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# ECONOMIC AND ENERGETIC ASSESSMENT OF INDUSTRIAL-SCALE SOLAR THERMAL ENERGY IN THE VISEGRAD REGION

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**ABSTRACT**

The Visegrád group's energy security is attributed to the national energy potential of each country. The energy potential results from the lack of crude oil and natural gas resources, limited access to the transmission network, and limited fuel storage. This bloc relies on raw material supplies from Russia, which is not evenly applied to all group members. Poland and Hungary have good storing potential, but it is not enough to achieve energy security and independence. Russia aims to keep control of this market while group members try diversifying their supplies to increase energy security. The purpose of this article is to present the energy balance in the Visegrád region. The analysis is based on the status of the renewable energy targets in the production, demand, import and export. Also, to determine the stability degree of these energy parameters. The material source is the literature and the energetic data from the European statistic official agency Eurostat and European commission reports. From an energetic aspect, the four capitals were considered as a case study for a food processing plant with annual hot water demand of 43 MWh to evaluate the performance oe solar thermal energy. The simulation was conducted using T*Sol software considering 16 evacuated-tube collectors B. Schweizer Energy AG manufacturer. The chosen process heating system has a buffer tank and a continuous flow heater. Each collector was inclined according to the optimum angle for each case study. As a result, it was found that the energy demand in the Visegrád region is entirely related to the economic situation. In contrast, Political and energy development have a more significant impact than economic factors. From an energetic aspect, solar thermal energy is evident for Hungary and Slovakia since they have up to 20% solar yields compared to Poland and the Czech Republic. Nevertheless, the solar irradiation on the collector field is high enough to consider solar thermal energy solutions integrated into food and industrial processes.

Keywords: Visegrad group, industrial-scale, solar thermal, energetic assessment, modelling

## 1. INTRODUCTION

Energy can be extracted from many sources, such as fossil fuels, natural gas, and crude oil, representing conventional energy resources. On the other hand, renewable sources include energy extracted from wind, water, sun, biomass, and geothermal energy. Nevertheless, the structures of energy sources differ among countries [1,2]. The European Union (E.U.) has a standard energy policy based on sustainable development, competition, and security of supplies [3]. Energy security can be explained differently and has different specifics in each country or continent. Also, primary energy supply and geopolitics are essential. So, the energy security concept is comprehensive and will keep evolving [4]. In this context, relative price stability, high availability, and affordability significantly impact overall energy security. Renewable energies and diversification are essential to a secure national energy strategy [5]. Several indicators measure the energy security level, as Narula et al. and Stavytsky et al. described. [6,7]. The energy system has changed with policies favoring renewable energy sources and the emergence of new technologies. As a result, some countries described as energy exporters become increasingly in demand, and some energy importers become exporters. For each country, social, environmental, and economic conditions are essential [8,9].

The most critical policy in energy is to ensure its sustainable development continuously. Sustainable energy development can be guaranteed by dealing with market failures obstructing the transition toward a sustainable future [10]. These market failures include the insecurity of imported energy or fossil fuel needed to produce energy. To overcome these failures can promote renewable energy sources [11].

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Traditional energy resources significantly affect health, environment, and atmosphere, while renewables have shallow impacts [12]. It is essential to mention that the costs for solving the side effects of producing energy from traditional sources are not reflected in the electricity prices.

The European common electricity market has been there for almost thirty years. The objectives were to reduce greenhouse gas emissions, use the energy produced from green sources, and expand the electricity connection [13]. In 2011, the 2050 targets were set for becoming low-carbon E.U. economies. Nevertheless, different energy sources are used in each E.U. country. Besides this, severe energy crises are related to interruption in Russian natural gas supplies [14]. So, it is crucial to diversify the suppliers and energy sources. This complies with the E.U. target to afford citizens a secure, competitive, and sustainable energy. Many vital factors include regional cooperation and energy infrastructure development [15,16].

