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Article

Economic Analysis of Grid-Connected PV System Regulations: A Hungarian Case Study

Henrik Zsiborács [1], Nóra Hegedűsné Baranyai [1,*], Szilvia Csányi [1], András Vincze [2] and Gábor Pintér [1]

[1] Department of Economic Methodology, Georgikon Faculty, University of Pannonia, 8360 Keszthely, Hungary; ifj.zsiboracs.henrik@gmail.com (H.Z.); szilvia.csanyi15@gmail.com (S.C.); pg@georgikon.hu (G.P.)
[2] Department of Foreign Languages, Georgikon Faculty, University of Pannonia, 8360 Keszthely, Hungary; vinander@t-online.hu
* Correspondence: baranyai@georgikon.hu; Tel.: +36-30-373-8550

Received: 7 January 2019; Accepted: 26 January 2019; Published: 31 January 2019

Abstract: The energy demand of mankind is constantly growing, thus the utilization of various renewable energy sources, which also reduces negative environmental effects, is becoming more and more important. Because of the achievement of climate protection targets, photovoltaic (PV) energy has an increasing role in the global energy mix. This paper presents the technical and economic aspects of different photovoltaic system configurations designed to suit the Hungarian renewable energy regulations. In this study, five alternative PV configurations were examined for systems with a capacity from 50 kW to 500 kW, related to low- and medium-voltage installations. This article also introduces and explains the Hungarian economic PV and Feed-in-Tariff (FiT) regulations, where three different investment alternatives are analyzed with the help of economic indicators. This study could help stakeholders in the market (e.g., the Hungarian industry sector and local governments) understand the possible directions of technical and economic PV development. According to the results, the payback periods in all the studied economic-technical cases were below 10 years. The experimental results show that each investment option may be a good decision from an economic and technical point of view under the Hungarian regulations in force in 2019.

Keywords: solar energy; PV system; renewable energy regulation; Feed-in-Tariff; Hungary

1. Introduction

1.1. Changes in the Spreading of Photovoltaic (PV) Technology

Nowadays more and more countries worldwide understand the harmful consequences of climate change. It is important to keep the global temperature rise below 2 °C compared to the preindustrial level and aim for a maximum increase of only 1.5 °C [1]. In the transition process that is needed to achieve these targets and to reduce the greenhouse effect, the use of variable renewable energy (VRE) will become more and more important in global energy systems. Advances in renewable energy technologies have provided several sustainable alternatives, and the role of solar energy sources is becoming increasingly important. As one of the consequences, many cities started to include solar energy programs in their urban planning all around the world in order to support sustainable development and environmental protection. The reasons are truly understandable; the energy from the Sun, which is the base of most natural processes, is available to everyone and it is a sustainable, plentiful and clean resource [2–11]. It can be stated that the annual solar energy potential on the surface of the Earth is thousands of times greater than the current global energy demand. PV technologies use photovoltaic cells, which transform the incoming solar radiation into DC energy [12–14]. Today, the most widely used PV technologies are the polycrystalline (p-Si), monocrystalline (m-Si) and amorphous silicon (a-Si) ones. Because of the good reliability of crystalline solar modules, their market share is about 90% currently. In the case of the p-Si and m-Si PV modules it is possible to achieve an efficiency of even 21.9% and 25.6%, respectively [15–24]. The efficiency of the most commonly used m-Si and p-Si modules is typically between 10–18% in the EU [25]. The a-Si photovoltaic technology is a type of thin film PV technology, which nowadays has a maximum efficiency of 10.5%. This efficiency value is typically between 4 and 6% in the case of the most commonly used a-Si modules. The market share of a-Si technology is unknown, but the share of all thin-film solar modules is around 10%. The price of a-Si technology may even be as low as 0.06–0.09 €/WP, which is a significant advantage promoting the spread of PV technology in the European Union (EU) [15,18–20,24–27]. The components of crystalline PV technology are shown in Figure 1.

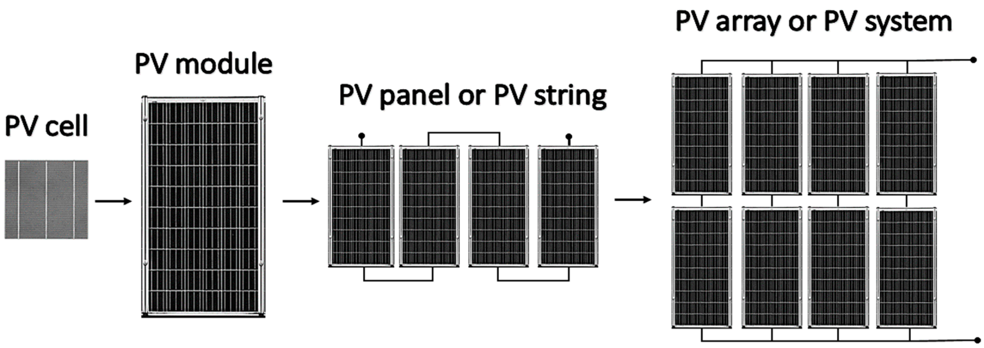

Figure 1. The components of the polycrystalline (p-Si) technology.

In the last 10 years, a significant market growth has been observed in the PV sector, mainly due to newly introduced governmental financial support, the Feed-in-Tariff, decreasing investment costs and dynamic technological developments [6,15,28]. In 2017, the renewable electricity generation amounted to 26.5% of the global electricity production, 1.9% of which was the share of PV technologies. In the same year, the whole global capacity of built-in photovoltaic systems was 402 GW. The leading producers were China with 131.1 GW, the European Union with 108 GW, the United States of America with 51 GW and Japan with 49 GW. It is interesting to note the change that PV technology became China's most significant new power capacity (Figure 2) [6,29].

