Estimating Solar Energy Potential of Hungary Based on Raster Maps

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Abstract: The transition to renewable energy sources is critical for reducing greenhouse gas emissions. This process changes the landscape structure. Through the example of Hungary, we presented the methods of estimating the annual electricity production based on solar energy at the national level using a GIS tool. In connection with the calculations, we summarized the landscape and environmental effects of different land uses, and we covered the physical characteristics of electric current which affect the spatial structure of production. In addition to determining the potential of solar energy, the environmental and physical characteristics determined the tasks, possibilities and limitations of landscape architecture in using solar energy.

Keywords: Energy transition, renewable energy, landscape planning, energy system

1 Introduction

In our research, we estimated the potential of solar energy at the national level using the Corine Land Use Cover (COPERNICUS 2018) and the Ecosystem Map of Hungary (AGRÁRMINISZTÉRIUM 2019) raster maps. In the documents defining the energy policy of the coming decades (Második Nemzeti Éghajlatváltozási Stratégia 2018) (Nemzeti Energia-és Klímaterv 2020), Hungary has set the goal of reaching 6,000 MW of solar energy capacity, which can produce 8700 GW electricity in a year. Recently, several studies have examined the efficiency of different solar technologies (ATSU et al. 2021), the solar potential and trends of Hungary and the surrounding region (KUMAR et al. 2021), and analyzed the potential of renewable energy sources at the regional level (HARTMANN et al. 2017), to name a few from the research of recent years. What new aspects can we shed light on from the perspective of landscape architecture? According to cultural history research, the transformation of the energy system is accompanied by a change in the landscape structure (MALM 2016), and the intensity of different renewable energy sources is different (FRITSCHE et al. 2017). In our research, we connected the solar energy potential and the land use classes of the two raster-based maps on a national level and determined which landscape categories have more favorable landscape and environmental effects. Furthermore, we examined whether, in addition to landscape use, it is worth further narrowing the areas at the level of location and potential at the national level. We also examined the possibility of narrowing down the possible locations, taking into account the physical characteristics of the electrical system at the national level and maps at the settlement level, while considering the location of the areas and terrain conditions.

2 Materials and Methods

We estimated the potential of solar energy based on territorial data; for this, we used two raster-based maps: Corine Land Use Cover and the Ecosystem Map of Hungary. The two

Journal of Digital Landscape Architecture, 8-2023, pp. 112-123. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-740-3, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537740013.

raster-based maps define different land use categories and are highly accurate. To determine the territorial data, we followed the following steps:

- We downloaded the raster data of the European land use map here: https://land.copernicus.eu/pan-european/corine-land-cover (COPERNICUS 2018). We downloaded the Ecosystem Map of Hungary here: http://alapterkep.termeszetem.hu/ (AGRÁRMINISZTÉRIUM 2019).
- We applied the following steps to get the raster data map of Hungary in ArcGIS: ArcToolbox – Spatial Analyst Tools – Extraction – Extract by Mask, and then we exported data into TIFF format.
- We finally used the following processes to calculate the area of land use types: ArcToolbox – Conversion Tools – From Raster – Raster to Polygon. This procedure converts the raster data to vector data to calculate the area of land use types in Attribute Table in ArcGIS.

After, we calculated the solar energy potential for suitable land uses. Even in the country, the conditions are different (Fig. 1), so we can define an average solar potential to count with. In Hungary, an average one kW panel can produce 1450 kW of electricity per square meter

