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EVALUATION OF THE TOTAL COST OF CHARGING ELECTRIC VEHICLES THROUGH DEDICATED PHOTOVOLTAIC INSTALLATIONS

Summary. Currently, the share of BEVs (Battery Electric Vehicle) in the automotive market in Poland is relatively small - 0.1%. That is caused by a number of barriers; one of them being the undoubted fact that BEVs are exceptionally expensive. Electric Vehicle enthusiasts express the opinion that the cost is offset by reduced running costs, in particular in cases where the electricity is generated from a photovoltaic (PV) installation. This article determines the cost of charging a battery electric vehicle with an electricity generated from a domestic photovoltaic installation consisting of various numbers of modules. The optimal yield of electricity generated by PV was determined, and then the charging costs in the current conditions in Poland. It was assumed that the electricity produced would be used exclusively for BEV charging, with the surplus sold to the power grid. The analysis shows that even for the maximum number of photovoltaic modules which can be installed on the study area, in some months the battery electric vehicle charging costs will not be zero. The issue related to the cost of charging BEVs with PV - generated electricity in the Polish conditions has not yet been addressed in any scientific publication and its problems concerning the issues may provide a source of preliminary analysis for other countries.

1. INTRODUCTION

The directions of contemporary development are based on the basic assumptions of the idea of sustainable development, which strongly emphasises the need to protect the environment. With regard to transport, sustainability shall be construed as being accessible to all users and safe for the people as well as the ecosystems. This approach emphasises that the development of transport should be shaped in such a manner that it simultaneously takes into account the economic, social and environmental needs.

Globalisation and the reorientation of the world's economies from high-resource and high-carbon to resource-efficient and low-carbon have contributed to the formation and development of new forms, techniques and transport technologies. They have also brought about significant changes in the automotive industry, which has faced the need to adapt its production processes to the requirements posed by sustainable transport. The changes affect many aspects, but one of the most important is reducing the negative impact on the environment. This primarily involves introducing environmentally friendly transport solutions, especially in conurbations, and transitioning from combustion engine-based propulsion systems to electric ones.

Vehicles which use electricity stored by connecting to an external power source for propulsion, such as a BEV (Battery Electric Vehicle), are notably characterised by significantly lower emissions (Fig. 1) and noise (Fig. 2) compared to cars with a conventional engine.

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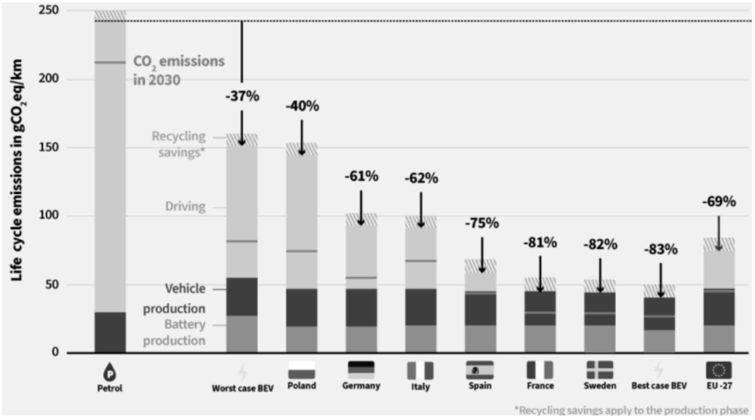

Fig. 1. LCA analysis of medium-sized car, battery assumed to be produced with the EU27 average grid. [1]

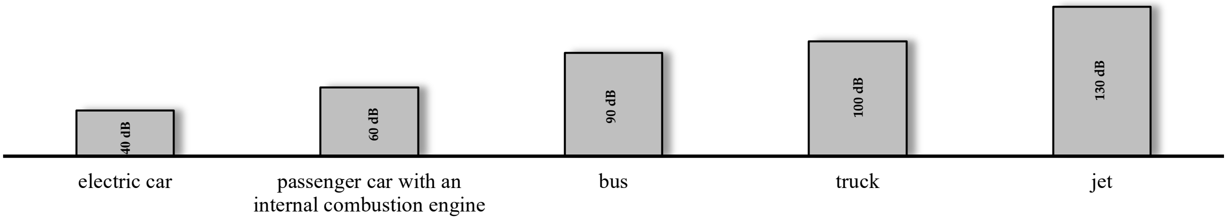

Fig. 2. Noise emissions in urban traffic [2]

In addition, such vehicles are characterised by, for instance:

- independence from oil and its prices at the world markets [3];
- reducing the vehicle energy costs by up to 80%;
- the energy conversion efficiency of electric drive trains is now at around 70-80%, while that of fuel-burning vehicles is around 15-20%.

