THE COSTS OF CHARGING ELECTRIC VEHICLES IN POLAND

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Resume

The very important factor that influences the decision of those interested in buying a vehicle is its operating costs. This paper determines the costs of driving 100 km for various electric vehicles, charging service providers and chargers, which was then confronted with the costs of refueling. Based on the analysis carried out, it was determined that, at present, the lowest costs of fueling/charging of a vehicle in Poland are connected with use of an electric vehicle, but only when the charging is performed with use of public AC chargers. Moreover, it was determined that the savings that will result from charging electric vehicles at AC charging stations as compared to filling up internal combustion engine vehicles are small and do not compensate for the purchase price of an electric vehicle.

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1 Introduction

Nowadays, serious problems and threats to civilization are connected with emission of harmful components of fuel combustion to the atmosphere and gradual exhaustion of fossil fuels. Air pollution is largely attributed to transport, especially motorization. Operation of an internal combustion engine powered by diesel or gasoline causes emission into the atmosphere of such combustion components as carbon dioxide, carbon monoxide, sulfur compounds, nitrogen oxides, hydrocarbons, lead compounds, which contribute to destruction of the ecosystem and threaten human health on a global and local level. Moreover, their emissions cause global climate warming [1-5]. Nevertheless, an important problem associated with use of motorized transport is the noise level, which is harmful to human health, as well. In an ad hoc way, these problems may be minimized by improving the design of internal combustion engines to drastically reduce their specific fuel consumption, introducing fuels with very low or no carbon content (e.g. hydrogen) and using combustion-electric hybrid propulsion systems. Ideally, electric vehicles should be widely available, especially when electric energy is obtained from renewable sources [6-8]. The development of electromobility creates real prospects for improving the air quality and reducing transport related noise in cities, as well as in Poland [8-9]. On 20 September 2016. The Ministry of Energy in cooperation with the Ministry of Development presented the "Package for Clean Transport", a set of three documents that define the strategy for electromobility development in Poland [10-13], i.e.:

- Electromobility Development Plan,
- National policy framework for development of alternative fuels infrastructure,
- Low Emission Transport Fund.

Complementing the cited regulations is the project adopted in September 2019 entitled: "Strategy for Sustainable Transport Development until 2030" in which, in particular, modern solutions are indicated to facilitate the functioning of the entire transport sector and reduce its negative impact on the environment and climate, so that it is possible to create a sustainable transport system of the country by 2030. The strategy envisages that the number of passenger cars from 2022 will remain at the level of 26 - 27 million units, but there will be changes in the structure, i.e. an increase in the fleet of electric and hybrid vehicles, the number of which in 2030 may reach over 600 thousand units [14].

2 The current BEV electric vehicles market in Poland

The process of electrification of road transport in Poland is currently at a relatively early stage of development, which is reflected, among other things, by a small share of electric vehicles in the automotive market. Despite the fact that the number of registrations of the new Battery Electric Vehicles (BEV) in Poland grew in 2011-2019 by 56% on average from year to year,

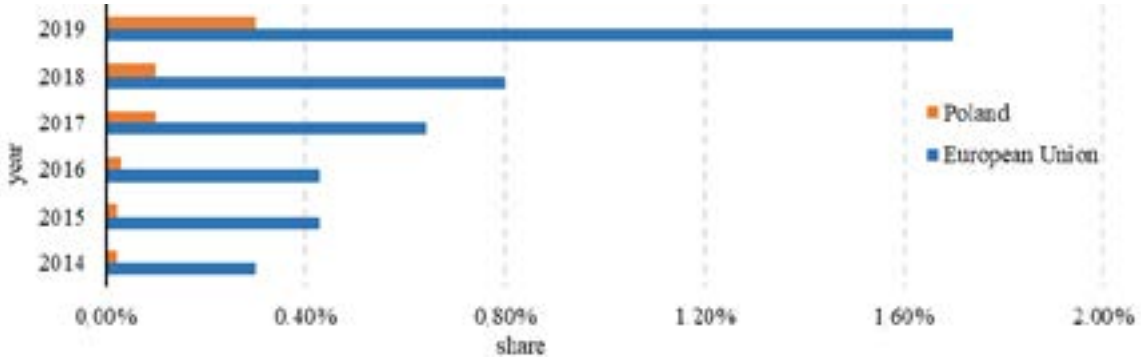

Figure 1 *Share of the BEV vehicles in the automotive market in Poland in 2014-2019 (based on [15])*

