.3. Response Factor

The response factor in this study was selected as the energy production amount of the installed 85 wind power plants that are in operation in Turkey. The output factor data obtained from the facilities belonged to the year 2018. Response factor values were considered with respect to hub height (m) and wind speed (m/sec) data of operational facilities in Turkey. The two input factors, hub height (m) and wind speed (m/sec), were taken into consideration on their effect on the output factor for this study. However, there are many other factors that might influence the energy generation amount. These parameters may be taken into account in other studies.

3. Statistical Computation and Results

This study deals with three different variables or factors. These are the hub height (m), wind speed (m/sec), and the amount of energy produced (kWh). Two of these variables (hub height and wind speed) are considered as the input factors and one as the output factor (amount of energy produced). Descriptive statistical data of these variables were shown in **Table 2**.

Table 2. The descriptive statistics of the data used

Statistics	Hub Height (m)	Wind Speed (m/sec)	Energy (kWh)
N	86.00000	86.00000	86.0000000
Mean	86.05000	6.800600	86924928.0
SE Mean	1.150000	0.050600	4737900.00
StDev	10.67000	0.469100	43937479.0
Variance	113.8100	0.220000	1.93E+1500
CoefVar	12.40000	6.900000	50.5500000
Sum of Squares	646400.7	3996.023	8.14E+1700
Minimum	64.00000	5.400000	2495469.00
Q1	80.00000	6.500000	47659533.0
Median	84.00000	6.800000	90046260.0
Q3	91.00000	7.000000	1.17E+0800
Maximum	117.0000	7.750000	1.83E+0800
IQR	11.00000	0.500000	69794302.0
Mode	80.00000	7.000000	96009613.0
Skewness	1.370000	-0.340000	0.20000000
Kurtosis	2.470000	0.370000	-0.74000000

The data obtained from 85 installed wind power plants were statistically analyzed using the ANOVA method to determine the impact of input factors on the output factor. ANOVA data were given in **Table 3**.

Table 3. Variance analysis results of the data used

Source	Degree of Freedom	Adj Sum of Squares	Adj Mean of Squares	F-Value	P-Value
Model	2.00	1.45E+16	7.23E+15	4.01	0.022
Hub Height	1.00	7.29E+15	7.29E+15	4.04	0.048
Wind Speed	1.00	1.10E+16	1.10E+16	6.09	0.016
Total	85.0	1.64E+17	***	***	***

*** The data is not available

According to the ANOVA table, both hub height (m) and wind speed (m/sec) were statistically very effective in the amount of energy from wind power plants. The statistical significance level was calculated as 0.048 as a result of ANOVA for hub height. This value statistically showed that this input factor had a significant effect on the output factor. Likewise, the statistically calculated significance level of wind speed (m/sec) was 0.016, and it was understood that this parameter was also effective for the output factor. For this study, the following regression equation was obtained by considering two different input variables:

$$y_{energy\ production} = -16189124 + 902028hh_i + 25174448ws_i + \in_i \quad (4)$$

where $y_{energy\ production}$ represents the amount of energy produced, hh_i denotes the hub height and ws_i symbolizes the wind speed. $\in_i$ means the margin of error, but $\in_i$ value is considered as zero for this study. This study aimed to calculate the output variable according to the wind speed data of Yozgat province by considering two different input variables. The energy amount to be produced was estimated by keeping the value of one of the two input variables constant and changing the value of the other during the calculation process. **Table 4** is the demonstration of the potential amount of energy to be generated with altering hub heights within the range of 64-117 m by keeping the wind speed constant at minimum (2.47 m/sec), maximum (7.43 m/sec) and average (4.68 m/sec) level.

Table 4. The amount of potential energy to be obtained according to the maximum, minimum and average wind speeds of Yozgat province

Status	Energy kWh [Wind speed 2.47 m/sec]	Energy kWh [Wind speed 7.43 m/sec]	Energy kWh [Average wind speed]
Minimum	102259081.2	228586816.6	165873962.9
Maximum	149164537.2	276394300.6	212779418.9
Average	125304582.3	252490558.6	188897570.5

Hub height values varied between 64 and 117m, and according to this data range, 54 scenarios were created by increasing each meter. The energy amounts obtained as a result of 54 scenarios were shown in **Figure 3**. Considering the standard deviations of the energy amounts received according to these scenarios, it has been observed that the values of the height of the hub between 75 and 105 meters were feasible results.

