Analysis of Photovoltaic Systems from Energy Supply Security, Technological and Economic Aspects

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In order to design the right solar panel system, it is essential to think carefully about every decision. To select a system, investment costs and payback time are examined. In many cases, these calculations are only done in a simplified way, with which we can get a more inaccurate result than what actually happens with a system over the years. In order to be able to optimize a system as a whole, it is necessary to examine it not only from the economic side, but also from the energy supply safety and technology side. It is necessary to develop a decision support system in order to get a comprehensive picture of the individual systems and not only examine them from an economic point of view. The triangular model is a decision-supporting decision-making method that enables the evaluation of different systems from the point of view of three disciplinary approaches. The model implements an optimum search procedure.

Keywords: photovoltaic systems, economic analysis, energy supply security, payback, decision-supporting system

1 Introduction

During the process of finding the optimal system for solar power systems, many questions arise that need to be examined from several sides. There are many ways to go about sizing and selecting a solar panel system. However, many factors that may change the selection result are not examined. In terms of energy supply security, several aspects are authoritative. One is that loss of power means something different for each type of solar power system. In addition, for users, the continuity of the energy supply is not a negligible factor. Another consideration is whether the system is suitable for energy storage or not. Another evaluation aspect is the technological side. In the case of solar power systems, it is important to examine its effect on the grid, because in certain cases, inverter shutdown due to increased grid voltage may cause a loss of production. Furthermore, the spread of large-scale solar power systems can basically change the power flow processes known so far. There is a possibility of cases where the net power output exceeds the net consumption requirements, in such cases the power flow reverses and flows from the medium voltage side to the high voltage side. The appearance of harmonics can cause similar problems, especially if the harmonics caused by individual devices affect each other. Reverse power current and harmonics can affect protection systems. Taking all of this into account, it is advisable to further examine the individual systems and check, compare and interpret the individual relationships separately. In order to recognize the impact and weight of all important and apparently less important factors during the decision-making process, the use of a comprehensive model becomes justified. [1]

2 Triangular model

In order to select the optimal system structure for a system, it is necessary to examine it not only from the point of view of investment and return. A comprehensive examination requires the involvement of additional examination areas. It became necessary to develop a decision support system that enables the evaluation of different solar power systems from the point of view of three scientific fields. The main pillars of the triangle model are:

- Security of energy supply
- Technological examinations
- Economic analysis.

Three additional subsections were introduced to examine each pillar, which examine in detail the individual properties of the systems. For each subsection, a scoring system based on a five-point number system had to be developed. Accordingly, a given system may receive a score of '0', '1', '2', '3' or '4' according to the evaluation criteria for each sub-point.[1] The principle structure of the triangle model can be seen in Figure 1

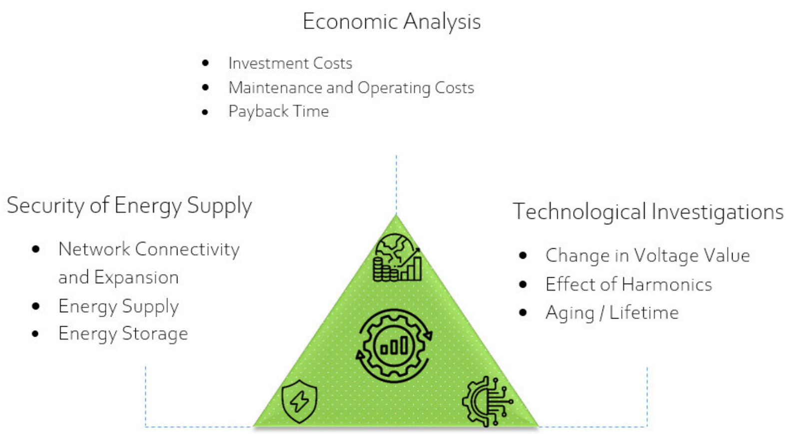

Figure 1
The principle structure of the triangle model

2.1 Security of Energy Supply

Energy is necessary for almost every segment of life. Within this, electricity supply is very important for modern society. It plays a key role in many areas. Some of these important areas are healthcare, transport, water supply, communication, households, industrial activities, etc. without claiming to be exhaustive. We examine the security of the energy supply by introducing three additional points in connection with solar power systems. The electricity network, energy supply to consumers and the energy storage capacity of the system. [2, 3]