The E.U. relies on 78% of the imported gas, and 40% is Russian gas, while the V4 group accounts for approximately 90%. Hungary has a favourable position regarding natural gas and oil resources [17]. In the 1980s, natural gas imports accounted for only 34%, while domestic resources provided the remaining. While for oil, it was sufficient to meet the national requirements. Currently, the own resources of gas cover only 22% of the demand. On the contrary, the Czech Republic's natural gas production accounts for only 2% of the national demand. However, the national market is the most diversified among all bloc members and can receive gas from different sources. The natural gas used in Czech is Norwegian and Russian gas compensation. Slovakia is the weakest member of natural gas and crude oil [18].

This paper aims to present the energy balance in the Visegrád region V4. The specific objective is to show the dynamic direction and concentration of demand, production, import, and export of energy from a statistics aspect. At the same time, the energetic aspect is to analyse the feasibility of integrating solar thermal energy systems with industrial processes such as food processing. The literature is saturated with research illustrating the current status of the economic factors, but the energetic analysis is still missing knowing that the solar system received more than one thousand watts per square meter in all the bloc territories, as shown in Fig 1. The importance of the energetic analysis is to show that alternative solutions like solar energy can help achieve sustainable and unmanipulated energy sources.

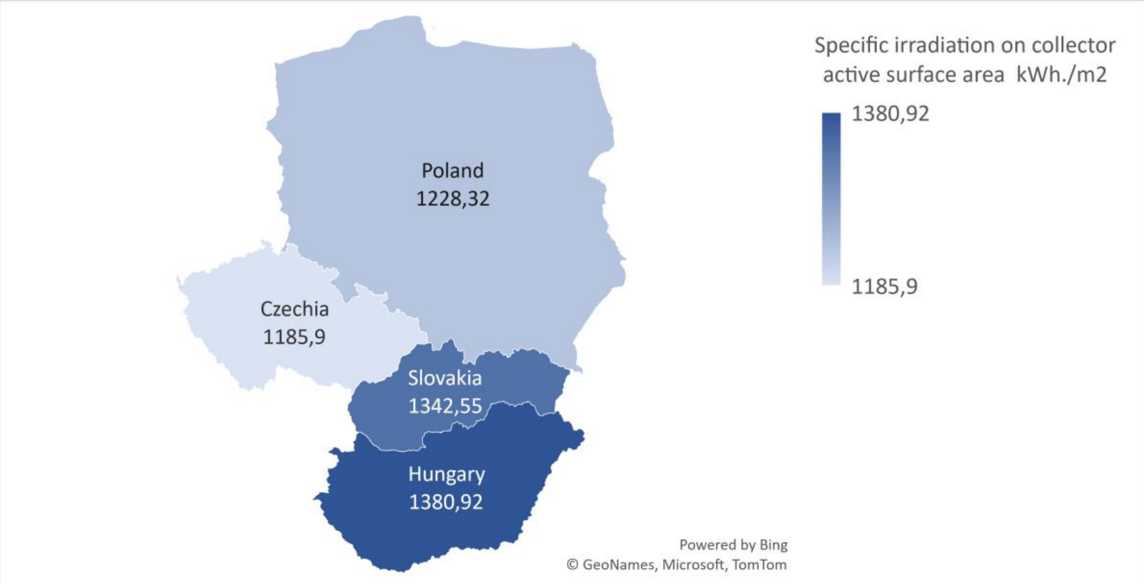


***Figure 1. Specific solar irradiation on collector active surface area kWh/m²***

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## 2. MATERIALS AND METHODS

As illustrated in Fig 2, the conventional heat processing system consists of a 1.75 $m^3$ buffer tank (50 litres per gross square area of the solar collector) and a 53.1 kW boiler responsible for affording the required heat demand heat process (technically a heat exchanger). The boiler can be connected in series or parallel. Most recent research in central Europe for heat processing systems shows that a series configuration can yield higher than a parallel one. Nevertheless, the differences are not significant. The right side of the scheme represents the existing heat process, while the left one is an integral part of the solar collector system using either an external heat exchanger or an integrated heat exchanger in the buffer tank.