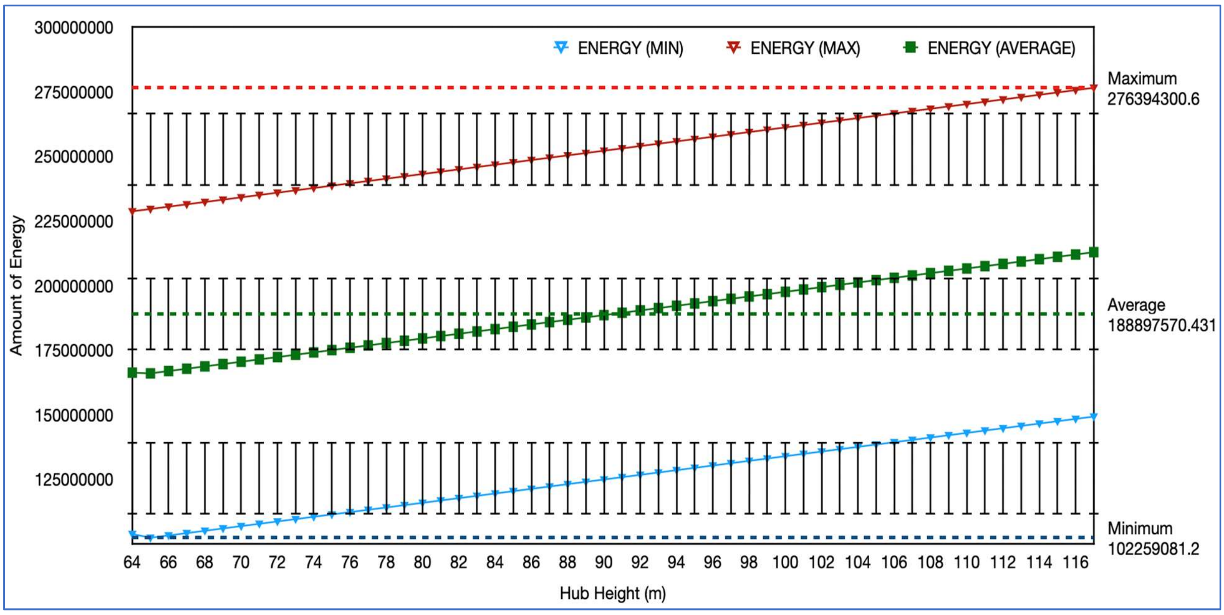

Figure 3. Amounts of energy generated according to variable hub height levels depending on constant wind speed

By keeping the hub height constant at the minimum (64 m), maximum (117 m) and average level, the maximum, minimum and average energy (kWh) amounts to be generated as a result of changing the wind speed values (for the range 2.47-7.43 m/sec) were shown in **Table 5**.

Table 5. The amount of potential energy to be obtained according to the maximum, minimum and average hub heights for Yozgat province

Status	Energy kWh [Hub height of 64 m]	Energy kWh [Hub height of 117 m]	Energy kWh [Average hub height (m)]
Minimum	103721555	151529038.6	127625296.6
Maximum	228586817	276394300.6	252490558.6
Average	168452519	216260003.5	192356261.5

Wind speed (m/sec) values varied between 2.47 and 7.43 m/sec, and according to this data range, 52 scenarios were created by increasing each meter. The potential wind energy amounts to be produced as a result of 52 scenarios were shown in **Figure 4**. Considering the standard deviations of the energy amounts obtained according to these scenarios, it has been observed that the values of the wind speed between 4.5 and 5.7 m/sec were feasible results.

