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Analysis of electric motor vehicles market

The increasingly restrictive standards related to exhaust emissions from cars make difficult the development of internal combustion engines. The activities undertaken in the design of internal combustion engines are mainly based on downsizing, e.g decreasing the engine's displacement. The main direction in the development of vehicle propulsion is to reduce carbon dioxide emissions. It is expected to reduce CO_2 emissions in 2020 to reach 95 g/km. Electric vehicles achieve low noise levels and do not emitted a burn, and thus, their use leads to a reduction in the amount of toxic exhaust gases in the air. The aspect of reducing emissions of harmful exhaust compounds and activities focusing on downsizing on the market of combustion engine cars leads to a significant increase the number of electric vehicles. In 2018 around 95 million motor vehicles were registered in the world, of which around 12 million in the European Union and 273 thousand in Poland. The number of electric vehicles among all sold is around 5.5%. Every year new, more technologically advanced models appear on the electric vehicle market. In 2018, the most popular model was the Nissan LEAF and the BAIC EC-Series. A large number of Renault ZOE have also been sold. In article analyzed different models of electric vehicle, which are available on market and presented the characteristics based on e.g. price per 100 kilometers, range for every model or charging time.

Key words: *electric propulsion market, toxic exhaust emission, costs of charging electric vehicle*

1. Introduction

The increasingly restrictive standards related to exhaust emissions [14, 16] from cars make difficult the development of internal combustion engines. The activities undertaken in the design of internal combustion engines are mainly based on downsizing, which means decreasing the engine's displacement. The main direction in the development of vehicle drives is to reduce carbon dioxide emissions. It is expected that the 2020 CO_2 emission reduction will reach 95 g/km [1]. When analyzing, the market for electric vehicles with electric propulsion, at first the construction of such a propulsion should be known (Fig. 1). The electric drive consists of such elements as: the drive accumulator, engine, tachometer, vehicle network battery, power unit and control unit, converter [3].

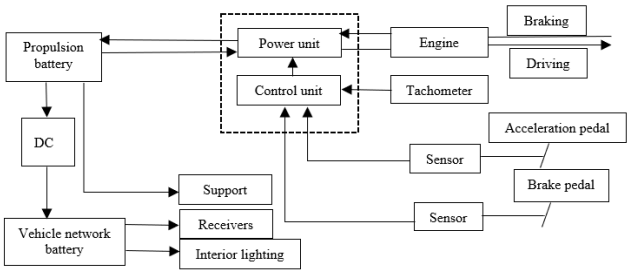


Fig. 1. The scheme of configuration motor vehicle with electric propulsion [3]

The use of electric propulsion lead to achieves low noise levels and do not emit a toxic exhaust emission, and thus, their use leads to a reduction in the amount of toxic exhaust gases in the air. The aspect of reducing emissions of harmful exhaust compounds and activities focusing on downsizing, on the market for combustion cars, leads to a significant increase in the pace of development of electric drives, not only passenger cars, but also various types of aircraft and yachts. In 2018 alone (Fig. 2) 49.1% cars registered in Norway was electric cars, in Iceland it was19.1%. The biggest market of electric vehicles are China and USA [2].

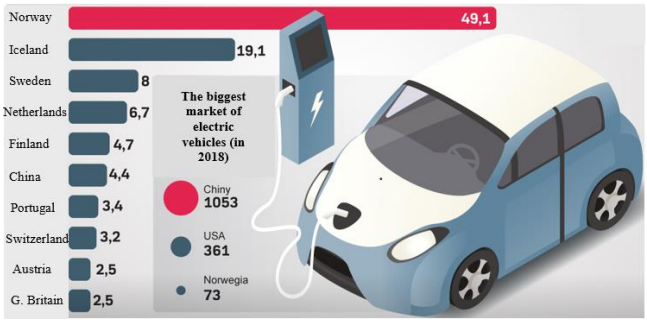


Fig. 2. The part of electric cars in new car registrations in 2018 [2]

The percentage division of fully electric cars among those registered by November in 2018 is shown in Fig. 3.