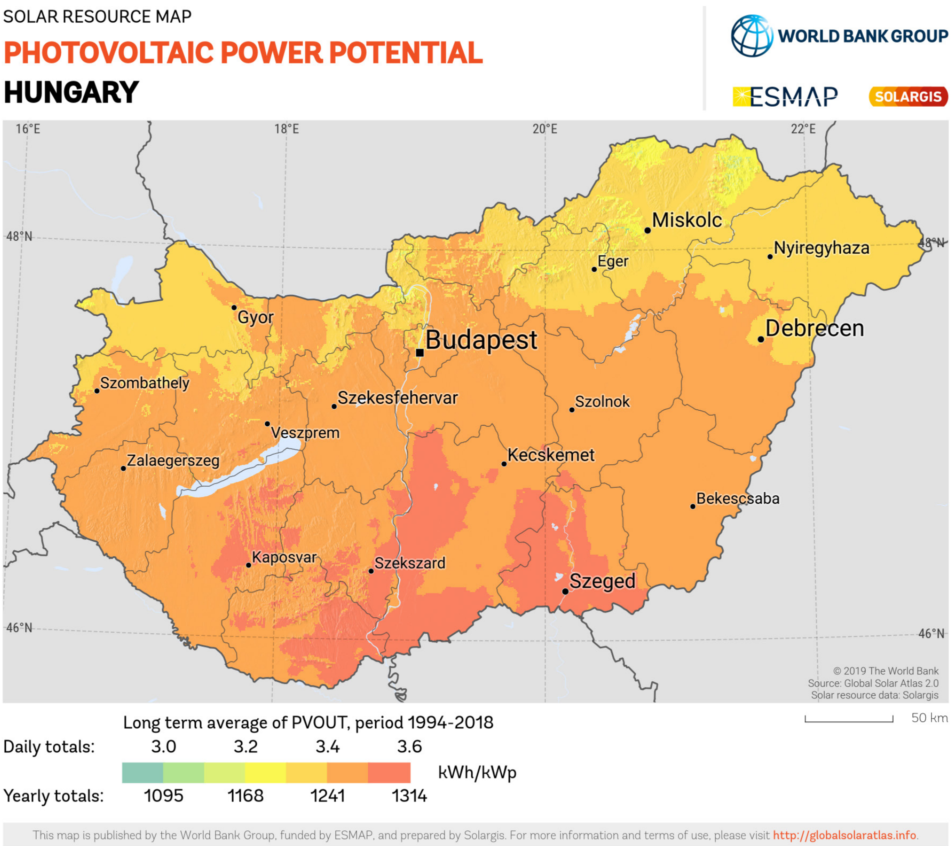

Fig. 1: Photovoltaic power potential of Hungary (Photovoltaic Electricity Potential of Hungary 2020)

(VARGA 2005), and the average efficiency of solar panels is approx. 18 % ('Most Efficient Solar Panels' 2022), Therefore, 261 kWh of electricity can be produced per square meter in a year. Can we count on an increase in the efficiency of producing electricity from solar energy? On the one hand, there are physical limits to the increase in performance: according to the laws of thermodynamics, energy conversion always involves energy loss (KLEIDON et al. 2016), which is also true for environmental systems (ODUM 2007). Research is currently being carried out in two directions for the development: on the one hand, to increase the lifetime of solar panel systems (EL-KHAWAD et al. 2022), or the efficiency can be increased by possible cooling of the systems (SIECKER et al. 2017) (PENG et al. 2017), but we cannot accurately count on these contingencies at the moment. In Hungary, solar panels are installed with two land covers: grassland and built-up area (MUNKÁCSY 2021). We counted these two categories and connected them with the environmental impacts of installation, use and abandonment of energy production.

Another critical question from the point of view of the calculations is whether it is worth narrowing down the possible places. The national radiation map shows a difference between the northern and southern areas (Fig. 1), but the difference is not significant. The annual radiation per square meter of Szeged in the south is 1600 kWh/m^2, while Miskolc in the north is 1503 kWh/m^2 (CATTANEO 2018), The difference is not relevant from an energy point of view. By examining the annual distribution, there is a difference between the yearly radiation distribution. In the south, there are more minor differences between the summer and winter months (Fig. 2) than in the north (Fig. 3).

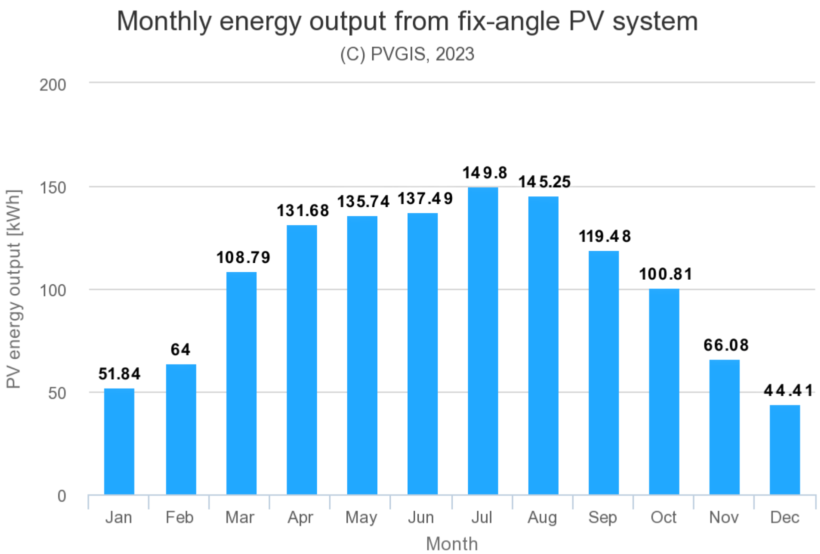

Fig. 2: Monthly energy output example of Szeged (CATTANEO 2018)