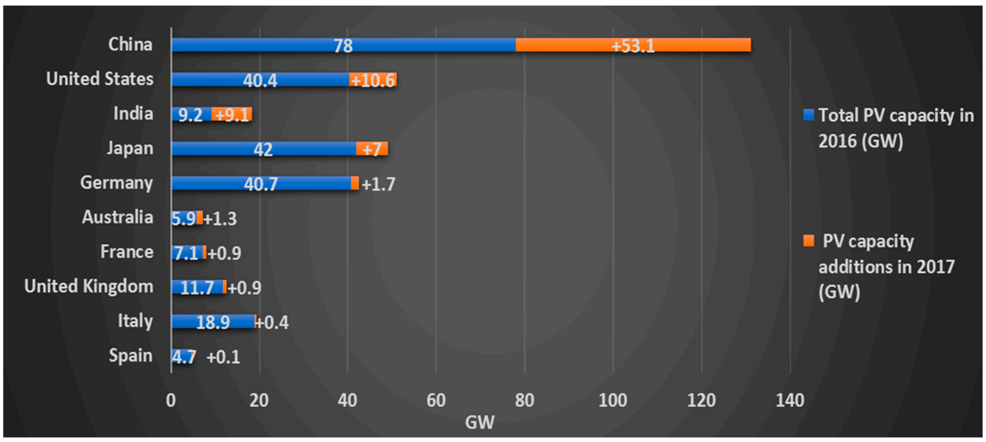

Figure 2. The photovoltaic (PV) capacity and the additions in the case of the top 10 countries, 2017 [6,30–34].

In Hungary, the cumulative installed PV capacity was around 0.31 GW in 2017 and 0.7 GW at the end of December 2018. The main reason for this growth was the modified PV regulation [35].

The amount of PV energy produced depends primarily on the solar radiation, the technology, the temperature, the current natural factors, the composition of the particular module, the combined effect of the installation and the efficiency rates. Based on the European PV power potential map it can be concluded that the yearly average amount of the PV energy that can be generated is between 700–1900 kWh/kWp depending on the various geographical locations. In Hungary, these values range between 1050–1250 kWh/kWp (Figure 3). For economic reasons, large (>50 kWp) PV systems are primarily mounted on fixed mounting systems in Hungary [19,36–40].

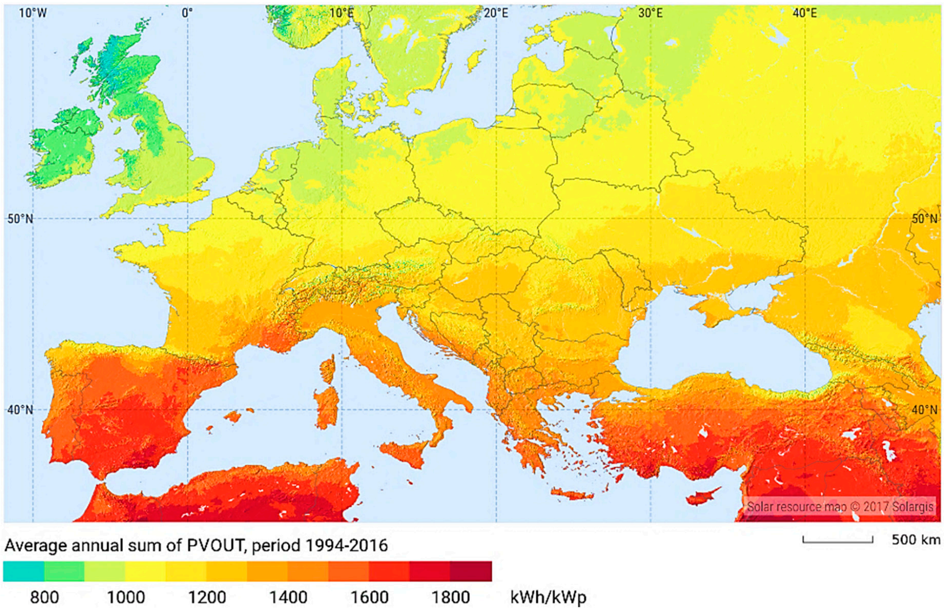

Figure 3. The photovoltaic power potential, Europe [39].

1.2. *Feed-in-Tariff (FiT) in Hungary—Overall Summary*

Various countries use diverse schemes to support green energy usage. These concepts are typically modified from year to year, and the country-specific changes are difficult to follow (Figure 4) [41]. Also, the information is often several-years-old and, therefore, unreliable. Currently, no reliable summarized data are available from Hungary. The most common schemes are various investment supports (IS), the Feed-in-Tariff (FiT) and the net metering system (NS) [42–46].

