sustainability

MDPI

Article

Aspects of Determining the Energy Storage System Size Linked to Household-Sized Power Plants in Hungary in Accordance with the Regulatory Needs of the Electric Energy System

Gábor Pintér, Henrik Zsiborács * and Nóra Hegedűsné Baranyai

Renewable Energy Research Group, Soós Ernő Research and Development Center, University Center for Circular Economy, University of Pannonia, 8800 Nagykanizsa, Hungary; pinter.gabor@uni-pen.hu (G.P.); baranyai.nora@uni-pen.hu (N.H.B.)
* Correspondence: zsiboracs.henrik@uni-pen.hu

Citation: Pintér, G.; Zsiborács, H.; Baranyai, N.H. Aspects of Determining the Energy Storage System Size Linked to Household-Sized Power Plants in Hungary in Accordance with the Regulatory Needs of the Electric Energy System. *Sustainability* **2022**, *14*, 2622. https://doi.org/10.3390/su14052622

Academic Editors: Inga Zicmane, Gatis Junghans, Svetlana Beryozkina and Sergey Kovalenko

Received: 7 January 2022
Accepted: 23 February 2022
Published: 24 February 2022

Abstract: The global energy markets of the last decade have been characterized by an ever-increasing share of electric power, more than half of which is projected to come from renewable energy sources by the year 2030. Such a remarkable rise in the quantity of renewable energy, of course, will induce a series of related changes as, without the successful integration of all that unconventional type of energy into the existing energy systems, the sustainability and security of the electricity supply cannot be maintained. As a result, new legislation and energy policies are required all over the world to accommodate not only the latest technological solutions but also a variety of previously unknown market actors. In the institutions, businesses and households of Hungary, the notion of sustainability has been gaining more and more importance lately, which is manifest in the efforts to reduce the use of electricity from the public grid, which is generated by burning fossil fuel. This endeavor is facilitated by the installation of photovoltaic (PV) household-sized power plant (HMKE) systems. Currently, the Hungarian electric energy system does not possess sufficiently flexible capacities; moreover, even this capacity is expected to decrease considerably in the future due to the phasing out fossil fuel power plants. Furthermore, dynamically growing HMKE penetration means an increasing frequency of technical problems in the macroenergy system (e.g., reverse energy flow in the local grid). It is such challenges that energy storage technologies can provide a solution for. Presently, there is insufficient information available on the recommended energy storage size necessary for the efficient integration of Hungarian HMKE systems into the electric energy system and the related investment needs. The innovative novelty of this study is that it examines the quantity and power of Hungarian HMKEs in the districts of the various electric companies over time with a view of exploring a possible way of their efficient integration into the electric energy system by determining the nominal energy storage power and energy capacity of the proposed energy storage systems. In addition, the paper also presents the expected investment needs associated with these energy storage systems.

Keywords: solar energy; PV integration; energy storage; grid flexibility; Hungary

1. Introduction

1.1. The Significance of Photovoltaic Technology in the World, in the European Union and Hungary

As human-induced climate change is currently one of the greatest threats to our planet as we know it, it is no wonder that an increasing amount of research activity is devoted to deepening our scientific knowledge on it globally, while on the one hand, there are still ongoing debates about the nature and degree of its negative effects, and scientists—urged on by growing public interest—are making enormous efforts to gain more insight into these [1–3]. As an act of turning scientific theory into practical action and political will, the international community has set targets for itself to decrease greenhouse gas emissions considerably in order to keep the rise in global average temperatures below 2 °C [4–6].

Contrary to the above efforts, humanity is also faced with an endless growth of energy demand and consumption, induced by the perpetual development of technology and standard of living [7]. It is this trend and the fact that the world's supply of fossil fuels is not inexhaustible, exacerbated by the detrimental impacts of burning fossil fuels, that has triggered the transition from the traditional energy sources to new ones [8,9]. As a consequence, a range of new, renewable energy sources, such as hydro, solar, wind and biomass, whose use is considered to result in much less or zero environmental pollution, is believed to be able to replace today's common energy sources in the future [10].

Since solar energy is probably the clean energy that exists in the greatest—practically infinite —amount, it attracts the most attention [11]. Compared to other sources of renewable energy, solar energy is practical to use due to the easy availability of technologies that can turn the radiation from the sun into electric or thermal energy. Considering this, it is no surprise that the global total of solar photovoltaic capacity amounted to about 760 GW in 2020 [7]. The year 2020 also saw around 20 countries installing new PV capacities with a total of more than 1 GW each. What is more, 14 of these now have total installed capacities above 10 GW each, and 5 of them even possess more than 40 GW each. After the European Union's (EU) dominance of the list of total installed PV capacities, which ended in 2015, a considerable reordering took place among the nations with the world's top PV capacities, with China (253.4 GW) in first place, the EU (151.3 GW) in second, the USA (93.2 GW) in third and Japan (71.4 GW) in fourth place in 2020. Considering projections, it can be said that the nominal power of globally installed PV systems is expected to be in the range of 1043 GW–1610 GW by 2023 [12].

Concerning the future role of electricity production by deploying PV technologies in the European Union, there seems to be a universal agreement that it will keep growing and gain even more significance. This is also supported by the different projections that the European Network of Transmission System Operators for Electricity (ENTSO-E) has prepared. According to these, the Union's capacity to generate power by PV power plants will lie somewhere within a wide range from 378 to 875 GW by the end of the fourth decade [13]. Interestingly, the EU Reference Scenario 2016 [14] provides a significantly more conservative estimate of only 295 GW by the middle of the 21st century, while other predictions seem to be less extreme, with their numbers between 295 and 603 GW [15].

Since, according to current forecasts, it is expected that PV energy will play a major part in the energy mix of the EU by the middle of the century [16–18], it has become unavoidable to determine how great that role should be when taking all the significant factors into consideration. The decisive factors concerning the optimal proportion of variable renewable energy (VRE) range from the geographically determined climatic conditions [19–21] and the quality of the transmission system, in terms of the back-up capacity and the flexibility of the grid [22–25], to typical load performance [26–28]. In order to keep the electricity system balanced and thusly tackle the problem of uncertainty caused by the intrinsic intermittency of PV technology, the electricity grid needs to be made more flexible by updating it, which can be achieved by utilizing the back-up potentials of integrated storage facilities that can smooth out the peaks and valleys of electricity production [19,20,29].

According to the Hungarian Transmission System Operator's (MAVIR) forecast regarding fossil fuel power stations and the use of nuclear energy, it is expected that power plants using fossil fuels will become less in important, while there will be an increase in the use of the latter [30]. This predicts a decrease in the flexibility of the Hungarian electric energy system. What is more, it is not only the thusly lost flexibility capacity that needs replacing; the regulatory ability needed for the newly installed VRE generation capacities has to be created as well. In other words, while a significant decrease is expected in the regulatory capacities in Hungary in the near future as a result of the phasing out of the fossil fuel power plants, the growing PV power plant capacity calls for an increasing amount of regulation. Furthermore, among the variable renewable energy sources, it is PV technologies whose use is expected to grow dynamically by the market, and it is believed that the total PV power plant capacity may reach 6 GW by 2030, a considerable growth from the 1.3 GW in 2019 [30].

Individual governments have devised greatly differing systems to promote the deployment of green energy in their respective countries. Moreover, these systems tend to be modified year by year, so country-specific changes are difficult to follow. Information on specific countries is often outdated, even several years old [31,32]. Nonetheless, this is a dynamically developing area, which has a constantly increasing impact on the electric energy system; thus, research on Hungarian PV power plants, including the PV HMKE systems, has become unavoidable by now [33].

1.2. Challenges Associated with the Spread of Photovoltaic Technology

It is only natural that the present infrastructure needs to undergo substantial changes if it is to accommodate a higher ratio of variable renewable energy sources (VRES), such as wind and PV energy. The intermittent nature of these sources means that it is difficult to provide reliable forecasts for them [34], making the provision of the appropriate amount of energy that can meet demands at the right time a considerable challenge [35–37] and thusly jeopardizing the balance of any energy system with a high proportion of VRES [38]. Under the new conditions, the solution to the problem of making sure that the operational parameters of the power system remain between the required values involves making changes in the grid and/or its use patterns. Today, the most widespread method of dealing with the discrepancies in supply and demand is to use traditional, dispatchable sources of energy to compensate for the power deficit at times of low energy generation from VRES on the one hand and decreasing the production of power when there is an excess of VRES energy on the other hand [39–41]. The increased pace of the spread of VRES in the world's energy systems, however, means that these issues will have to be solved in other ways to support the energy transition [42].

The imperative of guaranteeing stable energy supplies in spite of the drastically changing environment puts an enormous pressure on network managers [43]. The rising proportion of VRES in the energy mix, together with new energy consumption patterns, indicates a growing need for grid balancing. Not only is the electrification of numerous sectors an ongoing trend today but, thanks to today's prolific smart solutions, consumers can also control their consumption to an unprecedented degree, with more and more of them producing electricity themselves, thusly becoming so-called prosumers. As for grid balancing solutions, despite the fact that there are quite a number of them, practically only two can be described as common: electricity production by burning natural gas and pumped hydro storage (PHS), both of which raise further issues. Natural gas is not only mostly imported to the European Union; it is also a fossil fuel, the use of which counters environmental efforts. Concerning PHS technology, it must be stated that, besides its inherent environmental risks, it is not available in many locations, as it is extremely limited by geographical conditions. In the Alps of Europe, for example, where most of the continent's PHS potential is found, a significant amount of the storage capacity is already utilized for balancing energy generation from VRES [44,45]. In Hungary, the object of this study, the development of PHS systems is not to be expected due to their significant area requirements and the unique geographic conditions [46]. In the future, it is the need for electrochemical and chemical storage technologies that will become crucial [33].

