1. David MARTINKO[1], 2. Dusan MEDVED[1], 3. Michal KOLCUN[1], 4. Damian MAZUR[2]

Technical University of Kosice, Faculty of Electrical Engineering and Informatics (1); Rzeszow University of Technology (2)
ORCID: 1. 0000-0003-0880-5711; 2. 0000-0002-8386-0000; 3. 0000-0002-8041-9076; 4. 0000-0002-3247-5903

doi:10.15199/48.2024.01.22

Planning of the Optimal Performance of Household Photovoltaics and Battery Storage within Consideration of Investment Return

***Abstract**. This paper provides the assessment of the profitability of investing in household photovoltaic system in combination with a battery storage, either physical or virtual, and the optimal choice of the combination of the ratio of the power of photovoltaic system and the battery storage with respect to the return on investment in local conditions and pricing policies in Eastern Slovakia.*

***Streszczenie.** W artykule przedstawiono ocenę opłacalności inwestycji w domowy system fotowoltaiczny w połączeniu z magazynem baterii, fizycznym lub wirtualnym, oraz optymalny wybór kombinacji stosunku mocy systemu fotowoltaicznego i magazynu baterii w odniesieniu do zwrotu z inwestycji w lokalnych warunkach i polityce cenowej we wschodniej Słowacji. (**Planowanie optymalnej wydajności domowej fotowoltaiki i magazynowania baterii z uwzględnieniem zwrotu z inwestycji**)*

Keywords: Return of Investment, Photovoltaics, Battery storage, Virtual battery
Słowa kluczowe: Zwrot z inwestycji, Fotowoltaika, Magazynowanie baterii, Wirtualna bateria

Introduction

By its very nature, a household PV plant must be considered as an investment tool for household income appreciation. In any case, the installation of a photovoltaic source represents a big investment for the homeowner, and as an investment tool it must be evaluated and compete with other options in the field.

We define an investment as a portion of resources to be used on a one-time basis with an expected benefit and purpose in the future. [1]

The essence of investment appraisal is the comparison of the capital employed and the returns that the investment will bring, i.e. the profitability of the investment.

Increasing demands on energy resources, caused by high economic development and the fact of limited traditional energy resources due to rapid economic development, and the awareness of the negative impacts of the use of fossil fuels in energy production on the environment and the health of society, are one of the main reasons for the increasing interest in renewable sources of energy.

Today, solar energy is considered to be the most promising and important renewable energy source and the amount of solar energy reaching the Earth still exceeds the requirements and can be considered as inexhaustible.

The disadvantages of solar energy are its diffusivity, we cannot use it to the maximum extent as it arises in its source, and the main disadvantage is the time limitations of its use due to the physical conditions of the movement of the earth around its axis and around the sun.

This imposes direct constraints on the use of solar energy as an investment cost of PV systems and battery storage, for the use of energy also in non-solar times, the high dependence of system performance and electricity supply on location and season, factors reducing system performance by its viability and degradation, and last but not least country-specific economic and legal conditions that to a large extent influence positively or negatively the decision-making of customers or investors.

PV market

Despite the above, there is a global increase in the use of solar energy for power generation from 72.2 GW of installed solar capacity to 843.1 GW in 2021.

The year-on-year global increase in installed photovoltaic power between years 2020 and 2021 is 19%, but in certain countries the year-on-year increase in solar capacity is more than double, for ex. in Europe, Poland 137.2%, Romania 106.3%, Turkey 102.6%, Russian Federation 206.1%, in Asia and the Middle East Jordan with an increase of 185%, Malaysia 124.7% and Vietnam 127.3%. In the Americas it is Brazil with an increase of 115.3% and Argentina with a 96.4% increase.

The share of solar electricity generation in global installed capacity in these countries is negligible, despite the high numbers of increase in installed capacity, ranging from 0.1% to 0.9% and 1.5% in the case of Brazil.

The biggest players in terms of the amount of installed capacity of solar power plants in terms of global capacity in 2021 were China with 36.3%, the US 11.1%, Japan 8.8%, Germany 6.9%, and India with 5.9% of the global total installed PV capacity. [2]

The dynamic growth of the installed capacity of photovoltaic systems may have several reasons across regions, such as a time- and investment-saving way to cover the population with electricity in underdeveloped countries, growing social awareness and support programmes in the field of environmental protection, or the targeted reduction of CO2 emissions and the limitation of the increase of the average temperature due to climate change by 1.5°C in the sense of the Paris Agreement of 2016 in the European Union by 2030 [3]. The EU's 2030 target is to at least double the share of renewable energy from the current level of 32% to around 65% or more. [4]

The process of electricity market liberalisation started the transition of the energy sector from centrally controlled sector, where the state had a central role, to a market-based sector in which the price of electricity is determined by a number of commercial factors and electricity market participants themselves.

The shift of electricity trading to the free market has brought with it the negative impact of external factors on the rapid change in traded electricity prices, including benefits for the end-customer such as price reductions and an increase in competitive market power across the EU market.