In Hungary, the government supports electric power generated by utilizing renewable sources by means of a FiT in the case of installations of a peak power between 50–500 kWp, while those with a kilowatt-peak of 500–1000 kWp enjoy the market premium. The green premium is awarded to PV power plants of a peak power over 1000 kWp only as a result of taking part in a tendering process, whereas household-sized power plants (HMKE) with a maximum 50 kWp peak power can profit from net metering. Moreover, the application of renewable energy sources is usually also subsidized in the heating and electricity category. The most commonly realized subsidy programs within the Economic Development and Innovation Programme (EDIOP) and the Environment and Energy Efficiency Operational Programme (EEEOP) in 2017 were those that provided non-repayable loans and grants, among others combined with the FiT. Most of the calls for tender are still to be published. The most important program intended to support the use of green energy is a system of quotas coupled with the reimbursement of an excise duty in the category of transportation. Priority grid access and grid connections are to be granted to the producers of green power. The costs of expanding the grid and of connecting the renewable energy plants to it are to be covered by the grid operator or the plant owner, subject to a number of conditions. Numerous measures designed to encourage the development, building and use of green energy installations have been introduced [45,47,48]. The year 2017 saw non-repayable loans and grants combined with the FiT distributed as a part of the Economic

Development and Innovation Programme (EDIOP) and the Environment and Energy Efficiency Operational Programme (EEEOP). Also in the same year, on 1 January 2017, the new Renewable Energy Support Scheme (METÁR) came into force to partly supplant the older Hungarian system of supporting green energy from renewable energy sources (KÁT), which had been amended a year earlier, in 2016. Electricity-producing facilities over the size of 50 kWp are required to make 15-minute electricity production forecasts for each day under the current system. Furthermore, PV system owners are to pay a surcharge for any divergence of more than +/−50% (in the case of 15-minute intervals between measurements) from 1 July 2018. If the deviation is less than +/−50%, it is possible to get a FiT bonus. This is a motivating regulation, which helps create more accurate energy forecasts. For example, if the deviation in the case of 15 mins measurement intervals is +30%, a 20% bonus will be available for this period [45,47,48].

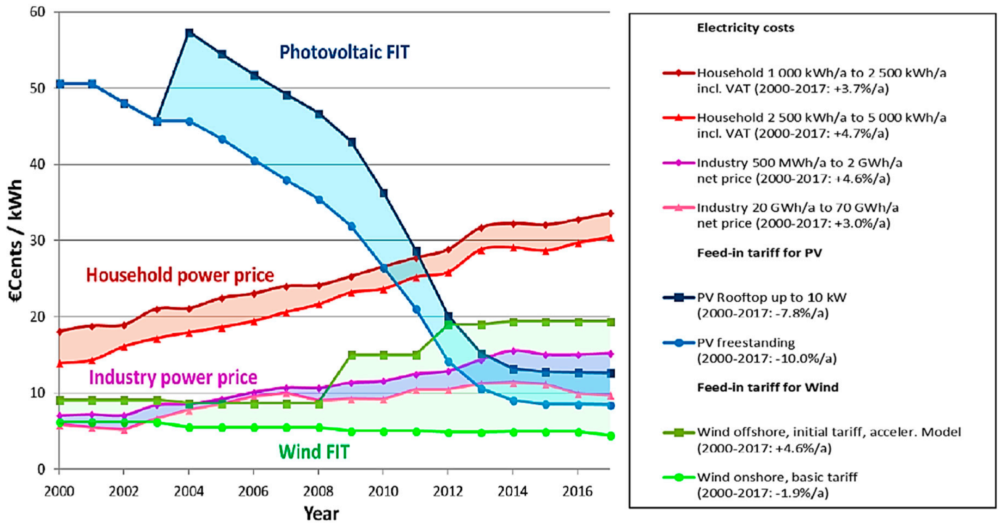

Figure 4. The electricity costs and FiT changes in Germany [41].

Another scheme of support meant for business customers, local governments and even residential customers, called HMKE, was designed for PV systems with capacities of less than 50 kW which feed the energy produced by the PV modules into the grid in addition to purchasing energy. According to this scheme, the owner or operator of the PV system is required to pay only the balance of the quantity of energy they have consumed from the grid and the amount of energy they have fed into the system, which is calculated once annually (only the difference has to be financially settled). Under this scheme, 15-minute energy production forecasts are not required, and thus, there is not a surcharge either. In the event of excess consumption by the owner of the PV system he/she needs to pay, but if the amount of power generated exceeds that of the consumption, it is the service provider who has to pay (about 50% less) the consumer. In this system, storing the energy is the responsibility of the national grid, which means that consumers having relatively small PV systems can be self-sufficient and do not need to be concerned about the losses and costs associated with storage. From the point of view of the government, it is the potential economic benefits related to the production of green energy that can also be crucial considerations with regards to this regulation [40,49].

When the goal is only to reduce one's own energy consumption in larger buildings, it is a possible solution to build a Small-scale PV system (>50 kWp), which can be done in two alternative ways. In the first option, the PV system may only produce as much electric energy as the user needs at a given moment. In this case, the feeding of the PV energy into the grid is not allowed, which is guaranteed by a regulatory device. The device can even stop the energy generation of the entire PV system if self-consumption is less than the electricity production. In the second option, it is allowed to feed the extra PV energy into the grid when the amount of the generated PV energy exceeds that of the consumption. Besides the fact that the licensing process is much more complicated and a contract must be also concluded with the service provider concerning the extra PV energy, the FiT is also much lower (about 0.015 €/kWh/2019) than in the cases of KÁT, METÁR or HMKE [50].

According to current regulations, PV system owners do not have the opportunity to sell their CO_2 savings on the global market and the state does not compensate them. For this reason, this study does not deal with this market regulation [47,51].