2.1.1 Network Connectivity and Expansion

In the case of a network connection, the connection distance must be taken into account. This distance means the distance between the given consumer and the nearest electrical network connection point. Depending on the distance, this can lead to significant cost increases and many challenges. Long connection distances may require expansion of the electrical network or modification of the existing network. The costs may be higher than average if longer distances are involved, as the installation of wires and cables is expensive and, in some cases, the installation of a transformer may also be necessary. [2,3] Figure 2 shows the relationship between the cost of connecting to the electricity network and the distance. In design, proper sizing, energy efficiency and reliability are key to ensuring long-term sustainable operation.

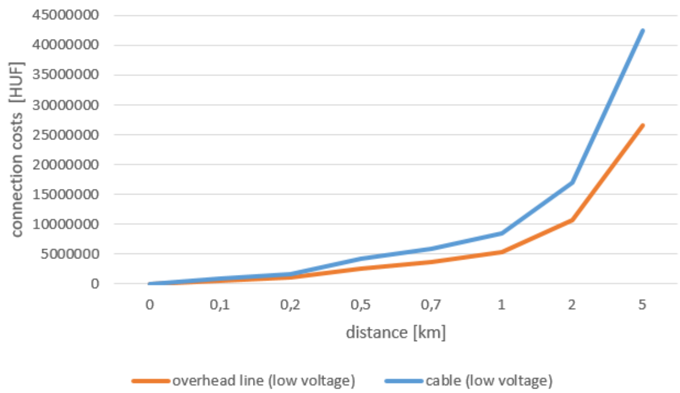

Figure 2

The cost of connecting to the electricity network and the distance [3]

In the case of solar power systems, a number of requirements must be met in order to be connected to the electricity grid. If the measuring site is not suitable for receiving the solar power system, then modernization is necessary. This includes the possible expansion of the number of phases, the possible expansion of the main line and protections, as well as the modernization of the grounding system. [3] The scoring system for the assessment related to the electricity network is contained in Table 1.

Table 1

The scoring system of the electricity network

There is no electrical network connection, but there is no need for it	0
There is no electrical network connection, the possible connection is very far from the network	1
There is no electrical network connection, the possible connection is at a very short distance from the network	2
There is an electrical network connection, but modernization is required (expansion of the number of phases, main line and possible expansion of the protections)	3
There is an electrical network connection and no expansion is required	4

2.1.2 Energy suppy

The traditional electricity system is built to lead electricity from power plants to consumers centralized in industrial sites and households.

The production of electricity and its transport over long distances also involve large losses. Another disadvantage of this topology is the vulnerability to total power failure if mass outages occur in any part of the network. If as many devices as possible are used in a building or facility that require electricity and their failure can cause serious damage, some kind of energy storage and trouble-free operation must be ensured. Solar power systems can act as a source of energy when the traditional energy supply ceases or is damaged and goes out. This can help maintain critical services and continue important operations. Solar power systems enable local energy production where the electricity grid is not present or where it could only be delivered at high cost. However, it does not increase the security of the electricity supply to a great extent, if solar radiation is not available for a few days due to the weather and the batteries are discharged, in which case the entire electricity supply is practically cut off. Although the autonomy of the system increases with the increase of battery cells, it also greatly affects the costs. [3,4] Solar power systems are a good alternative to increase energy supply security, as solar power systems contribute to the diversification of electricity supply, which reduces its exclusive dependence on traditional energy production. The scoring system for the evaluation of the energy supply of consumers is included in Table 2.