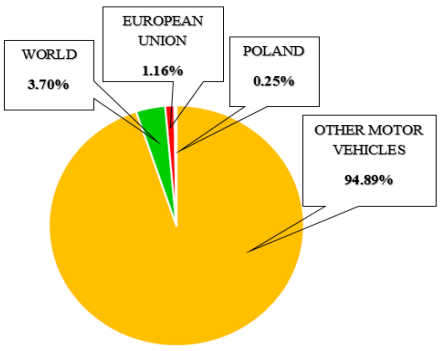


Fig. 3. Percentage part of fully electric cars among those registered by November 2018

Can be seen the number of electric vehicles of all sold cars is around 5.5%. In the European Union, around 1.16% of them were sold, where the largest number of fully electric vehicles were registered in Norway. Every year new, more technologically advanced models appear on the elec-

tric vehicle market. In 2018, the most popular unit was the Nissan LEAF. A large number of Renault ZOE have also been sold. This model has been eagerly bought in Poland, mainly due to belonging to the car sharing system – Traficar.

2. The most modern solutions for electric cars

The latest models of cars with electric propulsion available on the market in 2019 include Hyundai KONA electric (Fig. 4). The Hyundai company was founded in 1967 and is a South Korean automotive group. This model is a Sport Utility Vehicle (SUV) with electric propulsion.

Fig. 4. Hyundai KONA electric [5]

Data regarding the electric drive are shown in Table 1. As can be seen (on the basis of Table 1) Hyundai KONA electric has a very large range and battery capacity with fast charging (up to 80%). In about an hour, charging with a high voltage charger can reach a range of about 300 km. The maximum speed that this car model can reach is about 170 km/h. This vehicle develops a speed of 100 km/h in less than 8 seconds.

Table 1. Technical data for Hyundai KONA electric [5]

Type of data	Value
Battery capacity	64 kWh
Maximum power	204 hp
Maximum velocity	167 km/h
Acceleration (0-100 km/h)	7.6 s
Time of fast charging	54 min
Time of normal charging	9 h 40 min
Range	470 km

One of the most popular electric cars bought in 2018 was Renault ZOE (Fig. 5). It is a car often using in cities, as Traficar (car sharing system in Poland), which is a car rented for a minute's drive. This form of Renault ZOE is from August 2018. The based data concerns this model of car are performed in Table 2.

Fig. 5. Renault ZOE [6]

Analyzing Table 2, it can be concluded that the discussed model is a small unit (4.084 m/1.95 m/1.5 m). It is a car vehicle suitable mainly for moving around the city, but it also provides a range of up to around 300 km (Table 2). The possibility of fast charging ensures a charge up to (80%) in about 2 hours. Renault ZOE is a vehicle mainly used for urban driving. The maximum speed that this model can reach 135 km/h. The disadvantage of this vehicle is that acceleration to 100 km/h takes about 13 seconds.

Table 2. Technical data for Renault ZOE [6]

Type of data	Value
Battery capacity	41 kWh
Maximum power	92 hp
Maximum velocity	135 km/h
Acceleration (0-100 km/h)	13.2 s
Time of fast charging	1 h 40 min
Time of normal charging	7 h 25 min
Range	300 km

When reviewing the market for motor vehicles with fully electric drive, it is necessary to characterize the unit, which in 2018 was the most frequently purchased electric car. In the same year, around 42,000 Nissan LEAF models were sold (Fig. 6).

Fig. 6. Nissan LEAF [7]

Table 3 summarizes the basic technical data for the vehicle. It is a model with a capacity of 40 kWh batteries and a range of 380 km. The obtained power is about 150 hp. Up to 80% can be charged in 60 minutes using a high voltage charger (at least 40 kW). The maximum speed that this vehicle can reach is 140 km/h and up to 100 km/h accelerates in less than 8 seconds.

Table 3. Technical data for Nissan LEAF [7]

Type of data	Value
Battery capacity	40 kWh
Maximum power	150 hp
Maximum velocity	140 km/h
Acceleration (0-100 km/h)	7.9 s
Time of fast charging	60 min
Time of normal charging	6 h 30 min
Range	380 km

In 2018, on the market of fully electric motor vehicles, also e-GOLF occur (Fig. 7). It is one of two models of cars with electric propulsion produced by Volkswagen.