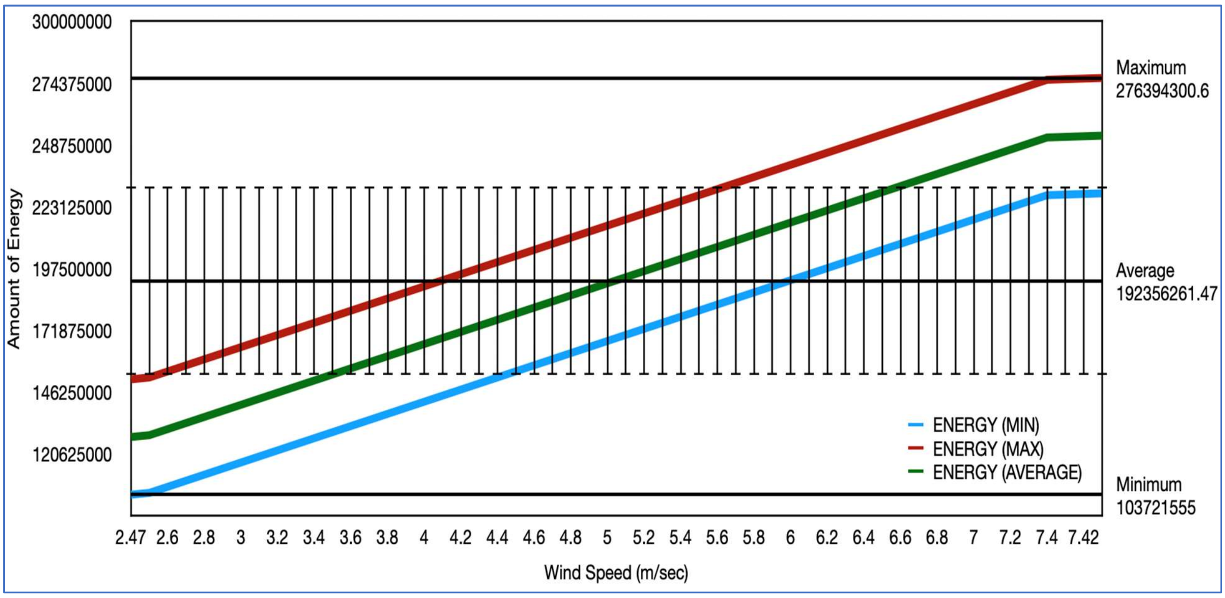

Figure 4. Amounts of energy to be generated according to variable wind speed levels depending on constant hub height

4. Conclusion

Energy is a significant factor in fulfilling human needs in all areas of daily life, such as transportation, communication, manufacturing and heating, etc. It is publicly accepted that renewable energy resources are sufficient enough to supply increasing energy demand. Wind energy, one of the promising types of alternative energy sources, offers a reliable, cost-effective and eco-friendly way of producing energy.

In this respect, the potential of wind energy in Yozgat Province was calculated depending on the hub height (m) and wind speed (m/sec) in this study. The data of 85 wind power plants installed and operating in Turkey were employed. The data of the amount of generated energy in these wind power plants belonged to the year 2018. The Multi-factor Anova method was utilized in order to statistically analyze the significance levels of the data set. For the methodology part of the study, tower height and wind speed were determined as input factors and the amount of energy produced selected as the output factor. The statistical significance level for hub height (m) was calculated as 0.048 as a result of the ANOVA test. The significance level for wind speed (m/sec) was statistically computed as 0.016. According to the statistical analysis, it was observed that both input factors had an impact on the response variable. Considering these results, the potential energy amount to be produced by the wind power plants to be established in Yozgat province has been estimated for the future. Based on the results, it was understood that Yozgat is a suitable region for wind power plants taking into account the parameters and variables considered for this study.

Declaration of Conflicting Interests
The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Author Contributions
Conceptualization, Y.A.A.; Data curation, Y.A.A.; Formal analysis, Y.A.A.; Methodology, Y.A.A.; Software, Y.A.A.; Supervision, Y.A.A.; Writing-original draft, Y.A.A.; Writing-Review & editing, Y.A.A.

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