The data stated above means that the automotive market for the BEVs is rapidly growing on a global scale (Fig. 3) and currently accounts for 12% of global car sales [4].

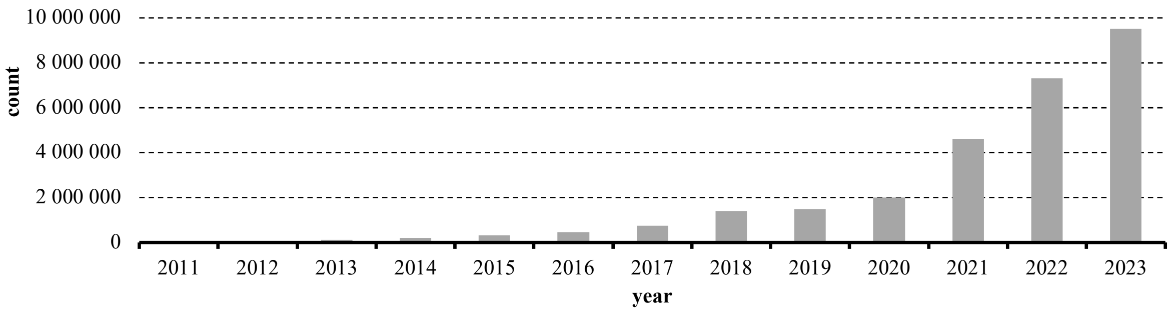

Fig. 3. Battery electric vehicle registration in the world [5]

Whereas in Poland, a Member State of the European Union, the share of such vehicles in the automotive market remains small - 0.2% (Fig. 4) and it remains one of the lowest in the entire European Union (Fig. 5).

Currently factors with key impact on the hindered development of the Electronic Vehicles Market in Poland include the relatively poorly developed publicly available charging infrastructure for such vehicles (Fig. 6), the long time required to charge such battery and the wide array of available connectors.

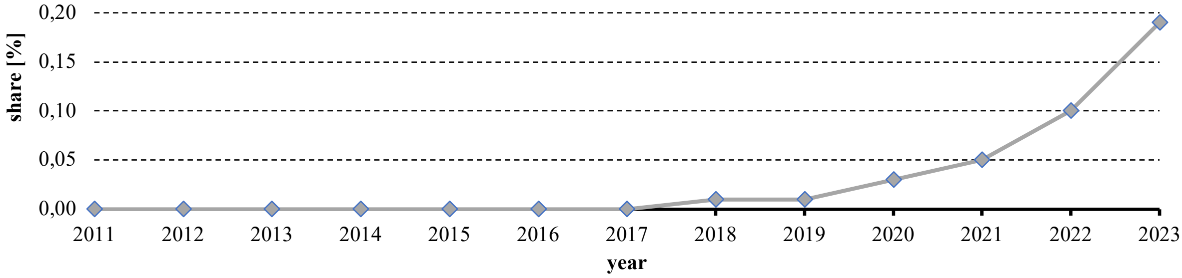

Fig. 4. Share of BEVs in the passenger car market in Poland [6]

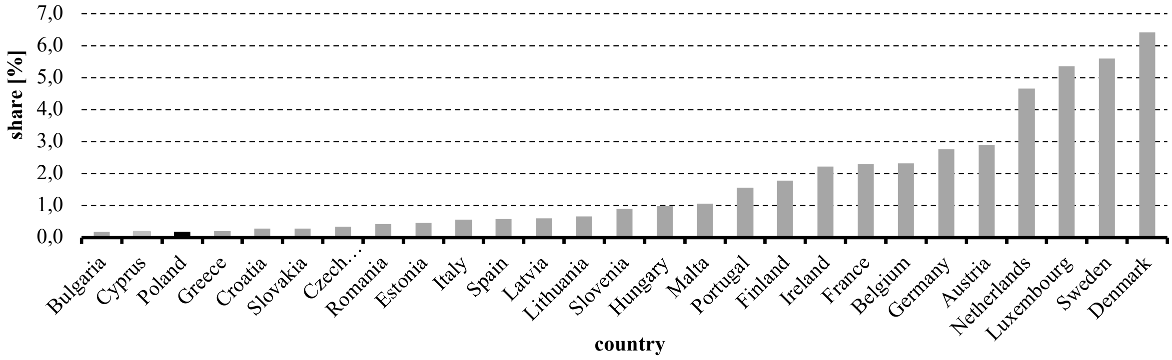

Fig. 5. Percentage of the total passenger cars and vans fleet (M1+N1) that is full battery-electric in European Union (battery electric vehicle), 2024 [6]