Fig. 7. Volkswagen e-GOLF [8]

The basic technical data on the Volkswagen e-GOLF vehicle drive is shown in table 4. This model has 36 kWh batteries, which deliver 134 hp to the drive. Using the quick-charger chargers most often available in Poland (charging 40 kW), we will charge the car up to 80% in about an hour. The maximum speed that the drive starts is 150 km/h. On the other hand, reaching 100 km/h takes about 10 seconds.

Table 4. Technical data for Volkswagen e-GOLF [8]

Type of data	Value
Battery capacity	36 kWh
Maximum power	134 hp
Maximum velocity	150 km/h
Acceleration (0-100 km/h)	9.6 s
Time of fast charging	60 min
Time of normal charging	6 h
Range	300 km

The next analyzed model is Audi e-TRON (Figure 8). The Audi company is a German car manufacturer belonging to the Volkswagen group. The company was founded in 1909. The premiere of this electric car model in Poland took place in November 2018. This vehicle has a fully electric propulsion and is a SUV. The e-TRON model is the first electric car released by Audi.

Fig. 8. Audi e-TRON [9]

Table 5 contains the technical data. Audi e-TRON has a battery with a very large capacity – 95 kWh. This car with fully charged batteries reaches a range up to 400 km. The obtained power is up to 408 hp. The maximum speed that a vehicle can reach is 200 km/h. The Audi model reaches speed of 100 km/h in 6 seconds. The disadvantage of the car is the charging time, because the basic charger, available on Polish stations can be charged up to 5 hours.

Table 5. Technical data for Audi e-TRON [9]

Type of data	Value
Battery capacity	95 kWh
Maximum power	408 hp
Maximum velocity	200 km/h
Acceleration (0-100 km/h)	6 s
Time of fast charging	5 h*
Time of normal charging	10 h
Range	400 km
*for charger with 22 kW power	

BMW is a German car company that was founded in 1916. The production includes two models of electric cars: i3 and i8. The i3 model (Fig. 9) will be described. It has been in production since 2013 and belongs to minivan vehicles. According to ACEA (European Automobile Manufacturers Association), in 2017 it was the second most-bought electric car model in Poland [14].

Fig. 9. BMW i3 [10]

Table 6 contains the basic technical data for the BMW i3 drive. The battery capacity is 33 kWh. The car can be charged in about 45 minutes, with a quick charger up to about 80%. The maximum power that can be obtained 170 hp. The vehicle accelerates to 100 km/h in about 7 seconds, and the maximum speed that it can reach is 150 km/h. Batteries allow the range of the car for about 300 km.

Table 6. Technical data for BMW i3 [10]

Type of data	Value
Battery capacity	33 kWh
Maximum power	170 hp
Maximum velocity	150 km/h
Acceleration (0-100 km/h)	7.2 s
Time of fast charging	45 min
Time of normal charging	3 h 45 min
Range	300 km

Jaguar I-PACE S is the first car in this brand's electric car (Fig. 10). The Jaguar company was founded in 1922 and is a British brand owned by the Tata Motors group. The manufacturer's goal was to construct an electric car with high performance. This model is equipped with two electric

motors. The premiere of Jaguar I-PACE was launched in March 2018. Jaguar I-PACE is an SUV.

Fig. 10. I-PACE S Jaguar [11]

Technical data provided by the car manufacturer is shown in Table 7. The battery capacity is very large, it is 90 kWh. Obtained power is 400 hp, and the maximum speed that can reach a car is 200 km/h. The fully charged vehicle provides a range up to 470 km. With a fast charger, the car can be charged up to 80% in about 2.5 hours.

Table 7. Technical data for Jaguar I-PACE [11]

Type of data	Value
Battery capacity	90 kWh
Maximum power	400 hp
Maximum velocity	200 km/h
Acceleration (0-100 km/h)	4,8 s
Time of fast charging	2 h 30 min
Time of normal charging	12 h
Range	470 km

The next discussed model is a Tesla brand car (Fig. 11). This is an American manufacturer of fully electric cars. The company was founded in 2003. Tesla manufactures just 4 models of electric cars. This model – Tesla 3 is the newest and is in production from 2018. It is a medium-class sedan car.