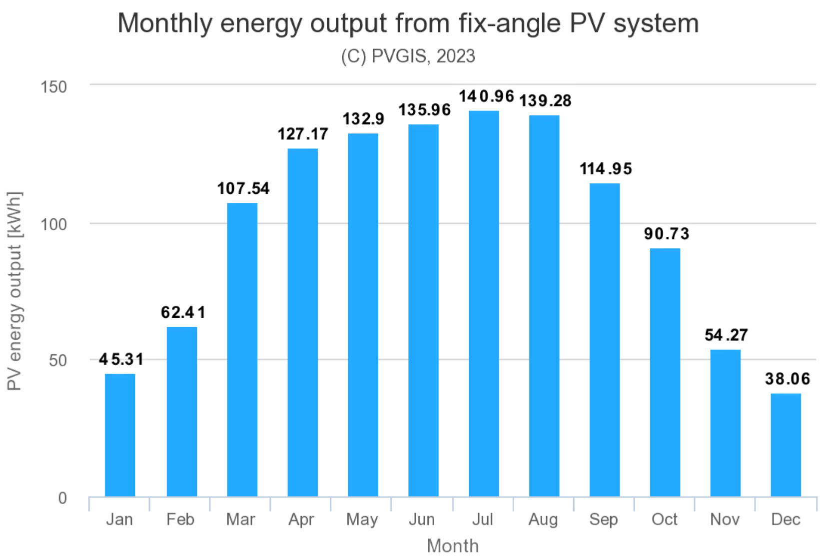

Fig. 3: Monthly energy output example of Miskolc (Cattaneo 2018)

3 Results

First, we introduced the results of the Corine Land Cover and the energy potential in Table 1. Based on the categories defined by the map, we found four suitable land used types for installing solar panels: natural grasslands, discontinuous urban fabric, continuous urban fabric and industrial or commercial units. In Table 2, the results of the solar energy potential reference to the entire area. The potential of the areas far exceeds the set goals based on the results. According to the national plan, the production should reach 8700 GW, possibly with 0,06 % of the grasslands and built-up area. If only considering the built-up area, the 0,07 % area should be covered with solar panels. For example, in the case of 10 % solar panel coverage of all the examined areas, the electrical capacity is 1,253,973 GW/year. This result is more than 144 times the set goal.

Table 1: Land use classes in square meter and solar energy potential according to Corine Land cover

Land use types	**Area (sq m)**	**Energy potential MWh/year full cover**
Natural grasslands	2307570000	602275770
Discontinuous urban fabric	4502480000	11751472800
Industrial or commercial units	710510000	185443110
Continuous urban fabric	20530000	535833

As it is clear that the solar energy potential is higher than the calculated plan, we can compare the impacts of solar installations in different land use classes to exclude those more exposed to negative effects. We summarized the results in Table 3 as there are not many differences. However, the environmental impacts of grassland installations are more intense than former studies have shown (FRITSCHE et al. 2017). The significant differences appear primarily during construction: large-capacity solar farms involve significant earthworks, and large surfaces can harm wildlife during operation (TURNEY & FTHENAKIS 2011). Furthermore, built-up areas have significant advantages, as they are connected to the grid, which minimizes the environmental impacts. In this case, we can estimate the solar energy potential of the built-up area. With 10 % solar panel density, discontinuous urban fabric has 1,175,147 GW/year, industrial and commercial units have 18,544 GW/year, and the continuous urban fabric has 54 GW/year electricity potential. 10 % of built-up areas have solar energy potential of more than 44 times the country's electricity production in 2020, which was 26,738 GW (INTERNATIONAL ENERGY AGENCY n. d.).