Table 2

The scoring system for the evaluation of the energy supply of consumers

Electricity supply at the facility is not relevant.	0
There is energy storage, but no network	1
There is energy storage, there is a network connection, but in the event of a network failure, the entire system is switched off.	2
There is energy storage, there is a network connection, but in the event of a network failure, dedicated consumers can operate.	3
There is energy storage, and the entire system can continue to operate in the event of a power outage.	4

2.1.2 Energy storage

Another important part of the electricity supply is the energy storage capacity of the system. In this point, we are not examining the facility's energy supply diversity or method, but its extent. There is an important difference between the following cases. One of the cases when the electricity consumers of a facility can safely shut down due to a possible power grid failure, a smaller battery capacity is also sufficient. The other case is when, as a result of an outage, it is able to supply the entire building or dedicated consumers with electricity for several hours or even for a day. This definitely requires a larger storage capacity. The scoring system for the evaluation of the system's energy storage capacity is included in Table 3.

Table 3
The scoring system for the evaluation of the system's energy storage capacity

There is no energy storage and it is not needed	0
There is no electricity network connection, but the electricity supply can be maintained for 5-10 hours	1
There is no electricity network connection, but the electricity supply can be maintained for 1-2 days	2
There is an electrical network connection, but the electricity supply can be maintained for 5-10 hours after the outage	3
there is a network connection, but the electricity supply can be maintained for 1-2 days after the outage	4

2.2 Technological Investigations

Solar power systems should also be examined from the point of view of their impact on the network, as some solar power systems can in many cases have a negative effect on the electrical network and thus on other systems as well. Furthermore, system degradation is often influenced by sizing and system type. It is also necessary to examine these aspects in order to get a comprehensive picture.

2.2.1 Change in Voltage Value

Among the networks of the Hungarian electricity system, the 20 kV overhead and 10 kV cable networks are typically tree topological networks. The internal electricity supply of industrial consumers with lower security requirements can also be designed with a tree topology. These are usually 10, 6, 3, 0.4 kV cable networks. The tree topology is the 0.4 kV overhead line supply configuration for low-voltage, low-power, scattered, rural consumers. The control of the network voltage is based on the control of the node voltages. With the spread of distributed generation units that feed into the grid, the principles of voltage regulation are fundamentally changed, as the voltage value at the nodes close to the generation units may even be higher than the original supply point voltage as a result of the feeding. If the number of solar panel systems increases on the given electricity network section, it can also cause phenomena such that the output voltage value of these production units raises the value of the network voltage so much that the inverter operation of some units can be negatively affected. For example, at a time of day when the system should be producing, the inverter shuts down because the value of the network voltage is outside the acceptable range. [5, 8] An example of this case can be seen in Figures 3 and 4.

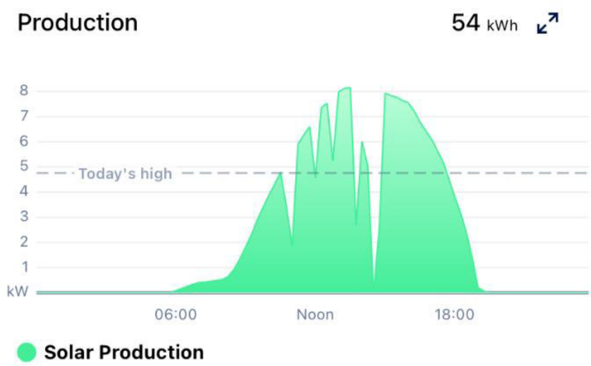

Figure 3
Solar production in normal operating conditions

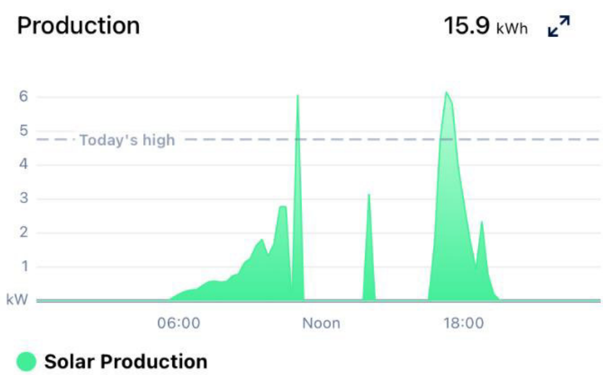

Figure 4
Loss of solar production due to voltage increase

This manifests itself to a much greater extent in the case when a solar power system does not have self-consumption at a given time of day, but the operating state of feeding back to the grid exists. If the building has self-consumption, be it any kind of consumer or battery charging, then the voltage rise is less. [5, 8] The scoring system for the evaluation related to the change in voltage value is included in Table 4.