With regard to the above and the problems facing today's networks, as well as power plants caused by the combined use of VRES and conventional base load power plants for electric energy production, it seems that more viable solutions are needed for the future. One answer to the problem could be storing the superfluous amount of energy produced during times of excess energy generation from VRES and using it when there is an appropriate demand due to altered weather conditions. Integrating storage facilities in distribution networks with VRES power plants is also necessary to prevent bidirectional flows, which are a threat to the quality of the electricity supply, resulting in additional costs for system operation. Additional storage capacities are also required when electricity-generating plants are linked to distribution systems rather than transmission networks.

Another characteristic of today's energy system is the trend of decentralization, facilitating the emergence of microgrids of communities that produce electricity. On the one hand, such communities have the potential to be independent from national electricity networks, but, on the other hand, decentralized electric energy production from VRES cannot be absolutely reliable unless it is complemented with some solution for balancing. It is important to state here, however, that regardless of the challenges enumerated above, the deployment of decentralized electricity generation and the utilization of the appropriate storage capacities are generally considered to be conducive to enhancing energy independence and the general sturdiness of the entire energy system [47–50]. Consequently, it is not surprising that the integration of VRES, especially that of PV energy, is seen as crucial for both the sustainability of the energy supply and its security in the European Union, so the problems of balancing the networks are often the focus of research and development nowadays.

1.3. EU Policy in the Making and Developments in the EU Energy Storage Market

According to the Energy Union strategy, the European Union's vision for its energy future can be best summarized by listing its five mutually reinforcing pillars, called dimensions by the strategy itself. The most fundamental one that the whole system is based on is the pillar of trust, solidarity and energy security. The second item on the list is a continent-wide, wholly integrated energy market. The third dimension names energy efficiency as a factor that contributes to the decreasing energy demand. The decarbonization of the economy is the fourth one, while the final, fifth pillar is that of research and innovation together with competitiveness [51]. As the achievement of the above goals is difficult to imagine without increasing the weight of VRES in the European energy mix, storage systems are bound to play a crucial part in the process, since it is envisaged that the grids of the future will have to be more flexible than those of the present. If the European Union is to retain its leading role in the field of storage technologies, it is obvious that it needs to intensify the related scientific and technological development efforts—all the more so because new advances in the industry may create new opportunities in general, and more employment in particular. Notwithstanding the above, it must not be forgotten that energy storage is not the only method of enhancing the electricity system's flexibility. Other solutions include interconnections, the use of flexible electricity production units and demand side management. On the other hand, there is also a wide range of possibilities in the field of flexibile storage, which also needs to be kept in mind and considered during the process of developing the capacity markets of Europe. The advantage of using energy storage technologies is that they can benefit the transmission and distribution networks by ensuring higher degrees of reliability, stability and resilience of the power supply. As a consequence, it can also prevent spending resources on transmission and distribution infrastructure development by rendering it unnecessary. At present, energy storage solutions are not commonly utilized by national network operators, and it is sometimes proposed that other actors should be provided with access to storage technologies within the frameworks of new business models, meaning that not only grid operators but also industrial and even residential customers could invest in and make use of energy storage services [51].

In terms of legal regulation, energy storage in the European Union in the future will be greatly determined by Regulation (EU) 2019/943 on the internal market for electricity, which is an an essential constituent of the EU's Clean Energy Package. The document redefines the role of consumers in the electricity market by assigning greater significance to demand-side response as well as energy storage. The regulation also facilitates the emergence of power systems that are not only more flexible but can successfully cope with both a higher level of renewable energy penetration and an endlessly rising demand for energy, simultaneously [52]. As the European Union has set itself a laudable goal to achieve carbon neutrality by the middle of the 21st century [53], it is obliged to support the speedy spread of technologies involving renewable energy, which prompts further electrification and the quest to meet the constantly growing demand for energy storage. Under this new regulation, balancing the markets requires, on the one hand, an unprecedented openness of the whole system towards various actors in the market and, on the other hand, towards new and novel technical solutions in connection with the generation and storing of electricity, demand-side response and the integration of different storage facilities into the systems. It is interesting to note that the new regulation does not regard energy storage to be realizable only by reconverting stored energy into electricity but also through other forms of energy. As the distribution system operators (DSOs) are compelled by the new policy to integrate elements of the electricity network, including VRES and decentralized power generation, into an effective colloboration with new, higher-level, transmission system operators (TSOs), these systems have also become indispensable [52,54].

Objectives and Measures in Hungary related to Flexible Energy Generation and Energy Storage

In accordance with the energy strategy of the EU, the Hungarian Ministry of Innovation and Technology produced a National Battery Industry Strategy 2030 [55], in which it set down the objectives and measures related to flexible energy generation and energy storage that can create a base for the creation and spread of Hungarian energy storage systems. Concerning climate-friendly and flexible electric energy generation in Hungary, several goals have been set:

- Promoting electrical energy production from renewable sources;
- Improving the cost-efficiency of renewable investments;
- Enhancing the security of supply and system control;
- Ensuring the cost-efficiency of transmission and distribution network flexibility demand;
- Preparing the power grid for the cost-efficient integration of decentralized capacities;
- Replacing energy generation from fossil fuels with low-carbon-intensity electrical energy production [56].

In order to meet transmission and distribution network flexibility demands in a cost-efficient way, the following measures have been formulated concerning battery systems:

- Supporting the appearance of new types of flexibility services in the market by encouraging energy storage investments and the mobilization of the possibilities of demand-side regulation;
- The simplification of the licensing process and regulatory market accreditation of energy storage facilities;
- The creation of regulatory products that can utilize the technical capabilities of energy storage facilities better;
- Supporting innovation in seasonal energy storage;
- Including the highly developed demand-side intervention possibilities in system-level regulation;
- Introducing a separate product for flexible consumption in the market of system-level services;
- Supporting virtual generation integration, local energy communities and microgrid solutions;
- Facilitating the deployment of renewable energy sources and energy storage facilities on the same premises by regulatory tools [56].

1.4. An Outline of the Hungarian Regulations Pertaining to PV Systems

The beginning of the 21st century has seen the use of renewable sources of energy spreading at a speed higher than ever before all over the world, with nations developing specific schemes to promote them [31]. These supporting systems, however, constantly vary to a great degree depending on not only geographical location but also the current level of development prevalent in the particular countries and the state of the art of renewable technologies [32].

Hungary is, of course, no exception and it has also created its own system of schemes. An essential part of this is the mandatory off-take system, commonly referred to as the Hungarian acronym KÁT [57], which is meant to encourage the production of electric energy using renewable energy sources and waste. Under the KÁT system, electricity is sold [58] at a legally regulated price, higher than that prevailing in the market. The most essential characteristic of this scheme is that it only provides support to producers of electricity during the payback period. This is achieved by clearly defining the period during which they are eligible and the eligible amount of electric energy. Should the producer be granted any other support, the eligible period is decreased proportionally. The KÁT scheme was only available in Hungary for applications made prior to 1 January 2017 [59]. The same date, 1 January 2017, saw the launching of the Renewable Energy Support Scheme (METÁR) [60] in Hungary. One of the conditions for receiving support under this new scheme is that the realization of the project must not begin before the date of submitting the application [61]. A further characteristic of METÁR is that it only supports the use of renewable energy, meaning that power stations that use waste and/or mixed materials as fuel are only given support proportionate to the renewable sources of energy that they utilize in their operation. It must be noted here that HMKE systems whose power does not exceed 50 kW (fed into the grid) constitute a special category in the METÁR system, as they are excluded from benefitting from it. Another prerequisite for being granted support in this scheme is that applicants must receive green-premium-type eligibility in the course of the application process. Beneficiaries of the support are obliged to sell the electricity they produce themselves via MAVIR. In addition, they also have to pay for the expenses associated with any deviation from the 15 min power generation schedule [62]. Although the METÁR scheme was launched in 2017, it was not until the autumn of 2019 that the first call for applications by the Hungarian Energy and Public Utility Regulatory Authority (MEKH) appeared [63]. The overwhelming majority of the submitted applications were related to PV projects [64]. The beneficiaries of the METÁR support are entitled to be paid the selling price according to their proposal for 15 years, annually indexed to the inflation rate minus one percentage point, after signing an agreement with MAVIR. The reason for applying an indexing mechanism below the inflation rate is justified by the projected advances in technology that are expected to keep the rise in operating costs below the inflation rate [63].

Small power plants are characterized by the fact that they produce energy for their own consumption, and their power is over 50 kW. They can be classified into two groups:

- The first one includes small power plants that generate electric energy solely for their own use. These power plants are equipped with protection against backfeeding. This protection ensures that no power is fed back into the grid from the PV system, i.e., the PV system only feeds power into the consumer network up to the level of the current consumption. This, however, leads to the problem that the amount of generated energy exceeding their own consumption is not utilized if there is no energy storage installed at the small power plant.
- The second category comprises those small power plants that also feed energy into the grid as well as producing it for their own consumption. The latter solution is not very common in Hungary because of the bureaucracy that is required in connection with it and the lower electricity purchase price compared to other solutions [65,66].

