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The Economic and Geographical Aspects of the Status of Small-Scale Photovoltaic Systems in Hungary—A Case Study

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Abstract: The use of solar energy is an obvious choice; the energy of the sun is not only indispensable for most processes in nature but it is also a clean, abundant, sustainable, and—most importantly—universally available resource. Although the further spread of photovoltaic systems, which make use of this source of energy, is expected in the future all around the world, no comprehensive investigation has been conducted into the current situation of the small-scale photovoltaic power plants in Hungary, where this type of photovoltaic system is the most popular. By means of a case study, whose novelty lies in its focus on small-scale power plants and their complex examination, including economic and geographic indicators, this paper analyzes their status in Hungary. The study endeavors to establish the reasons for the popularity of this type of power plant and to identify some typical geographical locations with well-illustrated photovoltaic density. Residential, as well as business prosumers, were examined with the aim of learning more about the density of the small-scale photovoltaic systems and their geographical locations. Another goal was to calculate the average size of small-scale photovoltaic power plants and to gain more understanding of their economic aspects. The outcomes of this research include maps displaying the density of the small-scale photovoltaic power plants in Hungary and the results of the economic calculations for such investments.

Keywords: solar energy; photovoltaic system; small scale power plant; renewable energy regulation; feed-in-tariff; Hungary

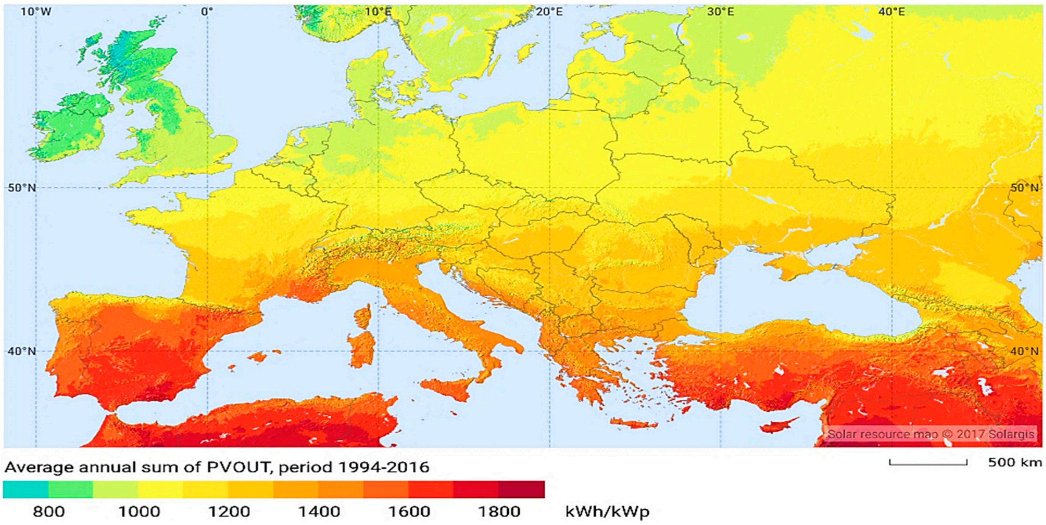
1. Introduction

1.1. Changes in the Spreading of Photovoltaic Technology

With an increasing number of countries gaining insight into the negative impacts of climate change, the mitigation of the detrimental developments has become a global goal. One of the most crucial objectives for mankind today is to limit the increase in global temperatures to less than 2 °C measured against preindustrial ones. To achieve this, we must aim for a rise of 1.5 °C, at most [1]. Among a number of various solutions for the transformation of energy systems aiming to reach the above goals and to lessen the greenhouse effect, the utilization of variable renewable energy (VRE) has also come to the fore. Thanks to rapidly developing technology, more and more sustainable options become available, including solar energy, which has been gaining much significance recently.

As an ever-increasing proportion of the Earth's population lives in cities, it is an important development that many cities worldwide have launched their solar energy programs with a view to protecting the environment and supporting sustainable development. The use of solar energy is an obvious choice since the energy of the sun is not only indispensable for most processes in nature but it is also a resource that is clean, abundant, sustainable, and—most importantly—universally available [2–10]. It is a reassuring thought that the potential of solar energy reaching the surface of our planet each year is several thousand times greater than mankind's energy demand at present. A widespread method for utilizing this energy is photovoltaic (PV) technology, which uses PV cells to transform solar radiation into electricity [11–13].

Several factors determine the quantity of produced PV energy, including, first of all, solar radiation, the applied technology, the temperature, the prevailing natural conditions, the composition of the specific module, and the collective effect of the installation itself and the rates of efficiency. In the map of PV power potentials in Europe, one can see that the annual amount of PV energy that can be generated averages between 700–1900 kWh/kWp according to geographical location (Figure 1). The same values for Hungary range between 1050–1250 kWh/kWp (Figure 1). Another important piece of information is that in the case of small-scale (>50 kWp) PV systems in Hungary, fixed mounting systems are mainly used instead of more advanced solutions due to financial reasons [14–19].



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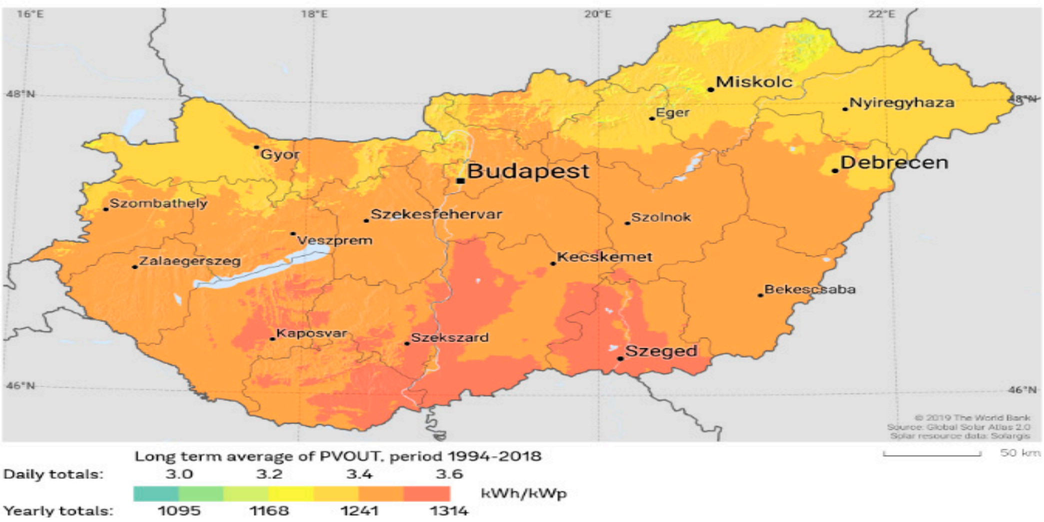

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Figure 1. The photovoltaic power potential, Europe (**a**) and Hungary (**b**) [18].

Currently, monocrystalline (m-Si), polycrystalline (p-Si), and amorphous silicon (a-Si) technologies are the most common PV technologies. With a market share of approximately 90%, crystalline solar modules are the most popular ones thanks to their high reliability. Concerning their efficiency, with p-Si and m-Si PV modules, an efficiency of up to 26.7% and 22.3% can be reached, respectively [15,20–26], while the efficiency of the m-Si and p-Si modules, most frequently in use, normally ranges between 10–18% in the territory of the European Union (EU) [27]. The greatest efficiency that can be achieved with a-Si photovoltaic technology, a thin-film PV technology, is 10.5% at present. However, the efficiency of the most widely used a-Si modules normally ranges from 4% to 6%. Although there is no available information on the market share of a-Si technology, the share of all thin-film solar modules amounts to circa 10%. With a price as low as 0.03–0.2 €/Wp (m-Si, p-Si: 0.2–0.3 €/Wp), a-Si technology may play a great role in the promotion of spreading PV technology in the countries of the EU [15,20,23,24,27–29].