Table 4
Scoring system related to the voltage value change

Not relevant because there is no network connection	0
It always causes a voltage increase and to a large extent if there is no self-consumption	1
It always causes a voltage rise and to a small extent if there is no self-consumption	2
If the building has no self-consumption, it may cause an increase in voltage, but due to the battery capacity connected to the system, this may occur after charging	3
If the building does not have self-consumption, there is very little chance of causing a voltage increase due to the large battery capacity	4

2.2.2 Effect of harmonics

Harmonic currents are created by the non-linear load. More precisely, the currents converted from the fundamental harmonic to the harmonic by the load are closed through the network impedances. As a result, harmonic voltage drops occur on network elements and harmonic voltages appear on all elements of the entire installation. Voltage harmonics are caused by current harmonics, which distort the voltage waveform. These voltage harmonics affect the entire system, not just the loads that cause them. Their effect depends on the distance of the load causing the harmonics from the power source. Problems caused by harmonic currents can be overloading of neutral conductors, overheating of transformers, and incorrect tripping of circuit breakers. Furthermore, problems caused by harmonic voltage can be voltage distortion, increased losses of induction motors or zero transient uncertainty. The most common non-linear loads that generate harmonic currents are switching power supplies, fluorescent lamps with electronic ballasts, uninterruptible power supplies, and variable speed drives. In addition, the increased number of inverters in solar power systems in the distribution network in recent years also contributes to the rise of harmonic components. [6, 8, 11, 12] In order to improve the harmonic profile of a system, there are many methods of regulation. One is the use of filters and controls. These can be passive or active filters or regulators. Furthermore, the selection and proper setting of inverters of the right quality can also contribute to the reduction of harmonics in the system. Proper cabling and the creation of a grounding system also help to reduce the negative effects of harmonics. Depending on the type of inverter, you can improve the harmonic profile of the network by using a battery pack. Charging electric cars usually has a negative effect on the value of harmonics, but in the case of fixed-installation battery cells, it can improve this depending on the system. The scoring system for the Total Harmonic Distortion value is included in Table 5.

Table 5

The scoring system for the Total Harmonic Distortion value

Not relevant because there is no network connection	0
It causes high THD	1
It causes moderate THD	2
It causes low THD	3
It causes negligible THD	4

2.2.2 Aging and Lifetime

All of the different types of solar power systems have aging and lifetime issues. These can affect the efficiency and operation of the systems. Solar panels degrade over time and lose their efficiency. Furthermore, environmental influences such as UV radiation, weather and pollution can contribute to a decrease in the performance of the panels. The electronic components used in inverters may be prone to failure and loss of performance in the long term. Especially if the sizing of these devices is not appropriate. This can reduce system efficiency and reliability. It can also be important to check and monitor its regular performance. These measurements can help in the early detection of possible problems and errors, enabling quick and effective intervention and timely repairs. [7,8]

For a solar power system, the selection of system components is crucial in terms of lifespan. An inverter, if it is undersized, may spend many operating hours at the upper limit of the working point range during its operation. This can lead to relatively earlier failure of the inverter. In the case of battery cells, if the sizing is not well chosen, it can lead to an early reduction in capacity or even destruction of the battery cells. This is independent of whether it is under- or over-sized. If it is undersized, too many charge and discharge cycles will be harmful. If the battery pack is over-sized, continuous "trickle charging" will be dangerous. [7,8] The scoring system for the aging-related evaluation is included in Table 6.

Table 6

The scoring system for the aging-related evaluation

Undersized inverter and undersized battery	0
Undersized inverter	1
Undersized battery	2
Oversized battery	3
Optimally designed system	4

2.3 Economical Analysis

In the case of solar power systems, as with all investments, there are significant costs. Its most important and significant cost is the investment cost, which includes planning, licensing and construction costs. In addition, there are costs related to the operation and maintenance of the system, depending on the nature of the system and the size of the system.