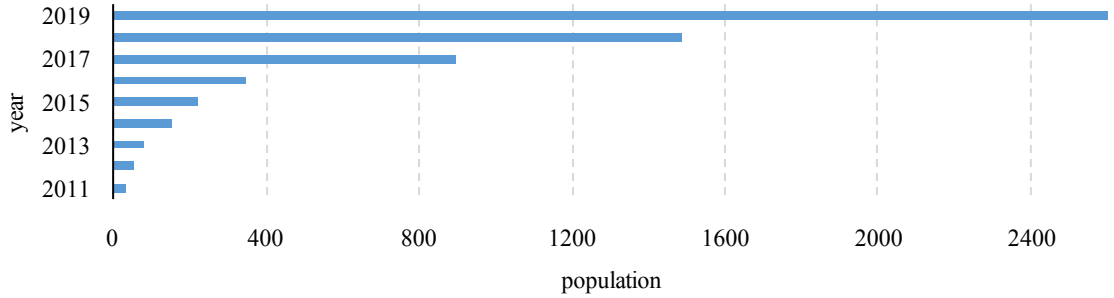

Figure 2 *Total number of the BEV vehicles in Poland (based on [15])*

Table 1 *List of prices of selected new passenger vehicles with different engines in Poland [Euro] [21-23]*

brand	model EV	price	model ZS*	prince	model ZI**	price
Nissan	Leaf	568320 - 732600	Juke	319680 - 372960	Juke	319680 - 395160
Renault	Zoe	541236 - 634920	Clio	250860-279720	Twingo	204240 - 275280
Volkswagen	e-golf	723231	golf	381840 - 523920	golf	355200 - 417360
Volkswagen	e-Up!	511443	-	-	Up!	177600

ZS*- compression ignition
ZI**- spark ignition

the share of such vehicles in the automotive market in 2019 was 0.3% (2607 units) (Figure 1, 2).

According to [16-20] and the surveys carried out among Polish drivers, such a low interest in the purchase of electric vehicles is chiefly caused by their high price and technical limitations, such as the lack of generally accessible infrastructure for the charging of such vehicles, short driving range on a single charge (battery capacity), long charging time and great diversity of connectors.

Currently, even taking into account the proposed subsidies for the purchase of an electric vehicle, higher costs apply to t purchase of this type of vehicle compared to a combustion vehicle. A car whose size is sufficient for a family of 4 will costs from about Euro 444000. In general, a combustion engine car of a similar class can be bought for 50% of the price of an electric vehicle. Table 1 compares the prices of electric vehicles with combustion engine-powered cars available in Poland in 2019.

Moreover, potential EV users are concerned about the potential costs and location of vehicle servicing. At present, there are no independent service points for electric vehicles, which is a result of the lack of access to servicing procedures for this category of vehicles. This situation may give rise to consumers' fears of higher prices of the BEV servicing. Not without significance for development of electromobility is the limited number of electric vehicle models that potential buyers have to choose from. In 2019 in Poland, consumers had only eighteen BEV models to choose from [24], which, in addition, can often not be seen in a vehicle showroom and after their purchase you have to reckon with a longer waiting time for pick-up. Moreover, not all the dealers sell such vehicles. For example, Volkswagen electric vehicles can be bought in Poland and then serviced in only four out of eighty-five Volkswagen dealerships [23]. Another very important impediment is the insufficient charging infrastructure for electric vehicles in Poland, which makes the electric vehicle essentially a city vehicle. According to estimates [15], there are currently over 945 publicly accessible electric vehicle charging points in Poland (Figure 3).

Although Poland has a very high ratio of charging stations to the number of vehicles of this type (one charger for every five vehicles), this is an effect of a very low number of electric vehicles registered in the country (Figure 4).