The PV sector has seen a remarkable increase in the past decade thanks to a variety of measures and developments, including not only rapid advancements in technology but also new financial support schemes by governments, the feed-in-tariff, and the falling costs of investment [20,30,31]. In 2017, 26.5% of the electricity generated in the world came from renewable sources of energy, with 1.9% from PV technologies produced by a global built-in photovoltaic capacity of 402 GW. The world's highest-ranking producers in a descending order were China (131.1 GW), the European Union (108 GW), and the United States of America (51 GW), followed by Japan (49 GW). It is a remarkable development that, with the shift in technologies, PV technology has become the most important new power capacity in China [30,32].

As for Hungary, according to the figures of the past three consecutive years, the total installed PV capacity in 2017 was approximately 0.31 GW, in 2018 0.7 GW, while at the end of December 2019, 1.3 GW, showing an increase, which was mainly due to amendments in PV regulation [33,34]. In the long run, PV systems are expected to experience a considerable increase in their spread. By 2030 the Hungarian transmission system operator predicts the integration of 2.5–6.7 GW, while by 2040, that of 4.3–12 GW from PV into the system according to three distinct scenarios [35–37].

1.2. Hungary's Feed-In-Tariff System—Overview

The schemes designed to support green energy utilization show a great diversity across the various countries, which also tend to change them yearly, making it a challenging task to keep up with the latest developments [38]. The situation is further exacerbated by the fact that the available information is often untrustworthy because it is not up-to-date. This is also true for Hungary, from which a summary of dependable data is not obtainable at present. However, the feed-in-tariff (FiT), the net metering system (NS), and the various forms of investment support (IS) seem to be the most frequent schemes [39–43].

According to Hungarian regulations, in the case of plants with capacities ranging from 50 kW to 0.5 MW or in the case of demonstration projects, electricity production from renewable sources of energy and waste is supported by FiT. In the case of every entitled electricity producer, the Hungarian Energy and Public Utility Regulatory Authority (HEA) determines the maximum quantity of eligible electricity as well as the period of eligibility. The provisions of Decree No. 389/2007, regulating FiT, are to be applied to renewable energy installations approved eligible for the FiT before 31 December 2016 (§1 (6). The standard feed-in periods for various installations (landfill gas and PV below 2 MW, biogas below 5 MW, and biomass below 20 MW), which may be reduced if further investment schemes are also utilized for the same particular project, are also set out in the same decree. Annex No. 5 of Decree No. 389/2007 stipulates that the FiTs are fixed, and they are annually adjusted according to the consumer price index or the inflation minus one percentage point. The differentiation of the tariffs is based on several criteria: the sizes of the plants, time of licensing, time zones (three daily), and technology, to a certain extent. Plants that applied for the FiT later than 31 December 2016 are governed by a new decree, Decree No. 299/2017. (X. 17.), which provides different regulations for renewable energy plants ranging from 50 kW to 0.5 MW and for installations between 0.5 and 1 MW. Up to 0.5 MW, plants can apply for the FiT or the green premium (market premium), but for plants with capacities of 0.5–1 MW, the green premium is compulsory [44].

Concerning the eligible technologies in the case of plants that were approved after 01 January 2017, with the exception of wind power, every technology for renewable energy generation is eligible for the FiT up to a capacity of 0.5 MW if the eligibility has been confirmed by the competent authority and if it is a new plant conforming to the other stipulations of §20 (1) (§10 a–d) of Decree No. 299/2017 [45]. These include a number of requirements. First of all, no one is allowed to apply if they have outstanding debts to the state or the local government or the recipient (Transmission System Operator). If the applicant has been the beneficiary of financial support in the last three years before their application, they are obligated to provide proof that they have satisfied all the requirements associated with the grant they have received. Applicants are excluded from participation in the support scheme if a grant repayment decision from the European Commission is in force against them, if they have violated the competition law within three years of their application, or if they have used false information during the process of establishing eligibility, or they have been found guilty of a criminal offense by a court of law within three years before the application. In the case of combined heat and power plants (CHP) or ones using renewable biomass fuel, the applicants are obligated to provide certificates of origin. The installations also have to satisfy the technology-specific technical requirements prescribed in Decree 55/2016. According to the law (§9/A. j Decree No. 389/2007 and §7 (1) Decree No. 299/2017), to be allowed to use FiTs for electricity from renewable energy sources and CHP, the electricity produced must have a valid qualification concerning the certificate of origin under Government Decree No. 309/2013. Plants with installed capacities of less than 50 kW are not eligible for FiTs; they are subject to net metering. Furthermore, power plants with capacities exceeding 50 kWp are obligated to provide 15-min electricity production forecasts daily. Should any discrepancy of more than 0% occur, the owner of the installation has to pay a surcharge from 1 July 2018 [42,45–47].

Another scheme called HMKE (Hungarian abbreviation for household-size small power plant) was designed to suit local governments, corporate clients, and even residential customers with PV systems with capacities below 50 kW who feed the generated energy into the grid besides purchasing energy. In this arrangement, the PV system operator or owner has to pay only for the difference between the amount of electricity used from the grid and that of the energy fed into it. The balance is calculated yearly. This scheme does not necessitate the provision of 15-min electricity generation forecasts either. The operator/owner of the PV installation has to pay only if their consumption exceeds the amount of energy generation. However, if the electricity produced by them is more than the consumption, the service provider will have to pay the client. As for the storage of the energy, in this system, it is the national grid that is responsible for it. Thus, consumers who own comparatively small PV systems can be self-sufficient without having to worry about any costs and losses resulting from storage. From the government's perspective, the prospective economic benefits connected to the generation of green energy can also be important to consider in the context of this regulation [19,48].

The installation of a small-scale PV system (>50 kWp) for the sole purpose of decreasing energy consumption in big buildings is also an existing alternative. This is achievable in two different ways. The first option only allows the PV installation to generate enough electricity to cover the user's actual needs at any time. This arrangement excludes the possibility of feeding PV energy into the grid, which is ensured by a special regulatory device. The whole electricity production by the PV system can even be terminated if it exceeds the self-consumption. Conversely, in the second alternative, the surplus PV energy may be fed into the grid. However, in such a case, the process of licensing is not only far more complicated, and there is an obligation to sign a contract with the service provider regarding the extra PV energy, but the FiT is also much lower (approx. 0.015 €/kWh/2020) than in the other schemes [49].

As shown in Figure 2, power from HMKEs is definitely increasing in Hungary. In 2030 more than 1 GW HMKE power is expected. This power is less than 0.5 GW now, in 2020. Regarding the sales of CO_2 savings in the global market, the present regulations do not allow PV system owners to sell them, and they are not given compensation by the state either. This is why this paper does not cover issues related to carbon emissions trading [46,50].

