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ELECTRIC VEHICLE VS. INTERNAL COMBUSTION CAR IN THE SMART CITY CONCEPT

Abstract

Replacing traditional internal combustion cars with electric vehicles is one of the most important aspects of the concept of electro-mobility which means environmentally friendly and clean transport. Such means of passenger transport logically fit in with the Smart City concept, as theoretically they could create opportunities for reducing traffic congestion and greenhouse gas emissions. The presented research results are an attempt to verify this hypothesis based on the opinions collected in a survey randomly conducted on users of two types of automobiles with electric and internal combustion engines. The results of the survey are not unambiguous since the development of electromobility is not supported by higher occupancy rates in electric cars and their more frequent use on short distances, but the argument for promoting them is their better operating and economic performance.

Introduction

The main objective of creating smart urban systems is their sustainable social and environmental development. The increasing use of cars in the city has negative impacts in the form of noise accumulation and fuel consumption as well as higher emissions of harmful substances to the environment. Electric vehicles which are powered by clean energy (preferably from renewable sources) can significantly contribute to reducing pollution and noise in cities. In addition, these vehicles are less expensive in terms of maintenance and have lower failure rates than their internal combustion counterparts.

Nowadays, cities are developing rapidly, which is accompanied by growing mobility of residents and the emergence of demand for electric vehicles. Cities are the major recipients of energy, however, there are great opportunities for change and improvement in this area. The two most important technologies gaining importance in European cities are electric vehicles and renewable energy. Both these technologies offer enormous potential for mitigating the climate change.

The development potential of urban road electric vehicles should be rationally incorporated into the Smart City concept, which includes the following six dimensions (aspects): (1) smart economy, (2) smart mobility, (3) smart environment), (4) smart people, (5) smart living, (6) smart governance (Giffinger, 2007). The development of intelligent forms of mobility (including electromobility) must be complementary with other smart forms of life in cities.

A Smart City is an efficiently and intelligently managed city. New innovative technologies can significantly improve the climate and increase the energy efficiency of cities and improve transport. An important issue is intelligent integration of energy and mobility systems. Such effective integration will significantly improve the use of energy, enhancing the public transport, and reducing traffic at the same time. According to some specialists, the most important thing is to improve transport and public transport specifically. They note it should be endeavoured to limit the use of private cars in increasingly crowded cities and replace them with public transport, which will contribute to the discharge of traffic jams and reduction of carbon dioxide emissions. Other experts emphasize the importance of waste segregation, which increases the recovery of raw materials, thus contributing to the protection of the natural environment (Bogobowicz, Domański, n.d.). The development of technology creates new opportunities for offering better services to residents, more efficient and intelligent public and private management, which is a huge market for business development.

1. Significance of electromobility in cities

Electromobility is a technology that integrates with the concept of smart cities. Its implementation would mean that electric vehicles, houses, offices, companies and public transport would create an integrated whole. Electric vehicles (EV) are equipped with technologically advanced batteries and electronic management and control systems whereby they efficiently use the energy resources, they can be used as a means of transport on short and medium distances in urban and suburban areas. The environmental parameters of electric vehicles allow them to enter city centres, forest areas or nature reserves without adversely affecting the environment.

The technique, technology, integration, all this is supposed to serve man to improve the quality of life. In all of this, electric vehicles are perceived by users of internal combustion cars as inferior because of the short range and the need for long charging. Most vehicle users think that they need a combustion car because it better suits their needs and, above all, allows them to travel long distances, while EVs do not allow this.

An important aspect is also coordination of the impact on electromobility at various political levels. It should be avoided to create contradictory strategies or policies that would undermine one another, for example, supporting integrated transport and providing spatial planning (transport accessibility). It is necessary to develop a series of actions that could provide significant assistance to decision-makers and all stakeholders (at European, national and municipal levels). Well-coordinated activities in practice should make it possible to accomplish the transport objective in the city (Orcholska, 2015).