Due to the current geopolitical situation in Europe, from the beginning of 2022 the traded price of electricity on the Prague Stock Exchange, which is the exchange for the sale of electricity in the Central Europe region and serving countries such as Poland, Czech Republic, Slovakia, Hungary and others, has increased from an average price of €120 per MWh in January and February 2022 to a level of €1,000 per MWh at the end of August and beginning of September this year. The current market price of electricity at the time of writing, November 2022, stands at €350 per MWh of electricity. [5]

The trend in electricity prices has led to an increase in requests for the connection of photovoltaic sources to such an extent that, for example, for the local distributor in the Czech Republic, EG.D., the number of requests for the connection of small photovoltaic sources in 2022 is many times higher than the sum of the requests in the intermediate years 2020 and 2021, Figure 1. [6]

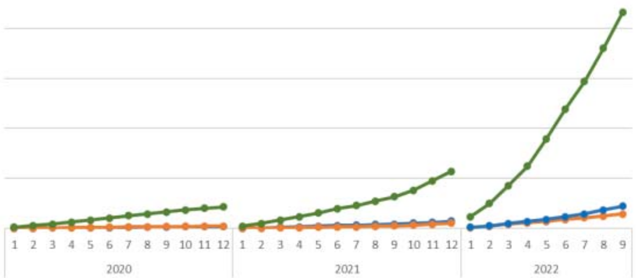

Fig.1. Cumulative evolution of the number of PV connection requests per month in EG.D from 2020 to 2022

The Slovak situation

Households in the Slovak Republic can use renewable sources of electricity, or photovoltaic panels with a maximum system output of 10 kW. The electricity produced from them cannot be sold to the distribution grid as, for example, households in neighbouring Austria. To promote the use of renewable sources, the national project Green Households (Zelená domácnostiam) was established in 2015, funded from European sources through the Operational Programme Environmental Quality, which ends in December 2023. The Slovak Innovation and Energy Agency will continue to support installations in households in the future through the Slovakia Programme (Program Slovensko), which is currently under preparation. Since 2015, a total of more than 36,000 households have benefited from the subsidy for renewable energy sources, including biomass boilers and heat pumps. The greatest interest is in photovoltaic panels, with 2,396 households having applied for support for photovoltaic panels by mid-July 2022 alone [7]. The allowance for the installation of photovoltaic panels is at the level of 500€ per kW, with a maximum of 1500€.

The ratio of the price of electricity itself to the price of distribution for households in 2022 in the territory of Eastern Slovakia is approximately 50% to 70% electricity and the other 50% to 30% distribution charges, depending on the supplier and tariff. At higher rates, where high electricity consumption is expected, for example for heating, the electricity price share is around 70%.

Calculations

Our research concerns the cost-effectiveness of installing a PV system in the home, or the profitability of investing in a PV system for the home in combination with battery storage. Accordingly, for the analysis we have chosen the annual household electricity consumption as the basis for which we have selected a suitable combination of PV panel capacity at 0.5, 0.75, 1, 1.25, 1.25 and 2 times the annual consumption and battery storage capacity at 0.5, 1, 1.5, 2, 2.5, 2.5 and 3 times the PV panel capacity or in combination with a virtual battery and the possibility of PV panels alone without energy storage.

The standard calculation of the return on investment of a photovoltaic system is based on the solar radiation map and the potential output of the photovoltaic system per 1 kWp of installed capacity. For the region of Slovakia, this is on average 1.2 kWh produced per year per 1 kWp of installed solar panels, with optimal placement of the panels with respect to angle and azimuth, shown at Figure 2. [8] For these calculations we can use for example the online calculator Photovoltaic geographical information system. [9]

The amount of solar radiation that hits the PV system has a big impact on the production, and higher production means faster payback, but we can only consider the full potential of the energy produced if we as a consumer can use all of the electricity over the full-time scale of the PV system's production.

The electricity consumption of a typical household is mainly distributed in the early morning hours and in the afternoon or evening. These times are in contrast to the maximum solar insolation, which is predominantly in the daytime intervals around midday. For these reasons, we chose to calculate PV system payback based on 15 minutes of consumption data for households that have installed IMS smart metering systems, and to calculate PV system output, we chose a methodology to calculate PV system production based on historical meteorological data. [10]

The photovoltaic systems power output can be described as a relationship between weather conditions and rated power output based on standard test conditions [11]:

$$P_{PV(t)} = \eta \cdot P_{PV\mathrm{ref}} \cdot \frac{G}{G_{\mathrm{ref}}} \cdot \left(1 + \gamma \cdot \left(T_{\mathrm{c}} - T_{\mathrm{ref}}\right)\right) \tag{1}$$

where: $P_{PV(t)}$ - power output of photovoltaic system in time interval, η - photovoltaics system efficiency, respectively the summary of different losses, G - the solar irradiance (W/m^2) received on module plane, γ - temperature correction for maximum power, T_c - panel temperature.

Subscript "ref" refers to panel standard testing conditions (STC) as G = 1000 W/m^2, T = 25°C. PPVref is maximum panel power output at reference conditions.