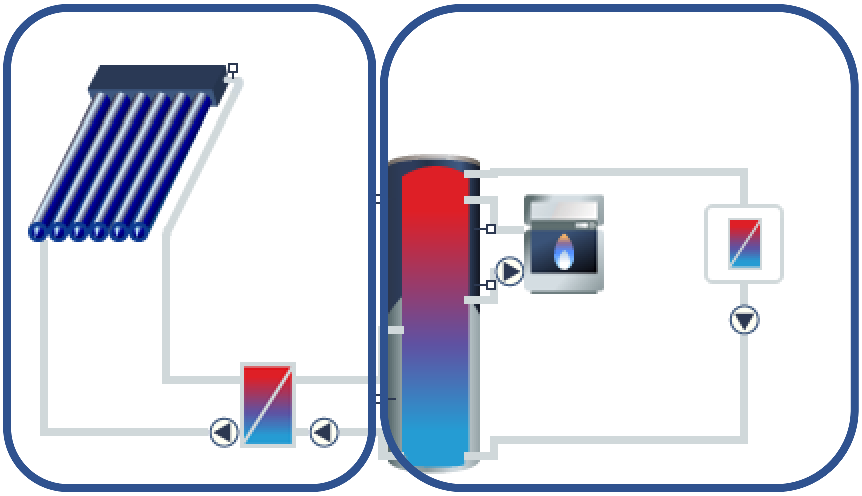

*Figure 2. Process heating system with a buffer tank and continuous flow heater*

The solar collector field comprises 16 evacuated tube collectors B.Schweizer Energy AG manufacturer and Swisspipe 2 type. The main characteristics of the collector are shown in Table 1. The collectors' orientation uses 0º azimuth angle and lengthwise direction of tubes.

*Table 1. ETC collector specifications [19]*

| Collector | Characteristics | Value |
|---|---|---|
| Evacuated-tube collector (ETC) | Absorber area | 1.31 $m^2$ |
| | Optical efficiency ($a_0$) | 87.8 % |
| | Heat loss coefficient ($a_1$) | 1.43 W/$m^2$ K |
| | Heat loss coefficient ($a_2$) | 0.0038 W/$m^2$ $K^2$ |

The studied locations are the capitals of each country, where the meteorological data are shown in Table 2. It is noteworthy that the optimal inclination angle is different for each location based on the optimum suggestions for each case. It is noted that Budapest and Bratislava have the highest global solar radiation compared to Warsaw and Prague. Also, the diffuse solar radiation is 2-5% smaller for Budapest and Bratislava than in Warsaw and Prague. From this, it is noted that the lower the diffuse radiation, the higher the total global radiation because it results in a higher amount of direct solar radiation.

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*Table 2. Primary meteorological data of the studied locations*

| Station | Latitude | Longitude | Total annual global radiation (kWh/m$^2$) | Mean outside temperature °C | Diffuse radiation percentage (%) | Optimal tilting angle |
|---|---|---|---|---|---|---|
| Budapest | 47.5º | 19.0º | 1,222.4 | 11.4 | 53.6 | 34.6º |
| Warszawa | 52.3º | 21.0º | 1070.8 | 9.3 | 55.9 | 36.3º |
| Bratislava | 48.2º | 17.1º | 1,192.4 | 11.3 | 52.0 | 34.8º |
| Prague | 50.1º | 14.3º | 1,055.0 | 9.2 | 57.2 | 35.5º |

Finally, the data are used to simulate the heat processing in the four locations using T*Sol software using the abovementioned scheme. The T*Sol software is a dynamic simulation program minute by minute for calculating, designing, and optimising variant solar thermal systems. The most critical output is the annual yield (solar fraction) which is the core of this study.