The problem is a rational perception of electric cars by users and their preferences. The rationality of choice faced by the consumer every day is the dilemma whether to choose one's own vehicle or use the public transport. The transport possibilities available to residents serve primarily to ensure the comfort and availability of the means of transport at a given time and place. Using a passenger car, the journey can be completed "at any time", while ensuring the second important condition, which is the traveller's intimacy. Both of these features are not provided by the public transport at the same time. One of the features of motorization is the possession of cars by household members that live in centres of large urban agglomerations with a developed public transport system. Residents from this group of transport users have access to a wide range of public transport services, including subway, buses and trams, which provide regular transport services around the clock. However, for this group of consumers, access to the station or bus stop or waiting for a means of public transport can be treated as great nuisance. As a result of such an attitude, some residents are of the opinion that it is extremely important to use one's own vehicle. It is preferred by reason of other advantages and benefits, such as avoiding getting wet in the rain, having the possibility of taking more luggage, greater convenience of movement (especially with small children), and sometimes holding a position at work is associated with the prestige of owning a car. Having one's own means of transport becomes all the more important the farther the distance of the household from the transport nodes (Gajewski, Paprocki, Pieriegud, Eds., 2015).

The costs of commuting to work have decreased as a result of the development of transport systems. The workplace has ceased to determine the place of residence. Owing to that, increasing numbers of the population can live outside or on the boundary of an urban agglomeration. These phenomena are described as suburbanisation, which is one of the aspects of the process of expansion and spatial reorganization of cities. Suburbia are densely populated areas that are located beyond the historic boundaries of cities. Despite this, they are clearly functionally linked to the city centres (Palak, 2013, p. 161).

Public transport has a great potential in the combat for reducing the demand for individual transport. Electromobility is a sensible solution that takes into account challenges in the public and private transport sector, contributing to reduced dependence on oil and hard coal mining and reduced pollution and noise. Electric vehicles have different characteristics and require a different infrastructure than internal combustion vehicles. Successful completion of implementation of electromobility will be achieved only if the appropriate technology is affordable and appreciated by users. This means that vast knowledge about technology, business strategies, user behaviour and consumer expectations is required. The use of electric vehicles encounters certain barriers, which are usually of a social, economic and, to a certain extent, psychological nature, or barriers resulting from the lack of sufficient knowledge about electric cars.

The inefficient use of vehicles by users generates heavier traffic in cities and has negative impact on the environment, which is the case with combustion cars. Basic knowledge about the transport behaviour of travellers not only shows the current status, but allows offering suggestions for the future of specific areas as well. Therefore, it is important to properly reflect such issues as, *inter alia*, the relationship between the distance and the type of the means of transport. A systematic approach should be employed to fulfil the desire to change the modal split of traffic. This goal can be achieved through activities in the field of spatial planning, including initiatives to develop the transport infrastructure and improve the flow of information (Sierpiński, 2011).

2. Comparison of electric and combustion car users

Road mobility of people in economically developed countries is described and characterized in numerous publications (Cadar, Boitor, Petrelli, 2017; *Berlin. Mobility in the City*, n.d.), however, there are some aspects that require additional observation and research. The ways of using passenger cars vary between countries and social groups. This study presents the results of a randomized survey of the behaviour of passenger car users in recent years.

The questionnaire method was used in the survey whereby the preferences of users of vehicles with both drives (internal combustion and electric) were compared. The survey taken on with 944 participants was conducted using an online questionnaire. 497 users of combustion vehicles accounting for 52.6% of the respondents and 447 users of electric cars representing 47.6% of the respondents participated in the survey. Answers to the survey questions show that cars with both drives are not used effectively.

The Smart City idea in respect of road mobility can be achieved if traffic congestion of road vehicles is successfully reduced. It can be reduced in various ways, in particular by increasing the number of people travelling in a passenger car and reducing the number of travels required as a result. The difference in the average occupancy rate of an internal combustion car and an electric vehicle when travelling was examined in the conducted survey. The survey indicates that 41% of the respondents – users of internal combustion vehicles are alone in the vehicle while travelling, and 39% of them are travelling with a passenger. In the remaining 20% of the cases, the respondents declared that the number of people in the vehicle was more than two. There were even fewer people travelling in the case of electric car users, where 64.0% of the journeys were made by the driver alone, and the driver had a passenger in the case of 39% of the trips.