The calculations are based on 15-minute time series of historical meteorological dataset from Solcast. The historical data set includes air temperature, wind speed and direction, humidity, cloud cover, and several types of solar radiation calculated for specific GPS coordinates, tilt, and azimuth. [12]

Modelling of different combinations of installed PV systems and battery storage in households was carried out on a group of consumption points, family houses, in the village of Mala Ida, which has the highest share of installed IMS among the substations of the distribution system operator in the east of Slovakia. The number of consumption points in that substation is 97, of which 5 are without IMS and 4 family houses already have a PV system installed, they are not suitable for the calculation. The total sample for power modelling was in the number of 88 sampling points. The input data from the IMS was anonymized with a time interval of 15 minutes, the same as the historical meteorological data, and contained the P power taken or supplied to the distribution network by the customer in the time interval. The input data covered the years 2020 and 2021, with a total of approximately 6.5 million IMS records.

For these selected household customers locations, we calculated the PV output for a 15-minute time interval during 2020 and 2021 based on PV selection from a dataset of more than 70 selected real PV systems installed at the beginning of 2022, out of a total of more than 500 installed and registered PV systems in the distribution system in the east of Slovakia, based on the required output for a given PV combination. The dataset of real PV includes the type and number of panels, panel parameters, system power, inverter type and parameters needed for the calculation.

The price of electricity for households consists of two basic categories of components: electricity as such, the price of power electricity, and distribution charges including other tariffs, namely the variable component of the distribution tariff, the tariff for system operation, for system services, for electricity losses during distribution and the levy to the nuclear fund.

Another key factor influencing the price of electricity, including the price of distribution, is the tariff group of the point of consumption. Consumption points are divided into several tariff groups based on their expected annual consumption or the nature of their consumption. The standard division is a 2 tariff billing of the electricity price. Where we talk about high or low tariff or time bands with higher or lower price respectively. The new trend is a multiple tariff division of days, into weekdays and weekends, followed by for example a 4 tariff division into 4 time bands. The distribution of the day into different tariff bands and tariffs in the distribution territory of Eastern Slovakia is shown in Table 1.

Table 1. Tariff times during the day

	Hour of the day																							
Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2T D1, D2	HT																							
2T D4	LT						HT																LT	
2T D5	LT								HT	LT	HT	LT							HT			LT		
4T	1T						2T			3T				4T						2T			1T	

The choice of the appropriate tariff depends on the purpose for which the electricity is used (current consumption, heating, water heating) and the estimated amount of electricity the household will consume per year. The right tariff is the basis for achieving lower electricity consumption costs in the household.

The payback for the chosen solution or combination of PV panels and battery storage was based on a comparison of the differences in total annual charge savings for each combination versus the total annual charges at the customer's point of consumption input, i.e. without the PV system.

On the territory of Slovakia, customers can choose so-called traditional electricity suppliers, which are historically based on local electricity distributors in the west, centre or east of Slovakia, or so-called new electricity sellers, which are not historically associated with the sale of electricity in the selected territory and their operation began with the liberalisation of the electricity market.

Table 2. Regulated households electricity prices in 2022

Electricity seller	Tariff	Monthly [€]	High Tarrif [€]	Low Tarrif [€]
VSD	D1	1,32	0,0974	
VSD	D2	1,32	0,0974	
VSD	D4	1,32	0,1136	0,0703
VSD	D5	1,32	0,1169	0,0862
ZSE	D1	1,32	0,0846	
ZSE	D2	1,32	0,0971	
ZSE	D4	1,32	0,1106	0,0715
ZSE	D5	1,32	0,1208	0,0804

When calculating the annual electricity charges, we chose the traditional electricity sellers VSE and ZSE, whose pricing policy is approximately the same, prices for households are regulated by the state, but have different views on the price of the virtual battery, and the company MAGNA, which offers unregulated 4 tariff variable tariffication of the consumption points and a differently constructed pricing policy for the virtual battery. Tables 2 and 3 show electricity prices including monthly charges including VAT.

Table 3. The parameters of the sensor Unregulated households electricity prices in 2022

Electricity seller	Monthly	Type of day	Time zone			
			1P [€]	2P [€]	3P [€]	4P [€]
MAGNA	1,32	work days	0,06024	0,120492	0,092376	0,076308
MAGNA	1,32	week end	0,049404	0,098808	0,075744	0,06258

To calculate the total annual price of electricity, it is necessary to calculate the total price of electricity, the electricity itself and the distribution charges. These are shown in Table 4. Distribution prices are derived from the final electricity prices for households in the distribution territory of Eastern Slovakia.

Table 4. Distribution prices based on tariff in 2022

Distribution Company	Tariff	Monthly [€]	High Tarrif [€]	Low Tarrif [€]
VSD	D1	1,56	0,1019	
VSD	D2	5,7853	0,0692	
VSD	D4	8,862	0,0518	0,0517
VSD	D5	8,862	0,0517	0,0517

Selected electricity suppliers offer different options for virtual batteries. Traditional suppliers have a battery capacity limited by the annual consumption of the customer's point of use or in tiers, whichever the customer chooses. In both cases, the period of electricity storage in the virtual battery is limited to the annual consumption billing period. Magna electricity seller company has a monthly consumption billing cycle for this unregulated 4 tariff product and the virtual battery is charged on that base, the monthly charge is based on the amount of electricity used. Stored electricity not consumed is carried over into the next month. Due to the fact that in the case of a virtual battery there is no physical storage of electricity on the customer side and there is only a balance difference between the electricity actually consumed and the surplus electricity virtually stored, the annual electricity consumption on the distribution and distribution charges side is charged at the full amount of electricity consumed. The price saving occurs only on the power side of the electricity price itself.