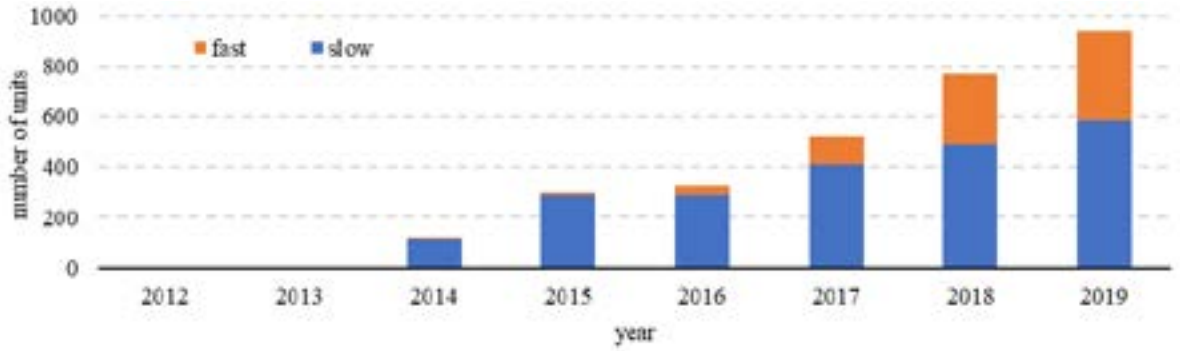

Figure 3 *The number of publicly available electric vehicle charging points in Poland (based on [15])*

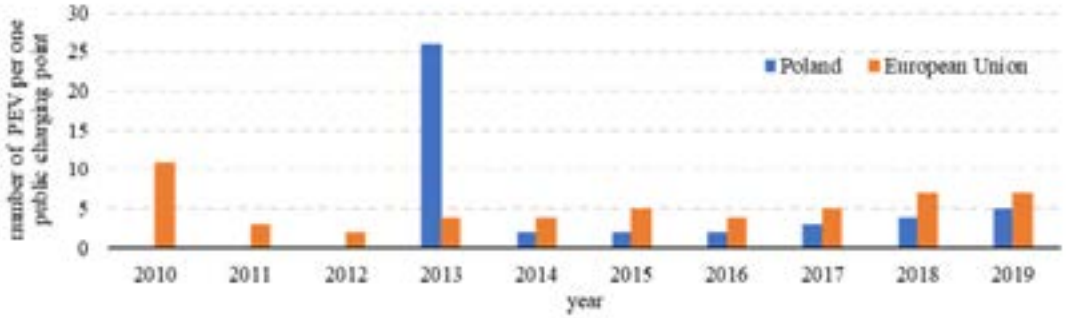

Figure 4 *Number of electric cars per one public charging point (based on [15])*

Figure 5 *Distribution of EV charging stations in Poland, in 2020 (as of March 2020) [25]*

The distribution of charging stations in Poland, as shown in Figure 5, indicates that they are chiefly located in large cities (48%) and along main transport routes. Lack of a sufficiently developed network of charging infrastructure, the current range of electric automotive vehicles and battery charging times make it necessary to plan longer trips in advance and spread them out in stages, which certainly limits the number of people interested in using electric vehicles.

Another, undoubtedly very important factor influencing the decision of those interested in buying a vehicle, is the costs of refueling/charging. Until now, charging of electric vehicles on majority of charging stations available in Poland was free of charge. However, an increasing number of charging service providers operating in Poland have recently introduced and others are planning to introduce or increase, the currently binding charges for the of chargers provided by them. Therefore, the costs of driving 100 km for various electric vehicles, charging point operators and chargers has been determined below and then compared to the costs of refueling.