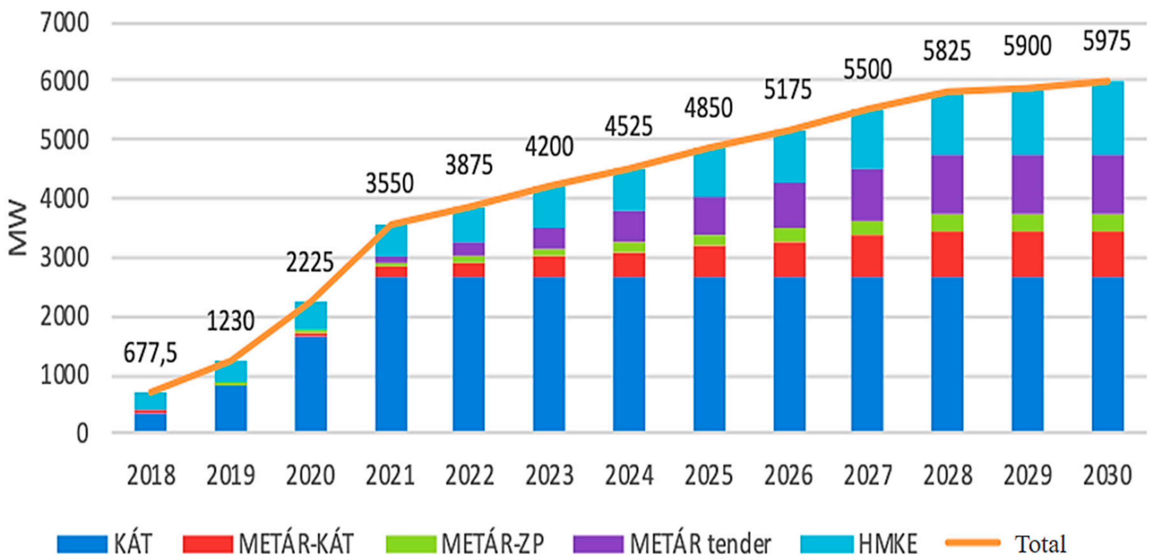


Figure 2. Expected photovoltaic (PV) power in Hungary [51] * (* Hungarian abbreviations of Hungarian PV power plant sizes and support schemes: KÁT—Hungarian system of supporting green energy from renewable energy sources, METÁR—Renewable Energy Support Scheme, ZP—Green Premium, HMKE—household-size small PV power).

Although there are more and more small-scale power plants (HMKE) in Hungary, and in Europe in general, so far, no comprehensive examination has been carried concerning them. The novelty of this paper, on the one hand, is its focus on the HMKE systems and, on the other hand, their complex study, including economic and geographic indicators. The authors also undertook to provide reasons for their great popularity and to identify some typical geographical locations characterized by high HMKE density.

1.3. The Economic Indicators of the NUTS2 Regions Hungary

Hungary has eight Nomenclature of Territorial Units for Statistics (NUTS2) regions. On 1 January 2018, the NUTS2 classification was changed in Hungary: The formal region of Central Hungary was split into two regions: that of the capital city of Budapest and that of Pest County. The following Table 1 displays some of the key economic indicators of the Hungarian regions. The Southern Great Plain region, including the counties Bács–Kiskun, Békés, and Csongrád, was not examined in this publication because no useful data was available from the regional Distribution System Operator (DSO).

Table 1. Indicators of the seven examined regions of Hungary based on [52]. (* Hungarian forint, HUF).

Region/Economic Indicator	Southern Transdanubia	Northern Great Plain	Northern Hungary	Central Transdanubia	Western Transdanubia	Pest	Budapest
GDP/capita [thousand HUF *]	3001	3010	2804	4024	4419	3460	8886
Average monthly gross earnings [HUF]	244,300	243,074	229,826	280,603	280,640	272,948	375,881
Population	879,596	1,450,960	1,126,360	1,058,236	989,343	1,278,874	1,752,286
Number of enterprises	170,277	288,317	165,484	175,563	189,764	230,675	455,144

2. Methods and Details of the Study

2.1. The Geographical Scope of the Examination

Seven of the eight Hungarian regions were examined:

- Northern Hungary, including the counties Borsod–Abaúj–Zemplén, Heves, and Nógrád;
- The Northern Great Plain, including the counties Hajdú–Bihar, Jász–Nagykun–Szolnok, and Szabolcs–Szatmár–Bereg;
- Pest, including, the county of Pest;
- Budapest, including the capital city of Budapest;
- Central Transdanubia, including the counties Komárom–Esztergom, Fejér, and Veszprém;
- Western Transdanubia, including the counties Győr–Moson–Sopron, Vas, and Zala;
- Southern Transdanubia, including the counties Baranya, Somogy, and Tolna.

The Southern Great Plain region, including the counties Bács–Kiskun, Békés, and Csongrád, was not examined in this publication because no useful data were available from the regional DSO.

The study was carried out not only at a regional level but also at the level of the settlements, and cartograms were created to demonstrate the differences better.

The HMKE data for the paper were provided by the local DSOs of Hungary concerning business and residential customers. Both sets of data were given in terms of power [kW] and quantity [pieces]. Residential customer here means a private person, and a business customer is a business with a tax and a registration number.

All the data used herein refer to the status on 31 December 2019.

In the maps, quantile scaling was used (instead of interval scales).

All the maps of this article were created by the QGIS 3.10.5 software.

2.2. Statistical Analyses of the HMKE Densities in Hungary

In trying to establish statistical relationships between the power/number of HMKEs and the economic indicators, as well as in the attempts to discover the reasons for the different densities of HMKEs, analyses based on the multivariate distribution (correlation and regression) were carried out.

Correlation analysis shows what affects one or more independent variables have on the dependent variable and the strength of their relationship. In the case of metric variables, the Pearson correlation (parametric), while in the case of ordinal ones, the Spearman correlation (nonparametric) can be applied. When examining the relationships between quantitative indices, before the determination of the correlation index, it is worth creating a so-called scatter plot. Based on the empirical data, from the pattern of the dots, one can make deductions concerning the strength and direction of the relationship. More exact results can be achieved by determining the value of the correlation coefficient (r) in the case of a linear relationship or the correlation index (I) in the case of nonlinear ones. The value of the correlation coefficient ranges from −1 to +1, and the closer the absolute value of r to 1 is, the stronger the relationship is. If the value of r is a positive number, it indicates a direct relationship, while a negative number signals an inverse one. A strong correlation can only exist in the case of a significant result ($p < 0.5$) [53].

2.3. Materials and Methods of the Economic Calculations

With the help of economic indicators, this study investigated one of the PV techno-economic and FiT solutions available in Hungary with the most frequently used crystalline PV facility. The Hungarian average generated power used for the calculations was of 5 kWp per residential HMKE prosumer and 15 kWp per business prosumer. The goal of the economic calculations was to identify the reasons for the extremely high increase in HMKE power generation. The calculations only involved net values for business and gross values for residential prosumers. By prosumers consumers, we mean consumers who not only consume but also produce electricity.

By performing these economic calculations, answers were delivered to the questions regarding the amounts of the investments necessary for PV systems, as well as the financial expenditure and the extra annual yields, taking the regulatory environment currently prevailing in Hungary into account. Regarding potential future changes in FiT, which may greatly affect the investment indicators, a sensitivity analysis was also done. It is important to note at this point that the HMKE option, which is the most straightforward solution for PV installations, is available on an annual basis for both business and residential customers [19,48,54,55].

Another important factor that had to be considered was the annual performance degradation, which is a characteristic of crystalline PV modules. Its value was determined based on the commonly accepted rate of 0.5% for the purposes of this study [20,56]. As for the operation time, a 15-year period, based on the present-day general European investment practice, was selected. Normally, the devices (PV modules and inverters) are still in good condition after 15 years, and can even be sold at a relatively good price. The two main benefits of this are the following:

1. Investors can upgrade to the latest and more efficient PV technologies every 15 years;
2. More affordable PV technologies are available to people with fewer funds [27,57].