Table 5. Virtual battery prices in 2022

Electricity seller	Battery Capacity [kWh]	Monthly [€]	Storage period
VSE	1000	2	annually as billed, without transfer
VSE	2000	4,8	annually as billed, without transfer
VSE	3000	7,2	annually as billed, without transfer
VSE	4000	9,5	annually as billed, without transfer
VSE	6000	11,9	annually as billed, without transfer
ZSE	annual electricity consumption	2	annually as billed, without transfer
Magna	undetermined	0,0045*	monthly, with transfer

Table 5 shows the prices of the virtual battery for each vendor.

Based on the above input data, we simulated the electricity production from the combination of the PV system and battery storage separately for each single point of consumption for all 15-minute time intervals in 2020 and 2021. When calculating the PV system output, it was assumed that the above combination is feasible in reality on a family house and has the correct azimuth and inclination with respect to the latitude of the location of Mala Ida and the Slovak Republic, respectively. This assumption is currently feasible for panels with an output between 450 and 500 W, as 2 panels with an area of only about 4.5m2 are sufficient for 1kW of installed power.

We can balance the calculated PV production against the actual household consumption at each 15-minute interval. In the case of battery storage, the excess energy is stored locally in the battery for use later. A PV system without physical storage distributes all the generated and unconsumed electricity to the distribution system.

These calculations resulted in different electricity consumption per household divided into 15-minute intervals for all combinations of PV and battery storage.

The results excluded combinations of systems at low annual consumption, where for some combinations the installed PV panel capacity would be below 2kW, which is the smallest model available in the PV system vendors' quotes. Systems with lower output do not benefit economically due to the incomparable cost of the panels relative to the cost of other parts such as the inverter. Also, combinations where the required PV system output is higher than the legislative power cap of 10 kW for small electricity sources in the residential segment have been excluded.

We considered the cost of installing the PV system as an upfront investment. These amounts varied for the same performance parameters, differed by individual component and probably by the company's margin, so they are averaged for each performance level.

The lifetime of a PV system is a critical factor for assessing investment and payback. For panels, the manufacturers state a warranty of 10-30 years and an inverter warranty of up to 20 years. The total lifetime of the PV system at acceptable PV performance is estimated at 25 years. In the case of batteries, the warranty is also given in the range of 25 years, but the real lifetime depends on the number of charging cycles and the intensity of discharging. In this case, battery replacement should be considered after 10 years.

However, battery replacement is no longer covered by the subsidy under current conditions. Battery storage prices are not expected to decrease in price at the same parameters, but due to the high demand for batteries in electromobility there has been a 10-20% increase by the end of 2021. [13] Recycled lithium-ion cells are cheaper than newly produced ones and are expected to start to have a significant impact on the supply chain around 2027, with the expectation of breaking the downward trajectory of battery prices. The normalized cost trajectories for the median projection consider a 42% and 57% price decline in 2030 and 2050, respectively, and 50% for a linear path in 2040. [14][15][16]

Results

Table 6 shows the median percentage savings in annual charges for using combinations of PV systems without a battery, with a physical battery or with a virtual battery, relative to the original annual electricity charges for all 3 of these tariff types on the input set of households. The line labels "PVx" denotes the PV system capacity multiple and "x Battery" denotes the battery capacity multiple relative to the PV The full ranges of percentage savings in annual charges are shown in Figure 2, so that in the rows for each combination of PV systems, the tariffs of VSE, ZSE and MAGNA are shown above each other in that order, for quicker comparison.

system capacity.

Table 6. The median percentage savings in annual charges for using combinations of PV systems and battery combinations battery prices in 2022