1.3. Popular PV Inverter Technologies and Systems in Hungary

Grid-connected PV systems have the fastest growth rate in the international energy industry, and this sector plays a dominant role in the global market. Grid-connected or on-grid PV systems only generate energy when the utility power grid is available. They need to connect to the grid to function, and they can send excess power generated back to the grid when the energy consumption of the building or facility is low. Moreover, these systems are characterized by low costs, high efficiency, strong scalability and high reliability [52–57].

The following main components, services and materials are required for on-grid PV systems in Hungary [38,50,58,59]:

- PV modules, PV-inverter, frames, cable with outlets, AC/DC overcurrent and overvoltage protection, grounding network, additional electric outfit, costs of design, installation and transportation.
- Optional: fence, fence alarm system, cabling of a compact station, piling, camera security system, access control system, transformer station and maintenance [38,58].

It can be seen, that a PV system requires a number of devices, among which one of the most important ones is the inverter.

There are many inverter manufacturers in the world, of which the three most significant ones are Huawei Technologies Co., Ltd., Sungrow Power Supply Co., Ltd. and SMA Solar Technology AG [60]. In Hungary, the use of SMA inverters is popular for PV systems with sizes ranging from a few kWp to MWp sizes [61–63]. However, Growatt inverters (Growatt New Energy Technology Co., Ltd.) are also becoming increasingly popular in Hungary because all Hungarian service providers authorize their installation on their grids. In the Hungarian HMKE regulation, PV systems can only connect to the low voltage grid (0.4 kV) with a maximum performance of 50 kVA (3 x 63 A) (Figure 5). A three-phase inverter block diagram shows (Growatt 30000TL3-S, 33000TL3-S, 40000TL3-NS/50000TL3) the main logical structure of such a configuration in Figure 6 [64–68].

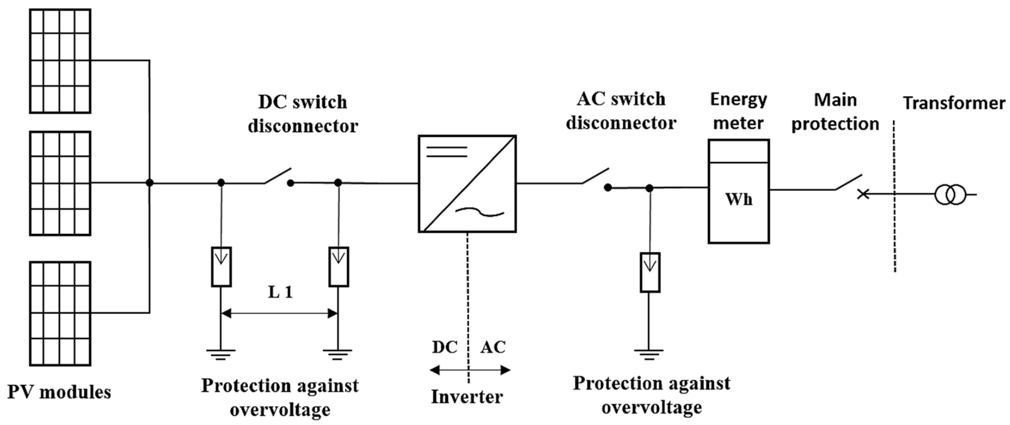

Figure 5. A block diagram of a grid-connected PV system in Hungary based on Growatt New Energy Technology Co., Ltd. [68,69].

In the case of Small-scale or KÁT PV systems, the connection to the low- (0.4 kV) or medium-voltage (22 kV) network has to be examined individually [48,66,70–76]. For medium-voltage connections, SMA's MV Power Station configurations are the preferred technology in Hungary because these are plug and play concepts, easy to plan, transport, install and the inverters include PID protections.

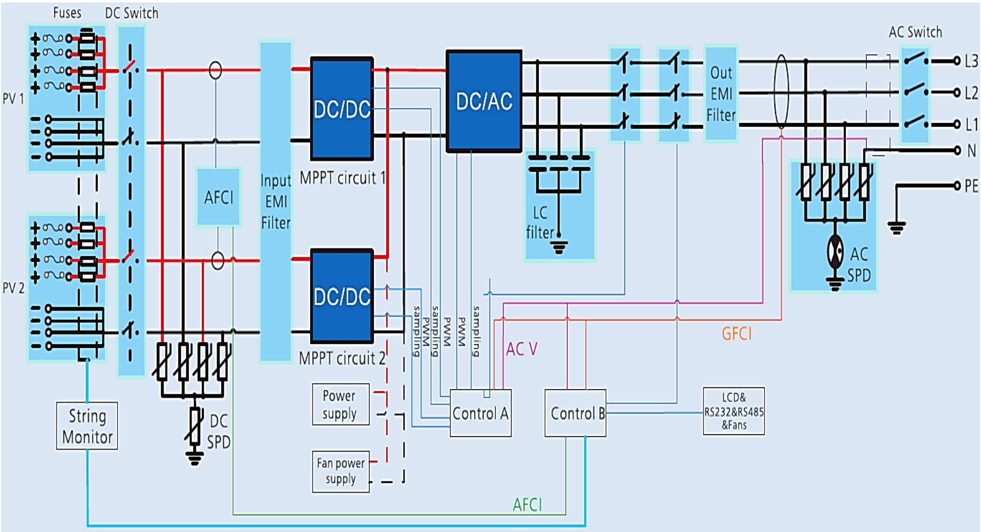

Figure 6. A Growatt 30-50kTL3-(N)S topology block diagram [68,69].