Table 1 shows that in the group of 447 users of electric cars surveyed in 2018, the average occupancy rate in a car during the travel was 1.46 people. However, Table 2 proves that in the same year, the occupancy rate in the surveyed population of 497 users of internal combustion cars was higher amounting to 1.94 people, which is a high indicator, significantly differing from other surveys conducted in this field in Europe[1]. The difference shown in the analyzed survey may result from a greater number of seats in combustion cars (at least 5 seats) than in electric vehicles (most often 4 seats). The lower the occupancy rate in electric cars can also be caused by their innovative nature and lesser interest in them in more numerous families. This is a surprising and pessimistic fact that puts into question the usefulness of electric cars in implementing the Smart City concept and in reducing urban traffic congestion.

Table 1. Occupancy rate in electric vehicles in 2018 (number of people)

Passenger configuration in the car during the journey	Cases of using an electric vehicle	Share (%)
Driver	286	64.0%
Driver and passenger	133	29.8%
Driver plus 2 passengers	15	3.4%
Driver plus 3 passengers	10	2.2%
Driver plus 4 passengers	3	0.7%
Total	**447**	**100.0%**

Source: (own online questionnaire survey "Survey on the way of using internal combustion and electric cars in 2018", 2018)

Table 2. Occupancy rate in internal combustion vehicles in 2018 (number of people)

Passenger configuration in the car during the journey	Cases of using an internal combustion car	Share (%)
Driver	202	40.6%
Driver and passenger	195	39.2%
Driver plus 2 passengers	49	9.9%
Driver plus 3 passengers	30	6.0%
Driver plus 4 passengers	21	4.2%
Total	**497**	**100.0**

Source: (own online questionnaire survey "Survey on the way of using internal combustion and electric cars in 2018", 2018)

Another parameter characterizing individual road mobility is the distance travelled by car. In the survey the respondents were asked about this distance in two ways: a) the annual mileage of the car (results shown in Tables 3 & 4), b) the daily distance of travels by such car (results shown in Tables 5 & 6). Some difference might be expected between the figures provided in response to these two questions, since in the former case, the average distance travelled during each of the statistical 365 days in the year in practice is probably reduced by those days when the car is not used at all. The daily distance covered by car is the product of the number of trips made and the average distance travelled, which requires additional surveys to be conducted. In the conducted survey, respondents were asked about the total car

[1] According to the survey of the European Environment Agency in 2004-2008, the average occupancy rates of passenger vehicles in the countries surveyed (Great Britain, Denmark and the Netherlands) was about 1.45 people (*Occupancy rates of passenger vehicles*, n.d.).

mileage during the year or day, without distinction between urban and extra-urban traffic.

Table 3. Average annual mileage of electric vehicles in 2018 (km)

Annual mileage (km)	Cases of using an electric vehicle	Share in the total number of electric vehicles (%)
3 000–5 000 km	30	6.71%
6 000–10 000 km	71	15.88%
11 000–20 000 km	185	41.39%
Over 20 000 km	161	36.02%
Total	**447**	**100.00%**

Source: (own online questionnaire survey "Survey on the way of using internal combustion and electric cars in 2018", 2018)

Table 4. Average annual mileage of internal combustion cars in 2018 (km)

Annual mileage (km)	Cases of using an internal combustion car	Share in the total number of internal combustion vehicles (%)
3 000–5 000 km	120	24.14%
6 000–10 000 km	153	30.78%
11 000–20 000 km	145	29.18%
Over 20 000 km	79	15.90%
Total	**497**	**100.00%**

Source: (own online questionnaire survey "Survey on the way of using internal combustion and electric cars in 2018", 2018)

The conducted survey revealed a surprising result, as according to the respondents, trips at a distance of 3 000–10 000 km per year accounted for approx, about 22–23% of all trips by electric cars only, and for as many as 55% of all trips by internal combustion cars. In other words, journeys at distances over 10 000 km per year accounted for approx. ¾ of the total number of trips by electric cars and about 45% of trips by internal combustion cars, and it might seem that it should be the other way around.