PV combination	VSE 2T [%]	ZSE 2T [%]	MAGNA 4T [%]
PV 0.5x - No Battery	27,645	27,48	27,745
PV 0.5x - Virtual Battery	36,055	41,53	38,66
PV 0.5x - 0.5x Battery	34,28	33,905	34,245
PV 0.5x - 1x Battery	38,825	38,675	39,055
PV 0.5x - 1.5x Battery	42,715	42,605	42,875
PV 0.5x - 2x Battery	45,76	45,69	45,94
PV 0.5x - 2.5x Battery	48,12	47,905	48,19
PV 0.5x - 3x Battery	49,625	49,435	49,455
PV 0.75x - No Battery	31,925	31,58	31,79
PV 0.75x - Virtual Battery	50,07	58,515	47,2
PV 0.75x - 0.5x Battery	41,53	41,295	41,605
PV 0.75x - 1x Battery	48,825	48,725	49,24
PV 0.75x - 1.5x Battery	54,325	54,19	54,65
PV 0.75x - 2x Battery	58,5	58,415	58,43
PV 0.75x - 2.5x Battery	61,41	61,34	60,92
PV 0.75x - 3x Battery	62,89	62,79	62,41
PV 1x - No Battery	34,735	34,415	34,505
PV 1x - Virtual Battery	54,095	64,05	49,145
PV 1x - 0.5x Battery	47,38	47,29	47,43
PV 1x - 1x Battery	56,655	56,645	56,56
PV 1x - 1.5x Battery	62,765	62,5	62,385
PV 1x - 2x Battery	66,18	66,165	65,825
PV 1x - 2.5x Battery	68,06	67,99	67,585
PV 1x - 3x Battery	69,29	69,21	68,86
PV 1.25x - No Battery	36,815	36,69	36,93
PV 1.25x - Virtual Battery	54,095	64,9	50,89
PV 1.25x - 0.5x Battery	53,125	52,04	53,33
PV 1.25x - 1x Battery	64,205	63,735	64,18
PV 1.25x - 1.5x Battery	69,455	69,28	69,24
PV 1.25x - 2x Battery	72,17	71,955	71,805
PV 1.25x - 2.5x Battery	73,54	73,435	73,13
PV 1.25x - 3x Battery	74,81	74,625	74,385
PV 1.5x - No Battery	37,5	37,395	37,595
PV 1.5x - Virtual Battery	51,115	64,63	50,715
PV 1.5x - 0.5x Battery	56,755	56,365	56,485
PV 1.5x - 1x Battery	68,015	67,895	67,295
PV 1.5x - 1.5x Battery	72,255	72,235	71,58
PV 1.5x - 2x Battery	74,46	74,405	73,835
PV 1.5x - 2.5x Battery	75,79	75,54	75,175
PV 1.5x - 3x Battery	76,73	76,38	76,095
PV 2x - No Battery	37,155	37,145	37,02
PV 2x - Virtual Battery	49,375	63,3	49,845
PV 2x - 0.5x Battery	62,46	62,37	62,845
PV 2x - 1x Battery	72,55	72,49	71,93
PV 2x - 1.5x Battery	75,15	75,13	74,53
PV 2x - 2x Battery	76,94	76,92	76,335
PV 2x - 2.5x Battery	78,01	77,985	77,41
PV 2x - 3x Battery	79,325	79,305	78,68

Based on the price development over the last 5 years, the average year-on-year increase in regulated end-use electricity prices, including distribution charges, is 5.75%.

Table 7 shows the median ROI for each PV combination for all 3 tariff types listed considering the average year-on-year increase in end prices and the need to replace the battery after an estimated 10 years in the cases of combinations with a physical battery. The labelling of the combinations is the same as the previous table. Then in Figure 2 we can see the complete ROI ranges for each combination with the assumed PV system lifetime of 25 years shown.