In this solution, the inverters are installed in the center of the inverter compartment with an air outlet facing backward, and the terminals for the DC area can be connected to either the front or the back. The inverter compartment of a medium-voltage power station includes two standard sun protection roofs and two standard service platforms. The outdoor transformer has been optimized without an active fan for reduced maintenance. In addition to the medium-voltage switchgear, other features have also been installed with three panels, including two cable panels with a load-break switch, one transformer panel with a circuit breaker or a load-break switch with fuses (Figure 7) [77–79].

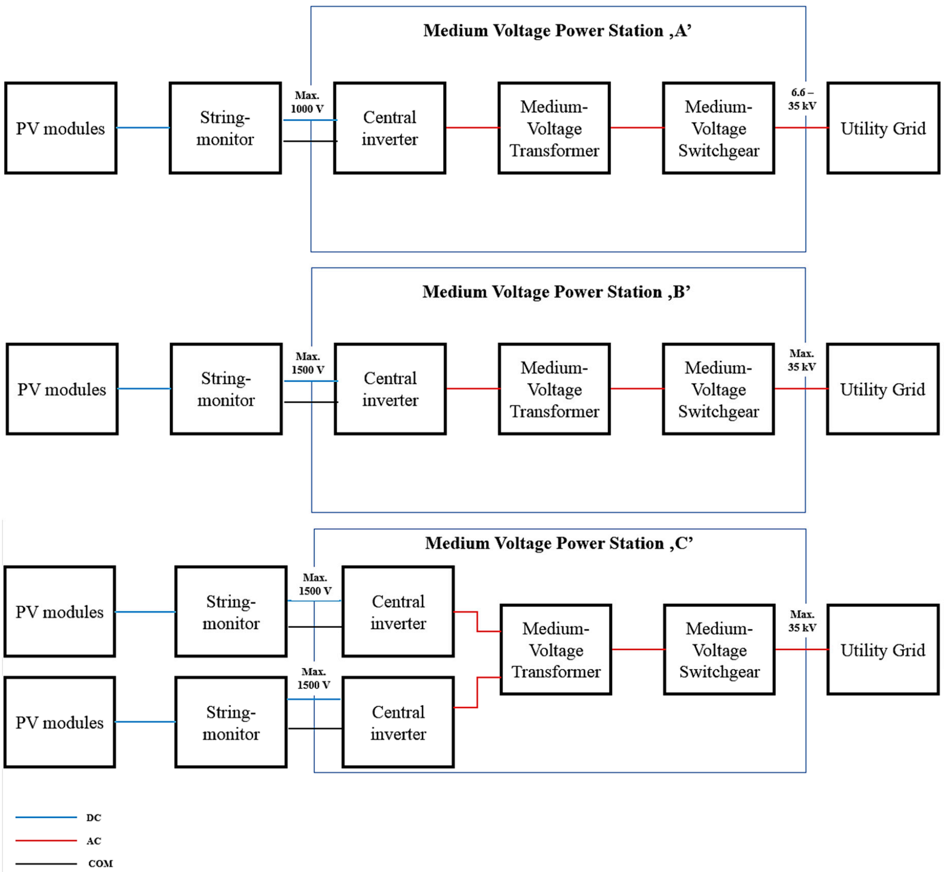

Figure 7. Medium voltage power station configurations based on SMA Solar Technology AG. [77–79].

2. Material and Methods

Methods and Details of the Technical and Economic Assessment

Our work deals with the Hungarian PV techno-economic and Feed-in-Tariff (FiT) options where three different, most commonly built crystalline PV facility alternatives were examined with the help of economic indicators:

- a 50 kWp PV system subject to the HMKE regulation (NS + FiT);
- a 500 kWp Small-scale PV system, where feeding into the grid is not allowed (only NS); and
- a 500 kWp PV system subject to the 31.12.2016 KÁT regulation (FiT + FiT bonus) (Table 1).

In the course of these economic calculations, not only the investment needed for each PV system but also the annual extra yield and financial expenditure under the respective regulations currently in force in Hungary are examined. The authors carried out a sensitivity analysis for the future changes of FiT because they may have significant effects on the investment indicators. The HMKE option is available for residential, business and local government customers on a yearly basis, and this option is the simplest solution for PV construction [40,49,80,81]. In the HMKE or Small-scale market environment, it is not necessary to create an electricity production forecast (see KÁT) [47].

For the validation of the model, PANNON Pro Innovations Ltd., based in Hungary in Budapest, made the necessary empirical data available. Hungary's foremost private PV development firm, Pannon Green Power Ltd. (Budapest, Hungary), was also established by the same PANNON Pro Innovations Ltd., which had developed a profitable business model for the PV project development [82].

In the case of a well-planned Small-scale PV system where the goal is to achieve annual energy savings of 20%, the annual PV energy available for use will be reduced by about 5% if feeding into the grid is not allowed (due to the regulatory device). If the PV system investor wants to save 25% of the energy per year, the annual profitable PV energy will be already 10–11% less. In our calculations, a PV energy loss of 5% was estimated annually [82]. We did not calculate with the second option in which feeding the extra PV energy into the grid is allowed because that involves a great number of various options, which will be the subject of a future study.

The KÁT regulation presents a much heavier administrative burden due to the required procedure of the electricity production forecasts. Many PV system owners overcome this difficulty with the help of companies who specialize in this problem and take care of all the difficulties of administration and forecasting in exchange for 54% of the FiT bonus. Accordingly, in the calculations, the remaining 46% of the FiT bonus was considered [83].