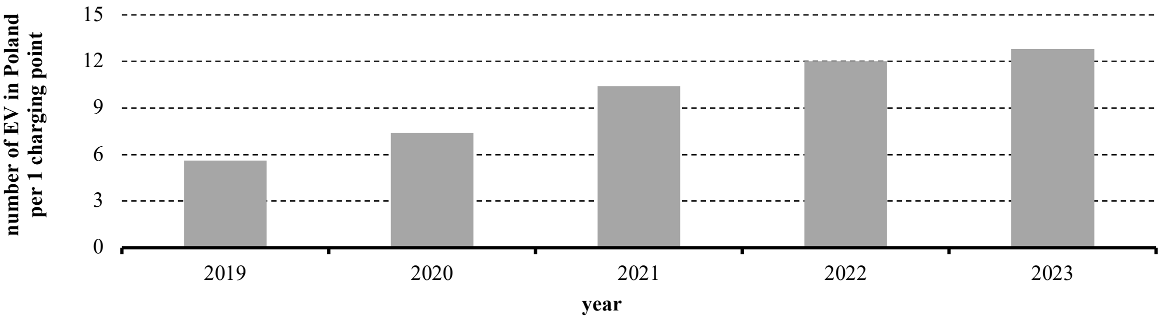

Fig. 6. Number of electric cars per 1 charging point installed at a public charging station in Poland (proprietary compilation based on [6])

In addition, the concerns expressed by the potential users of battery electric vehicle relate to the possible cost and location of vehicle servicing. Currently, there are no independent service points for electric cars in Poland due to the lack of access to servicing procedures for this specific vehicle category.

However, the key aspect which has hindered the development of zero-emission transport in Poland for many years now, remains the high cost of purchasing electric cars compared to their combustion engine equivalents [7-13].

The catalogue price of a new electric car is approximately 80% higher compared to a similarly equipped model offered with an internal combustion engine by the respective brands. This constitutes an averaging, as depending on the brands, the price difference may range from approximately 30% to as much as 120%.

Table 1 compares the price of electric BEVs with conventionally powered cars with similar power and equipment.

However, advocates of such vehicles believe that the high purchase price is offset by the relatively low costs related to operating a battery electric vehicle.

Table 1

Prices of selected new passenger cars with various engines [PLN]

Make	BEV model	Price value	Model with spark-ignition engine	Price value	Model with compression-ignition engine	Price value
1	2	3	4	5	6	7
BMW	iX7	650000	X7	492500	X7	502500
Citroën	e-C4	186400	C4	96350	C4	127150
Hyundai	Kona Electric	168900	Kona	95900	-	-
Opel	Corsa-e	160300	Corsa	71900	Corsa	82600
Peugeot	e-208	156600	208	71900	208	87200
Volkswagen	ID.3	191290	Golf	123890	Golf	136390

Table 2 presents the costs associated with refuelling/charging vehicles with different propulsion types of the same model in Poland. Their analysis shows that they are comparable. Even if the cost of charging BEVs is lower than the cost of refuelling, the difference is not noteworthy enough to be used as an argument speaking in favour of them.

The charging costs presented in Table 2 were calculated based on the car's initial and final battery levels (20% and 80%, respectively) and the operator's tariffs. The calculation also considered the energy consumed and the possible charging time. The average energy consumption was estimated using the battery capacity and the average range declared by the manufacturer under the Worldwide Harmonized Light-Duty Vehicles Test Procedure (WLTP).

Table 2

Cost of driving 100 km for vehicles of the same model, [PLN]

	REFUELLING COST	
Petrol	35.31	
Diesel	25.45	
	COST OF CHARGING	
Operator	Braking type	
	AC	DC
greenway	21.29-167.14	26.72-52.06
ORLEN	31.89	36.85-39.95
EV+	20.19-22.93	25.46-36.56
PGE	36.85	40.40-42.08
E.ON Polska S.A.	27.26	-
LOTOS	60.00	69.00
IONITY	-	47.95
GO+Eauto	26.72	33.57
TAURON	16.58-17.95	27.26-31.65
charging from a mains socket at home	19.47-22.00	-
charging from the Wallbox	18.25-22.89	-

An idea for a solution that may undoubtedly reduce the costs associated with battery electric vehicle charging is the use of electricity generated from the sun's rays by a domestic photovoltaic (PV) installation. Publicly distributed materials often state that it may be possible to charge an electric vehicle free of charge.

In connection with the above, this paper determines the costs of charging an electric battery electric vehicle with electricity obtained from photovoltaic installations configured with a different number of photovoltaic modules. The study assumed that all the energy produced by a photovoltaic installation would be used only to charge the batteries installed in such vehicles. Conducting such an analysis is very important from the point of view of users of electric vehicles in Poland. As it results from [14], over 90% of them would like to charge their car at home, and operating costs are one of the main factors taken into account by drivers when buying a car (Figure 7).