Furthermore, the calculation of the payback time is also an important factor, which is meant to show to what extent and when the given investment will pay off for the investor from an economic point of view. [9]

2.3.1 Investment Costs

Each type of solar power system has a different structure. Depending on the type of system, different requirements apply to it from the electricity provider's side and the investment costs will also be different. In the case of an isolated system, there is no need for a licensing procedure, so planning and licensing costs do not apply to this type. However, it is worth noting that the sizing of the system components (solar power system devices, protections, cables, etc.) is also necessary for this system, as serious material damage can occur in the event of a failure due to sizing. In the case of the stand-alone system, it is the battery pack that accounts for the significant additional cost compared to a traditional grid-connected solar power system. In the case of a grid-connected solar power system, the costs of the previously listed planning and licensing procedure will apply. The system is able to feed electricity from unused solar energy back into the grid, which is taken over by the electricity provider in accordance with the current legal regulations. However, this system is not able to manage the battery, so these additional costs do not apply. In terms of initial capital, this system has the lowest investment costs. Hybrid systems operate as a combination of stand-alone and grid-connected systems, where two-way consumption measurement is not a requirement, but not excluded - (feedback to the grid depends on the tariff), if there is, the first in the charge control priority is the own top-up storage capacity. Comparing the grid-connected and hybrid system, the hybrid system will also be more expensive due to the investment cost of the battery cells, and in this case, too, individual components (such as solar cells or battery cells) may have been overdesigned during the system design, but this system can be used in many more cases. In the event of a power outage, off-grid operation is also possible if solar energy is available or the battery charge allows. [9,13,14] Table 7 shows the investment-related parts of solar power system types.

Table 7
Investment-related parts of individual solar power systems [9]

	Off-grid system	Grid-tied system	Hybrid system
Photovoltaic panels	✓	✓	✓
Charge controller	✓	✘	✘
Off-grid inverter	✓	✘	✘
Grid-tied inverter	✘	✓	✘
Hybrid inverter	✘	✘	✓
Battery storage	✓	✘	✓
Surge protectors	✓	✓	✓
Support structure	✓	✓	✓
Accessories: junction boxes, cables etc.	✓	✓	✓
DC side isolating main switch	✓	✓	✓
Load switching station	✘	✘	✓
Grounding	✓	✓	✓
Work fee (design, construction, etc)	✓	✓	✓

The scoring system for the assessment related to investment costs is contained in Table 8.

Table 8
Scoring system related to investment costs

Oversized panels or oversized battery pack	0
Hybrid system with battery pack and panels (with normal dimensions)	1
Isolated power system (with normal dimensions)	2
Hybrid system with panels only (normal size) without battery	3
Grid-connected system (with normal dimensions)	4

2.3.2 Maintenance and operating costs

The maintenance and operating costs of solar power systems are relatively low, but there are some potential costs and cost elements to consider. Regular cleaning of the solar panels may be necessary to maintain efficient operation and maximum performance. Furthermore, in the case of stand-alone and hybrid solar power systems, the batteries may have replacement and maintenance costs. Especially in the long term, when the capacity of the batteries may decrease. Installing a solar power system can increase the value of your property insurance. This can also be classified as maintenance and operating costs. If the solar power system requires regular monitoring, maintenance or operating costs can be added to the annual budget. This usually applies to larger systems. In addition, if administrative tasks related to accounting also arise, this can also increase the annual costs. [9] The scoring system for the evaluation related to maintenance and operation costs is contained in Table 9.