Crystalline PV modules are characterized by an annual performance degradation. For this research, its value was set at 0.5%, which is the generally accepted rate [15,84]. Regarding the operation time, a 15-year period was chosen, since presently, that is the most frequent investment practice in Europe. In addition, in Hungary, about 15 years will soon become the FiT support time in the KÁT regulation (Table 1). After 15 years, the devices (PV modules and inverters) still remain in good condition, and they can be sold at reasonable prices. This practice has two advantages:

- This solution makes it possible for investors to use new and more efficient PV technologies every 15 years.
- It is also possible for poorer people to buy PV technologies at a more affordable price [25,85].

Based on practical experience, the maintenance costs were considered (PV washing, lawn mowing, unexpected technical failure, etc.), while the replacement of the inverter was not taken into account in this time period. Furthermore, we calculated with a 10% PV system loss, and the model featured a tilt angle of 35°. The internationally accepted methodology in the literature helped us with determining the profitability indices (PI), the discounted payback periods (DPP) and the net present values (NPV) associated with the PV systems as well as with the economic calculations (Table 2) [44,86]. The standing of the long-term Hungarian bond yields dated 13 November 2018 was the basis of the 4.36% interest rate that was used in the calculation of the time values of the dynamic economic indicators. For the yearly alterations in the HMKE and the Small-scale PV electricity FiT, which were considered to have a value of 3.07%, the inflation rate between 2003 and 2017 was taken as a basis.

Considering government bond yields are necessary for forecasting future incomes, changes in the Feed-in-Tariffs depend on the current rate of inflation [40,87,88]. The KÁT FiT changes were calculated based on the 4 years' features because in this set of regulations, the degree of change can be more accurately predicted by using such a period. The changes in the FiT bonus are uncertain, so its amount was regarded to be constant. For the calculations, an exchange rate of 322 Hungarian forints against the € and net values were applied [89]. The costs of land purchases were not taken into account; we considered land to be already available. All the important primary information is shown in Table 1 [90]. Our grid-tied PV system simulations benefitted from data from the JRC Photovoltaic Geographical Information System (PVGIS), which also contained several decades' real climatic data series. With this online software, it is possible to estimate the average monthly and yearly energy production of typical grid-tied and off-grid PV systems. The calculation takes into account the solar radiation, the temperature, the wind speed, the installed peak PV power, the tilt angle, the azimuth, the system loss, the mounting position and the type of the PV module. The user can set any values and can easily generate estimates for PV energy production. For this model average, easily accessible crystalline PV modules were taken into account [91]. The data used for the average electric energy production of 1 kWp PV systems were validated by data from real PV systems (Table 1) [92–94]. In our model, the PV modules and inverters will be sold and a demolition fee will be charged at the end of the investment period.

Table 1. The initial economic-technical data for the calculations. [15,25,38,49,58,61,82,84,85,87,88,90–98].

Content	Value
Average validated electric energy production of a 1 kWp HMKE or KÁT PV system in Hungary, first year (kWh/a)	1200
Average validated electric energy production of a 1 kWp Small-scale PV system with a regulatory device in Hungary, first year (kWh/a)	1140
Decrease of 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
Household-sized power plant (HMKE) (kWp)	50
Small-scale PV system (kWp)	500
31 December 2016 KÁT regulation (kWp)	500
Average delivery price for electric energy for business customers in the HMKE and in the Small-scale PV system (€/kWh/2019)	0.1175
KÁT FiT (€/kWh/2019)	0.1095
KÁT FiT bonus for daily forecast (€/kWh/2019)	0.0093
Rate of average inflation (2003–2017) (%)	3.7
Bond yield interest rate (%)	4.36
Financial support (%)	0
Investment costs, HMKE PV system, net, 2019 (€)	41,817
Investment costs, Small-scale or KÁT PV system, net, 2019 (€)	447,205
Average price of 1 kWp used crystalline PV modules, 2019 (€)	100
Average price of 1 kW used PV inverter power, HMKE, 2019 (€)	56
Average price of 1 kW used PV inverter power, Small-scale or KÁT, 2019 (€)	52

Table 2. The main context for the calculations.

Description	Context	Ref.
Annual PV system energy output (kWh/a)	First year: $\mathbf{E_1}$ = The software results of PVGIS Other years: $E_t = E_{(t-1)}(\mathbf{1 - 0.005})$	[91] [15,47,84]
Total cash flow (€)	$\mathbf{CF_{total}} = [(\mathbf{E_{total}FiT_{total}}) + \textbf{Sales of photovoltaic modules and inverters}] - (\mathbf{C_0} + \mathbf{C}_{O\&Mtotal} + \textbf{Demolition fee})$	[15,44,47,82,84,99]
Net present value (€)	$\mathbf{NPV = -C_0 + \sum_{t=1}^{n} \frac{C_t}{(1+r)^t}}$	
Internal Rate of Return (%)	$\mathbf{0 = -C_0 + \sum_{t=1}^{n} \frac{C_t}{(1+IRR)^t}}$	[86,100]
Discounted payback period (€)	$\mathbf{C_0 + \sum_{t=1}^{DPP} C_t = 0}$	

3. Results

The Economic-Technical Aspects of the Examined PV Systems

Tables 3 and 4 show us the comparison of the different investment alternatives. In every case, the net present value was positive, so the investments can be profitable in the studied economic situation.