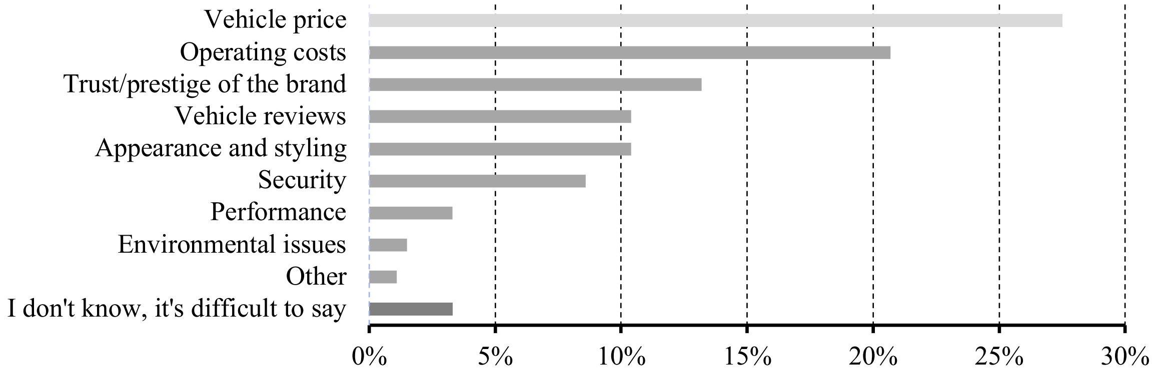

Fig. 7. Results of responses to the question "Which factor mainly influenced your decision on which car you use most often?" in the New Mobility Barometer 2020/21 survey [14]

Reviewing the literature on the cost of charging BEVs with electricity generated from PV installations, the author of this publication noted that the number of scientific publications in this area is small, while for Polish conditions this problem has not been addressed in any of them so far.

Meanwhile, according to the results presented in [15] electricity generated by photovoltaic installations can cover between 62% and 90% of the vehicle's recharging energy needs, depending on the vehicle's annual mileage, contributing to a significant cost reduction compared to using grid electricity. It also highlights that the total cost of ownership of a PV-powered electric car is more competitive for higher annual mileage and, with appropriate government subsidies, can become cheaper than owning an internal combustion vehicle. Specifically, at an annual mileage of 10 000 km, a PV-powered electric vehicle becomes cost-competitive compared to an internal combustion car, but without financial support the break-even point rises to 25 000 km per year.

The problem of the cost of charging BEVs with electricity generated from photovoltaic installations has been addressed, among others, in [16]. There, the potential to reduce the cost of charging BEVs by more than 50% compared to a reference charging system by optimizing charging based on the price of electricity, weather and household baseline consumption was demonstrated. Simulation results for 2017-2022 showed that charging costs could be reduced by more than 50% compared to the reference charging system. Further cost reductions can be achieved using energy storage [17, 18].

The paper [19] estimated the amount of electricity generated, the efficiency of the photovoltaic system, the financial analysis in terms of investment costs and return on assets, and the ability to reduce CO2 emissions. After conducting the financial analysis over a 20-year period: the cost of electricity production is \$0.0032/kWh, and the payback period for the proposed system is about five years. It was calculated that the annual savings in energy consumption after the installation of such photovoltaic installations systems yielded 21% in financial terms. Also in [20], a technical, economic and environmental feasibility analysis of electric vehicle charging stations is presented. The one of the most obvious findings to emerge from this study is that the design PV system may significantly reduce the charging cost. Even in the most expensive scenario, the charging cost can be reduced by about seven times.

This article is therefore a first attempt to explore the research topic of charging costs for electricity obtained from PV systems and BEVs, considering optimal conditions.

The structure of the article is as follows. Chapter 2 analyses the cost of charging a battery electric vehicle with electricity, including that generated by photovoltaic cells. Section 2.1 presents the monthly electricity yield for different numbers of photovoltaic modules that can be installed on the analysed roof surface. It also identifies cases where the electricity yield from the photovoltaic panels is insufficient to meet the monthly energy demand of the battery electric vehicle under study. Section 2.2 proposes a calculation model used to analyse the cost of charging the battery electric vehicle with electricity drawn from both the electricity grid and the PV installation. This analysis is conducted for various numbers of PV modules and over successive months. Chapter 2.3 discusses the study results along with their interpretation. Finally, Chapter 3 presents the conclusions, highlighting the study's limitations, practical applications, and future research directions in this field.

2. A CASE OF STUDY

The costs of charging an battery electric vehicle -BEV with electricity generated from photovoltaic cells were determined for the most frequently purchased BEV in Poland in 2022 (Fig. 8), whose basic technical parameters are given in Table 3.