The calculations, of course, also involved taking into account a number of other factors. Although for the 15-year time frame, the replacement of the inverter was not envisaged, we calculated maintenance costs based on experience (e.g., lawn mowing, washing of PV panels, unforeseen technical issues, etc.), and a 10% PV system loss was also taken into account. Our model had a tilt angle of 35°. Other values, namely the net present values (NPV), the profitability indices (PI), and the discounted payback periods (DPP) related to the PV systems and the economic calculations, were determined according to established methodology found in the international literature (Table 2) [41,58]. The 2.775% interest rate applied for calculating the time values of the dynamic economic indicators was based on the long-term Hungarian bond yield data of 22 April 2020. Furthermore, the annual HMKE and small-scale PV electricity FiT changes were based on the inflation rate between 2005 and 2019 at a value of 3.37%.

Table 2. The initial economic–technical data for the calculations [20,44,56,59–71].

Content	Value
Average validated electric energy production of a 1 kWp HMKE PV system in Hungary, first-year (kWh/a)	1200
Decrease in the annual performance of average crystalline modules after the 1st year (%)	0.5
Duration of the investment (year)	15
System loss (PV inverter, grid) (%)	10
Tilt angle of PV modules (°)	35
Orientation (azimuth) (°)	180
Average PV system of an HMKE residential customer (see calculation in Chapter Results) (kWp)	5
Average PV system of an HMKE business customer (see calculation in Chapter Results) (kWp)	15
Average delivery price for electric energy for business customers in the HMKE PV system, net (€/kWh/2020)	0.136
Average delivery price for electric energy for residential customers in the HMKE PV system, gross (€/kWh/2020)	0.100
Rate of average inflation (2005–2019) (%)	3.37
Bond yield interest rate (%)	2.775
Financial support (%)	0
Investment costs, 5 kWp residential HMKE PV system, gross, 2020 (€)	4535
Investment costs, 15 kWp business HMKE PV system, net, 2020 (€)	7985
Average price of 1 kWp used crystalline PV modules, gross, 2020 (€)	100
Average price of 5 kW used PV inverter power, HMKE, gross, 2020 (€)	300
Average price of 15 kW used PV inverter power, HMKE, net, 2020 (€)	500

For simulating a grid-tied PV system, the online software JRC Photovoltaic Geographical Information System (PVGIS) proved to be a great tool, providing data, which also contained real climatic data series from several decades. This allowed us to make estimates for the average energy production of typical grid-tied and off-grid PV systems on both a monthly and a yearly level. The software calculates a number of variables regarding the PV system, as well as the weather conditions: the type of the PV module, the installed peak PV power, the mounting position, the tilt angle, the azimuth, the system loss and, on the other hand, the solar radiation, the temperature, and the wind speed. In the course of generating estimates for PV energy production, all the values can be conveniently set by the user. For the purposes of our model, we chose widely available, average crystalline PV modules [59]. For the validation of the data applied for the average electric energy generation of 1 kWp PV systems, data from real PV systems were used (Table 2) [60–62]. According to our model, at the end of the investment period, the inverters and the PV modules were sold, and a demolition fee had to be paid.

3. Results

3.1. Gross HMKE Density in Hungary

According to the results (see Table 3) of the examination of the average power of the HMKEs in Hungary (split into total, business, and residential prosumers), an average business prosumer has 15–16 kW HMKE power (**P**) except for the regions of Northern Hungary and Pest, where these amounts are 11 and 13 kW. An average residential prosumer has 5–6 kW in Hungary.

Table 3. Average household-size small photovoltaic power plants' power in the seven examined regions of Hungary.

REGION/HMKE	Southern Transdanubia	Northern Great Plain	Northern Hungary	Central Transdanubia	Western Transdanubia	Pest	Budapest City	Average
P average [kW]	8	9	6	7	8	5	6	7
P average business [kW]	15	16	11	15	15	13	16	15
P average residential [kW]	6	6	5	6	6	5	5	5

Investigating the aggregate HMKE data (Table 4) for seven of the eight Hungarian NUTS2 regions delivered the following results.

Table 4. HMKEs in the seven examined regions of Hungary. (* Quantity, Q)

REGION/HMKE	Southern Transdanubia	Northern Great Plain	Northern Hungary	Central Transdanubia	Western Transdanubia	Pest	Budapest City
P total [kW]	57,966	73,529	27,098	56,731	50,156	46,458	26,742
P residential [KW]	29,912	34,192	14,347	36,797	29,535	39,180	21,221
P business [kW]	28,054	39,338	12,751	19,934	20,621	7278	5521
Q * total [pieces]	7244	8010	4171	7771	6680	8609	4287
ṃidrule1-8 Q* residential [pieces]	5432	5619	2966	6404	5274	8047	3927
Q * business [pieces]	1812	2391	1201	1367	1406	548	353

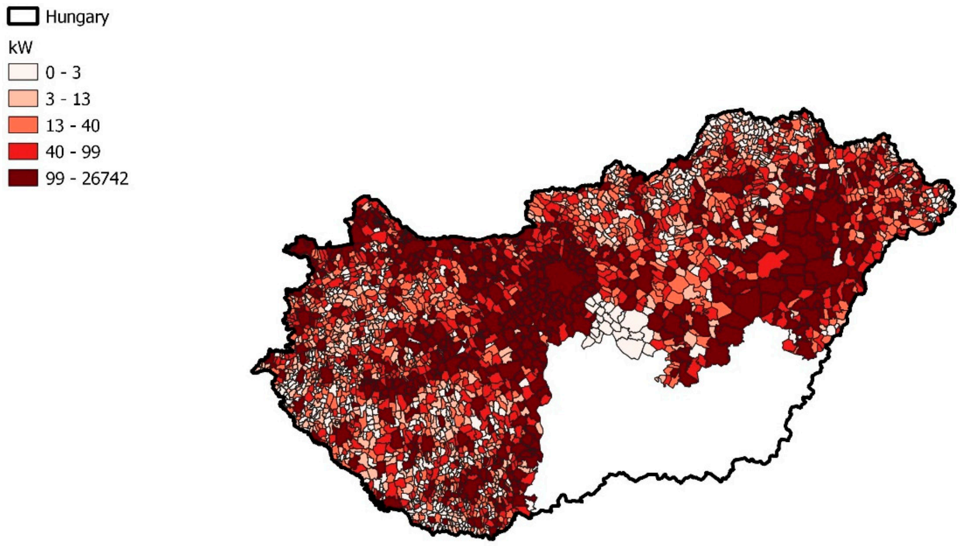
The Northern Great Plain had the highest HMKE figures (in terms of power as well as numbers). All three Transdanubian regions were a bit above the average, but Northern Hungary was far below that.

After examining the HMKE figures in the NUTS2 regions of Hungary, the investigation focused on the HMKE prosumers at the level of the settlements of the country.

The following six maps show the gross HMKE power and the number of HMKEs in the Hungarian settlements. The first two maps present the totals, while the second two display the figures of only the residential and the third two those of the business prosumers.

3.1.1. Total Gross HMKE Power

The Northern Great Plain, the area along the border in Northwest Hungary, Budapest, the Lake Balaton region, and the big cities had the most HMKEs. These areas had higher populations than the Hungarian average, except for the Lake Balaton region. (Figure 3).