An HMKE is a power plant whose power is below 50 kW, and it is owned either by a private person, a business or an institution. Their characteristic feature is that, besides their own consumption, they feed into the grid a voltage not higher than 1 kV (low-voltage network) without having to keep a schedule, and they have an annual account settlement obligation. The owners or operators have to settle the difference between the consumption and the energy generation with the electric energy service company (in the event of overconsumption, they have to pay for the difference between the energy consumption and production, while in the case of overproduction, the electricity service company has to pay the purchase price of the balance). In Hungary, the size of an HMKE system is mostly designed to cover their own consumption due to the fact that the electric energy from the grid is more expensive than the selling price one can receive for the energy produced. The present system can be regarded basically as a kind of free energy storage thanks to the annual account settlement. Surplus power generated by the PV system that is not needed at a precise moment can be fed into the grid free of charge and can be 'retrieved' according to consumption demand, also free of charge. However, with the rise in the number of HMKEs, it is becoming increasingly difficult for the network to fulfill this role of a free energy storage facility [65,67]. The increasing pace at which HMKEs are spreading in Hungary is to a great extent thanks to the fact that since 2013, Hungarian state institutions (e.g., hospitals, kindergartens, schools, places of accommodation) have been granted 60–100% nonrefundable project funding [68], and since 2021, even residential clients have been able to apply for 100% nonrefundable funding [69]. Due to the significant spread of PV HMKE systems, it has become unavoidable to prepare studies regarding the districts of the various Hungarian electric companies as well. Although internationally, one can encounter a significant amount of research that presents country-specific information (e.g., [46,70,71]), the topic of Hungarian HMKEs is still a less-investigated area at present; however, its deeper examination is becoming more and more necessary for the efficient integration of PV technologies into the electric energy system.

2. Materials and Methods

The goal of this study was to establish the quantity and power of Hungarian photovoltaic HMKEs in the districts of various electric companies while also exploring a possible way to efficiently integrate them into the electric energy system by determining the nominal energy storage power and energy capacity of the energy storage systems recommended to be used with them. These figures were not determined only for the period between 2013 and the third quarter of 2021 but also for 2025. Furthermore, the paper also presents the expected magnitude of the necessary investments associated with the energy storage systems. In order to achieve these goals, the electric company districts, the databases used and the methods relevant for the research are all described herein.

2.1. The Districts of the Hungarian Electric Companies and the HMKE Database

In 2021, six regional electric companies, whose names and locations are shown in Figure 1, were responsible for the HMKE systems of Hungary [72].

In the third quarter of 2021, the Hungarian Energy and Public Utility Regulatory Authority (MEKH) published a database that contains the figures of the Hungarian HMKE systems broken down into electric companies. The document provides information on the utilized energy sources at the level of the electric companies from 2008 to the third quarter of 2021. The reason why this paper focuses on examining PV HMKEs is that this is the dominant technology in this market segment [73]. Table 1 illustrates that the share of PV technology in the total HMKE capacity in Hungary was 99.8% in the third quarter of 2021.

Although the database would have allowed an analysis starting from 2008, the research project carried out deeper analyses only with data from after 2013. The spread of the use of the technology was slow-paced at the beginning and it was not until 2013 that the proliferation of HMKE systems gained more momentum. This was because that was the time when the period was marked by an increased availability of support schemes with more funds and 60–100% nonrefundable grants. The trend of capacity changes is well-illustrated by Figure 2 [68,69].

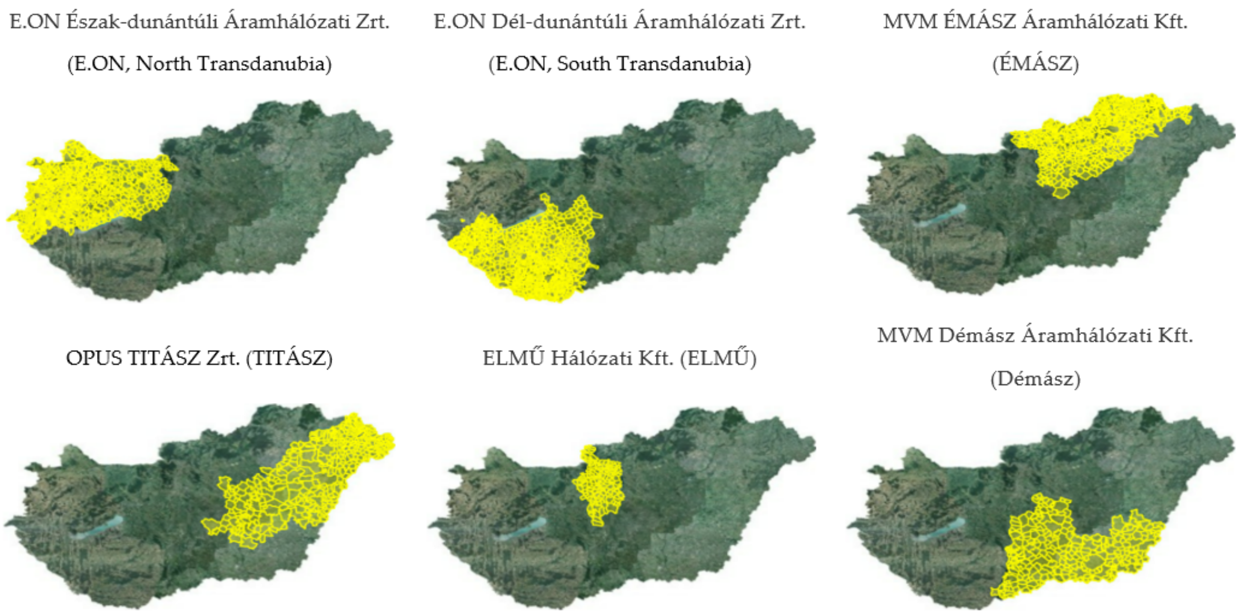

Figure 1. The districts of the Hungarian electric companies in 2021, based on [72].

Table 1. Total HMKE capacities in Hungary by energy source Q3 2021, based on [73].

	Year: Q3 2021	
Technology	**Total Power of Power Plants (kW)**	**Percentage of Total Power of Power Plants (%)**
PV	1,022,522	99.78
Wind	1164	0.11
Natural gas	497	0.05
Thermal methane	274	0.03
Biogas	120	0.01
Water	109	0.01
Biomass	70	0.007
Other	40	0.004
Diesel	7	0.001
Total	**1,024,803**	**100**

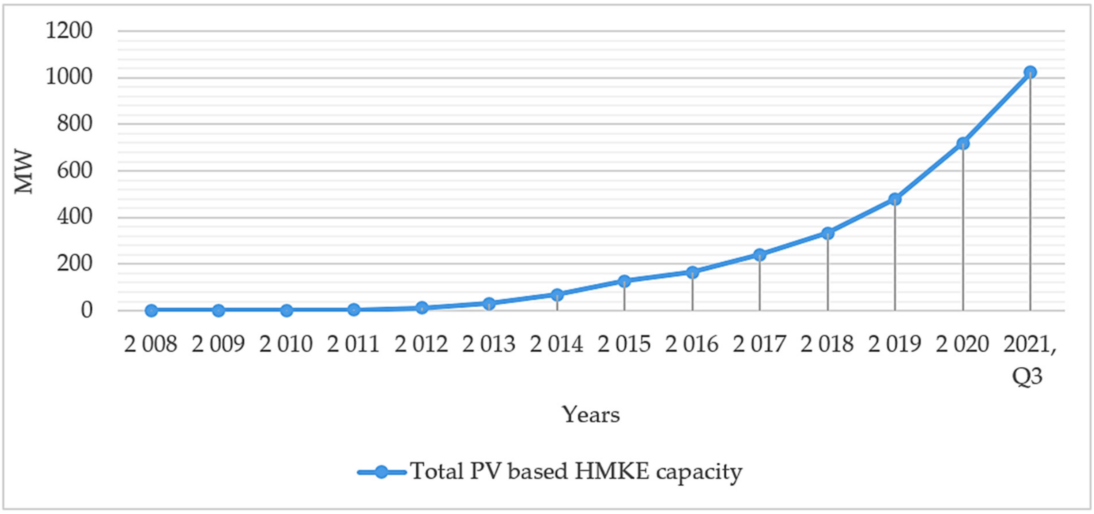

Figure 2. Changes in the capacity of household-sized PV power plants between 2008 and Q3 2021, based on [73].

The information on integrating PV HMKEs into electric energy systems concerning energy storage systems, which is elaborated on in the results section, is based on the recommendations of MVM Partner Energiakereskedelmi Zrt. (MVM Partner Zrt.). MVM Partner Zrt. is Hungary's most significant Hungarian-owned electric power company (MVM Group), the only electricity wholesaler and a decisive actor in the Hungarian energy market as a result of its dynamic development [74].

The figures of the investment needs of the energy storage systems were determined for 2021 and 2025 based on the document Technology Pathways in Decarbonisation Scenarios published by the European Commission [75]. The document [75] presents the future investment and operational costs for several technologies. This paper based its calculations on the category of large-scale batteries and considered the expected changes in investment costs to be linear between 2015 and 2030.

2.2. The Database of the Examinations

The database of the examinations was made available by the Hungarian Energy and Public Utility Regulatory Authority (MEKH) [73]. As mentioned earlier, time series data are available from 2008 onwards. The analyses herein encompass the period of 2013–2021 and concern the quantity and capacity of household-sized PV power plants as well as the energy storage power and energy capacity of the energy storage systems recommended for the PV HMKE capacities derived from these.