## 3. RESULTS AND DISCUSSION

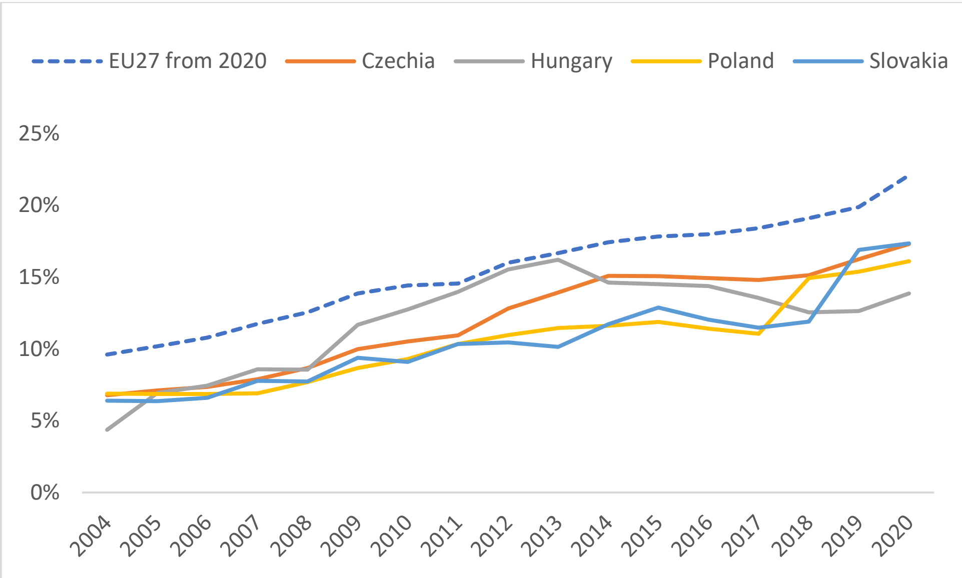


*Figure 3. Renewable energy in V4 countries*

It can be noted that the share of renewable energies in V4 countries is in the stagnation stage, as shown in Fig 3. Also, V4 countries have not been overachievers regarding increasing the share of renewable energies. No aim for more than necessary with lower-than-average targets seems to be the status. The renewable energy targets of V4 countries are considerably lower than the E.U. target of 32% in 2030. Poland indicates a 21-23% renewables target by 2030, while Hungary 21%, Slovakia 19.2%, and Czechia 22%. Sadly, all V4 countries failed to meet their renewable energy 2020 targets from June 2019, as shown in Fig 4.

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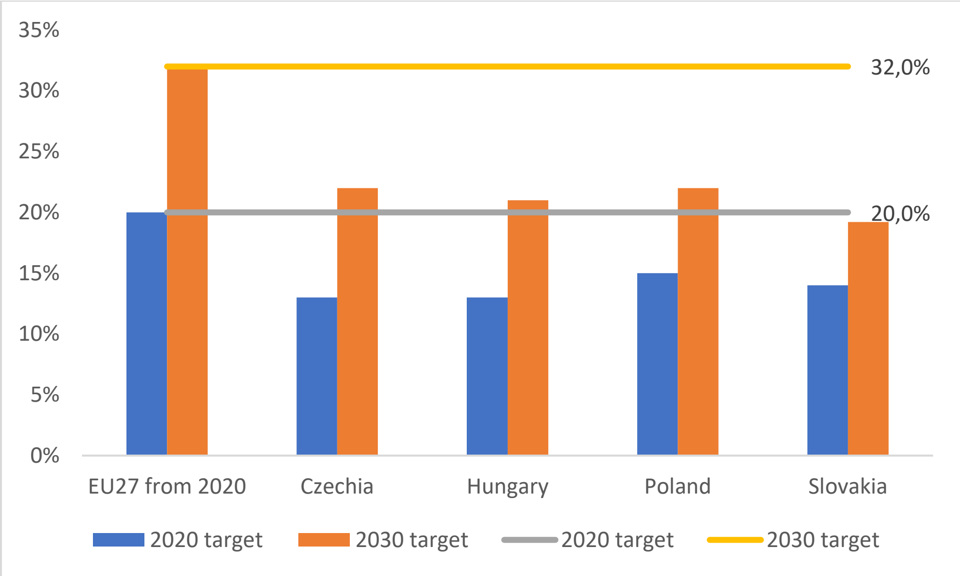


***Figure 4. V4 countries and their renewable energy targets in 2020 and 2030***

The first step is calculating the dynamic indices for the energy balance parameters such as import, export, energy supply, and production. The 2004 level was adapted to be the reference. Then, the results were ordered in descending order according to the energy import values. Over the fourteen years of study, energy imports have increased in many E.U. countries except nine countries. Poland has the most significant increase in energy imports where the imports have approximately been doubled. The energy demand in most E.U. countries has decreased with time. The highest fluctuations occurred in the case of energy production and exports, as in the case of Hungary and the Czech Republic. Beyond it, energy is being traded as a commodity, which means that more and more energy is purchased to meet speculative purposes and energy demands. Half countries have recorded energy production declines in the E.U., and the other half incline. This is due to half of the countries selling energy and buying their missing raw materials from their market.