Table 9

A scoring system related to maintenance costs

Annual cleaning, insurance, battery maintenance, system monitoring staff, administrative costs (e.g. accounting)	0
Annual cleaning, insurance, battery maintenance, system monitoring staff	1
Annual cleaning, insurance, battery maintenance	2
Annual cleaning, insurance	3
Annual cleaning	4

2.3.2 Payback time

The payback period means the time required to pay back the funds spent on the investment. The simplified payback calculation is a very simple method that ignores the time value of money, but provides some insight into the economic value of a project. Calculation of the simplified payback time: it can be calculated by dividing the investment cost of the solar panel system with a unit of power by the price of the electricity produced by the system in one year. [9, 13, 14]

$$PP = \frac{I}{C} \tag{1}$$

where, PP is the Payback Period, I is the Initial investment, C is the Cash inflow per year.

Many important factors were not taken into account during the simplified calculation. The quality of the system components, the technology of the solar power system, the efficiency of the solar panel system (pollution, shading of solar panels) annual performance degradation, since a certain degree of performance reduction of solar panels occurs over time, performance reduction occurs, the location of the building, the size and inclination of the roof, the number of hours of sunshine in the given geographical location, maintenance and insurance costs, the inverter/battery is replaced approximately every 10-15 years, the rate of inflation, the increase in the price of electricity, financing issues (applicable state subsidies or borrowing). If most of the above parameters are included in the study, we get the compound payback time. The complex payback time calculation allows a more complicated and accurate calculation than the simplified calculation. The calculation is divided into years in several steps [9, 13, 14]. The scoring system for the payback time evaluation is included in Table 10.

Table 10

Payback time scoring system

The payback period is more than 26 years / in the case of a value greater than 30 years, this value will be -10	0 / -10
The payback period is between 21-25 years	1
The payback period is between 16-20 years	2
The payback period is between 11 and 15 years	3
The payback period is between 0 and 10 years	4

In the payback time calculation, the score of 0 was supplemented with a value of -10 if the payback time is greater than 30 years. Because the scoring system does not take this into account normally. However, this is not a negligible factor, otherwise the costs will not be taken into account by the system.

3 Examination of solar power systems using a triangle model

Using the triangle model, five solar power systems were examined. Examining the three main basic types of solar power systems, there are two different configurations in the case of the stand-alone system, and in the case of grid-connected systems, 1 configuration that operates without a battery pack and 2 configurations that are equipped with a battery pack.

3.1 Examination of the Off-grid solar power systems

In the case of Off-grid solar power systems, only the electricity produced by the solar power system is available to users. The energy is stored in a battery. The reliability of the system is determined by the battery charger and the associated batteries, as well as the properly chosen charging characteristics, which can ensure the battery's service life in the long term. In the case of Off-grid systems, two different configurations were investigated. In the first case, a battery pack with a capacity of 5kWh was connected to a 10kWp system. In the second case, the capacity of the battery for the same system was doubled for the sake of system autonomy [9,10]. Table 11 contains the costs of Off-grid systems.

Table 11
The costs of the examined Off-grid systems

<table>
<tr><th>Configuration</th><th>Investment Costs</th><th>Comment</th><th>Amount</th><th>Unit price (HUF)</th><th>Total price (HUF)</th><th>Summary (HUF)</th></tr>
<tr><td rowspan="4">Offgrid (Case 1)</td><td>Solar panels</td><td>450Wp/pcs</td><td>22</td><td>60 000</td><td>1 320 000</td><td rowspan="4">4 120 000</td></tr>
<tr><td>Inverter + Charge controller</td><td>10kW</td><td>1</td><td>500 000</td><td>500 000</td></tr>
<tr><td>Cables, accessories, installation, support structure</td><td></td><td></td><td></td><td>600 000</td></tr>
<tr><td>Battery pack</td><td>5 kWh</td><td>1</td><td>1 700 000</td><td>1 700 000</td></tr>
<tr><td rowspan="4">Offgrid (Case 2)</td><td>Solar panels</td><td>450Wp/pcs</td><td>22</td><td>80 000</td><td>1 760 000</td><td rowspan="4">6 260 000</td></tr>
<tr><td>Inverter + Charge controller</td><td>10kW</td><td>1</td><td>500 000</td><td>500 000</td></tr>
<tr><td>Cables, accessories, installation, support structure</td><td></td><td></td><td></td><td>600 000</td></tr>
<tr><td>Battery pack</td><td>5 kWh</td><td>2</td><td>1 700 000</td><td>3 400 000</td></tr>
</table>

The stand-alone system can operate independently of the electrical network. So, in the event that a facility is located very far from the connection point of the possible electrical network, it provides a good solution for the electrical supply of a building.