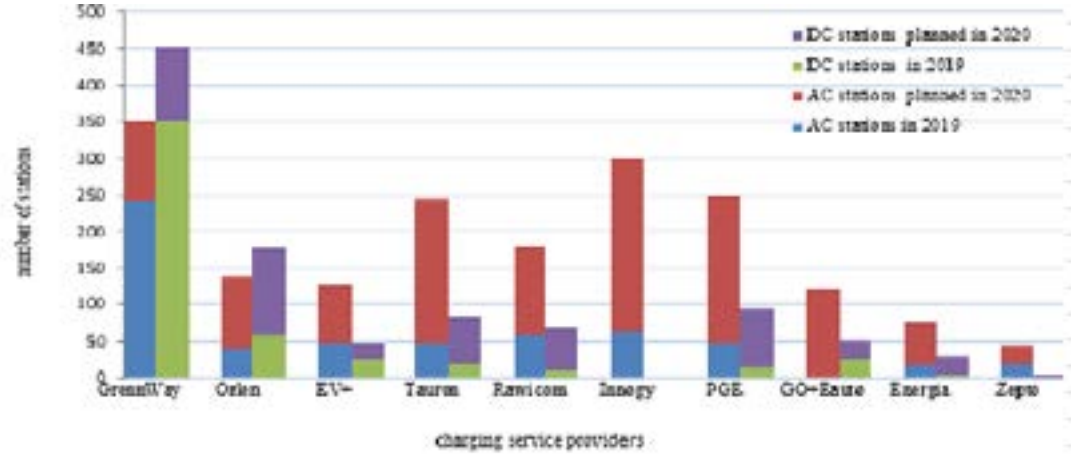

Figure 6 *Ten largest electric vehicle charging networks in Poland [27-38]*

Table 2 *Costs of 1 kWh consumption at public charging stations in Poland in 2020 [27, 29-30, 34, 36-37] [Euro]*

charging service provider	type of charging	
	AC	DC
GreenWay*	5.06	5.15
		5.72
		6.34
		6.61
		7.05
		8.74
		9.72
		11.49
Tauron	7.10	9.81
EV+	5.32	7.99
GO+Eauto**	5.10	7.10
Elocity	4.44	-
Zepto **	3.99	-
	4.44	
charging at home - G11 fare	2.44	-
charging at home - G12 tariff	1.11	-

*price depends on subscription
**price varies depending on location

3 Charging service providers in Poland

According to the Act of 11 January 2018 on electromobility and alternative fuels, at least one charging service provider should operate in a publicly available charging station. According to this Act, the charging service provider [26]:

- concludes with the electricity seller a contract for the sale of electricity, referred to in Article 5 (2) (1) of the Act of 10 April 1997. - Energy law;
- provides a charging service including charging and provides the opportunity to use the charging station infrastructure for charging purposes;
- provides, on its website, information about the price of the charging service and the conditions for its provision;
- provides the electric vehicle user with the option of paying for electricity collected to charge the vehicle under the conditions specified in the sales contract.

In Poland, the largest suppliers of electric vehicle charging services are: GreenWay Polska Sp. z o.o., PGEPolish Energy Group, TAURON Polish Energy, Polish Oil Company Orlen, Innogy Stoen Operator Sp. z o.o., Rawicom, EVplus Sp. z o.o., GO + EAUTO Sp. z o.o., Energa, Zepto, EKOEN, IONITY, which jointly provide 86% of public charging points in the country, i.e. 1094 pieces, of which 55% are the fast chargers (DC).

According to the information obtained from the suppliers of the charging station, a total of another 17,469 charging points are to be launched by the end of 2020 [26-38]. Figure 6 shows the current and announced number of public charging points for major charging service providers in Poland.

3.1 Toll collection system in Poland

The price of the charging service is determined for a single charging point and may consist of three different charges:

- initial: fixed costs charged at the beginning of the charging session, regardless of duration and energy consumption;
- calculated based on energy consumption: costs proportional to the energy (kWh) used for charging;
- calculated based on charging time: hourly costs calculated from the beginning of the session to the end of the session.

In all the cases, the price of the charging service consists only of a charge based on energy consumption (kWh).

In Poland, the charge for electricity collected to charge a vehicle is binding at GreenWay Polska Sp. z o.o., TAURON Polish Energy, EVplus Sp. z o.o., GO + EAUTO Sp. z o.o., Elocity Sp z o.o., Zepto, Lotos Group S. A.

Currently, the costs of 1 kWh consumption at high-speed direct current stations at these suppliers' ranges from Euro 5.15 to Euro 11.49.