***Table 3. Dynamic indicators for energy parameters in V4 countries***

| Country | Dynamic indicators for energy parameters collected between 2004-2018 | | | |
|---|---|---|---|---|
| | Primary production | Import | Export | Total energy supply |
| Poland | 78.62 | 189.65 | 79.78 | 115.99 |
| Hungary | 106.35 | 127.99 | 294.41 | 100.86 |
| Czechia | 81.65 | 116.54 | 86.53 | 94.41 |
| Slovakia | 94.66 | 88.12 | 90.45 | 93.23 |
| EU | 80.87 | 105.58 | 115.19 | 90.10 |

By conducting the variation coefficient of the energy balance parameters, it was noted that the variation of the energy demand was not too substantial. This means that there were no sharp changes in energy consumption. The most significant variability was in Poland. At the same time, energy production was stable in Slovakia. Also, the slightest fluctuation in the energy exports was in the Czech Republic and Slovakia.

In conclusion, high stability in the energy parameters in developed economies was noted. While in developing countries, the variability was much higher. It should also be considered that each E.U. country had different energy development levels due to the applied government policies. On the other hand, the simulation process of each country's most significant industrial location was taken place in the capitals since it hosts most of the big industrial cities. The annual demand of the assumed industrial plant is around 43 MWh/year, which is needed for making hot water. Fig 5 shows the most critical parameters of the solar system. The specific irradiation of the collector active surface area is between 1,185-1,380 kWh/m$^2$, which is higher than the total annual global radiation mentioned in Table 1 since it is falling on optimum tilting angle. Budapest and Bratislava have the highest irradiation, which is also evident by the specific energy delivered by the collector loop. It is noted that Budapest has about 18% higher solar radiation compared to Prague. We can obtain the collector loop efficiency by subtracting the solar contribution from the energy delivered by the collector loop. Finally, the total solar fraction of the process heat indicates a ratio between 39.5-46.9%, while the system efficiency is 69.1-70.4%.

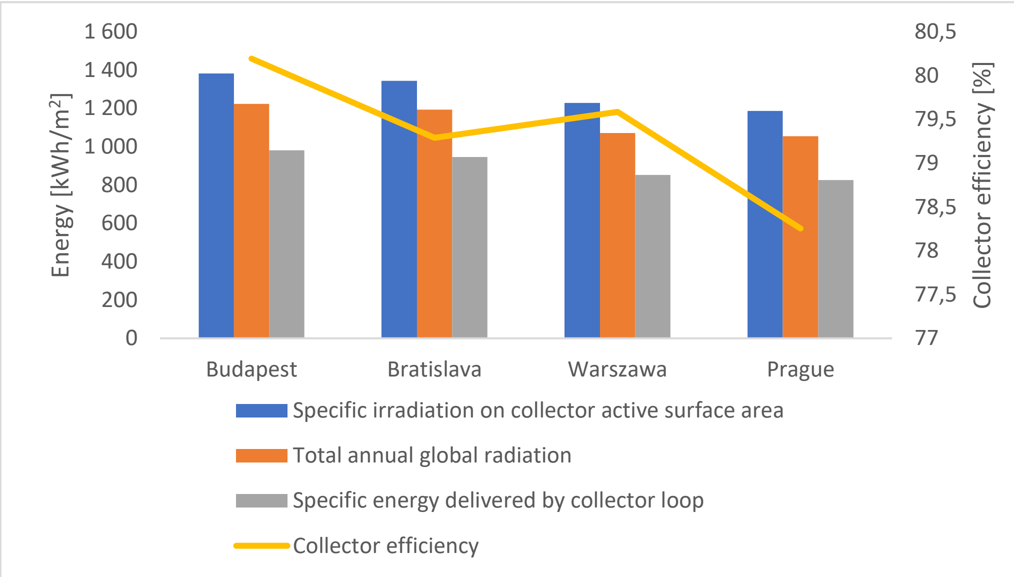


***Figure 5. Analysis results in V4***

On the other hand, the linear correlation between the solar fraction and the location has been plotted as in Fig 6. The results show that Budapest and Bratislava have the highest potential compared to Warsaw and Prague, with up to 20% more yields. Also, it was considered both the specific irradiation on the collector active surface area and the specific energy delivered by the collector loop.