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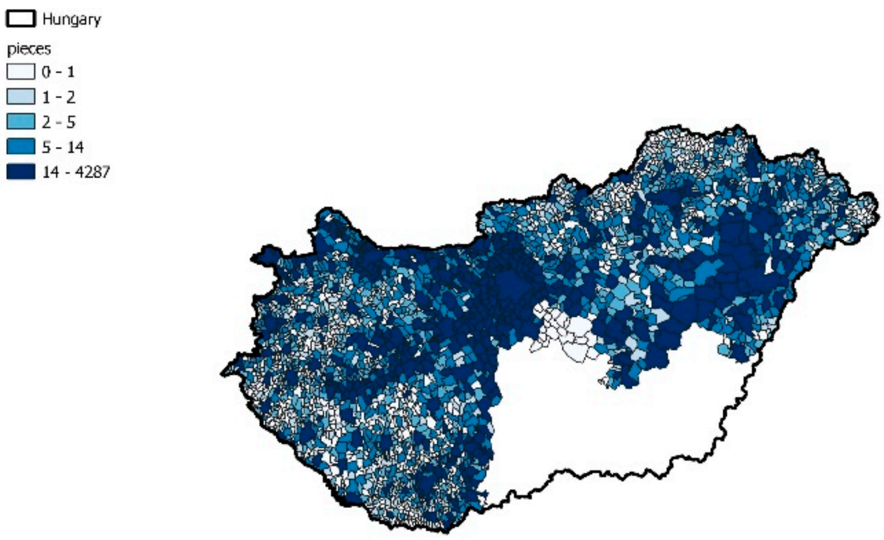

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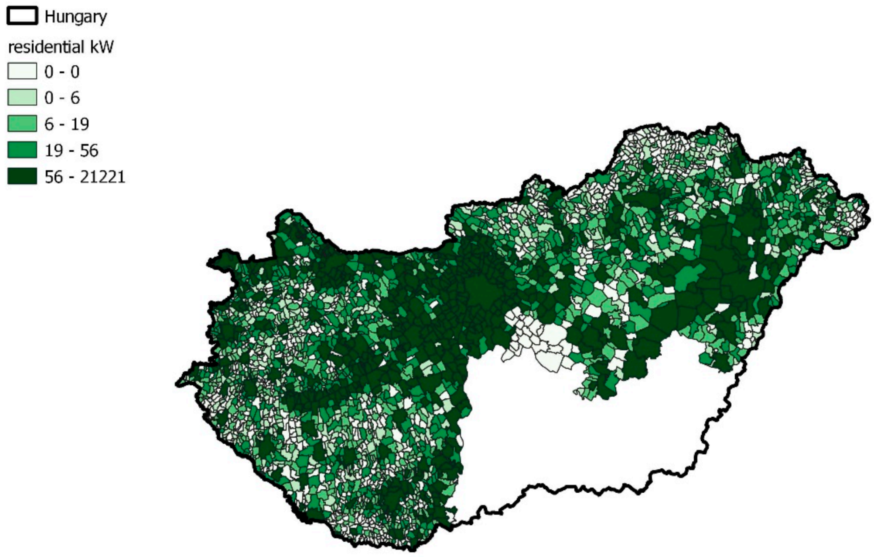
Figure 3. Total household-size small PV power plants' (HMKE) power (**a**) and the number (**b**) of HMKEs in the settlements of Hungary.

3.1.2. Residential Gross HMKE

Looking at the residential customers, one sees two maps, which are very similar to those presenting the total HMKE figures, as the residential customers greatly outnumbered the business ones (Figure 4).



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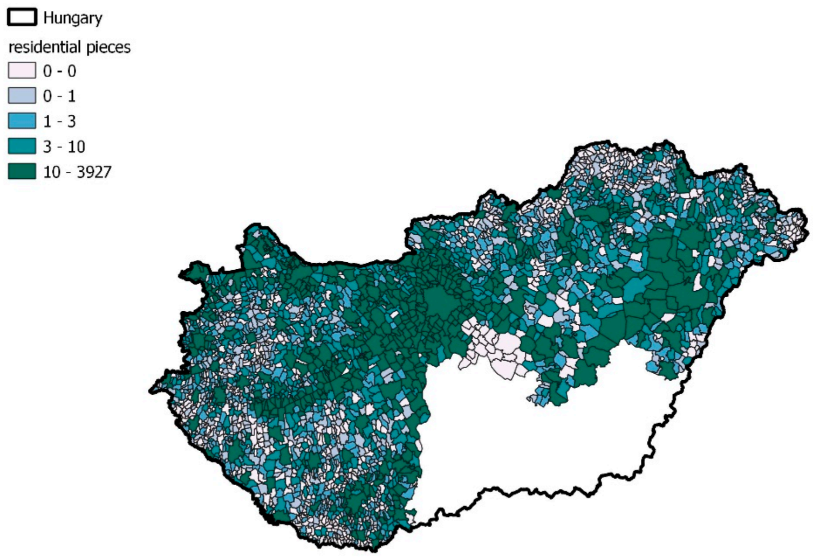

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Figure 4. Total residential HMKE power (**a**) and the number (**b**) of residential HMKEs in the settlements of Hungary.

3.1.3. Business Gross HMKE

If only the business HMKEs are shown in the maps, a rather different pattern appears than before: The region of Lake Balaton almost disappeared, but the line of the river Danube could be seen very distinctly, just like the industrial areas of Debrecen–Nyíregyháza in the Great Plain in the east and those of Győr–Sopron next to the Austrian–Slovakian–Hungarian border (Figure 5).

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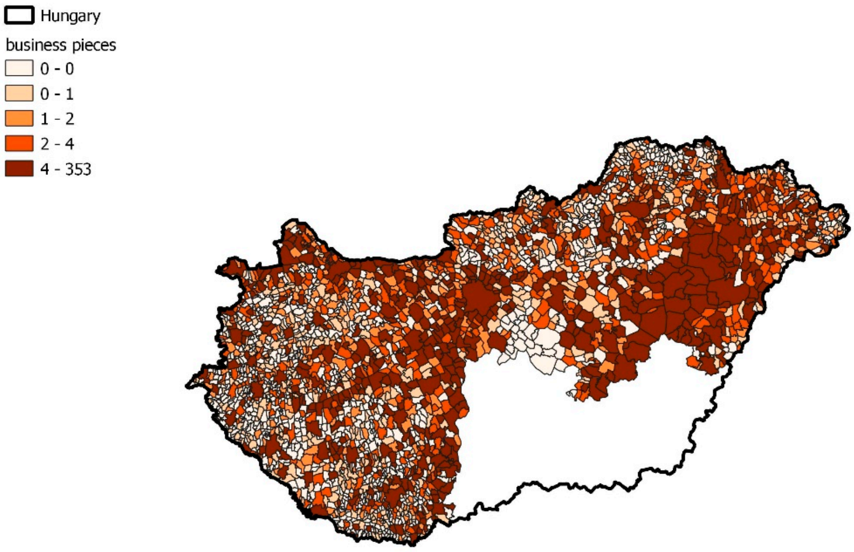