Fig. 11. Tesla 3 [12]

Technical data provided by the manufacturer is included in Table 8. The vehicle has 80 kWh batteries, and the maximum power provided by the electric engine is 257 hp. When the car is 100% charged, this model has a range of about 500 km. Charging time Tesla 3 with charger with capacity about 40 kW take one and a half hours. The car achieves a top speed of around 250 km/h, while the speed of 100 km/h can develop in about 3 seconds.

Table 8. Technical data for TESLA 3 [12]

Type of data	Value
Battery capacity	80 kWh
Maximum power	257 hp
Maximum velocity	250 km/h
Acceleration (0-100 km/h)	3.3 s
Time of fast charging	1 h 30 min
Time of normal charging	8 h
Range	499 km

3. Comparison of available solutions for electric cars

Analyzing commercially available solutions for fully electric cars, the most important aspects taken into account are the price of the car and of its maintenance, e.g. the cost of one full charge of the car. An important feature of this type of vehicle is also the possible range and speed. In Poland, the largest charging network for electric cars is Greenway. According to data from the Greenway report for 2018, there are currently 115 charging stations in Poland. They are 85–100 km apart (Fig. 12), and the sum of energy is 350 kWh [4].

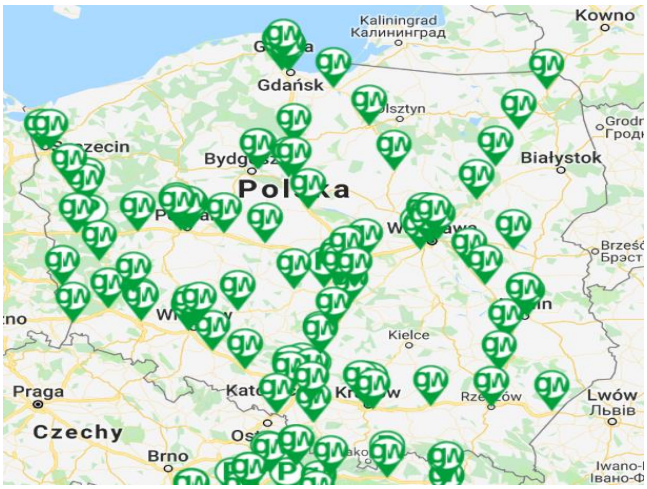
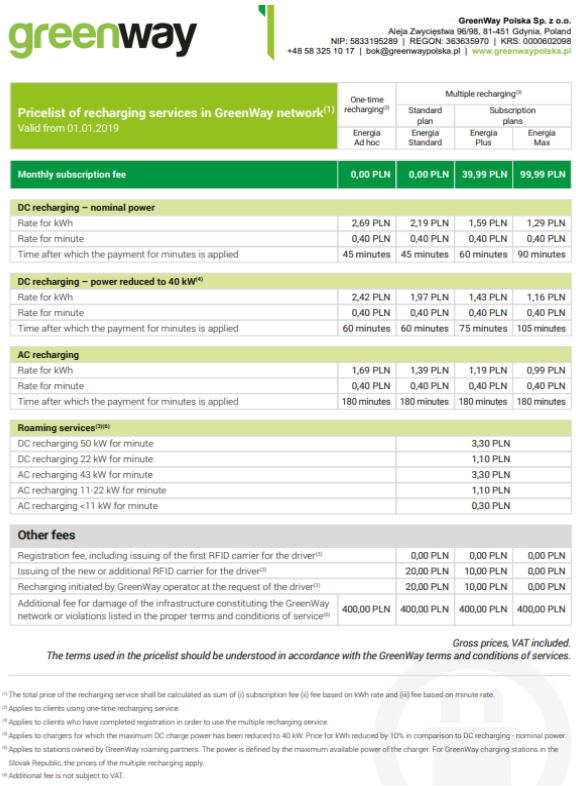


Fig. 12. Location of electric car charging stations in Poland [4]

Currently, chargers in Poland have a charging power of 40 kW, which significantly increases the time of charging the car. The Greenway company plans to introduce 136 new chargers by 2020, mainly fast (50–150 kW) and ultra-fast (350 kW) [4]. These changes will enable charging of electric vehicles in a much shorter time. When analyzing the "cost-effectiveness" and costs associated with having an electric car, should refer to the price list of services provided by Greenway (Fig. 13).