Table 12
The payback period of the examined Off-grid systems

Configuration	Simplified payback calculation	Complex payback calculation
Offgrid (Case 1)	~ 7,2 years	~ 20 years
Offgrid (Case 2)	~ 11 years	~ 30 years

Table 12 contains the payback time of the tested stand-alone systems. Based on the compound payback time calculation, the value of the second configuration is 30 years. This is the case when the battery pack has been sized with double capacity. So if we want to increase the autonomy of the system by increasing the battery, in that case the payback time will increase drastically. These values can be reduced if we include tenders or grants.

Table 13

Scoring results of the triangular model for the examined Off-gird systems

Examined category		Offgrid (Case 1)	Offgrid (Case 2)
Security of energy supply	Electrical network connection and other extensions	0	0
	Energy supply to consumers	0	0
	Energy storage capacity of the system	1	2
	Partial score	1	2
Technological investments	Voltage change problems	0	0
	Effect of harmonics	0	0
	Lifespan and Aging	4	3
	Partial score	4	3
Economic analyses	Investment costs	2	0
	Maintenance and operating costs	4	4
	Payback time	2	-10
	Partial score	8	-6
Total score		**13**	**-1**

The scoring of the triangle model in the case of stand-alone systems is included in Table 13. Based on this, configuration 1 received 13 points. However, in the 2nd case, the payback time increased to 30 years due to the investment cost of the batteries. Due to the scoring system, this is not rated 0, but -10, so this system received a -1 point in total.

3.2 Examination of the Grid connected solar power systems

In the case of grid-connected solar power systems, the grid systems do not have their own energy storage, part of the produced energy goes to the consumers of our internal network. The produced but unused electricity is fed into the power supply network by the inverters through a so-called two-way consumption meter, which is used in practice as an energy storage [9,10]. From the economic point of view, this type of system received a very good evaluation in all three subsections, which is understandable from the point of view that apart from the solar panels and the inverter, the system does not contain anything else that would represent a serious cost. Compared to the stand-alone system, the planning and other licensing costs appear as investment costs. The 10kWp power system was also examined in the case of a grid-connected system

Table 14

The costs of the examined Grid connected system

<table>
<tr><th>Configuration</th><th>Investment Costs</th><th>Comment</th><th>Amount</th><th>Unit price (HUF)</th><th>Total price (HUF)</th><th>Summary (HUF)</th></tr>
<tr><td rowspan="3">Grid-connected system</td><td>Solar panels</td><td>450Wp/pcs</td><td>22</td><td>60 000</td><td>1 320 000</td><td rowspan="3">3 150 000</td></tr>
<tr><td>Inverter</td><td>10kW</td><td>1</td><td>730 000</td><td>730 000</td></tr>
<tr><td>Cables, accessories, installation, support structure</td><td></td><td></td><td></td><td>1 100 000</td></tr>
</table>

Table 15

The payback time of the examined Grid connected system

Configuration	Simplified payback calculation	Complex payback calculation
Grid-connected system	~ 5,5 years	~ 18 years

Table 15 contains the payback time of the examined grid-connected system. It is necessary to note that, based on the compound payback period calculation, the payback period of the system is 18 years. Based on the simplified payback calculation, this value is 5.5 years, which can be said to be quite inaccurate. In the case of all system calculations, it can be said that the simplified return calculation yielded a lower value than the complex return calculation.

Table 16

Scoring results of the triangular model for the examined grid-connected system

Examined category		Grid connected system
Security of energy supply	Electrical network connection and other extensions	0
	Energy supply to consumers	0
	Energy storage capacity of the system	3
	Partial score	3
Technological investments	Voltage change problems	2
	Effect of harmonics	2
	Lifespan and Aging	4
	Partial score	8
Economic analyses	Investment costs	4
	Maintenance and operating costs	3
	Payback time	2
	Partial score	9
Total score		**20**

From the evaluation of the grid-connected system, it can be seen that it is In terms of energy supply security, it received a better evaluation than the isolated systems, but this system did not achieve a high score in this subsection either. However, based on economic analyses, this system proved to be the most economical configuration. This system received 20 points based on the evaluation of the triangle model. The summary is contained in Table 16.