In turn, charging at slow or semi-fast stations involves an expenditure of Euro 3.99 to Euro7.10 per 1 kWh, which makes it cheaper by 2-127% compared to using a higher power charger, comparing the offer of one operator (Table 2).

From 27 January 2020, Grupa Lotos S. A. also charges a fee of PLN 24 for using its charging stations regardless of the length of charging and the amount of energy consumed [39].

On January 31, 2020, Ionity, the operator of the European network of ultra-fast charging stations, published a statement in which it stated that the expected price for each kWh collected at the station would be Euro 15.54 [40], while Innogy Polska would announce a rate for 1 kWh - Euros 4.44 and Ekoen, -7.05 Euros/kWh.

In addition, the PGE Polish Energy Group, Polish Oil Company Orlen , Energa intends to introduce a fee for electricity collected to charge the vehicle, the amount of which is not yet known.

3.1.1 Costs of driving 100 km

Below, Tables 3 and 4 show the costs of driving 100 km for various electric cars and charging service providers currently in force in Poland, while Table 5 presents the costs per 1 kWh determined in accordance with the rates announced.

The costs determined refers to the charging itself and does not include e.g. fees and commissions connected with the electric vehicle charging service or costs connected with the battery pack consumption.

The drive train in electric vehicles consists of an electric motor, a battery pack and controllers (Figure 7).

This means fewer parts and therefore fewer components that could fail and lower operating costs, which are also omitted. The only maintenance tasks in their case are replacement of the battery coolant, oil in the transmission and replacement of worn out

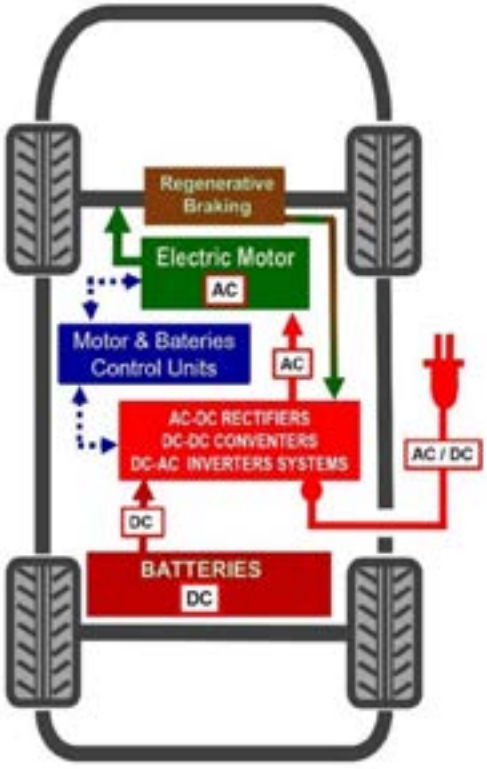

Figure 7 *The BEV type car drive system [41]*

Table 3 *The costs of charging electricity per 100 km traveled in Poland [Euro]*

brand	model	actual average electricity consumption per 100km, (kWh)	charging service provider							
			Tauron		EV+		GO+Eauto		Elocity	Zepto
			AC	DC	AC	DC	AC	DC	AC	AC
Hyundai	Ioniq electric	14.7	104.34	144.3	78.14	117.66	75.03	104.34	65.26	65.26
Volkswagen	e-golf	17.3	122.98	125.20	92.35	138.08	88.35	122.98	76.81	76.81
BMW	I3	17.4	123.43	170.94	92.79	131.08	88.8	123.43	77.25	77.25
Renault	Zoe	20.3	144.3	199.35	108.33	162.06	103.45	144.3	90.13	90.13
Nissan	Leaf	20.5	145.63	201.13	109.22	163.83	104.78	145.63	91.02	91.02
Tesla	SP90D	24.0	170.49	235.32	127.87	191.80	122.54	170.49	106.56	106.56
Tesla	100D	24.0	170.49	235.32	127.87	191.80	122.54	170.49	106.56	106.56