Based on the Greenway price list and technical data for a given electric car model (Table 9), it is possible to calculate the costs of its use.



greenway

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Pricelist of recharging services in GreenWay network[1]
Valid from 01.01.2019

	One-time recharging[2]	Multiple recharging[3]		
		Standard plan	Subscription plans	
	Energia Ad hoc	Energia Standard	Energia Plus	Energia Max
Monthly subscription fee	**0,00 PLN**	**0,00 PLN**	**39,99 PLN**	**99,99 PLN**
DC recharging – nominal power				
Rate for kWh	2,69 PLN	2,19 PLN	1,59 PLN	1,29 PLN
Rate for minute	0,40 PLN	0,40 PLN	0,40 PLN	0,40 PLN
Time after which the payment for minutes is applied	45 minutes	45 minutes	60 minutes	90 minutes
DC recharging – power reduced to 40 kW[4]				
Rate for kWh	2,42 PLN	1,97 PLN	1,43 PLN	1,16 PLN
Rate for minute	0,40 PLN	0,40 PLN	0,40 PLN	0,40 PLN
Time after which the payment for minutes is applied	60 minutes	60 minutes	75 minutes	105 minutes
AC recharging				
Rate for kWh	1,69 PLN	1,39 PLN	1,19 PLN	0,99 PLN
Rate for minute	0,40 PLN	0,40 PLN	0,40 PLN	0,40 PLN
Time after which the payment for minutes is applied	180 minutes	180 minutes	180 minutes	180 minutes
Roaming services[3][5]				
DC recharging 50 kW for minute		3,30 PLN		
DC recharging 22 kW for minute		1,10 PLN		
AC recharging 43 kW for minute		3,30 PLN		
AC recharging 11-22 kW for minute		1,10 PLN		
AC recharging <11 kW for minute		0,30 PLN		
Other fees				
Registration fee, including issuing of the first RFID carrier for the driver[3]		0,00 PLN	0,00 PLN	0,00 PLN
Issuing of the new or additional RFID carrier for the driver[3]		20,00 PLN	10,00 PLN	0,00 PLN
Recharging initiated by GreenWay operator at the request of the driver[3]		20,00 PLN	10,00 PLN	0,00 PLN
Additional fee for damage of the infrastructure constituting the GreenWay network or violations listed in the proper terms and conditions of service[6]	400,00 PLN	400,00 PLN	400,00 PLN	400,00 PLN

Gross prices, VAT included.
The terms used in the pricelist should be understood in accordance with the GreenWay terms and conditions of services.

[1] The total price of the recharging service shall be calculated as sum of (i) subscription fee (ii) fee based on kWh rate and (iii) fee based on minute rate.
[2] Applies to clients using one-time recharging service.
[3] Applies to clients who have completed registration in order to use the multiple recharging service.
[4] Applies to chargers for which the maximum DC charge power has been reduced to 40 kW. Price for kWh reduced by 10% in comparison to DC recharging - nominal power.
[5] Applies to stations owned by GreenWay roaming partners. The power is defined by the maximum available power of the charger. For GreenWay charging stations in the Slovak Republic, the prices of the multiple recharging apply.
[6] Additional fee is not subject to VAT.