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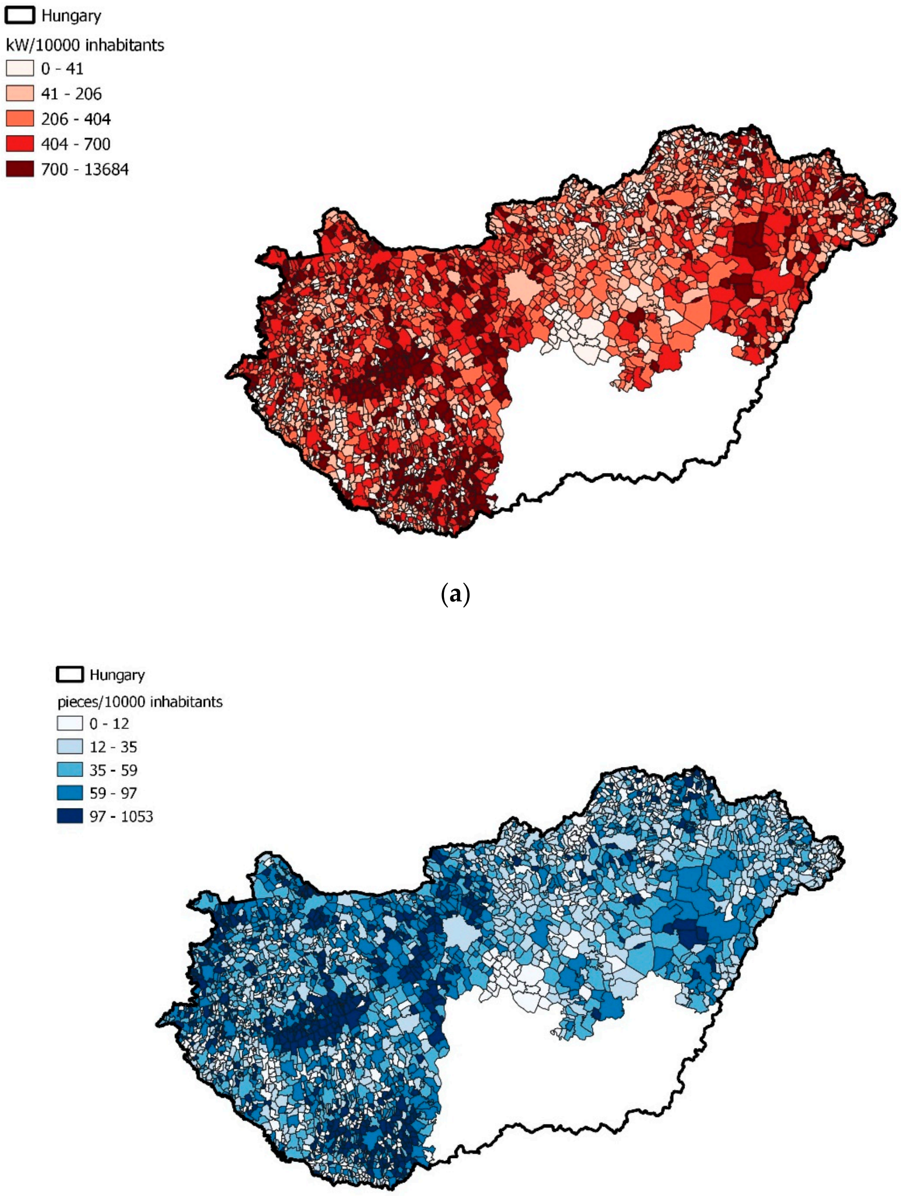
Figure 5. Total business HMKE power (**a**) and the number (**b**) of business HMKEs in the settlements of Hungary.

3.2. HMKE Density in Hungary Relative to Population Size

Due to the varying population densities of the regions and settlements of Hungary, it was important to examine the HMKE figures relative to population size. The HMKE power and the number of HMKEs per 10,000 inhabitants are shown in Figures 6–8. The first two of the following six maps show the settlements, the second two, the districts (subcounty administrative units), and the third two, the counties. The difference between the gross values and the figures relative to population size caused characteristic changes to the maps. The line along the Danube River disappeared, but Lake Balaton became very visible. If one looks at only the districts, the industrial regions of the country, situated in the northwest (Győr–Sopron), the east (Debrecen), and the south (Pécs) as well as just west of the capital (Székesfehérvár), become very conspicuous, while in the middle of the northeast the maps seem almost empty. The HMKE density was much lower here than in the other parts of Hungary.



(**a**)

(**b**)

Figure 6. Total HMKE power (**a**) and the number (**b**) of HMKEs per 10,000 inhabitants in the settlements of Hungary.

Using the data of the regions, the following specific values (Tables 5–7) were obtained, where the red cells indicate the above-average figures, while the color green signals values below the average.

Tables 5 and 6 show that the region of Northern Hungary and the capital city of Budapest had the least HMKE power and HMKEs per capita. However, these two NUTS regions of Hungary were totally different. Their differences are well illustrated in Table 6. All the displayed economic figures of Budapest were in great contrast to those of the region of Northern Hungary. Concerning the question of why Budapest had such low HMKE figures, the following answers can be provided within the framework of the present study. The capital city of Budapest had many more inhabitants than the other NUTS2 regions of Hungary, and that is one of the reasons for the low HMKE/10,000 inhabitants figure. The other reason was the high population density, which meant more blocks of flats and fewer detached houses. Consequently, the conditions for HMKE investments may be less than ideal. The Northern Hungary NUTS2 region had the lowest residential HMKE figures among the examined seven regions, shown in Table 5, where it was also seen that this region had only less than half of the HMKE power values of the other regions, except for Budapest.