2.3. Statistical Methods Used in the Study

The goal of the research was the application of a well-known statistical method in the context of the examined problems so that it could present the recommended size of the energy storage systems for the efficient integration of HMKEs in Hungary, in a way that is comprehensible to a wider audience.

Time series show the development of social and economic phenomena as a function of time. One of the components of a time series is the trend that represents the basic direction, i.e., the direction and rate of the development, of the time series. In this paper, the sustained trend of the time series was determined with the help of analytical trend calculation. The analytical trend was determined by the method of least squares. The character of the evolution of the time series determines which function type (linear, exponential, hyperbolic, polynomial, logistic) is used [76]. The polynomial trend function is used when the data fluctuate, in which case the trend is characterized by a curved line. (Equation (1)).

$$y_t = \beta_0 + \beta_1 + \beta_2^2 + \cdots + \beta_{\mathrm{p}}^p + \varepsilon_t, \quad (1)$$

In the case of an analytical trend, time is the independent variable, while the dependent variable is some stochastic process taking place in time. In the function, β_0, β_1 and β_p are parameters, and ε_t is the random factor. R^2 is the coefficient of determination, which takes a value from 0 to 1. It shows how far the values of the trend are from the values of the time series. The closer the R2 value is to 1, the more closely the trendline fits the time series. Any value in the trend can be calculated by substituting the t value in the estimated equation (t = 1, 2, 3 . . . n). This was also used in the projection of the time series. The prediction assumes that the past trend will also continue in the future; however, the prognosis must not lack appropriate corroboration either. The verification of the projections of the time series could be performed with the knowledge of the factual data [76]. The analysis began with the selection of the trend function that fit the time series the best, which was the polynomial-of-degree-five trend in every case, which was followed by the preparation of the forecast for 2025. The use of the statistical method applied in the study was justified by the fact that the official development forecasts published by the Hungarian TSO [77] had significantly underestimated the pace of the spread of HMKEs. For example, in the case of the total HMKE capacity of 718 MW reached in the year 2020 [73], they had only predicted 74% of the actual figure [77]. Therefore, it is an important task to realistically assess the expected spread of HMKE systems. During the evaluation of the HMKE data forecasted by the applied statistical forecasting method, the practical feasibility was also taken into account, just like the assumption that the trend witnessed in the past would continue in the future as well. This is considered plausible for a number of reasons. On the one hand, the population still has access to sources with significant amounts of funding [69], while on the other hand, a new regulatory environment is going to emerge [78]. Being aware of this information makes it possible to understand the magnitude of the challenges awaiting the Hungarian electric energy system caused by PV HMKE solutions.

The projections regarding the total quantity and capacity of PV HMKEs in 2025 in this study were based on a trend function. Nevertheless, for the prognoses for the individual electric companies, it was necessary to calculate the averages of their shares for the period between 2017 and Q3 2021, for which the forecast prepared for the national level was multiplied to predict the quantity and capacity of PV HMKEs for the individual companies as well.

3. Results

3.1. The Analysis of the Database of the PV HMKEs Belonging to the Districts of the Hungarian Electric Companies

The results first demonstrate the changes in the quantity and capacity of PV HMKEs, as shown in Figures 3 and 4 as well as in Tables 2 and 3. The number of PV HMKEs rose by 47.5% yearly on average nationwide between 2013 and 2021 (Figure 3). This figure shows minor variations in the districts of the different electric companies. Overall, it can be stated that significant quantitative increases were observed in the district of each service company, as follows:

- E.ON, North Transdanubia 49.2%;
- E.ON, South Transdanubia 47.7%;
- TITÁSZ 44.5%;
- ELMŰ 46.3%;
- ÉMÁSZ 50.1%;
- Démász 48.4%.

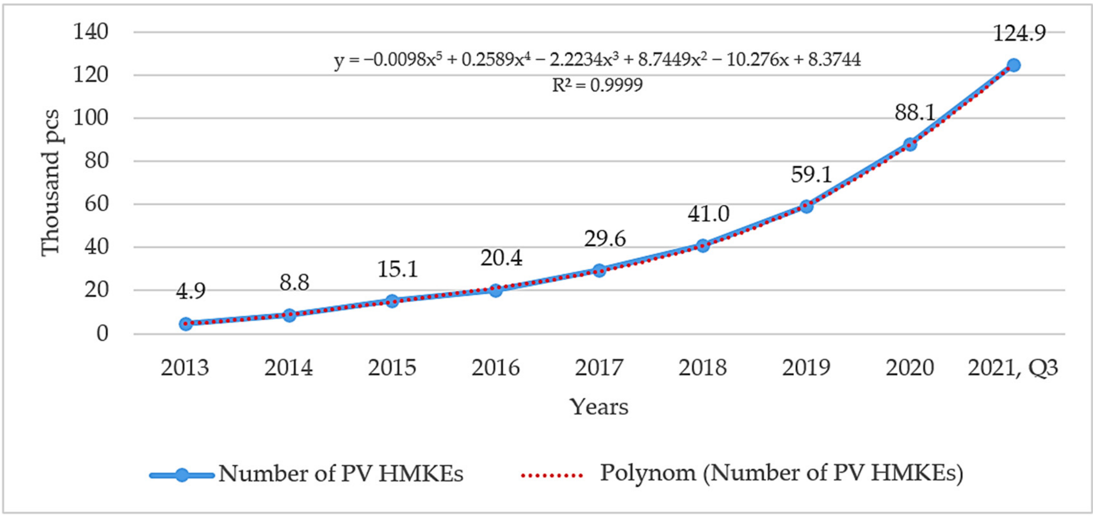

Figure 3. The changes in the number of PV HMKEs in Hungary between 2013 and Q3 2021.

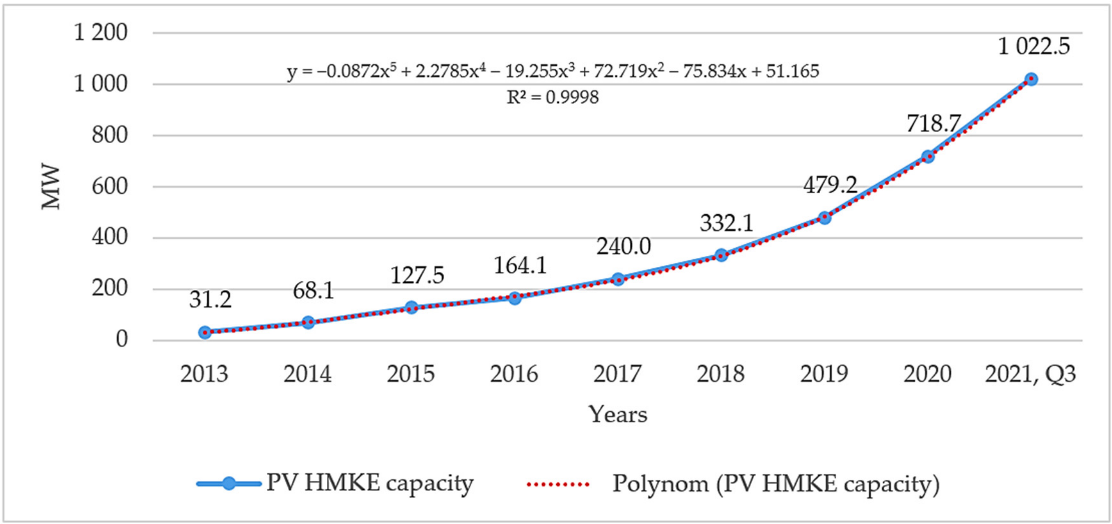

Figure 4. The changes in the capacity of PV HMKEs in Hungary between 2013 and Q3 2021.

Table 2. The number of PV HMKE systems in the past and projections for the future (thousand pieces).

Electric Company District	2013	2014	2015	2016	2017	2018	2019	2020	Q3 2021	2025
E.ON, North Transdanubia	1.0	1.7	3.0	4.0	6.2	8.5	12.6	19.2	27.5	50.6
E.ON, South Transdanubia	0.7	1.3	2.5	3.3	4.9	6.5	9.5	14.3	18.9	37.0
TITÁSZ	0.8	1.5	2.5	3.1	4.6	5.9	8.4	12.8	17.7	33.8
ELMŰ	1.3	2.1	3.2	4.6	6.8	10.0	14.0	19.3	28.7	53.9
ÉMÁSZ	0.4	0.8	1.6	2.1	2.8	4.0	5.8	9.3	13.2	24.1
Démász	0.6	1.4	2.3	3.2	4.2	5.9	8.7	13.2	19.1	35.0
Total	**4.9**	**8.8**	**15.1**	**20.4**	**29.6**	**41.0**	**59.1**	**88.1**	**124.9**	**234.4**

Table 3. The capacity of PV HMKE systems in the past and projections for the future (MW).