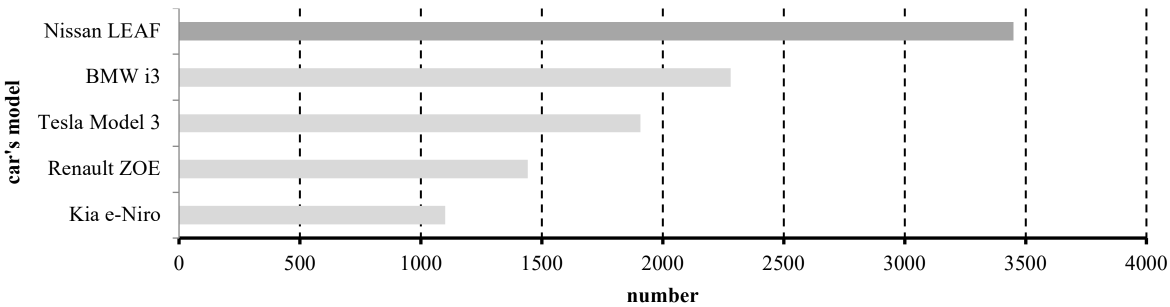

Fig. 8. TOP 5 most popular battery-electric vehicle models in Poland [21]

Table 3

Technical characteristics Nissan Leaf II (ZE1) [22]

Electric motor	
Engine type	Synchronous
Maximum power output	KM 150
Maximum net torque	320 Nm
Performance	
Maximum speed	144 km/h
Acceleration 0-100 km/h	7.9 s
Energy consumption	17.1 kWh/ 100 km
Total range	270 km
Battery	
(Gross tonnage)	40 kWh
Capacity (net)	39 kWh
Type	Li-Ion
Charging	
Charging connectors	Type 2 , CHAdeMO
Maximum AC charging power	6.6 kW
Maximum DC charging power	50 kW
Charging time	
Household mains socket 2.3 kW	19:20

Industrial mains socket 3.7 kW	12:01
Wallbox 7.4 kW	06:43
DC 50 kW station	00:32
Dimensions	
Length	4490 mm
Width	1788 mm
Height	1530 mm
Weight	
Minimum unladen mass	1543 kg
Maximum service mass:	1995 kg

Based on the estimates presented in [23], the average annual mileage of a passenger car in Poland is between 10 500 and 25 800 km – them mileage of 17 000 km/year was assumer. In contrast, the average energy demand of the vehicle analysed in the following months was determined from (1). The vehicle is charged only from a domestic mains socket.

$$C_i = \frac{E}{100} \cdot d_i, \tag{1}$$

where:
i – month number, i = 1,2...12;
C_i – average energy demand of the vehicle in the i-th month, [kWh];
E – electricity consumption of the battery electric vehicle per 100 km, [kWh/km];
d_i – distance traveled by the vehicle during the i-th month, [km].

2.1. Amount of electricity generated by a domestic photovoltaic system

The monthly electricity yield from the home photovoltaic installation was estimated under optimal conditions. These include a south-facing roof with no structural elements, such as chimneys, that would cause shading or reduce the usable area, and no other objects obstructing the photovoltaic cells. This setup ensures the maximum possible energy generation. Such assumptions made it possible to indicate the impact of key variables, i.e. installation power, vehicle energy requirements, on battery electric vehicle charging costs.

Table 4 shows the monthly electrical energy yield determined for a different number of photovoltaic modules that can be installed on the analysed roof surface (approx. 72 m^2). Additionally, Table 4 highlights the yield from photovoltaic panels, which is insufficient to cover the monthly energy demand of the tested battery electric vehicle.

Table 4

Electric energy production using photovoltaic installation

month	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Yearly**
	Anticipated electricity requirements for vehicles [kWh]												
	247	223	247	239	247	239	247	247	239	247	239	247	**2907**
Number of modules	Electric energy production using photovoltaic installation [kWh]												
1	10	15	25	32	36	35	36	35	25	20	11	8	**289**
2	20	30	50	63	73	71	73	69	51	40	22	16	**578**