According to the calculations, the best investment alternative is the HMKE. In this market environment, the important factors are the easy and quick licensing and realization, the positive market environment and the annual financial settlement. In this type of regulation, the amount of energy consumed and the amount fed into the system are calculated once a year and only the balance has to be financially settled. On the other hand, it is not necessary to create 15-min energy production forecasts. Local governments prefer the building of HMKE PV systems by the institutions they own, such as hospitals, libraries, schools, kindergartens, etc. because some renewable energy or energy efficiency investments can get 60% or even 85% non-refundable support in Hungary [48,49,64,101–103]. It is clearly visible (Tables 3 and 4) that the HMKE PV investment payback period was 7 years without financial support and that the internal rate of return was relatively high: 16.5% (Tables 3 and 4).

In the case of a well-planned Small-scale PV system where the goal is to reduce the own energy consumption in larger buildings, it is possible to save about 20–25% of the annual energy consumption due to the regulatory device. These values represent the economically reasonable limit because in these cases, the annual profitable PV energy is reduced by about 5–10% (due to the regulatory device) compared to the HMKE or KÁT systems. In the cases subject to this regulation, considering the used inflation values and the interest rate of the Small-scale system, the expected profit and the maintenance costs show us that the payback period was only 1 year worse than that of the HMKE solution. The internal rate of return was 14.7%, which is 1.8% lower than the previous one (Tables 3 and 4). To build a small case power plant, it is possible for self-consumption (with a device which does not allow feeding electricity into the grid) or for self-consumption plus electricity selling. We did not calculate with the second option where feeding extra PV energy into the grid is allowed because that could involve the examination of a number of further options, which will be the subject of a later study.

The KÁT legislation in force until 31 December 2016 was a better business opportunity for market investors in the case of larger (>50 kWp) PV systems than the new regulation of METÁR. Shortly before that date, 2428 PV building permit requests had been received by the Hungarian Energy and Utilities Regulatory Office [104]. The main reason for that high number was the modified 15-minute electricity production forecast regulation, which came into force on 1 July 2018. From that date, in the case of a deviation of more than +/−50%/15-min measurement interval, the PV system owners have to pay a surcharge for any PV size. All in all, this change reduces the FiT bonus. The KÁT investment alternative is the only one which does not have any self-consumption, so this is only a power plant which produces PV energy and feeds it all into the grid. In the KÁT system, having a fence, a fence alarm system, a camera security system, an access control system and more maintenance are highly recommended (Figure 8). These factors also affect the payback period, which was 9 years in this case. The internal rate of return was 12.2% (Tables 3 and 4).

For an easier comparison of the investments, the net present values and the investment costs were calculated for a 1 kWp system in Figure 9.

According to Tables 3 and 4, each of the studied investment alternatives can be a good choice for investors. All the three alternatives had a positive NPV, and the DPPs were less than 10 years. The shortest DPP belonged to the HMKE, and it had the lowest investment costs too. That means that a HMKE investment can be recommended to investors with lower financial powers who want to get the invested money back as soon as possible. That alternative required also the least administration-related costs, and there was no need to create any PV energy production forecasts, either. That is why we would suggest that alternative to municipalities, which are usually not very powerful financially and also have self-consumption.

Figure 8. The PV system subject to the KÁT regulation with reinforced fences in Kaposvár (0.565 MWp, upper photo) and Magyargencs (0.42 MWp, lower photo), Hungary [38].

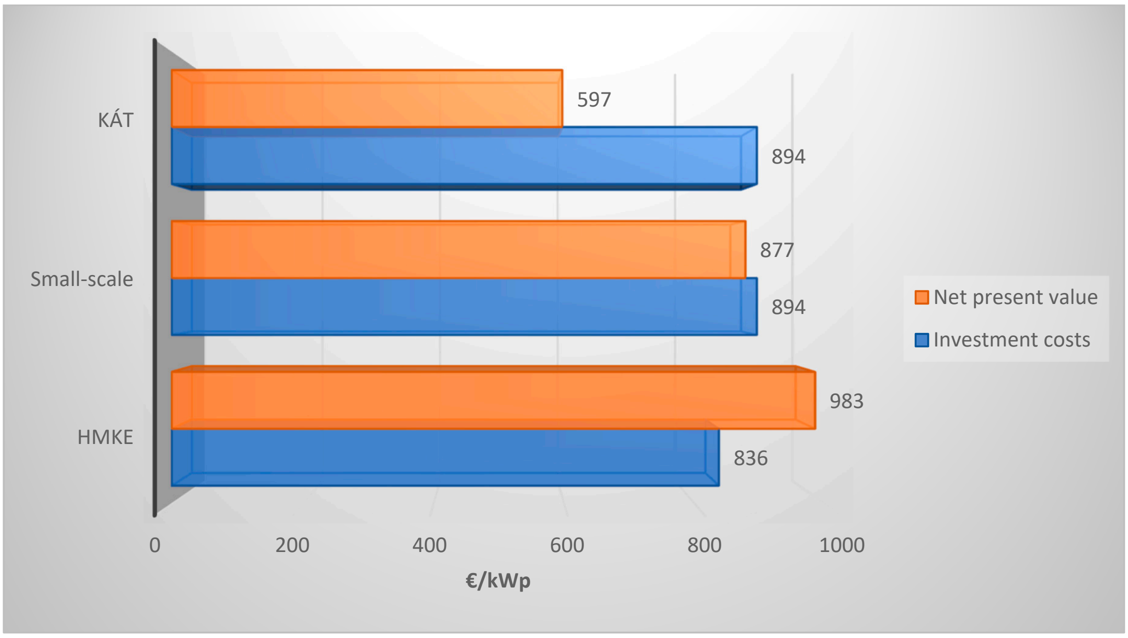

Figure 9. A comparison of the different investment alternatives studied and converted to a 1 kWp system in 2019.