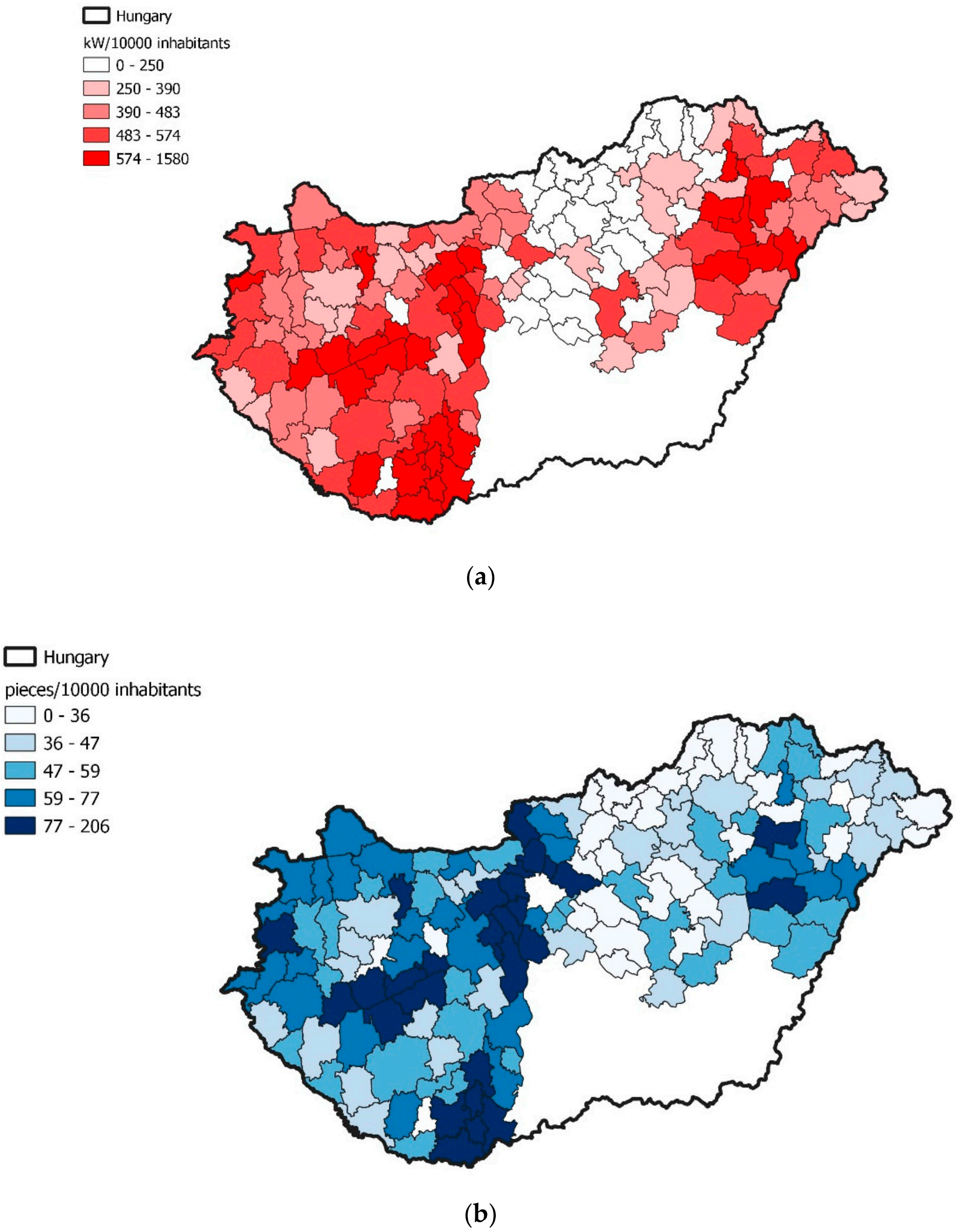
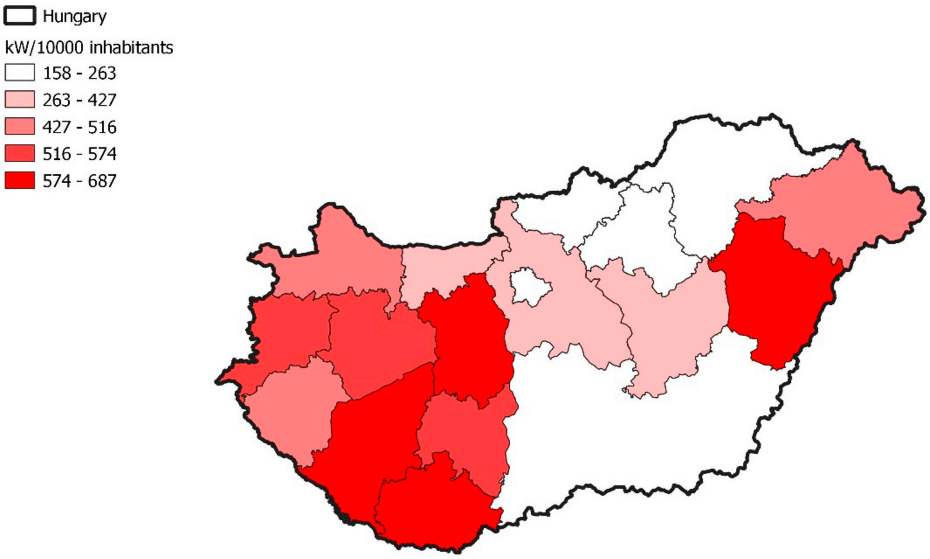


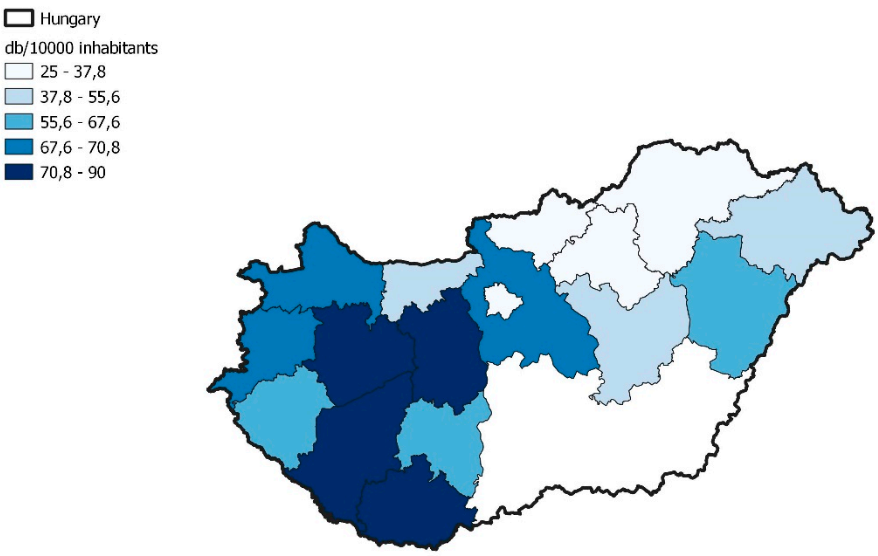
Figure 7. Total HMKE power (**a**) and the number (**b**) of HMKEs per 10,000 inhabitants in the districts of Hungary.

Despite calculations carried out to establish some correlation between the economic factors of Table 6 and the HMKE status in Hungary, no relationship was found.

Table 7 shows the business HMKE status in the examined seven regions of Hungary. This is similar to that of the residential HMKEs. The NUTS2 regions of Northern Hungary, Pest, and the capital city of Budapest have the fewest business HMKEs per 10,000 businesses. The reason is also similar to the above: Budapest has many more businesses and less space than the other regions. Northern Hungary is the economically least developed among the seven examined regions.



(**a**)



(**b**)

Figure 8. Total HMKE power (**a**) and the number (**b**) of HMKEs per 10,000 inhabitants in the counties of Hungary.

The authors analyzed the relationships between the economic indicators (Table 6) and the HMKE values (Tables 5 and 7) and obtained the results below. The relationships between any two variables (the indicators in Table 8) were displayed by scatter plots in every case so that the nature of the relationship could be established. It was shown that, either the distributions of the points did not indicate any relationship, or if they did, they suggested the existence of a linear correlation. Consequently, for the quantification of the strengths and directions of the relationships, the Pearson correlation coefficient was applied. The table illustrates at a regional level the strengths of the relationships between the GDP/capita, industrial production/capita, the number of registered enterprises, and the population density, on the one hand, and the power and quantity of the residential and business HMKEs, on the other hand. It was found that regarding the regions, there were no relationships between the indicators; the p-value exceeded 0.05 in every case.

Table 5. HMKE figures relative to population size in the seven examined regions of Hungary (red: above the average, green: under the average, blue: average).

REGION/HMKE	Southern Transdanubia	Northern Great Plain	Northern Hungary	Central Transdanubia	Western Transdanubia	Pest	Budapest City	Average
P total/10,000 inhabitants [kW]	659	653	187	536	507	363	153	437
P residential/10,000 inhabitants [kW]	340	304	99	348	299	306	121	259
P business/10,000 inhabitants [kW]	319	349	88	188	208	57	32	177
Q total/10,000 inhabitants [pieces]	82	71	29	73	68	67	24	59
Q residential/10,000 inhabitants [pieces]	62	50	20	61	53	63	22	47
Q business/10,000 inhabitants [pieces]	21	21	8	13	14	4	2	12

Table 6. Economic and demographic indicators in the seven examined regions of Hungary (red: above the average, green: under the average, blue: average).