Table 4 *The costs of charging electricity for 100 km travelled at GreenWay stations in Poland [Euro]*

brand	model	package									
		Energymax				Energyplus			Energystandard		
		AC	DC			DC			DC		
			≤40 kW	40<x ≤150 kW	>150 kW	≤40 kW	40<x ≤150 kW	>150 kW	≤40 kW	40<x ≤150 kW	>150 kw
Hyundai	Ioniq electric	74.59	75.92	83.91	97.23	93.24	103.89	123.43	128.31	142.96	169.16
Volkswagen	e-golf	87.46	89.24	99.01	114.55	109.66	122.1	145.18	151.40	168.27	198.91
BMW	I3	87.91	89.68	99.45	114.99	110.55	122.98	146.07	152.73	169.16	200.24
Renault	Zoe	102.56	104.34	116.32	134.53	130.53	143.41	170.49	177.6	198.91	233.54
Nissan	Leaf	103.89	105.67	117.21	135.42	130.09	144.74	171.82	179.37	199.35	235.32
Tesla	S P90D	121.65	123.43	137.19	158.50	152.29	169.60	201.57	210.01	233.54	276.16
Tesla	100D	121.65	123.43	137.19	158.50	152.29	169.60	201.57	210.01	233.54	276.16

Table 5 *Expected costs of charging electricity for 100 km traveled in Poland [Euro]*

brand	model	charging service provider		
		Ionity	Innogy Polska	Ekoen
Hyundai	Ioniq electric	228.66	65.28	106.11
Volkswagen	e-golf	269.06	76.81	122.1
BMW	I3	270.39	77.25	122.98
Renault	Zoe	315.68	90.13	143.41
Nissan	Leaf	318.79	91.02	144.74
Tesla	S P90D	372.96	106.56	169.60
Tesla	100D	372.96	106.56	169.60

Table 6 *Charging time for electric vehicles [42-45]*

brand	model	type of charging	
		AC (7.2 kW) (h)	DC (50kW) (h)
Hyundai	Ioniq electric	6.25	0.5
Volkswagen	e-golf	1.5	0.5
BMW	I3	4.5	0.35
Renault	Zoe	6.5	1
Nissan	Leaf	6	1
Tesla	S P90D	11	2
Tesla	100D	11	2.

Table 7 *Costs of charging electricity per 100 km traveled from an electrical outlet[Euro]*

brand	model	tariff	
		G11	G12
Hyundai	Ioniq electric	35.91	16.29
Volkswagen	e-golf	42.68	19.18
BMW	I3	42.49	19.31
Renault	Zoe	49.59	22.51
Nissan	Leaf	50.08	22.73
Tesla	S P90D	58.60	26.64
Tesla	100D	58.60	26.64

Table 8 *Technical parameters of the analyzed vehicles [23, 29]*

costs	Volkswagen Golf 5-door		
	Trendline 1.5 TSI ACT BlueMotion	Trendline 1.6 TDI	e-Golf
vehicle own weight (kg)	1 315	1 355	1 615
load capacity (kg)	418-575	402-574	408-480
overall length (m)	4.36	4.26	4.27
overall width (m)	1.79	1.79	1.78
fuel type	gasoline	diesel oil	electric current
average consumption of gasoline (l)/ diesel oil (l)/ electric energy (kWh) per 100 km	5	4.7	15.7
maximum power output (kW)	96	85	100
maximum torque (NM)	200	250	290
maximum speed (km/h)	210	198	150
acceleration to 100 km/h (s)	9.1	10.2	9.6
total driving range (combined) (km)	833.3	120.41	231
vehicle purchase costs (Euro)*	368342	392318	735663

Table 9 *The costs of charging / refueling per 100 km of analyzed vehicles*

	Volkswagen Golf 5-door			
	Trendline 1.5 TSI ACT BlueMotion	Trendline 1.6 TDI	e-Golf	
fuel type	gasoline	diesel oil	electric current	electric current
price for (1)/1kWh (Euro)*	20.64	20.60	4.88	17.13
average consumption of gasoline (l)/ diesel oil (l)/ electric energy (kWh) per 100 km	5.00	4.70	15.70	15.70
100 km journey costs (combined) (Euro	103.23	96.79	76.81	269.06

*Prices valid on February 10, 2021

suspension and friction elements of the braking system, which also takes place in a vehicle with a conventional engine.