Electric Company District	2013	2014	2015	2016	2017	2018	2019	2020	Q3 2021	2025
E.ON, North Transdanubia	6.3	11.8	22.4	28.2	45.9	63.3	93.6	146.0	212.5	353.7
E.ON, South Transdanubia	4.6	9.3	20.5	25.7	39.4	52.5	77.0	114.5	150.9	273.6
TITÁSZ	6.4	14.0	25.3	29.9	43.8	56.0	78.8	118.2	158.2	286.8
ELMŰ	5.8	13.5	22.5	31.5	46.5	70.3	99.2	140.0	212.5	358.3
ÉMÁSZ	2.6	6.5	13.9	18.3	24.5	34.1	49.6	79.3	112.8	189.3
Démász	5.4	13.0	23.0	30.5	39.8	55.8	81.1	120.7	175.6	298.0
Total	**31.2**	**68.1**	**127.5**	**164.1**	**240.0**	**332.1**	**479.2**	**718.7**	**1022.5**	**1759.6**

The capacity of PV HMKEs rose by 50.1% yearly on average nationwide between 2013 and 2021. This figure showed a significant growth in the district of every electric company, as follows:

- E.ON, North Transdanubia 52.5%;
- E.ON, South Transdanubia 51.3%;
- TITÁSZ 44.6%;

- ELMŰ 52.1%;
- ÉMÁSZ 51.3%;
- Démász 48.5%.

In Figures 3 and 4, a polynomial was placed on the time series of the quantity and capacity of HMKEs from 2013 to 2021, which is indicated by the dotted lines. As can be seen, the trend functions fit the time series very closely (R^2 = 0.9999 and 0.9998, respectively).

As the trend functions gave close fits ($R^2 > 0.99$), it was also possible to make projections for 2025, which are presented in Tables 2 and 3. Regarding the reliability of these projections, the present and expected future energy policy measures, such as the significant sources of funding that households can apply for, for their investments [69], as well as for the new regulatory environment, which has already been announced but will only be implemented in the future [78]. It was established that, if past trends continue, by 2025 the number and capacity of HMKEs in Hungary will reach a total of 234,352 pieces and 1759.6 MW, respectively. A significant growth is to be expected in terms of both quantity and capacity in the district of each service company:

- E.ON, North Transdanubia 50,588 pcs, 353.7 MW;
- E.ON South Transdanubia 37,046 pcs, 273.6 MW;
- TITÁSZ 33,794 pcs, 286.8 MW;
- ELMŰ 53,877 pcs, 358.3 MW;
- ÉMÁSZ 24,055 pcs, 189.3 MW;
- Démász 34,992 pcs, 298.0 MW (Tables 2 and 3).

3.2. The Energy Storage Power, Energy Capacity and Investment Requirement Figures of the Energy Storage Systems Recommended for the PV HMKE Systems Belonging to the Districts of the Hungarian Electric Companies

Concerning the battery strategy approved by the Government of Hungary, the MVM Group has formulated several necessary measures with technical aspects whose purpose is to ensure adequate reserve capacities in the market of system-level services [74]. The necessary measures concern the following areas in order of priority:

1. Installing large-scale (grid-size) energy storage systems in order to ensure balancing regulation;
2. Nonresidential solar power plants;
3. Residential solar power plants (HMKE).

Based on the proposals of the MVM Group regarding the integration of PV HMKEs into the electric energy system, it can be stated that:

- PV HMKE systems cannot be actively restricted, i.e., the inverters used in these systems are not able to limit backfeeding into the grid. This is why a PV capacity of 1 MW causes a reserve requirement of 0.6 MW in the system. This means that, proportionate to the realization of PV HMKE systems, energy storage facilities are necessary at least in a ratio of 60%, i.e., 6 kW of energy storage power for every 10 kW in a residential PV system [74];
- The recommended discharge time for energy storage devices is approximately 3 h [74]. In the case of energy storage equipment with an energy storage power of 6 kW, this means a nominal energy capacity of 18 kWh.

This study took the recommendations of the MVM Group, a dominant actor of the Hungarian energy market, into consideration while analyzing the database of PV HMKE systems and the forecasts. The discharge time of the energy storage systems was determined as 3 h. Figures 5 and 6 and Table 4 display the nominal energy storage power and energy capacity of the proposed energy storage systems, whose values for Q3 2021 were 613.5 MW and 1840.5 MWh, respectively.

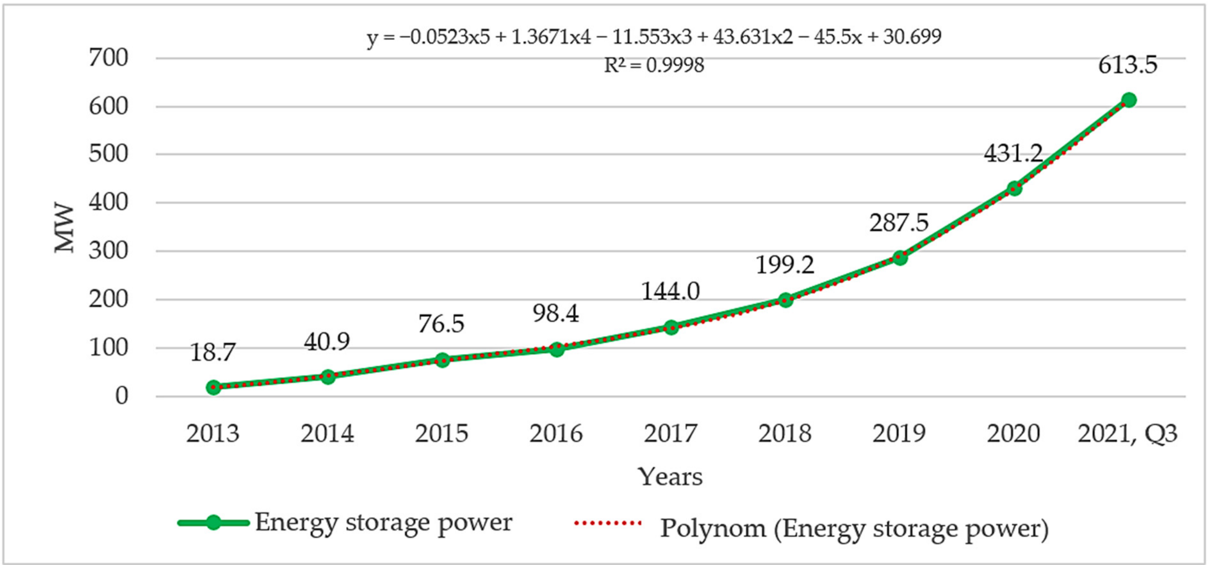

Figure 5. The nominal energy storage power of the energy storage systems recommended for the PV HMKE capacity up to Q3 2021.

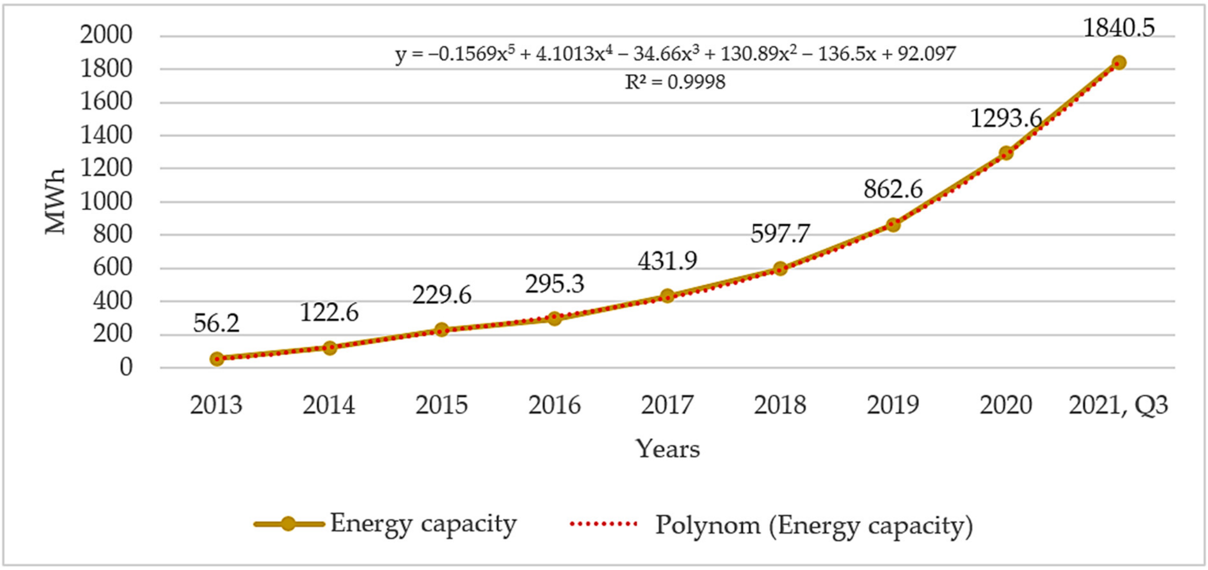

Figure 6. The energy capacity of the energy storage systems recommended for the PV HMKE capacity up to Q3 2021.

Provided the trends of the past continue in the future as predicted by the prognosis prepared for 2025, the nominal energy storage power requirement recommended for the PV-based HMKE capacity will rise to 1055.8 MW, while the energy capacity necessary for the energy storage facilities will increase to 3164.6 MWh.

A significant increase is expected both in the nominal energy storage power and the energy capacity of the energy storage systems in the district of every service company:

- E.ON, North Transdanubia 212.2 MW, 636.1MWh;
- E.ON South Transdanubia 164.2 MW, 492.1 MWh;
- TITÁSZ 172.1 MW, 515.7 MWh;
- ELMŰ 215.0 MW, 644.3 MWh;
- ÉMÁSZ 113.6 MW, 340.4 MWh;
- Démász 178.8 MW, 536 MWh (Table 4).

Table 4. The energy storage power and energy capacity of the energy storage systems recommended on the basis of the past and projected capacities of the PV HMKE systems up to 2025.