REGION/HMKE	Southern Transdanubia	Northern Great Plain	Northern Hungary	Central Transdanubia	Western Transdanubia	Pest	Budapest City	Average
GDP/capita [thousand HUF]	3001	3010	2804	4024	4419	3460	8886	4229
Industrial production/capita [thousand HUF]	1998	2529	4170	6372	6561	2660	2131	3775
Population density [pop./km^2]	62	82	84	95	87	200	3337	-
Number of enterprises/1000 people	194	199	147	166	192	180	260	191
Average monthly gross earnings [HUF]	244,300	243,074	229,826	280,603	280,640	272,948	375,881	275,325

Table 7. Business HMKE figures relative to population size in the seven examined regions of Hungary (red: above the average, green: under the average, blue: average).

REGION/HMKE	Southern Transdanubia	Northern Great Plain	Northern Hungary	Central Transdanubia	Western Transdanubia	Pest	Budapest City	Average
P business/10,000 Businesses [kW]	1648	2377	442	1135	1087	315	121	1018
Q business/10,000 businesses [pieces]	106	144	42	78	74	24	8	68

Table 8. The strengths of the relationships regarding the regions * (* Pearson correlation coefficient/*p*-value): There exists a significant, verified relationship between two variables if $p < 0.05$.

Indicators	P Total/10,000 Inhabitants	P Residential/10,000 Inhabitants	P Business/10,000 Inhabitants	Q Total/10,000 Inhabitants	Q Residential/10,000 Inhabitants	Q Business/10,000 Inhabitants	P Business/10,000 Businesses	Q Business/10,000 Businesses
GDP/capita	−0.545/0.206	−0.462/0.297	−0.521/0.231	−0.581/0.171	−0.478/0.277	−0.580/0.172	−0.509/0.243	−0.572/0.180
Industrial production/capita	0.097/0.836	0.206/0.657	−0.010/0.983	0.157/0.737	0.160/0.731	0.053/0.911	−0.030/0.949	0.032/0.946
Population density	−0.613/0.143	−0.584/0.169	−0.533/0.219	−0.677/0.095	−0.590/0.163	−0.594/0.159	−0.510/0.243	−0.576/0.176
Number of enterprises/1000 people	−0.177/0.705	−0.207/0.656	−0.121/0.797	−0.280/0.543	−0.250/0.588	−0.217/0.641	−0.111/0.813	−0.201/0.665
Average monthly gross earnings	−0.493/0.261	−0.328/0.472	−0.545/0.205	−0.471/0.286	−0.327/0.474	−0.611/0.145	−0.530/0.222	−0.596/0.158

3.3. Economic Calculation

According to the calculations, the HMKE was a good investment alternative for both business and residential prosumers. The easy and quick licensing and realization and the annual financial settlement are the important factors of the current rather positive market environment. The amount of energy consumed and the amount fed into the system are calculated only once a year, and only the balance has to be financially settled under this type of regulation. It is a very important argument for this type of investment that it is not necessary to create 15-min energy production forecasts. It was clearly visible (Table 9) that the HMKE PV investment payback period for residential customers was 12 years without any financial support, and for the business prosumers, it was much less: only 4 years. The internal rate of return for business prosumers was relatively high: 31.3% and for residential prosumers: 7.7%. (Table 9).

Table 9. The overall investment-efficiency indices for the HMKE regulations in 2020.

Content	Values	
Studied investment period (years)	15	
Studied PV economic environment	HMKE	
Type of prosumer	residential	business
Average system size (kWp)	5	15
Value-added tax	gross	net
Investment costs, 2020 (€)	4535	7985
Negative cash flow ($C_{O\&M,total}$ + Demolition fee), net (€)	3619	3232
Positive cash flow, (€)	12,066	47,636
Net present value (NPV) (€)	2088	27,211
Internal rate of return (IRR) (%)	7.7	31.3
Discounted payback period (DPP) (year)	12	4

Installing an HMKE system for a business prosumer is a really good investment if the business is calculating in net amounts since the value-added tax is reclaimable. In the past, there was a financial support scheme to install HMKE systems, but in the future, the termination of this scheme is expected.

4. Conclusions

To gain more insight into small-scale power plant investments, the status of the HMKEs in Hungary was investigated within the framework of a case study with a special focus on the geographical and economic aspects.

Based on the results, the density of the small-scale power plants showed no proven relationship with any of the studied economic factors (GDP/capita, average monthly gross earnings). Nevertheless, small-scale power plants constitute a great investment alternative for business customers because the calculated discounted payback period is only four years. In contrast, such an investment is not particularly positive for residential prosumers because their discounted payback period is twelve years.

As shown by this research, in the examined regions of Hungary, an average business prosumer had 15 kW power, while an average residential one, only 5 kW. Regarding the average HMKE power relative to population, it was found that it was 437 kW/10,000 inhabitants. This means 259 kW/10,000 inhabitants residential HMKE power and 178 kW/10,000 inhabitants business power. The average HMKE density was 59 pieces/10,000 inhabitants, which means 47 residential and 12 business HMKEs/10,000 inhabitants.

In the past, there were financial support schemes (mostly interest-free loans) to install HMKEs, and these made the investments much more acceptable to the population. This may be the reason for the rapidly increasing HMKE numbers in the last few years.

The maps of the HMKE density show a big variation among the studied settlements of Hungary. The reason for these discrepancies lies mostly in the differences in social innovation and not the economic factors. For example, if in a region there is a company with a good business proposal for potential HMKE customers, the density of the HMKEs becomes bigger. In Hungary, the tourist region of Lake Balaton was one of the regions characterized by a high HMKE density. This means that the region of Lake Balaton constitutes a unique unit on its own, suggesting that natural tourist regions have a different HMKE status than other places, probably not only in Hungary but also in the whole of Europe.

The capital city, Budapest, did not have as many small-scale power plants as could be expected based on its economic status, possibly because of the lack of space (which means roof area in this context). The city has a high ratio of blocks of flats relative to detached houses. The installation of an HMKE for a block of flats requires a significant amount of cooperation and paperwork from the property owners. The highly industrialized regions, such as the northwestern border region of Hungary (Győr–Sopron), the southern area around Pécs, and the area around the cities of Debrecen and Nyíregyháza, in the east of the Great Plain, also had high HMKE densities, while the northeastern part of Hungary had almost no HMKEs compared to the other regions of the country.

According to this study, the regions with the highest small-scale power plant penetration were the tourist regions and the well-developed industrial regions, where the population density was lower than in big cities but higher than in the countryside.

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Abbreviations

The following abbreviations are used in this manuscript:

a-Si	Amorphous silicon (-)
CHP	Combined heat and power plants (-)
DPP	Discounted payback period (years)
DSO	Distribution System Operator
EU	European Union (-)
FiT	Feed-in-tariff (€/kWh)
HMKE	Household-sized power plants (-)
HEA	Hungarian Energy and Public Utility Regulatory Authority (-)
IRR	Internal Rate of Return (%)
IS	Investment supports (-)
KÁT	Renewable Energy Support Scheme until 31 December 2016 (-)
m-Si	Monocrystalline silicon (-)
METÁR	Renewable Energy Support Scheme from 1 January 2017 (-)
NPV	Net present value (€)
NS	Net metering system (-)
NUTS	Nomenclature of Territorial Units for Statistics Regions (-)
P	Power
Q	Quantity
PV	Photovoltaic (-)
p-Si	Polycrystalline silicon (-)
PVGIS	JRC Photovoltaic Geographical Information System (-)
VRE	Variable renewable energy (-)
ZP	Green Premium (-)

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