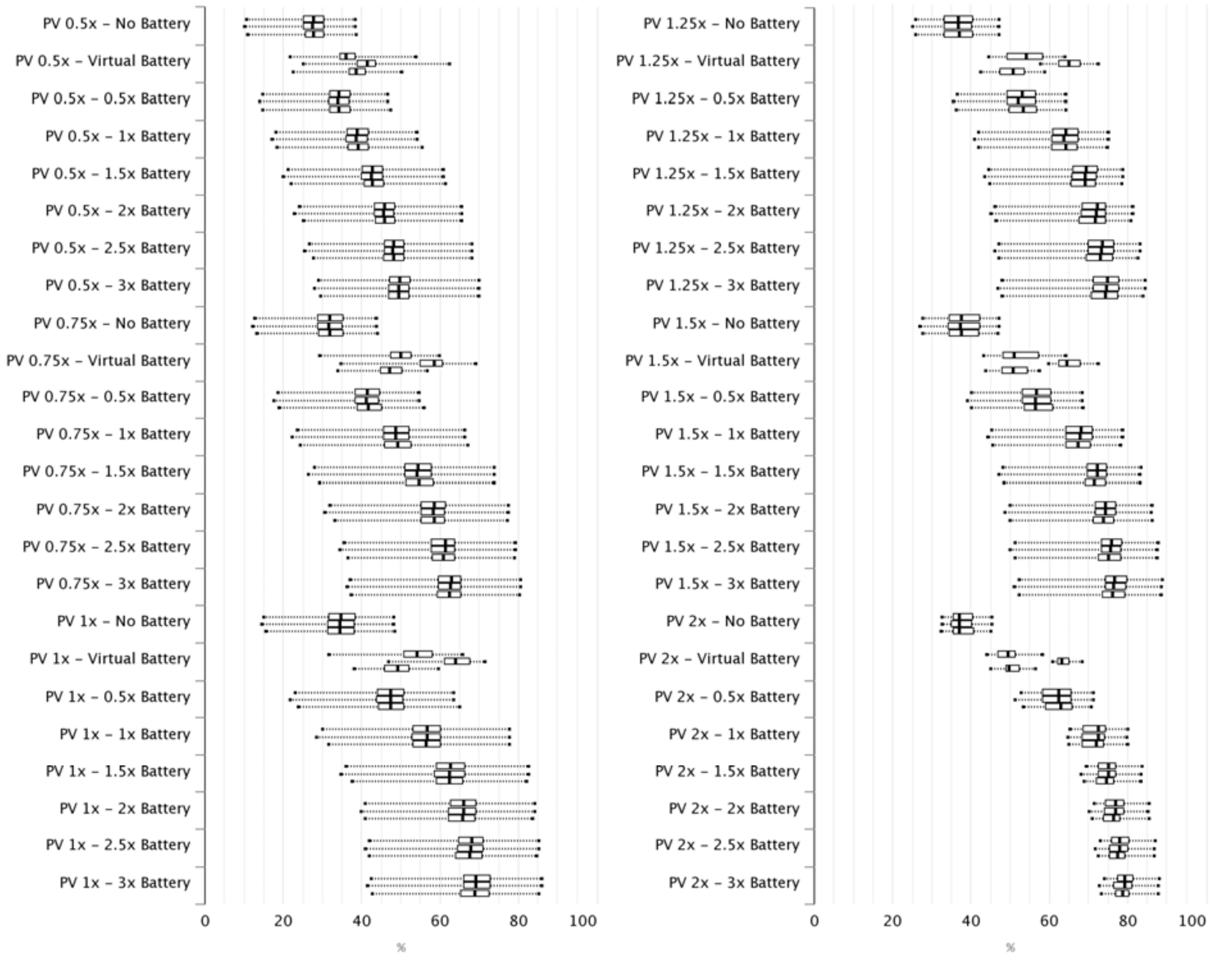

Fig.2. Percentage savings for photovoltaics and battery combinations. Individual graph rows sorted by VSE, ZSE and MAGNA tariffs

Table7. ROI median for photovoltaics and battery combinations at 2022 prices and an excepted average price increase of 5.75%

PV combination	VSE 2T [Year]	ZSE 2T [Year]	MAGNA 4T [Year]
PV 0.5x - No Battery	12,54	12,84	13,27
PV 0.5x - Virtual Battery	10,45	9,53	10,63
PV 0.5x - 0.5x Battery	14,88	15,21	17,65
PV 0.5x - 1x Battery	14,98	15,14	18,36
PV 0.5x - 1.5x Battery	16,21	16,28	22,41
PV 0.5x - 2x Battery	16,15	16,37	22,75
PV 0.5x - 2.5x Battery	16,05	16,07	22,79
PV 0.5x - 3x Battery	17,44	17,69	24,98
PV 0.75x - No Battery	13,335	13,5	14,16
PV 0.75x - Virtual Battery	9,88	9,09	10,825
PV 0.75x - 0.5x Battery	15,42	15,855	18,13
PV 0.75x - 1x Battery	15,545	15,965	21,22
PV 0.75x - 1.5x Battery	15,955	16,145	22,475
PV 0.75x - 2x Battery	16,4	16,63	23,3
PV 0.75x - 2.5x Battery	16,705	17,13	23,985
PV 0.75x - 3x Battery	17,88	18,04	25,835
PV 1x - No Battery	14,82	15,2	15,53
PV 1x - Virtual Battery	10,65	9,7	11,98
PV 1x - 0.5x Battery	16	16,04	18,92
PV 1x - 1x Battery	15,88	16,09	21,64
PV 1x - 1.5x Battery	16,69	16,91	23,13
PV 1x - 2x Battery	17,33	17,46	24,45
PV 1x - 2.5x Battery	17,78	17,87	25,38
PV 1x - 3x Battery	18,72	19,11	26,53
PV 1.25x - No Battery	15,465	15,86	16,31
PV 1.25x - Virtual Battery	12,015	10,795	13,34
PV 1.25x - 0.5x Battery	16,305	16,735	21,015
PV 1.25x - 1x Battery	16,655	16,795	22,345
PV 1.25x - 1.5x Battery	17,46	17,58	24,025
PV 1.25x - 2x Battery	18,36	18,595	25,775
PV 1.25x - 2.5x Battery	19,17	19,255	26,81
PV 1.25x - 3x Battery	19,515	20,23	27,54
PV 1.5x - No Battery	17,12	17,6	18,12
PV 1.5x - Virtual Battery	13,59	11,61	14,64
PV 1.5x - 0.5x Battery	16,93	17,11	21,29
PV 1.5x - 1x Battery	17,09	17,72	22,85
PV 1.5x - 1.5x Battery	18,39	18,52	25,28
PV 1.5x - 2x Battery	19,75	19,91	27,58
PV 1.5x - 2.5x Battery	20,17	20,52	28,13
PV 1.5x - 3x Battery	20,35	20,76	28,62
PV 2x - No Battery	20,58	20,895	21,615
PV 2x - Virtual Battery	17,52	14,56	18,1
PV 2x - 0.5x Battery	18,47	18,88	23,075
PV 2x - 1x Battery	19,28	19,305	25,43
PV 2x - 1.5x Battery	21,1	21,13	28,33
PV 2x - 2x Battery	23,14	23,175	33,52
PV 2x - 2.5x Battery	23,16	23,19	33,805
PV 2x - 3x Battery	22,99	23,02	33,605