We also examined the Ecosystem Map of Hungary with the same method which has a higher resolution (AGRÁRMINISZTÉRIUM 2019). Based on the results, if grasslands and other herbaceous vegetation and urban area are taken into account, 0.18 % of the area needs to be covered with solar panels to reach the set target of 8,700 GW, which is a three-fold difference compared to the Corine Land Cover calculation. If only the built elements are considered, then 0.35 % must be covered to reach the set electricity production, which means a five-fold difference. Based on the more accurate raster maps, a larger surface area is needed to achieve the objectives related to solar power generation. In the case of both raster maps, built-up areas can include roads, railways, other linear facilities, and green areas next to buildings, reducing the possible solar panel installation area. However, it is also essential to consider that, in the case of buildings, the examined maps did not consider the different building roofs, which can also modify the results. For example, a detailed solar map for Budapest examines the potential of building roofs: based on this, the settlement's potential with an area of 525140000 m2 is 4872 MW (Magyar Napkollektor Szövetség 2022). The less accurate Corine map is closer to this result, where an area of 297473276 m2 approximately covers this capacity. In the case of the ecosystem map, it is 2669365884 m2. At the settlement level, the estimated values need to be specified, but at the same time, the roof shapes presumably increase the potential area.

Table 2: Land use classes in square meter and solar energy potential according to Ecosystem Map of Hungary

Land use types	**Area (sq m)**	**Energy potential MWh/year full cover**
Grasslands and other herbaceous vegetation	9143706897	2386507500
Urban	9392561170	2451458465

Table 3: Solar panels and their environmental impacts (SPELLMAN 2015, RUTHERFORD & WILLIAMS 2015, SCIPIONI et al. 2017, SINGH et al. 2013, APERGIS et al. 2010)

		Grassland	**Built-up area**
Production of materials, mining	living world	X	X
	landscape	X	X
	geological formations	X	X
	water	X	X
	air	X	X
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
Installation	living world	X	X
	landscape	X	
	geological formations	X	
	water		
	air		
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
Production	living world	X	X
	landscape	X	X
	geological formations		
	water		
	air		
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X
Facility abandonment	living world	X	X
	landscape	X	X
	geological formations	X	
	water		
	air		
	climate		
	built environment, cultural heritage	X	X
	environmental elements, systems	X	X

The land use restriction also leaves room for significant, high-capacity installations; presented through a few concrete examples, the red line (Fig. 4, 5, 6) in the figures represents the existing electrical network. In the case of housing estates in densely built-up urban fabric (Fig. 4), in the example, a solar panel is located on top of one of the most extended blocks of flats in Budapest with the capacity of 1128 MW (FÜLÖP 2012). Significant capacity can also be built on top of industrial plants, logistics warehouses, and shopping centers, such as the Audi Logistics Center in Győr (Fig. 5), the capacity of the facility is 12 MW, which can produce 9.5 GWh of electricity annually (*Európa még nem látott olyan naperőművet, mint amilyet az Audi épít Győrben* 2019). Mine tailings are also suitable for the installation of solar panels, as was the case with the open pit coal mine in Visonta (Figure 6). The 16 MW solar power plant was installed in the tailings area of the lignite mine, which is connected to the nearby high-voltage line via an underground cable (*Visontai Naperőmű – Műszaki Magazin*, n. d.). In the case of all three examples, it is essential to have the option of connecting to the electricity network.