3	29	45	75	95	109	106	109	104	76	61	33	24	**867**
4	39	60	101	126	146	141	146	139	102	81	44	32	**1156**
5	49	75	126	158	182	176	182	173	127	101	55	40	**1445**
6	59	90	151	189	219	212	219	208	153	121	66	49	**1734**
7	69	105	176	221	255	247	255	243	178	142	77	57	**2023**
8	79	120	201	252	291	282	291	278	204	162	88	65	**2312**
9	88	135	226	284	328	317	328	312	229	182	99	73	**2601**
10	98	150	251	315	364	353	364	347	254	202	110	81	**2890**
11	108	165	277	347	401	388	401	382	280	223	121	89	**3179**
12	118	180	302	378	437	423	437	416	305	243	132	97	**3468**
13	128	195	327	410	474	458	474	451	331	263	143	105	**3758**
14	138	210	352	441	510	494	510	486	356	283	154	113	**4047**
15	147	225	377	473	546	529	546	520	382	304	165	121	**4336**
16	157	241	402	504	583	564	583	555	407	324	176	130	**4625**
18	177	271	453	567	656	635	656	624	458	364	198	146	**5203**
20	197	301	503	630	728	705	728	694	509	405	220	162	**5781**
21	206	316	528	662	765	741	765	728	534	425	231	170	**6070**
22	216	331	553	693	801	776	801	763	560	445	242	178	**6359**
24	236	361	604	756	874	846	874	833	611	486	264	194	**6937**
27	265	406	679	851	983	952	983	937	687	546	297	219	**7805**
30	295	451	754	945	1093	1058	1093	1041	763	607	330	243	**8672**
33	324	496	830	1040	1202	1164	1202	1145	839	668	363	267	**9539**

2.2. Costs of charging a battery electric vehicle with electricity generated with photovoltaic installation

Electricity prices in Poland depend on the region, tariff and selected seller. Currently, there are various energy tariffs in Poland. All of them belong to four types of tariffs (A, B, C, G), which are addressed to a specific type of recipient (Table 5).

Table 5

Basic electricity tariff groups divided by groups of recipients in Poland (proprietary compilation based on [24])

Recipient type	Types of tariffs and exemplary tariffs
Households	**G** (G11, G12, G12w, G12n)
Small and medium-sized companies, farms	**C** (C11, C12a, C21)
Large companies	**B** (B21, B23)
Major recipients (mines, factories)	**A** (A22, A23)

G11 is the most commonly selected energy tariff in Polish households. In the case of such tariff, the rates per kWh are constant for each hour within the period (in principle – a single year) for which the tariff has been approved by the Energy Regulatory Office President [24]. Table 6shows the average price per kWh of electricity applicable to a household in Poland in 2023 under the G11 tariff.

In the case of renewable energy prosumers (meaning persons who simultaneously consume and generate electric energy using Renewable Energy Sources) who produce electric energy by the means of their domestic photovoltaic installations, such energy is accounted for based on a net-billing model [25].

Table 6

Average price per kWh in Poland under the G11 tariff for the year 2023, [PLN] [24]

Tariff group	up to a limit of 2000 kWh / 2600 kWh / 3000 kWh per year	above the limit
G11 (applicable for the entire day)	0.77	1.27

Such a system is based on separate billing for electricity injected into the distribution network and electricity taken from the network based on the value of a unit of energy determined in accordance with the so-called EMP (Electric Market Price – on a monthly basis). A prosumer receives payment for the electricity fed into the grid from their own PV installation based on the applicable market price. In turn, such prosumer pays for the electricity collected from the grid, including all charges (including the distribution charge) and taxes based on all charges.

In turn, the costs of EMP charging costs for a varying number of PV modules presented in Table 7 were determined by assuming a rate per kWh of energy consumed equalling to PLN 0.77 (tariff G11) and energy produced of PLN 0.45 [26]. The assumption was that the electricity produced would be used exclusively to recharge the BEVs, whereas the surplus energy is going to be fed back to the grid. Accordingly, in Table 7, positive values indicate the cost of charging a battery electric vehicle using energy from the photovoltaic installation, while negative values represent the profit a prosumer gains from selling the surplus energy remaining after the vehicle has been fully charged with electricity from the PV system.

The battery electric vehicle charging cost for the projected electricity consumption from the household outlet K_{Gi}in the i-th month was determined from the formula (2):

$$K_{Gi}=C_i \cdot s_G, \tag{2}$$

where:

i – number of consecutive month, i=1,2,...,12;

K_{Gi} – the cost of charging the BEV from a household outlet, [PLN];

C_i – average energy demand of the vehicle in the i-th month, [kWh];

s_G – rate per 1 kWh of energy drawn from the power grid (0.77 PLN - tariff G11 (home outlet)).

Whereas, the cost of battery electric vehicle charging using the PV system in the i-th month and for the j-th number of PV modules was calculated from (3):

$$K_{PVij}=(C_i \cdot s_G)-\left(U_{eij} \cdot s_s\right), \tag{3}$$

where:

K_{PVij} – cost of BEV charging from photovoltaic installation in the$i$-th month and for the j-th number of modules, [PLN];

U_{eij} – electricity production in the i-th month for the j-th number of photovoltaic modules, [kWh];

s_s – rate per 1 kWh of energy injected into the power grid, produced by photovoltaic installations (0.45 PLN).