Fig. 13. Price list of Greenway's services [4]

Table 9. Collected data to the analysis [5-12]

Model of electric vehicle	Battery capacity [kWh]	Max. power [HP]	Price [PLN]	Max. velocity [km/h]
Hyundai KONA electric	64	204	136000	167
Renault ZOE	41	92	132000	135
Tesla 3	55	257	255000	250
I- PACE S Jaguar	90	400	356500	200
Nissan LEAF	40	150	155500	140
Volkswagen e-GOLF	36	134	187500	150
BMW i3	33	170	165000	150
Audi e-TRON	95	408	360000	200
Model of electric vehicle	Cost per 100 km	Range (WLTP)	Time of charging (for 7.2 kW charger)	Time of charging (for 40 kW charger)
Hyundai KONA electric	16.2	470	9.7	2 h
Renault ZOE	16.1	300	7.4	65 min
Tesla 3	18.58	310	8.25	1 h 30 min
I- PACE S Jaguar	25.9	470	12.7	2 h 30 min
Nissan LEAF	12.2	380	6.5	60 min
Volkswagen e-GOLF	9.8	300	6	60 min
BMW i3	15.2	300	3.75	45 min
Audi e-TRON	18	400	10	5 h*

Table 9 contains the data necessary to perform the analysis: the amount of kWh consumed per 100 km by each of the car models, their range, battery capacity and charging time. To perform the characteristics, the maximum speed of the vehicle model, maximum power and price will also be used. Detailed calculations will be carried out for one model – Renault ZOE, and the remaining results compiled in the form of characteristics. The range of the car is the results of tests in accordance with WLTP (Worldwide harmonized Light duty vehicle Test Procedure) [15], which is a cycle of research on CO_2 emission standards, fuel consumption and energy consumption. WLTP tests were introduced in 2017. From that date all cars with the new homologation have values according to WLTP, and from 1 September 2018, all registered vehicles will require WLTP entries [13].

Being a Renault ZOE user (selected for detailed analysis), the costs related to use will be as follows:

– subscription purchase: it is assumed that the user performs full registration and subscribes to Energy standard, which monthly costs 0.00 PLN,
– it is assumed to charge the vehicle with direct current (DC) – with the charger power reduced to 40 kW (such chargers most often occur in Poland).
– Cost of charging vehicle Renault ZOE up to 100%

$$C_{100\%} = P_A \cdot C_{1kWh} + [(T_{char} - 60) \cdot C_{LIMIT}]$$

where: $C_{100\%}$ – cost of charging vehicle up to 100%, P_A – capacity of battery [kWh], C_{1kWh} – cost for 1 kWh charging in energy standard subscription, T_{char} – time of charging with 40 kW voltage charger, C_{LIMIT} – cost of one minute charging after exceed the time limit – in Energia standard subscription after 60 min

$$C_{100\%} = 41 \cdot 1.97 \cdot [(65 - 60) \cdot 0.40] = 82.77 \text{ PLN}$$

– Cost of overpower 100 km by vehicle

$$C_{100\,km} = W \cdot C_{1kWh}$$

where: $C_{100\ km}$ – cost for overcome 100 km by each car model, W – number of kWh necessary to overcome 100 km, $C_{1\ kWh}$ – cost for 1 kWh charging in Energia standard subscription.

$$C_{100\,km} = 16.1 \cdot 1.97 = 3.72 \text{ PLN}$$

Based on the results, it can be said that users will pay about 83 PLN for driving 300 km (city driving). For comparison, for 300 km, for example Volkswagen Polo, which consumes approximately 7 liters of gasoline for every 100 km, the user will incur costs equal to:

$$C_{VW} = S \cdot W_{l/100km} \cdot C_G = 3 \cdot 7 \cdot 4.8 \approx 100 \text{ PLN}$$

where: C_{VW} – cost of overcome 300 km with Volkswagen Polo vehicle, S – road to overcome, $W_{l/100\ km}$ – volume of gasoline consumed by vehicle per 100 km, C_G – cost of gasoline.

As can be seen, the result is comparable. The calculations presented were made for all the models discussed, and the results will be presented in the form of characteristics (Figs 14 and 15).

Figure 14 shows the cost of moving 100 km of the electric vehicle models. These costs reach values between 20 and 50 PLN. The lowest cost and at the same time comparable to the price of moving a car with gasoline-powered combustion engine (green color) is characteristic for

Volkswagen e-GOLF and Nissan LEAF cars. In the case of these two models, the price per 100 km is 19.31 PLN and 34.03 PLN respectively. The least profitable types of electric vehicles are SUV cars – Audi e-TRON and Hyundai KONA, for which the cost for covering a distance of 100 km is 35.46 and 31.91 PLN, respectively. The most expensive in operation are cars reaching high values of maximum power and maximum speed – I-PACE Jaguar and Tesla 3 (red color). However, it should be noted, that the price per 100 km for Hyundai KONA electric and Renault ZOE is very similar, although these are two very different types of cars. This means that Hyundai KONA, which is an SUV, is characterized by low costs, in terms of its type.