Electric Company District	**Parameter**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Q3 2021**	**2025**
E.ON, North Transdanubia	energy storage power (MW)	3.8	7.1	13.4	16.9	27.5	38.0	56.2	87.6	127.5	212.2
	energy storage energy capacity (MWh)	11.3	21.2	40.3	50.7	82.6	114.0	168.5	262.7	382.4	636.1
E.ON, South Transdanubia	energy storage power (MW)	2.8	5.6	12.3	15.4	23.6	31.5	46.2	68.7	90.5	164.2
	energy storage energy capacity (MWh)	8.3	16.7	36.9	46.2	70.9	94.4	138.5	206.0	271.6	492.1
TITÁSZ	energy storage power (MW)	3.9	8.4	15.2	18.0	26.3	33.6	47.3	70.9	94.9	172.1
	energy storage energy capacity (MWh)	11.6	25.2	45.5	53.9	78.9	100.7	141.9	212.8	284.8	515.7
ELMŰ	energy storage power (MW)	3.5	8.1	13.5	18.9	27.9	42.2	59.5	84.0	127.5	215.0
	energy storage energy capacity (MWh)	10.5	24.4	40.5	56.7	83.7	126.6	178.5	252.0	382.5	644.3
ÉMÁSZ	energy storage power (MW)	1.6	3.9	8.3	11.0	14.7	20.5	29.8	47.6	67.7	113.6
	energy storage energy capacity (MWh)	4.7	11.7	25.0	33.0	44.1	61.4	89.3	142.7	203.1	340.4
Démász	energy storage power (MW)	3.3	7.8	13.8	18.3	23.9	33.5	48.6	72.4	105.4	178.8
	energy storage energy capacity (MWh)	9.8	23.5	41.4	54.9	71.6	100.5	145.9	217.3	316.1	536.0
Total	**energy storage power (MW)**	**18.7**	**40.9**	**76.5**	**98.4**	**144.0**	**199.2**	**287.5**	**431.2**	**613.5**	**1055.8**
	energy storage energy capacity (MWh)	**56.2**	**122.6**	**229.6**	**295.3**	**431.9**	**597.7**	**862.6**	**1293.6**	**1840.5**	**3164.6**

Nowadays, it is only on a case-by-case basis that investors choose to have energy storage units installed in the macroenergy system because of PV-based HMKE systems [79]. Thanks to the annual account settlement system under the present legal regulations, the current practice is that the clients use the public low-voltage network basically as a free energy storage facility [65,67]. This part of the regulation, however, will change from 1 January 2024, and the balance settlement system will be replaced by gross settlement [78]. The market expects the gradual spread of energy storage units [80] thanks to the new regulatory environment [78] and that the funding schemes available in 2021–2022 will already have included the new mode of settlement as a mandatory obligation [69,81]. According to the estimates of the Technology Pathways in Decarbonisation Scenarios document published by the European Commission [75], the investment cost of large-scale battery systems was EUR 461 200/MWh in 2021, while by 2025, this figure will decrease to EUR 368 667/MWh. Based on this information, it can be assumed that meeting the reserve requirement recommended for the entire PV-based HMKE capacity, which can be achieved by new energy storage systems, would necessitate investments in the range of EUR 849–1167 million until 2025. These figures are shown in Table 5 for each power supply district. Based on the assumed investment prices for 2021 and 2025 and the installed PV HMKE power, the percentage distribution of costs among the electric company districts would be as follows:

- E.ON, North Transdanubia 20.8% (2021), 20.1% (2025);
- E.ON, South Transdanubia 14.8% (2021), 15.5% (2025);

- TITÁSZ 15.5% (2025), 16.3% (2025);
- ELMŰ 20.8% (2021), 20.4% (2025);
- ÉMÁSZ 11.0% (2021), 10.8% (2025);
- Démász 17.2% (2021) 16.9% (2025).

Table 5. The estimated investment requirement of the energy storage systems recommended for the PV HMKE systems based on the European Commission's forecast.

Electric Company District	Parameter	Q3 2021	2025
E.ON, North Transdanubia	energy storage energy capacity (MWh)	382.4	636.1
	energy storage estimated investment cost (million EUR)	176	235
E.ON, South Transdanubia	energy storage energy capacity (MWh)	271.6	492.1
	energy storage estimated investment cost (million EUR)	125	181
TITÁSZ	energy storage energy capacity (MWh)	284.8	515.7
	energy storage estimated investment cost (million EUR)	131	190
ELMŰ	energy storage energy capacity (MWh)	382.5	644.3
	energy storage estimated investment cost (million EUR)	176	238
ÉMÁSZ	energy storage energy capacity (MWh)	203.1	340.4
	energy storage estimated investment cost (million EUR)	94	125
Démász	energy storage energy capacity (MWh)	316.1	536.0
	energy storage estimated investment cost (million EUR)	146	198
Total	**energy storage energy capacity (MWh)**	**1840.5**	**3164.6**
	energy storage estimated investment cost (million EUR)	**849**	**1167**

4. Discussion

The concept of sustainability plays an ever-increasing role in supplying energy for the world, which brings the successful integration of VRES, i.e., solar and wind energy, into the energy supply system more and more to the fore. The European Union (EU) has set a target of a 55% reduction in greenhouse gases compared to 1990 by 2030, which requires the member states to increase the share of solar and wind energy in their energy mix. However, in order to achieve these imposed goals, very important conditions must be met:

- The electricity system needs to be able to flexibly adapt to intermittent energy generation and to the increases and decreases in market supply.
- Adequate spare capacities are also required for periods when, due to weather conditions, energy production from VRES is insufficient.
- It is important to take into account that, even in the case of a smaller penetration, as in the present circumstances, the overall network is expected to accommodate an increasing amount of VRES in the future, which will lead to a growing number of technical problems in the macroenergy system.
- The use of solar and wind energy is not geographically uniform, as they depend on climatic conditions. This is why reverse energy flows may also occur in local electricity networks, which should be resolved at the local level. This may even require the optimization of the electrical parameters of an entire transformer area [82].

These problems can be solved by energy storage technologies, the spread of which is becoming more and more intensive both in the European Union and in Hungary [82]. In addition, the proliferation of energy storage systems may allow PV-based HMKE systems in Hungary to be actively controlled in order to increase the stability of the electric energy system [80].

5. Conclusions

In conclusion, it can be said that the energy market is facing great challenges both in the demand and the supply sides. The considerable spread of VRESs causes issues affecting electric energy systems, energy arbitrage, frequency and voltage regulation that need to be dealt with quickly. However, the technical and economic limitations of battery energy storage and regulation do not facilitate the speedy spread of the technology beyond primary regulation. The energy storage regulations currently in effect in the EU vary from country to country, but the growth in VRE capacities will result in a new regulatory and economic environment, which will assist the proliferation of energy storage technologies. According to the authors' opinion, although it is not possible to select 'the best' battery technology available in the market, the most important aspect of selection is that the technology must always be appropriate for performing the given task. Thus, different technologies will be preferred in different projects.

This research was also supported by up-to-date official documents published in Hungary, which are unknown internationally; therefore, presenting the information contained in them in English is of great importance. Additionally, it was only in Q4 2021 that one of the dominant actors of the Hungarian energy market released information related to the necessary integration of PV HMKEs into the electric energy system, including the PV HMKE reserve need, according to which a PV capacity of 1 MW results in a reserve requirement of 0.6 MW. This piece of information allowed us to determine, for the entire area of Hungary, the total nominal energy storage power and energy capacity of the energy storage systems recommended for the given PV HMKE capacity. Apart from this, it also became possible to find out about the possible distribution of these aspects among the districts of the different Hungarian electric companies. By 2025, it is expected that the nominal energy storage power requirement recommended for the PV-based HMKE capacity in Hungary will rise to 1055.8 MW, while the energy capacity necessary for the energy storage facilities will increase to 3164.6 MWh. In the case of developments of this magnitude, the investment requirement at the national level would exceed a total of EUR 1 billion.

Due to the significant spread of PV HMKE systems, it has become unavoidable to prepare studies regarding the districts of the various Hungarian electric companies. The further goal of the research is to analyze the data presented herein in the context of smaller administrative units as well, at the so-called county and district levels. This could provide even deeper and more area-specific insight in connection with the determination of the energy storage requirements of PV-based HMKE systems.

Author Contributions: H.Z. conceived, designed and performed the experiments. Conceptualization, G.P., H.Z. and N.H.B.; Data curation, G.P., H.Z. and N.H.B.; Methodology, G.P., H.Z. and N.H.B.; Supervision, G.P., H.Z. and N.H.B.; Validation, G.P., H.Z. and N.H.B.; Writing—original draft, G.P., H.Z. and N.H.B.; Writing—review & editing, G.P., H.Z. and N.H.B. All authors contributed equally to the analysis of the data and the writing and revision of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: We acknowledge the financial support of 2020-3.1.2-ZFR-KVG-2020-00006 and the 2019-2.1.13-TÉT_IN-2020-00061 projects.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available within the article.