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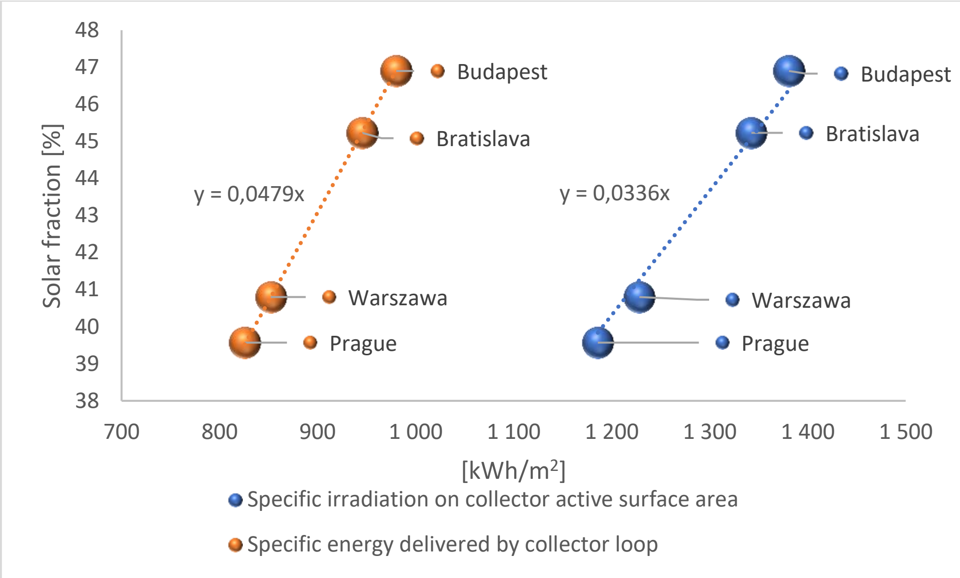


*Figure 6. Specific irradiation and delivered energy by the collector loop*

## 4. CONCLUSIONS

Traditional power generation has an external cost reflected in environmental and health issues, which facilitate the implementation of renewable energies. This implementation can be done either by supporting renewable energies or increasing the taxation of fossil fuel generation. The results show that public support for renewable energy has increased since 2004; however, Visegrád countries have made slow progress since 2010. The E.U. energy security depends on the solidarity between the bloc members. Recently, energy security has been a priority for all members and internal blocs like the V4 group, evidenced by the recent Ukraine-Russian war. The cooperation of the V4 members is undoubtedly needed to decrease the dependency on Russian gas supplies. Even though the level of addiction is uneven, it affects all the bloc members. In 2018, the V4 group imported about 88% of its natural gas demand from the Russian federation. Generally, V4 countries not just buy energy for their usage but also as a trade. Also, surplus energy production is exported. In V4, oil and natural gas are the primary energy sources, besides renewable and nuclear energy. Crude oil was the main import that accounted for 64% of all energy imports in 2018, mainly used in transportation. Then natural gas is 25% and solid fuel 7%. In all studied countries, renewable energies have recently become more critical and quickly increased. The European Commission reports gave an insight into the increase in renewable energy consumption in the V4 region. Czechia has an increase of 68% in the heating and cooling sector, while only 17% of the generated electricity comes from renewable sources. Poland has excellent potential for wind energy, and it occupies fifth place in the E.U. for using photovoltaic solar energy. It shows that Poland is significantly working on the decarbonisation prospect. Slovakia has the lowest target by 2030 compared to all other V4 members. The country's policy to shift towards renewable energies relies mainly on solar and wind production. Geographical maps show that the south of Slovakia and Hungary reveals the potential for solar thermal power plants. The analysis was produced using T*sol software. The data analysis results show that Hungary and Slovakia can yield up to 20% more solar energy than Poland and the Czech Republic. It can be concluded that solar thermal energy can be a good tool of reducing energy dependence on the Russia gas.

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