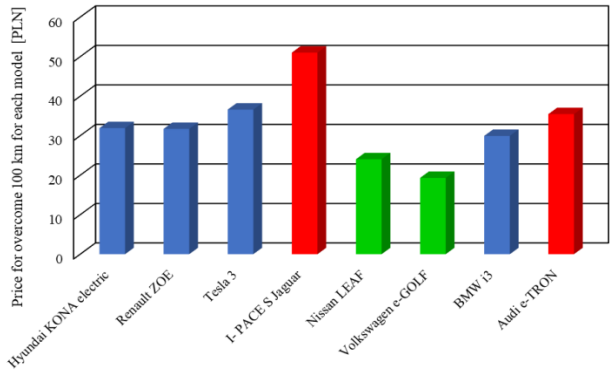

Fig. 14. The price for overcome 100 km for each model

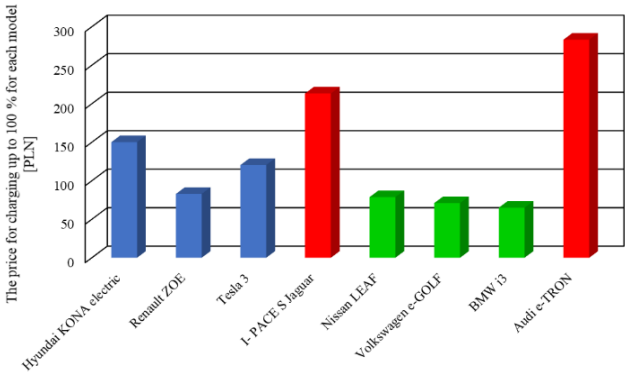

Fig. 15. Price for charging up to 100% for each model

Also, a differentiated charge for up to 100% of selected vehicle types was analyzed (Fig. 15). The lowest price, when loaded up to 100%, is modeled on small passenger cars – Volkswagen e-GOLF, Nissan LEAF and BMW i3 (green color). The range of costs for one charging is from 65 to about 80 PLN. The least favorable results concern I-PACE Jaguar and Audi e-TRON vehicles. In both cases, the price for a full charge differs significantly from the price for the other models and amounts to 213 and 283 PLN. Comparing the two SUV models – Hyundai KONA and Audi e-TRON, it can be seen a significant difference in the cost of use. The Hyundai brand car is about 130 PLN cheaper, despite the similar charging time. This is caused by a significant difference in the capacity of batteries for individual models (64 and 95 kWh). This affects the whole of the obtained results, hence their difference compared to those obtained during the analysis of the costs of covering a distance of 100 km.

The other characteristics created on the basis of the data from table 9 will be performed to make a more detailed analysis. Figure 16 shows two relations: maximum range (according to WLT) for individual car models and charging time up to 100% for a 40–kW charger. The largest range is provided by Hyundai, Audi and Jaguar. Can be seen with a long range, these models are characterized by longer charging times.