3.3 Hybrid solar power system

Hybrid systems operate as a combination of Off-grid and the Grid connected systems, where two-way consumption measurement is not a condition, but not excluded - (feedback to the network depends on the tariff), if there is, self-consumption and charging of own storage capacity are the first in the charge control priority [9,10]. In the case of hybrid systems, two different configurations were examined, similarly in the case of stand-alone systems. In the first case, a battery pack with a capacity of 5kWh was connected to a 10kWp system. In the second case, we doubled the capacity of the battery for the same system for the sake of the autonomy of the system.

Table 17

The costs of the examined Hybrid systems

Configuration	Investment Costs	Comment	Amount	Unit price (HUF)	Total price (HUF)	Summary (HUF)
Hybrid system (Case 1)	Solar panels	450Wp / pcs	22	60 000	1 320 000	5 270 000
	Inverter	10 kW	1	750 000	750 000	
	Cables, accessories, installation, support structure				1 100 000	
	Battery pack	5 kWh	1	2 100 000	2 100 000	
Hybrid system (Case 2)	Solar panels	450Wp / pcs	22	60 000	1 320 000	7 370 000
	Inverter	10 kW	1	750 000	750 000	
	Cables, accessories, installation, support structure				1 100 000	
	Battery pack	5 kWh	2	2 100 000	4 200 000	

Table 18

The payback time of the examined Hybrid system

Configuration	Simplified payback calculation	Complex payback calculation
Hybrid system (Case 1)	~ 9,2 év	~ 24 év
Hybrid system (Case 2)	~ 13 év	~ 36 év

The payback time of the examined hybrid systems is shown in Table 18. The compound payback time calculation is 24 years in the first case and 36 years in the second configuration. This is the case when the battery pack has been sized with double capacity. So, in this case, the system is able to supply consumers for a longer period of time due to a possible power outage. However, the payback time of the system increases drastically, similar to the isolated system. These values can be reduced if we include tenders or grants. The scoring of the triangle model in the case of hybrid systems is shown in Table 19. Based on this, configuration 1 received the highest score, which was 23. However, in the 2nd case, the payback time increased a lot and went up to 30 years. Due to the scoring system, this is not rated 0, but -10, so this system received -12 points in total.

Table 19
Scoring results of the triangular model for the examined hybrid systems

Examined category		Hybrid (Case 1)	Hybrid (Case 2)
Security of energy supply	Electrical network connection and other extensions	3	3
	Energy supply to consumers	3	3
	Energy storage capacity of the system	3	4
	Partial score	9	10
Technological investments	Voltage change problems	3	3
	Effect of harmonics	3	3
	Lifespan and Aging	4	3
	Partial score	10	9
Economic analyses	Investment costs	1	1
	Maintenance and operating costs	2	2
	Payback time	1	-10
	Partial score	4	-7
Total score		**23**	**-12**

Conclusions

In the case of stand-alone systems, there is no network connection, which is why several test points in the triangle model are not relevant for these systems. For this reason, it is worthwhile to examine these systems separately in the future and not to compare them with networked systems. Because in this case the security of the energy supply depends only and exclusively on the solar power system. So the facility is much more dependent on itself and cannot operate in a Microgrid network with several other facilities. In the case of grid-connected systems, it can be observed that the most economical configuration is the one that does not contain a battery, but in terms of energy supply security, it is significantly worse compared to the hybrid solar power system. Based on the results, if we examine only the economic side, the hybrid system received a worse evaluation in almost every case, but if we consider the energy supply security and technological side, it can be seen that this type of solar power system received a higher score. However, it is important to keep the payback period in mind. If investment and other costs are greatly increased, the payback period will increase drastically, which will negatively affect sustainability.

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