Acknowledgments: We acknowledge the financial support of 2020-3.1.2-ZFR-KVG-2020-00006 and the 2019-2.1.13-TÉT_IN-2020-00061 projects.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Escoffier, M.; Hache, E.; Mignon, V.; Paris, A. Determinants of solar photovoltaic deployment in the electricity mix: Do oil prices really matter? *Energy Econ.* **2020**, *97*, 105024. [CrossRef]
2. Fragkos, P.; Laura van Soest, H.; Schaeffer, R.; Reedman, L.; Köberle, A.C.; Macaluso, N.; Evangelopoulou, S.; De Vita, A.; Sha, F.; Qimin, C.; et al. Energy system transitions and low-carbon pathways in Australia, Brazil, Canada, China, EU-28, India, Indonesia, Japan, Republic of Korea, Russia and the United States. *Energy* **2021**, *216*, 119385. [CrossRef]
3. Shakouri, H. The share of cooling electricity in global warming: Estimation of the loop gain for the positive feedback. *Energy* **2019**, *179*, 747–761. [CrossRef]
4. Lacroix, K.; Gifford, R. Psychological Barriers to Energy Conservation Behavior: The Role of Worldviews and Climate Change Risk Perception. *Environ. Behav.* **2018**, *50*, 749–780. [CrossRef]
5. Kuthe, A.; Keller, L.; Körfgen, A.; Stötter, H.; Oberrauch, A.; Höferl, K.-M. How many young generations are there?—A typology of teenagers' climate change awareness in Germany and Austria. *J. Environ. Educ.* **2019**, *50*, 172–182. [CrossRef]
6. Jakučionytė-Skodienė, M.; Liobikienė, G. Climate change concern, personal responsibility and actions related to climate change mitigation in EU countries: Cross-cultural analysis. *J. Clean. Prod.* **2020**, *281*, 125189. [CrossRef]
7. Murdock, H.E.; Gibb, D.; Andre, T.; Sawin, J.L.; Brown, A.; Ranalder, L.; Collier, U.; Dent, C.; Epp, B.; Hareesh Kumar, C.; et al. *Renewables 2021 Global Status Report*; IAEA: Paris, France, 2021.
8. Fuke, P.; Yadav, A.K.; Anil, I. Techno-economic analysis of fixed, single and dual-axis tracking solar PV system. In Proceedings of the 2020 IEEE 9th Power India International Conference (PIICON), Sonepat, India, 28 February–1 March 2020. [CrossRef]
9. Kuo, K.-C.; Wang, J.-C.; Su, Y.-L.; Chou, J.-J.; Jiang, J.-A. A novel power benefit prediction approach for two-axis sun-tracking type photovoltaic systems based on semiconductor theory. *Prog. Photovolt. Res. Appl.* **2014**, *22*, 885–902. [CrossRef]
10. Awasthi, A.; Shukla, A.K.; Murali Manohar, S.R.; Dondariya, C.; Shukla, K.N.; Porwal, D.; Richhariya, G. Review on sun tracking technology in solar PV system. *Energy Rep.* **2020**, *6*, 392–405. [CrossRef]
11. de Paulo, A.F.; Porto, G.S. Evolution of collaborative networks of solar energy applied technologies. *J. Clean. Prod.* **2018**, *204*, 310–320. [CrossRef]
12. SolarPower Europe. *Global Market Outlook for Solar Power*; SolarPower Europe: Brussels, Belgium, 2019.
13. ENTSO-E. *European Power System 2040 Completing the Map*; ENTSO-E: Brussels, Belgium, 2018.
14. European Commission. *EU Reference Scenario 2016*; European Commission: Brussels, Belgium, 2016.
15. Zappa, W.; Junginger, M.; van den Broek, M. Is a 100% renewable European power system feasible by 2050? *Appl. Energy* **2019**, *233–234*, 1027–1050. [CrossRef]
16. Delucchi, M.A.; Jacobson, M.Z. Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies. *Energy Policy* **2011**, *39*, 1170–1190. [CrossRef]
17. Czisch, G. Szenarien zur Zukünftigen Stromversorgung, Kostenoptimierte Variationen zur Versorgung Europas und Seiner Nachbarn mit Strom aus Erneuerbaren Energien. Ph.D. Thesis, Universitat Kassel, Kassel, Germany, 2005.
18. ENTSO-E. *Maps and Data, TYNDP 2018*; ENTSO-E: Brussels, Belgium, 2018.
19. Heide, D.; von Bremen, L.; Greiner, M.; Hoffmann, C.; Speckmann, M.; Bofinger, S. Seasonal optimal mix of wind and solar power in a future, highly renewable Europe. *Renew. Energy* **2010**, *35*, 2483–2489. [CrossRef]
20. Heide, D.; Greiner, M.; von Bremen, L.; Hoffmann, C. Reduced storage and balancing needs in a fully renewable European power system with excess wind and solar power generation. *Renew. Energy* **2011**, *36*, 2515–2523. [CrossRef]
21. Rasmussen, M.G.; Andresen, G.B.; Greiner, M. Storage and balancing synergies in a fully or highly renewable pan-European power system. *Energy Policy* **2012**, *51*, 642–651. [CrossRef]
22. Czisch, G.; Giebel, G. Realisable scenarios for a future electricity supply based 100% on renewable energies in: Energy solutions for sustainable development. In Proceedings of the Risø International Energy Conference 2007, Roskilde, Denmark, 22–24 May 2007; Risø National Laboratory: Roskilde, Denmark, 2007. ISBN 9788755036031.
23. Kempton, W.; Pimenta, F.M.; Veron, D.E.; Colle, B.A. Electric power from offshore wind via synoptic-scale interconnection. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 7240–7245. [CrossRef] [PubMed]
24. Schaber, K.; Steinke, F.; Hamacher, T. Transmission grid extensions for the integration of variable renewable energies in Europe: Who benefits where? *Energy Policy* **2012**, *43*, 123–135. [CrossRef]
25. Schaber, K.; Steinke, F.; Mühlich, P.; Hamacher, T. Parametric study of variable renewable energy integration in Europe: Advantages and costs of transmission grid extensions. *Energy Policy* **2012**, *42*, 498–508. [CrossRef]
26. Widen, J. Correlations Between Large-Scale Solar and Wind Power in a Future Scenario for Sweden. *IEEE Trans. Sustain. Energy* **2011**, *2*, 177–184. [CrossRef]
27. Aboumahboub, T.; Schaber, K.; Tzscheutschler, P.; Hamacher, T. Optimal Configuration of a Renewable-based Electricity Supply Sector. *WSEAS Trans. Power Syst.* **2010**, *11*, 83–89.

28. Yao, R.; Steemers, K. A method of formulating energy load profile for domestic buildings in the UK. *Energy Build.* **2005**, *37*, 663–671. [CrossRef]
29. Hedegaard, K.; Meibom, P. Wind power impacts and electricity storage—A time scale perspective. *Renew. Energy* **2012**, *37*, 318–324. [CrossRef]
30. Hungarian Transmission System Operator—MAVIR ZRt. Capacity Analysis—Consultation Input Data 2020–2040. Available online: https://www.mavir.hu/web/mavir/kapacitaselemzes (accessed on 2 December 2020).
31. Fraunhofer Institute for Solar Energy Systems. *Photovoltaics Report*; Fraunhofer Institute for Solar Energy Systems: Freiburg, Germany, 2021.
32. European Commission. Legal Sources on Renewable Energy. Available online: http://www.res-legal.eu/ (accessed on 21 January 2022).
33. Steiner, A. The role of energy storage in Hungary. In Proceedings of the III. Hungarian Power-to-Gas Conference, Budapest, Hungary, 10 December 2021; Budapest University of Technology and Economics: Budapest, Hungary, 2021; pp. 1–10.
34. Frías-Paredes, L.; Mallor, F.; Gastón-Romeo, M.; León, T. Assessing energy forecasting inaccuracy by simultaneously considering temporal and absolute errors. *Energy Convers. Manag.* **2017**, *142*, 533–546. [CrossRef]
35. Akhmatov, V.; Knudsen, H. Large penetration of wind and dispersed generation into Danish power grid. *Electr. Power Syst. Res.* **2007**, *77*, 1228–1238. [CrossRef]
36. Eltawil, M.A.; Zhao, Z. Grid-connected photovoltaic power systems: Technical and potential problems-A review. *Renew. Sustain. Energy Rev.* **2010**, *14*, 112–129. [CrossRef]
37. Lund, H. Large-scale integration of wind power into different energy systems. *Energy* **2005**, *30*, 2402–2412. [CrossRef]
38. Wolfe, P. The implications of an increasingly decentralised energy system. *Energy Policy* **2008**, *36*, 4509–4513. [CrossRef]
39. Bird, L.; Lew, D.; Milligan, M.; Carlini, E.M.; Estanqueiro, A.; Flynn, D.; Gomez-Lazaro, E.; Holttinen, H.; Menemenlis, N.; Orths, A.; et al. Wind and solar energy curtailment: A review of international experience. *Renew. Sustain. Energy Rev.* **2016**, *65*, 577–586. [CrossRef]
40. Joos, M.; Staffell, I. Short-term integration costs of variable renewable energy: Wind curtailment and balancing in Britain and Germany. *Renew. Sustain. Energy Rev.* **2018**, *86*, 45–65. [CrossRef]
41. Schermeyer, H.; Vergara, C.; Fichtner, W. Renewable energy curtailment: A case study on today's and tomorrow's congestion management. *Energy Policy* **2018**, *112*, 427–436. [CrossRef]
42. Laugs, G.A.H.; Benders, R.M.J.; Moll, H.C. Balancing responsibilities: Effects of growth of variable renewable energy, storage, and undue grid interaction. *Energy Policy* **2020**, *139*, 111203. [CrossRef]
43. Gährs, S.; Knoefel, J. Stakeholder demands and regulatory framework for community energy storage with a focus on Germany. *Energy Policy* **2020**, *144*, 111678. [CrossRef]
44. Gurung, A.B.; Borsdorf, A.; Füreder, L.; Kienast, F.; Matt, P.; Scheidegger, C.; Schmocker, L.; Zappa, M.; Volkart, K. Rethinking Pumped Storage Hydropower in the European Alps. *Mt. Res. Dev.* **2016**, *36*, 222–232. [CrossRef]
45. Gyalai-Korpos, M.; Zentkó, L.; Hegyfalvi, C.; Detzky, G.; Tildy, P.; Hegedűsné Baranyai, N.; Pintér, G.; Zsiborács, H. The Role of Electricity Balancing and Storage: Developing Input Parameters for the European Calculator for Concept Modeling. *Sustainability* **2020**, *12*, 811. [CrossRef]
46. Pestiaux, J.; Matton, V.; Cornet, M.; Costa, L.; Hezel, B.; Kelly, G.; Kropp, J.; Rankovic, A.; Taylor, E. *Introduction to the EUCalc Model Cross-Sectoral Model Description and Documentation*; European Commission: Brussels, Belgium, 2019.
47. Liu, W.H.; Alwi, S.R.W.; Hashim, H.; Muis, Z.A.; Klemeš, J.J.; Rozali, N.E.M.; Lim, J.S.; Ho, W.S. Optimal Design and Sizing of Integrated Centralized and Decentralized Energy Systems. *Energy Procedia* **2017**, *105*, 3733–3740. [CrossRef]
48. Kursun, B.; Bakshi, B.R.; Mahata, M.; Martin, J.F. Life cycle and emergy based design of energy systems in developing countries: Centralized and localized options. *Ecol. Modell.* **2015**, *305*, 40–53. [CrossRef]
49. Ogunjuyigbe, A.S.O.; Ayodele, T.R.; Akinola, O.O. Impact of distributed generators on the power loss and voltage profile of sub-transmission network. *J. Electr. Syst. Inf. Technol.* **2016**, *3*, 94–107. [CrossRef]
50. Agora Energiewende and Sandbag. *The European Power Sector in 2017. State of Affairs and Review of Current Developments*; Agora Energiewende and Sandbag: London, UK; Berlin, Germany, 2018.
51. Ugarte, S.; Larkin, J.; van der Ree, B.; Swinkels, V.; Voogt, M.; Friedrichsen, N.; Michaelis, J.; Thielmann, A.; Wietschel, W.; Wietschel, R. *Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?—European Parilament, Directorate General For Internal Policies Policy Department A: Economic And Scientific Policy*; European Parliament Committee on Industry, Research and Energy: Brussels, Belgium, 2015.
52. EUR-Lex. Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity and Amending Directive 2012/27/EU (Text with EEA relevance). Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019L0944 (accessed on 21 January 2022).
53. Pfeifer, A.; Herc, L.; Batas Bjelić, I.; Duić, N. Flexibility index and decreasing the costs in energy systems with high share of renewable energy. *Energy Convers. Manag.* **2021**, *240*, 114258. [CrossRef]
54. Norton Rose Fulbright. Regulatory Progress for Energy Storage in Europe. 2019. Available online: https://www.nortonrosefulbright.com:443/de-de/wissen/publications/2019 (accessed on 15 January 2022).
55. Ministry of Innovation and Technology. *National Energy Strategy 2030, with a View to 2040*; Ministry of Innovation and Technology: Budapest, Hungary, 2020.