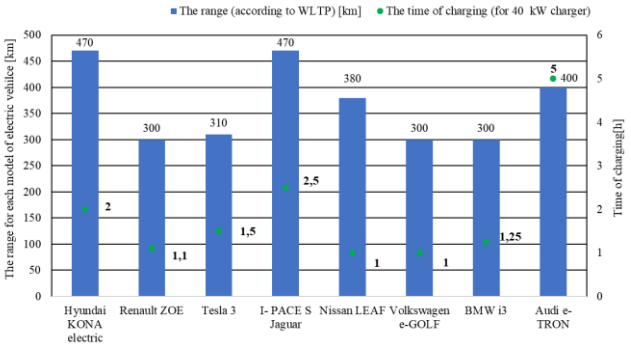

Fig. 16. The range and time of charging for each model

However, the shortest range and the shortest charging times are characterized by the following models: Volkswagen e-GOLF, BMW i3 and Renault ZOE. The most advantageous model at this stage of the analysis is the Nissan LEAF, which, after a full charge, lasting one hour, can provide a range of around 380 km. Tesla 3, on the other hand, despite high maximum power and high performance, can only beat 310 km on a single charge. This may be due to the lower capacity of the battery than in the case of models such as Audi e-TRON, or I-PACE Jaguar, having a battery capacity of about 90 kWh. In the case of Audi, the charging time shown is for a 22 kW charger (no manufacturer's information about charging time for a 40 kW charger). It can therefore be assumed that with a 40 kW charger, this time would be about 2.5 hours or up to a maximum of 3 hours. Based on this assumption, it should be noted that the charging time of the Audi e-TRON model is similar to the other models with a range of around 400/500 km.

The next discussed characteristic is the comparison of the range of individual models and their maximum power depending on the capacity of the batteries. It can be seen, the maximum power depends on the capacity of the accumulators (Fig. 17).

The models of cars with high capacity batteries (in kWh) provide vehicles with high maximum power values. Models such as Audi e-TRON and I PACE Jaguar, which have accumulators with a power of about 90 kWh, obtain maximum power at 400 hp. It should be noted that the Hyundai electric model, despite the greater capacity of batteries than the Tesla 3 car, is characterized by much lower maximum power.

It may be affected by the torque of the engine installed in these models. Smaller vehicles, mainly intended for urban driving (Nissan, Volkswagen or Renault), achieve the

most favorable results in the analysis. They have the lowest prices, their charging, thanks to the smaller capacity of batteries and lower maximum powers, is short, while providing a relatively large range. The Nissan LEAF is by far the best-performing model of an electric car, taking into account all the factors discussed, which also confirms the popularity of this model – in 2018 it was the most-bought fully electric car.

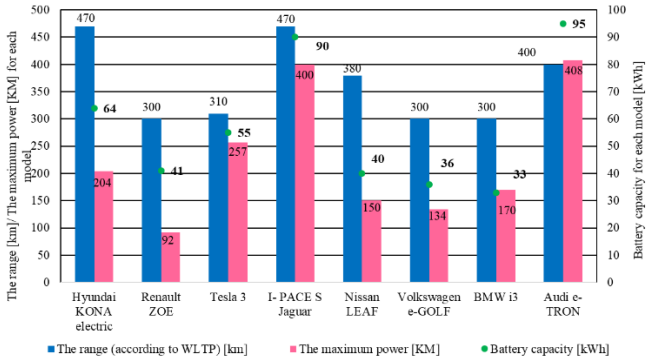

Fig. 17. The range, maximum power and battery capacity for each model

4. Conclusions

The increasingly restrictive standards regarding the emission of toxic exhaust components cause an increase in interest in means of transport with alternative propulsion sources. The article analyzes the available of cars with electric propulsion on the market. The latest and most frequently purchased models of electric cars were selected for the analysis. When making a comparison in the costs of use and basic technical parameters, no conclusive results were obtained. Referring to the costs: smaller electric cars, serving mainly for city driving, will generate similar costs as cars with internal combustion engines.

However, larger cars–e.g. SUVs generate significantly higher costs of use than cars with an internal combustion engine. Comparing the technical data of individual models, the following conclusions can be made:

– Nissan LEAF, Volkswagen e-GOLF, and Renault ZOE have much worse performance than similar types of vehicles with internal combustion engines,
– Tesla or Jaguar cars are characterized by very good performance, but their use is much more expensive than similar vehicles with internal combustion engines.

In the use of electric cars, the availability of charging points is very important. In Poland, in recent years, many stations have been built, but they are not well equipped. Only a small number of stations have chargers for quick charging. This is important, especially for high-powered cars. Then the charging time using the DC charger is significantly longer. Such situation has a negative impact on the increased sales of electric cars in Poland. To summarize, the availability of fully electric cars on the market is increasing. More and more car manufacturers are choosing to produce cars with fully electric drives. Small city cars, SUVs and sports cars can be found on the market. This shows that electric cars are very popular with the public and greatly affect the development of this type of vehicles.

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