Analyzing the above costs, it should be noted that the electric vehicle will be more cheaply charged using the AC charging stations. However, the battery will take longer to recharge (up to 80% compared to DC), as demonstrated in Table 6.

The calculations show that among the cars under consideration, the Hyundai Ioniq electric is the cheapest in operation, taking into account only the costs of battery charging. In the case when the AC Zepto or Elocity Sp z o. o. charger is used to charge it, the costs of charging electricity for 100 km are 65.31 Euro. The highest costs of charging electricity per 100 km for this type of charging are for TAURON Polish Energy and is 170.49 Euro.

Table 10 *Total costs of fueling/charging vehicles with various types of propulsion [Euro] and the differences between them*

cumulative refuelling/charging cost					cumulative savings			
	electric vehicle		internal combustion engine vehicle		BEV vs PB95		BEV vs ON	
distance travelled	charging AC	charging DC	PB95	ON	charging AC	charging DC	charging AC	charging DC
30 000	23043.6	80719.2	29046	30969	6002.88	-51672.72	7925.4	-49750.2
60 000	46087.2	161438.4	58097.4	61938	12010.2	-103341	15850.8	-99500.4
90 000	69130.8	242157.6	87143.88	92907	18013.08	-155013.72	23776.2	-149250.6

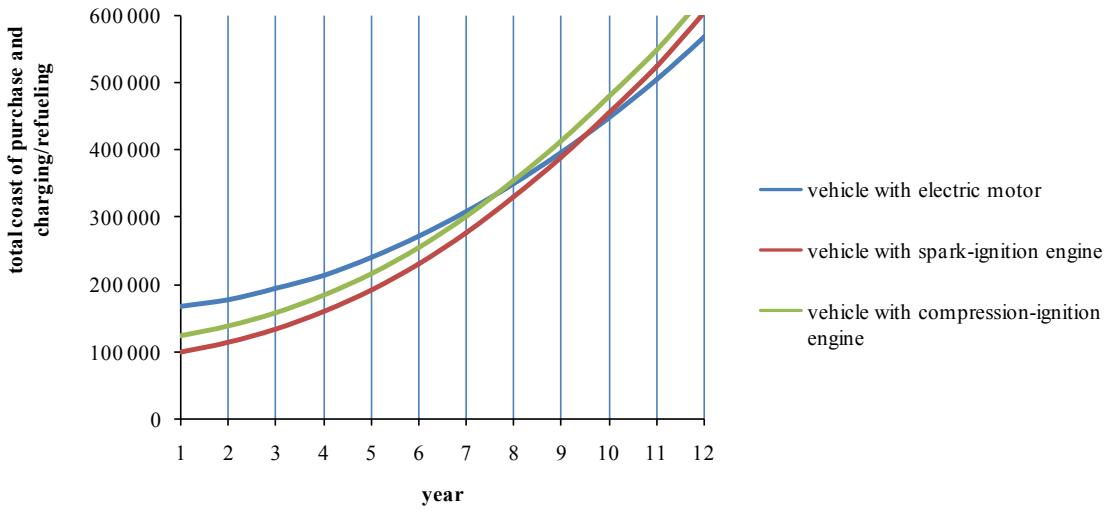

Figure 8 *Total costs of purchasing and charging/refueling a vehicle in Poland [PLN]*

In the case of the DC chargers, the lowest cost is 97.28 Euro, while the highest is 275.99 Euro. Even lower costs of charging an electric vehicle with electricity necessary to cover a distance of 100 km are recorded in the case of charging from an electric socket available e.g. in a garage. Table 7 presents such costs for all the vehicles analyzed.

3.1.2 Comparison of the charging costs of an electric vehicle to the costs of refueling a car with an internal combustion engine

In Table 9 are presented the costs of fueling/charging per 100 km one model of vehicles of the same make, with different propulsion sources and systems, assigned to the same market segment (B). They have the same or comparable total power, the same body type, type of drive (front-wheel drive) and transmission (vehicles with conventional engines - manual, with electric motors - automatic). The fuel/electricity consumption in the mixed cycle as given by the vehicle manufacturer and the annual mileage: 30 000 km were assumed. In the calculations are taken into account the lowest and the highest costs of electricity charging needed to drive per 100 km at public charging stations.