2.3. Results

The study carried out shows that the amount of energy produced by the photovoltaic installation is sufficient to cover the monthly energy requirements of the vehicle under study each month of the year (Table 4) only in the event of the use of the maximum number of photovoltaic modules that can be installed on the area under consideration.

In the case of an installation made up of up to six photovoltaic modules, each month's energy yield is insufficient to fully cover the energy requirements of a battery electric vehicle. However in the case of at least twelve modules, the amount of electricity produced by the photovoltaic cells in specific months is already sufficient not only to meet battery electric vehicle demand to the maximum but also to sell the surplus the prosumer is going make a profit on its sales.

Table 7

Charging costs for a BEV, [PLN]

month	January	February	March	April	May	June	July	August	September	October	November	December	Yearly	Balance
	BEV charging costs for projected electricity consumption from a domestic mains socket													
	190.2	171.2	190.2	184.0	190.2	184.0	190.2	190.2	184.0	190.2	184.0	190.2	2238.4	
Number of modules	The total cost of charging a BEV through a photovoltaic installation													
1	185.7	165.0	178.9	169.6	174.0	168.3	174.0	174.4	172.8	181.2	179.1	186.6	2108.3	130.1
2	181.2	158.2	167.7	155.7	157.3	152.1	157.3	159.1	161.1	172.2	174.1	183.0	1978.3	260.1
3	177.1	151.5	156.4	141.3	141.1	136.3	141.1	143.4	149.8	162.7	169.2	179.4	1848.2	390.2
4	172.6	144.7	144.7	127.3	124.5	120.6	124.5	127.6	138.1	153.7	164.2	175.8	1718.2	520.2
5	168.1	138.0	133.5	112.9	108.3	104.8	108.3	112.3	126.9	144.7	159.3	172.2	1588.1	650.3
6	163.6	131.2	122.2	99.0	91.6	88.6	91.6	96.6	115.2	135.7	154.3	168.1	1458.1	780.3
7	159.1	124.5	111.0	84.6	75.4	72.9	75.4	80.8	103.9	126.3	149.4	164.5	1328.0	910.4
8	154.6	117.7	99.7	70.6	59.2	57.1	59.2	65.1	92.2	117.3	144.4	160.9	1198.0	1040.4
9	150.6	111.0	88.5	56.2	42.6	41.4	42.6	49.8	81.0	108.3	139.5	157.3	1067.9	1170.5
10	146.1	104.2	77.2	42.3	26.4	25.2	26.4	34.0	69.7	99.3	134.5	153.7	937.9	1300.5
11	141.6	97.5	65.5	27.9	9.7	9.4	9.7	18.3	58.0	89.8	129.6	150.1	807.8	1430.6
12	137.1	90.7	54.3	13.9	-6.5	-6.3	-6.5	3.0	46.8	80.8	124.6	146.5	677.8	1560.6
13	132.6	84.0	43.0	-0.5	-23.1	-22.1	-23.1	-12.8	35.1	71.8	119.7	142.9	547.3	1691.1
14	128.1	77.2	31.8	-14.4	-39.3	-38.3	-39.3	-28.5	23.8	62.8	114.7	139.3	417.2	1821.2
15	124.0	70.5	20.5	-28.8	-55.5	-54.0	-55.5	-43.8	12.1	53.4	109.8	135.7	287.2	1951.2
16	119.5	63.3	9.3	-42.8	-72.2	-69.8	-72.2	-59.6	0.9	44.4	104.8	131.7	157.1	2081.3
18	110.5	49.8	-13.7	-71.1	-105.0	-101.7	-105.0	-90.6	-22.1	26.4	94.9	124.5	-103.0	2341.4
20	101.5	36.3	-36.2	-99.5	-137.4	-133.2	-137.4	-122.1	-45.0	7.9	85.0	117.3	-363.1	2601.5
21	97.5	29.5	-47.4	-113.9	-154.1	-149.4	-154.1	-137.4	-56.3	-1.1	80.1	113.7	-493.1	2731.5
22	93.0	22.8	-58.7	-127.8	-170.3	-165.2	-170.3	-153.2	-68.0	-10.1	75.1	110.1	-623.2	2861.6
24	84.0	9.3	-81.6	-156.2	-203.1	-196.7	-203.1	-184.7	-90.9	-28.5	65.2	102.9	-883.3	3121.7
27	70.9	-11.0	-115.4	-198.9	-252.2	-244.4	-252.2	-231.5	-125.1	-55.5	50.4	91.6	-1273.9	3512.3
30	57.4	-31.2	-149.1	-241.2	-301.7	-292.1	-301.7	-278.3	-159.3	-83.0	35.5	80.8	-1664.0	3902.4
33	44.4	-51.5	-183.3	-284.0	-350.7	-339.8	-350.7	-325.1	-193.5	-110.4	20.7	70.0	-2054.2	4292.6

Therefore, from the point of view of charging the vehicle under investigation, a domestic photovoltaic installation configured with 33 photovoltaic modules is the optimum solution; in such case, the charging costs will then be the lowest and yield the greatest profit. However, it must also be noted that also for a photovoltaic installation configured in such manner in the months of November, December and January the charging costs are not going to remain at zero.