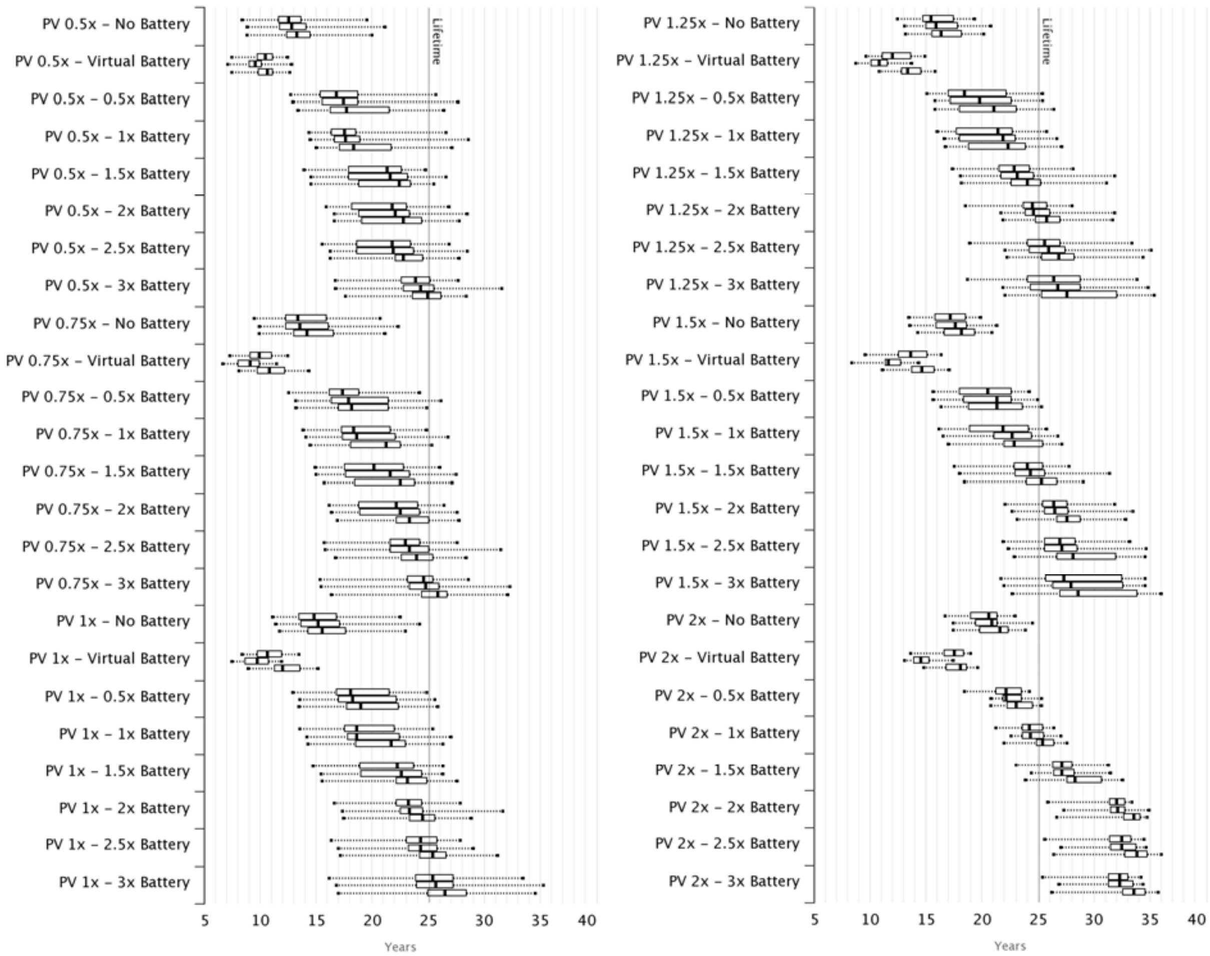

Fig.3. Return of investments in Years for photovoltaics and battery combinations. Individual graph rows sorted by VSE, ZSE and MAGNA tariffs

Conclusion

The intention was to determine the appropriate combination of PV system performance versus household consumption and in combination with different ratios of battery storage versus PV performance. To answer the question, therefore, is it appropriate to consider a PV home power plant? Certainly yes, with the appropriate panel capacity it is a profitable investment.

As we can see in Figure 3, and with a 25 year lifetime threshold, it is not appropriate for the broadest group of households, from a sample of typical households in a suburban location, to consider panel power above 1 times the average consumption and physical battery capacity above 1.5 times the panel power. The use of physical batteries is not preferable in terms of return on investment at the current ratio of electricity prices and increased battery storage investment costs, even though annual electricity bill savings can be as high as the 80% levels shown in Figure 3. The advantage of this solution for the customer lies in the possibility of electricity comfort in cases of interrupted electricity supply during outages. This advantage increases mostly with the distance of households from larger cities, thus the increased expectation of more frequent outages than in the case of suburban locations, and the size of the battery capacity. Table 6 shows the median percentage savings in annual charges for using combinations of PV systems without a battery, with a physical battery or with a virtual battery, relative to the original annual electricity charges for all 3 of these tariff types on the input set of households.

As we can see, the most advantageous choice from the point of view of return on investment and thus also the expected lifetime profits is the choice of a virtual battery under the current conditions on the Slovak market in the household segment.