56. Ministry of Innovation and Technology. *National Battery Industry Strategy 2030, Draft*; Ministry of Innovation and Technology: Budapest, Hungary, 2021.
57. Hungarian Transmission System Operator—MAVIR ZRt. Renewable Support System, Renewable Support Department Customer Service. Available online: https://www.mavir.hu/web/mavir/ugyfelszolgalat (accessed on 9 December 2021).
58. Hungarian Transmission System Operator—MAVIR ZRt. Renewable Support System—Current Information. Available online: https://www.mavir.hu/web/mavir/aktualis-informaciok (accessed on 10 December 2021).
59. Hungarian Energy and Public Utility Regulatory Authority. Renewable Energy Operating Aid. Available online: https://www.enhat.mekh.hu/mukodesi-tamogatas (accessed on 25 August 2020).
60. Hungarian Independent Transmission Operator Company Ltd. (MAVIR ZRt). Information on the Changes in the KÁT and METÁR System in 2020. Available online: http://www.mekh.hu/tajekoztato-a-kat-es-a-metar-rendszer-2020-evi-valtozasairol (accessed on 15 December 2020).
61. Hungarian Energy and Public Utility Regulatory Authority. *Information on the Renewable Energy Support System (METÁR)*; Hungarian Energy and Public Utility Regulatory Authority: Budapest, Hungary, 2020.
62. Hungarian Independent Transmission Operator Company Ltd. (MAVIR ZRt). Data Publication, Current VER Data. Available online: https://www.mavir.hu/web/mavir/aktualis-ver-adatok (accessed on 9 December 2021).
63. Hungarian Energy and Public Utility Regulatory Authority. *Summary Evaluation of the Evaluation Committee on the METÁR Tender Announced on 2 September 2019*; Hungarian Energy and Public Utility Regulatory Authority: Budapest, Hungary, 2020.
64. Hungarian Energy and Public Utility Regulatory Authority. *Tender Documentation—2020—Support for Electricity Produced from Renewable Energy Sources within the Framework of a Tender Green Premium Scheme*; Hungarian Energy and Public Utility Regulatory Authority: Budapest, Hungary, 2020.
65. Pintér, G.; Zsiborács, H.; Hegedűsné Baranyai, N.; Vincze, A.; Birkner, Z. The Economic and Geographical Aspects of the Status of Small-Scale Photovoltaic Systems in Hungary—A Case Study. *Energies* **2020**, *13*, 3489. [CrossRef]
66. Profi-Vill Kft. Wattage Protection—"Visszwatt Védelem". Available online: https://slrsolar.hu/visszwatt-vedelem/ (accessed on 9 December 2021).
67. E.ON Hungária Zrt. About HMKE in General. Available online: https://www.eon.hu/hu/hmke/tudnivalok.html (accessed on 9 December 2021).
68. Erdős, Z.B.; Hegedűsné, B.N.; Pintér, G.; Zsiborács, H. *The Role of Solar Energy in the Life of Settlements*; Szent István University: Szarvas, Hungary, 2018; pp. 280–287.
69. Új Világ Nonprofit Szolgáltató Kft. RRF-6.2.1 Tender. Available online: https://napelem.palyazat.gov.hu/lakossag/felhivas (accessed on 9 December 2021).
70. Wirth, H.; Bächle, S.J. *Current Facts about Photovoltaics in Germany*; Fraunhofer Institute for Solar Energy Systems: Freiburg, Germany, 2022.
71. Blanco, H.; Faaij, A. A review at the role of storage in energy systems with a focus on Power to Gas and long-term storage. *Renew. Sustain. Energy Rev.* **2018**, *81*, 1049–1086. [CrossRef]
72. Lechner Nonprofit Kft. Map of Utilities. Available online: https://www.e-epites.hu/e-kozmu (accessed on 9 December 2021).
73. Hungarian Energy and Public Utility Regulatory Authority (MEKH). Data on Small-Scale and HMKE PV System. Available online: http://www.mekh.hu/nem-engedelykoteles-kiseromuvek-es-haztartasi-meretu-kiseromuvek-adatai (accessed on 9 December 2021).
74. MVM Partner Energiakereskedelmi Zrt. *MVM Group's Proposals for the Concept Plans of the Battery Strategy Priority Project Approved by the Government*; MVM Partner Energiakereskedelmi Zrt: Budapest, Hungary, 2021.
75. European Commission. Technology Pathways in Decarbonisation Scenarios. Available online: https://ec.europa.eu/energy/studies_main/final_studies/technology-pathways-decarbonisation-scenarios_en (accessed on 11 December 2021).
76. Carlberg, C.G. *Business Analysis with Microsoft Excel*, 5th ed.; Pearson Education (US): New York, NY, USA, 2018; ISBN 9780134862538.
77. Hungarian Transmission System Operator—MAVIR ZRt. *Initial Data of the Electricity Network Development Plan 2021*; Hungarian Transmission System Operator—MAVIR ZRt: Budapest, Hungary, 2021.
78. E.ON Hungária Zrt. PV Installation? Worth to Implement! Available online: https://www.eon.hu/hu/lakossagi/termekek/solar/hirek/napelem-telepites.html (accessed on 12 December 2021).
79. Fülöp, M. The First Domestic Public Energy Storage Unit Is Operating in Hungary. Available online: www.villanylap.hu/hirek/4904-mukodik-az-elso-hazai-kozcelu-energiatarolo-egyseg (accessed on 1 August 2020).
80. Portfolio.hu. HMKE Economic Information. Available online: https://www.portfolio.hu/gazdasag/20211209/valosaggal-ravetettek-magukat-a-magyarok-a-napelemekre-515318# (accessed on 12 December 2021).
81. Solar Kit Hungary Kft. Balance Settlement or Gross Settlement. Available online: https://solar-kit.hu/szaldos-vagy-brutto-elszamolas/ (accessed on 6 January 2022).
82. Pintér, G.; Birkner, Z.; Hegedűsné Baranyai, N.; Zsiborács, H. A hazai energiatárolás lehetőségei 2030-ig—Possibilities of energy storage systems in Hungary until 2030. *Energiagazdálkodás* **2019**, *2019*, 1–44.