Technical parameters and costs related to, among others, the purchase of the considered vehicles contains Table 8.

The calculations show that currently the lowest costs, related to driving 100 km in Poland, are related to use of an electric vehicle, but only when charging is done with public AC chargers (the lowest price for 1kWh - Euro 4.88). The highest, when charging is carried out with use of DC Ionity chargers (price for 1kWh – 17.13 Euro). Then the costs of charging would significantly exceed the costs of refueling vehicles with a conventional engine and would be higher by over 160%.

Table 10 gives the total costs of refueling/charging vehicles with different propulsion types and the differences between them that will be generated after three years.

The savings that would result from charging an electric vehicle at AC charging stations, as compared to refueling an IC engine vehicle after 3 years, are small and certainly do not make up for the purchase price of an electric vehicle, which is currently at least 40% higher than that of a conventional engine vehicle (Table 1). When comparing the total costs of purchasing and refueling/charging a vehicle, the total costs of purchasing and charging an electric vehicle would be equal to those of a compression ignition engine vehicle after a minimum of 7 years and of a spark ignition engine vehicle after a minimum of 9 years (Figure 8).

Meanwhile, after about 8 years or driving 160 000 km by the BEV, it is planned to replace the battery used in such a vehicle. Currently, battery replacement in Volkswagen e-Golf costs 382396.12 Euro. Thus, the battery costs converted per 100 km will amount to 239.67 Euro.

Taking into account the costs of electricity consumption (4.88 Europer 100 km - the cheapest option) and the costs of depreciation of the battery - the costs of driving 100 km would then be 244.55 Euro. Assuming that the price of gasoline is /l, it corresponds to use of a combustion vehicle with an average fuel consumption of 11.97 l/100 km.

The advantage of electric vehicles is the simple structure of their drive system.

It is estimated that the driveline consists of around 4,000 components for a vehicle with a conventional engine and only 320 for the BEV.

The engine related devices are much simpler than in a combustion vehicle; for example, an electric motor does not require a cooling system. Its design itself is also much less complicated than that of an internal combustion unit. There are, for example, no intake or exhaust system, valves. Simple structure, relatively small dimensions and low weight allow to eliminate frequent maintenance and repairs connected with the necessary costs (fuel filter, air filter, oils, fluids, spark plugs, timing gears, adjustments, removal of leaks etc.).

However, all these do not compensate for the costs associated with buying an electric vehicle or a subsequent battery replacement.

4 Conclusions

Development of electromobility in Poland depends on overcoming a number of barriers, which are of different nature: technical, economic, social and organizational. The most frequently cited obstacle is insufficient infrastructure for charging vehicles. Potential consumers are also discouraged by the significantly higher purchase costs of an electric vehicle, as compared to a combustion vehicle, even after taking into account the proposed subsidies. In addition, there are concerns about the possible costs and location of vehicle servicing, as well as future costs of battery replacement. Added to this is the inability to determine the value of an electric vehicle in the aftermarket in the future.

This paper shows that another significant barrier may also be the costs of charging such vehicles. Although the costs of charging from a socket with energy needed for 100 km is presently maximum Euro 57.72, it is connected with significant difficulties (long charging time, difficulties in connecting to an electric socket).

Currently, an electric vehicle can be charged for 100 km at public charging stations for the price from62.16 Euro to 275.28 Euro. However, these amounts are not encouraging, considering the long charging time, short range of the vehicles ride, lack of a uniform charging standard and above all the costs of purchase of such a vehicle. The analysis shows that these costs will be compensated for after 7 years for a vehicle with a diesel engine and 9 years for a vehicle with a spark ignition engine. However, it should be noted that after 8 years or 160 000 km it is recommended to replace the battery in an electric vehicle, which generates a further costs of 381840 to 444000 Euro.

In 2020, Ionity charging stations were launched in Poland, where the average charging time was reduced to 15-25 minutes. However, the costs of charging at these stations turned out to be higher by up to 50 % compared to refueling the IC vehicles. Therefore, it should be clearly stated that another very significant barrier to the development of electromobility in Poland are the costs of charging such vehicles.

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