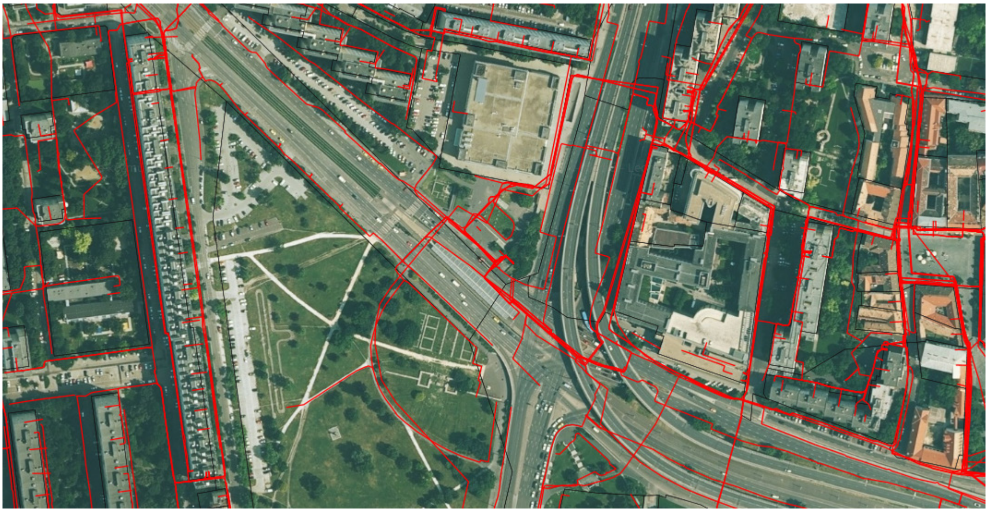

Fig. 4: Solar panels on roof top of block of flats. Budapest, Hungary (E-Közmű Lakossági Térkép, n. d.)

Fig. 5: Solar panels on roof top of Audi Logistics Centre. Győr, Hungary (E-Közmű Lakossági Térkép, n. d.)

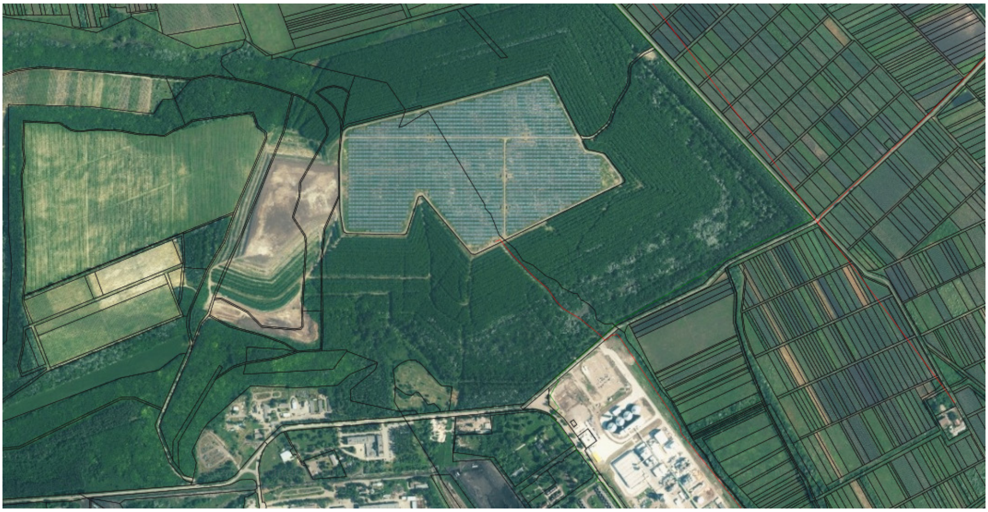

Fig. 6: Solar panels on coal spoil tip. Visonta, Hungary (E-Közmű Lakossági Térkép, n. d.)

The question is whether it is necessary to narrow down the results on a national basis based on the location of the areas, which affects the degree of radiation (BARTHOLY et al. 2013)? To do this, on the one hand, we examined the characteristics of the electrical network system and the possibilities of inserting solar energy. Solar energy is an uncontrollable energy source and can be described as a stochastic system (TSEKOURAS & KOUTSOYIANNIS 2014) (SHARMA et al. 2012). For the electricity system to be able to handle sudden production changes, it is worth geographically "scattering" the production, and the network itself can only store energy to a limited extent (YAZDANIE et al. 2016) (D'ANDRADE & SHAHSIAH 2017). For example, in the solar map of Budapest completed in 2022, where only buildings were taken into account, can be seen that there are buildings in poorly located areas where electricity can be produced efficiently (Fig. 7), thereby making use of the network's storage capacities. The southern orientation is the best in terms of insolation. However, in that case, it does not mean a significant drop in production: a study carried out in Újhartyán, Pest county, for a planned lawn area where there was a row of trees on the south side of the area, is why the production was simulated in the case of a southern orientation by cutting it, or by leaving the tree line, they concluded that no significant difference in production is expected if the orientation deviates from the southern direction by leaving the tree line (BARANYÁK & ZALAI 2016).

On the other hand, suppose the system characteristics are taken into account. In that case, if we limit the production of solar energy in the built-up areas, even in that case, we will significantly reduce the landscape and environmental effects. At the same time, we will give energy planning the opportunity to take advantage of the opportunities provided by the network.