The cost of a photovoltaic system consisting of 33 PV modules including installation is PLN 42 387 [27]. In addition, you should take into account the costs associated with its operation (e.g. cleaning the PV panels) and its insurance. In relation to the prosumer's annual profit obtained from the surplus electricity produced inside, the cost of such an investment is going to return about 20 years, however while taking into account not only the profit but also the annual cost of charging a battery electric vehicle borne by its user by charging the vehicle from a household socket, the investment is going to return itself after 10 years. Meanwhile, according to [28] the useful life of photovoltaic panels is estimated at 20-35 years.

In addition, PV panels can lose efficiency over time. Most manufacturers specify the efficiency of PV panels at 80% after 25 years.

Ideally, a photovoltaic installation would be equipped with energy storage. Such a solution would make it possible to store excess electricity produced, which would not have to be sold and later bought back again at a higher price. However, in Poland the cost of purchasing such a storage facility is very high, e.g. an energy storage facility with a capacity of 10 kWh costs about PLN 50,000 gross [29], which drastically increases the already significant cost of a domestic photovoltaic installation, i.e. PLN 42,387.

It should be emphasised that it is rare for a domestic photovoltaic installation to only provide power to electric vehicle batteries. Most often, the electricity generated by a domestic photovoltaic installation is used for various household needs, including powering household appliances: a refrigerator, a washing machine, a dishwasher. Therefore, the vehicle's demand should be considered a component of the household's overall electricity demand, thus driving the cost of charging an electric vehicle up, while the return on investment even longer. Typically, PV panels lose 2-3% efficiency in the first year, and lose 0.3% to 0.6% efficiency annually in the following years [30].

In addition, the Government Solidarity Shield introduced by the Legislator, ensures that the energy bills in Poland are going to remain at the at steady rates since 2022 throughout the end of 2023 [31]. Undoubtedly, there will also be an increase in electricity prices once the government support programme expires.

3. CONCLUSIONS

Electric vehicles are currently considered one of the best methods to reduce air pollutant emissions from road transport, including CO2 and noise pollution in cities. They can also make a significant contribution to reducing road transport's dependence on oil imports. The marginal number of BEVs currently in use in Poland demonstrates that the electric mobility market is still in its infancy. One of the main hindrances to the implementation of e-mobility within the country is the higher price of battery-powered electric cars compared to equivalent models with conventional internal combustion engines, which could be compensated by lower costs of use, in particular if electricity is obtained from photovoltaic installations.

The analysis carried out in this article shows that charging an electric car with electricity from photovoltaic panels certainly reduces the cost of charging, but it is not at zero, contrary to the information disseminated by the media. Even in the event that a domestic photovoltaic installation may produce enough electricity to fully meet the energy requirements of a battery electric vehicle, the costs of such an installation are so high that the return on investment is going to take multiple years.

However, combining the technology of electric vehicles with the ability to recharge them from photovoltaic installations is the greenest way to power vehicles. Such installations are among the cleanest and most nature-friendly sources of electricity generation. They produce no pollution or noise and emit no carbon dioxide. They can also be recycled. Under Directive 2012/19/EU, the development of photovoltaic panels requires achieving 85% efficiency in the recovery of recyclable materials [32]. The ecological benefits of solar thermal systems are due to the specific nature of sunlight itself. The most important advantage of solar energy is, above all, its unlimited supply. This method of obtaining electric energy is also considered sustainable, i.e. one that can meet current needs without putting future generations at risk. In addition, the carbon footprint created in the production of photovoltaic panels has been optimised due to the new technology. Current manufacturing processes have significantly reduced the production of toxic substances to a minimum – among others due to the reprocessing of high-purity silicon.

And specifically from the environmental perspective, electric cars should be combined with photovoltaic installations, using such combination to popularise electric cars. Very often, opponents of electric cars argue that they are not an environmentally friendly means of transport. One of the most common arguments repeated by them is the allegation that energy produced by burning coal is mostly used to charge the batteries of green vehicles. Charging an electric car with photovoltaics ensures that electric cars not only do not produce exhaust fumes, but they also do not require the use of 'dirty' energy.

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