In most cases, it is preferable to consider 2 tariff virtual battery balancing and selecting a product with the lowest possible monthly charge for virtual battery capacity. In the case of these 2 tariffs offers, the accumulated electricity during the year is deducted from the consumption over the whole time range, subject only to the distribution according to the ratio of low and high tariff. In the case of the 4-tariff option, the customer is limited to 2 bands of so-called peak demand where he cannot use the accumulated electricity and at the same time the electricity is the most expensive at these times. These facts increase the payback of the solution by about 1 to 2 years compared to the 2-tariff solution.

To guarantee objectivity, we must consider the fact that the above results are valid for the current conditions of the electricity market for households in the Slovak Republic, which is regulated and also does not allow households to sell electricity. For countries where the household price is unregulated and given that the electricity price market is generally volatile and also highly affected by geopolitical situations due to its interconnectedness across the EU and dependence on other energy sources outside the EU, the return on investment in the PV system may fluctuate. In most cases, the electricity price curve is upward sloping in the long term.

The most appropriate situation in terms of considering the return on investment of the PV system for households in general is in the case of markets that allow for the sale of non-consumed electricity. In this case, in a simplified example, it is sufficient to know the expected performance of the PV system at the point of consumption and the purchase price of the electricity.

This paper was supported by the Slovak Research and Development Agency, under the contracts APVV-19-0576, APVV-21-0312 and SK-UA-21-0024 and the Slovak Academy of Sciences, under the contract VEGA 1/0757/21.

***Authors**: Ing. Dávid Martinko, Technická univerzita v Košiciach, Katedra Elektroenergetiky, Mäsiarska 74, 042 01 Košice, E-mail: david.martinko@student.tuke.sk; doc. Ing. Dušan Medveď, PhD., Technická univerzita v Košiciach, Katedra Elektroenergetiky, Mäsiarska 74, 042 01 Košice, E-mail: dusan.medved@tuke.sk; Dr.h.c. prof. Ing. Michal Kolcun, PhD, Technická univerzita v Košiciach, Katedra Elektroenergetiky, Mäsiarska 74, 042 01 Košice, E-mail: michal.kolcun@tuke.sk; Associate Professor, DSc, PhD., Damian Mazur, Rzeszów University of Technology, Department of Electrical and Computer Engineering Fundamentals, Powstancow Warszawy 12; 35-959 Rzeszow; Poland; mazur@prz.edu.pl*

REFERENCES

[1] M. Synek, E. Kislingerova „Podniková ekonomika“, C. H. Beck, 2010
[2] BP Statistical Review of World Energy 2022, 71st edition, Available online: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf
[3] European Parliament and Council of the European Union, “Smernica európskeho parlamentu a rady (eú) 2018/2001 z 11. decembra 2018 o podpore využívania energie z obnoviteľných zdrojov“, Official Journal of the European Union, 2018.
[4] Council of the European Union, “Oznámenie komisie európskemu parlamentu, rade, európskemu hospodárskemu a sociálnemu výboru a výboru“, Available online: https://eur-lex.europa.eu/legal-content/SK/TXT/PDF/?uri=CELEX:52020-DC0562&from=EN, 2020.
[5] Kurzy: Electricity - electricity prices and charts, electricity price development 1 MWh - 1 year, Available online: https://www.kurzy.cz/komodity/cena-elektriny-graf-vyvoje-ceny/
[6] J. Jiřička, M. Kašpírek, M. Kurfiřt, Z. Máca, D. Kouba,“Výpočetní posuzování připojitelnosti Výroben s ohledem na zpětné vlivy na Napajecí distribuční síť.” CIRED Conference, 2022
[7] Slovak Innovation and Energy Agency, Conditions of support, Available online: https://zelenadomacnostiam.sk/sk/domacnosti/podmienky-podpory/
[8] Solargis: Solar resource maps and GIS data, Available online: https://solargis.com/maps-and-gis-data
[9] European Commission: Photovoltaic geographical information system, Available online: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html
[10] D. Martinko, M. Kolcun „Modelling photovoltaic system power output based on historical Meteorological data“, 22nd Scientific Conference of Young Researchers, 2022
[11] J.I. Rosell, M. Ibanez, “Modelling power output in photovoltaic modules for outdoor operating conditions”, Energy Conversion and Management 47, 2006, p. 2424–2430
[12] Solcast: Solcast API Toolkit, Available online: https://solcast.com/solar-data-api/api-toolkit/
[13] D. Gordon „Battery market forecast to 2030: Pricing, capacity, and supply and demand“, E Source Companies, March 2022
[14] IHS Markit: Battery prices won’t fall until 2024, Available online: https://www.pv-magazine.com/2022/03/07/ihs-markit-battery-prices-wont-fall-until-2024/
[15] W. Cole, A W. Frazier, C. Augustine „Cost Projections for Utility-Scale Battery Storage: 2021 Update”, National Renewable Energy Laboratory, June 2021
[16] D. Medved, et. al., Prediction of electricity production in island operation under the different wind generation modes. In: Przegląd Elektrotechniczny: Vol. 95, No. 7 (2019), p. 150-154. doi: 10.15199/48.2019.07.31.