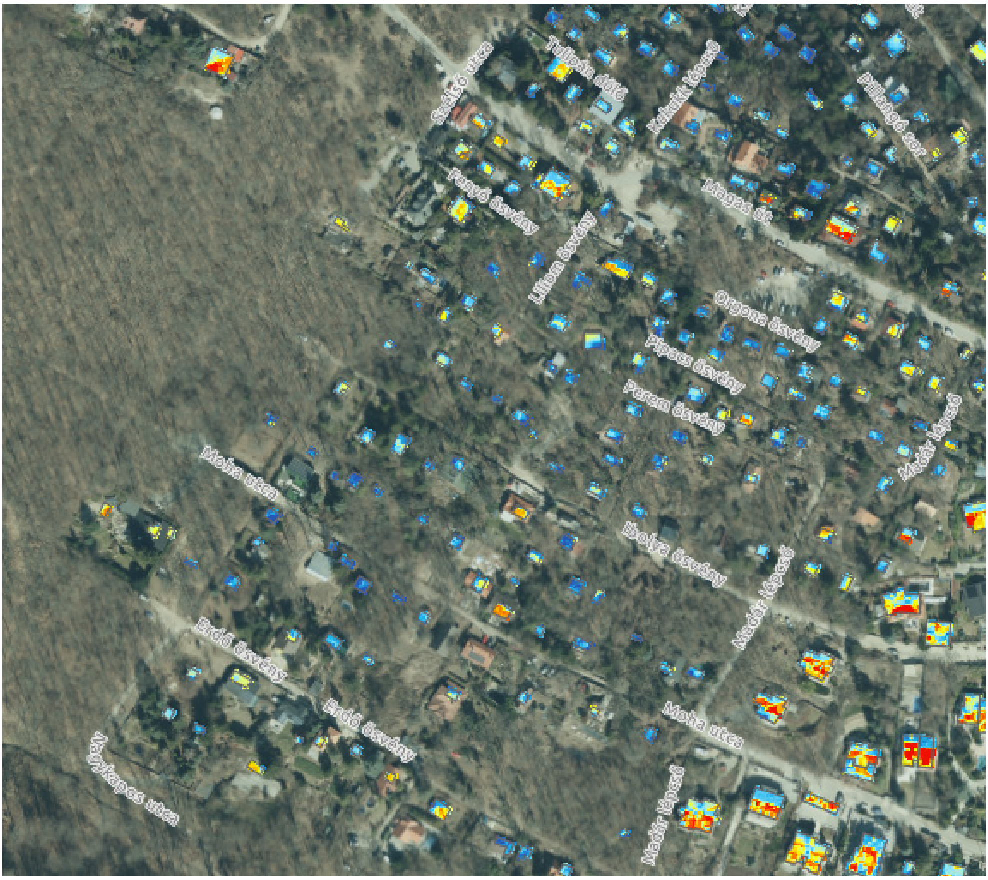

Fig. 7: Part of Budapest Solar Map (MAGYAR NAPKOLLEKTOR SZÖVETSÉG 2022)

4 Discussion and Conclusion

The results show that multiple times of solar energy potentials can theoretically provide not only the set goals but even the entire electricity requirement, but this is not possible due to the unique properties of electricity (VAJDA 2014). In order to reduce the environmental effects, it is worth considering the already built-up areas when planning the utilization of solar energy since the environmental effects, especially concerning installation and abandonment, are more favorable. It is even more important that the conditions are more favorable from the point of view of network development. The differences between the different scale raster maps in proportions are slight, but there are already significant differences between the area sizes. Taking into account the physical characteristics of electricity and the existing network conditions, the first thing to determine at the national level is the solar energy potential of the urban environment if these provide ample opportunities for energy planning, as can be seen in the Hungarian data, biologically active surfaces must be excluded, after that the system can support energy planning at the national level. At the national level, it is worth excluding land use categories with GIS tools and the orientation of the areas. The data show that the location does not significantly affect solar energy production. In spatial planning, it is worth considering that areas are falling apart (ÜRGE-VORSATZ & HERRERO 2012), where residential energy development is not significant. Therefore, these settlements must be supported in a targeted manner. These results call into question the establishment of new long-distance electrical networks between, for example, Azerbaijan and the European Union since EU countries located south of Hungary may have even more significant potential (EU and Azerbaijan Enhance Bilateral Relations, n. d.).

Acknowledgment

Supported by the únkp-22-4-I new national excellence program of the ministry for culture and innovation from the source of the national research, development and innovation fund.

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