Table 3. The evaluation of the three studied investment alternatives in 2019.

	HMKE	Small-Case		KÁT
Feeding energy into the grid	yes	no	yes	yes
Self-consumption	100%	100%	possible	no self-consumption
Energy trader	not necessary	not necessary	necessary	necessary
Energy billing/balance	annual	continuous	continuous	continuous
NPV calculation in our study	yes	yes	no	yes
NPV after 15 years	low	highest	not analyzed	medium
15-minutes forecast	not necessary	not necessary	not necessary	needed
Investment cost for the whole system	low	high	high	high
Administration needs	low	low	medium	high

Table 4. The overall investment-efficiency indices in the HMKE, Small-scale and KÁT regulations in 2019.

Content	Values		
Studied investment period (years)		15	
Studied PV economic environment	HMKE	Small-scale	KÁT
System size (kWp)	50	500	
Investment costs, net, 2019 (€)	41,817	447,205	
Negative cash flow ($C_{O\&M,total}$ + Demolition fee), net (€)	10,026	66,966	81,366
Positive cash flow, net (€)	140,681	1,344,867	1,140,558
Net present value (NPV) (€)	48,935	438,470	298,490
Internal rate of return (IRR) (%)	16.5	14.7	12.2
Discounted payback period (DPP) (year)	7	8	9
Needed support intensity for 0 NPV (%)		-	

It was found that the highest NPV belonged to the Small-scale power plant, which had an NPV of €438,470 by the end of the 15 years. This alternative had the highest investment costs (total) followed by the HMKE one, so investors need to be financially stronger than in the case of the HMKE alternative. As it can be seen in Figure 9, the HMKE alternative had the lowest investment costs as well as the highest NPV per kWp.

When choosing between the studied investment alternatives, the demand for self-consumption is an important factor. If there is no self-consumption, only the KÁT alternative is possible, but if self-consumption is also taken into consideration, the HMKE or the Small-scale alternatives represent the most favorable investment choices.

4. Conclusions

This study examined some technical and economic aspects related to the Hungarian renewable energy regulations. Five main technical options for PV systems ranging from sizes of 50 kWp to 500 kWp were analyzed related to low- and medium-voltage facilities. In the course of the economic calculations not only the financial investments needed for the PV systems but also the annual extra yields and the financial expenditures under the current regulations in Hungary were examined in the cases of the HMKE, the Small-scale and the KÁT market environments. According to the results, the payback periods were between 7–9 years in all the studied economic-technical cases. The best IRR, which was 16.5%, belonged to the HMKE alternative, while in the cases governed by the KÁT regulation, this value was 12.2%, because of the higher security needs. The experimental results show that each investment alternative can be a good decision from an economic and technical point of view under the Hungarian regulations in force in 2018. It is hoped that this study will help stakeholders of the Hungarian market understand the possible trends in future technical and economic PV developments.

Author Contributions: H.Z. was mainly responsible for the technical aspects, conceived and designed the manuscript and supervised the economic aspects. G.P. investigated the economic aspects and carried out the main economic calculations. N.H.B. provided invaluable help with the calculations and created the graphs and tables for the paper. S.C. helped the literature review. A.V. studied the international aspects related to the subject of the research and provided linguistic supervision and assistance.

Acknowledgments: The publication is supported by the EFOP-3.6.3-VEKOP-16-2017-00008 project. The project is cofinanced by the European Union and the European Social Fund.

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

Abbreviations

The following abbreviations are used in this manuscript:

AC	Alternating Current (A)
AFCI	Arc Fault Circuit Interrupter (-)
a-Si	Amorphous silicon (-)
CF_{total}	Total cash flow (not discounted) (€)
$C_{O\&M,total}$	Total operation and maintenance costs for the duration of the investment (€)
C_t	Discounted (net) cash inflow for the duration of investment (€)
C_0	Total initial investment costs (€)
DC	Direct Current (A)
DPP	Discounted payback period (years)
E	Annual PV energy output (kWh)
E_1	First year, annual PV energy output (kWh)
E_t	Other years, annual PV energy output (kWh)
E_{total}	Total PV energy output for the duration of the investment (kWh)
EDIOP	Economic Development and Innovation Program (-)
EEEOP	Environment and Energy Efficiency Operational Program (-)
EMI filter	Electromagnetic interference filter (-)
EU	European Union (-)
FiT	Feed-in-tariff (€/kWh)
FiT_{total}	Total feed-in-tariff for the duration of the investment (€/kWh)
GFCI	ground fault circuit interrupter (-)
HMKE	Household-sized power plants (-)

IRR	Internal Rate of Return (%)
IS	Investment supports (-)
KÁT	Renewable Energy Support Scheme till 31 December 2016 (-)
m-Si	Monocrystalline silicon (-)
METÁR	Renewable Energy Support Scheme from 1 January 2017 (-)
MPPT	Maximum Power Point Tracking (-)
NPV	Net present value (€)
NS	Net metering system (-)
PV	Photovoltaic (-)
PWM	Pulse-width modulation (-)
p-Si	Polycrystalline silicon (-)
PVGIS	JRC Photovoltaic Geographical Information System (-)
SPD	Surge Protection Device (-)
r	Discount rate (%)
VRE	Variable renewable energy (-)

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