If to convert the annual data shown in Tables 3 & 4 into one day (by dividing the calculated average annual mileage by 365 days of the year), the average daily mileage of an electric vehicle and an internal combustion car was 46.5 km and 32.7 km, respectively. In the conducted survey, the respondents were not asked what the share of the urban and suburban traffic in the total mileage of their cars was. Based on the observations of everyday life of urban residents, it can be assumed that the number of trips by car is 2–4 times a day. Assuming that about half of the car mileage is accounted for by urban traffic, it means that the average distance of one urban trip by electric car is in the range between 6 and 12 km, and this distance in the case of an internal combustion car will be in the range between 4 and 8 km.

Table 5. Average annual mileage of electric cars in 2018 (km)

Average annual mileage (km)	Cases of using an electric car	Share (%)
up to 30	98	21.92%
30–50	100	22.37%
50–70	104	23.27%
70–100	85	19.02%
over 100	60	13.42%
Total	**447**	**100.00%**

Source: (own online questionnaire survey "Survey on the way of using internal combustion and electric cars in 2018", 2018)

Table 6. Average annual mileage of internal combustion cars in 2018 (km)

Average annual mileage (km)	Cases of using an internal combustion car	Share (%)
up to 30	248	49.9%
30–50	136	27.4%
50–70	46	9.3%
70–100	32	6.4%
Over 100	35	7.0%
Total	**497**	**100.0%**

Source: (own online questionnaire survey "Survey on the way of using internal combustion and electric cars in 2018", 2018)

The average daily mileage of passenger cars resulting from the answers given by the respondents to a direct question about this indicator (results are presented in Tables 5 & 6) is slightly different. The average daily mileage of electric and internal combustion cars was estimated by respondents at 59.6 km and 40.4 km, respectively. Assuming that the average number of car trips is from 2 to 4 per day, and about half of the traffic takes place in cities, this would mean that the average distances of individual urban trips would be between 8 and 15 km and between 5 and 10 km by electric and internal combustion cars, respectively. Such a large difference in average distances travelled by electric and combustion cars requires additional surveys, given the fact that electric cars are still a novelty and the way in which they are used is assessed by a narrow group of users.

The driving range limited to approx. 100–160 km on one charge of vehicles of the VW eUP or Renault Twizy type would not be a major obstacle for the surveyed users to achieve a fairly high daily mileage. The range of electric vehicles is quite sufficient for urban driving even with the current technology. A poorly developed network of charging stations may be a barrier for the use of electric vehicles. However, this barrier can be removed in a fairly quick way. Charging stations are less expensive and easier to build than gas stations and require less space. An ordinary electrical socket which is commonly available is sufficient to charge a vehicle. Fast charging stations can recharge batteries in less than 30 minutes filling up to 80%

of the battery capacity. The fastest charging technology in the world supplied by ABB allows charging batteries mounted on bus roofs at selected stops with 600 kilowatts of power in 20 seconds (*Charging of electric buses in 20 seconds*, n.d.).

3. Comparison of operating features and costs of electric and combustion cars

There are many studies and publications comparing the performance characteristics of electric and combustion cars (Palinski, 2017; Schmidt, 2017; *Costs and benefits of electric cars vs. conventional vehicles*, n.d.; *Global EV Outlook 2016*, n.d.). These comparisons usually take into account the autonomy of the vehicle, the comfort of driving, the functionality of the design, reliability and failure free operation, the purchase price, fees and taxes, cost of fuel and lubricants, insurance rates, environmental performance, scrapping and recycling conditions. The main barrier to the development of electromobility so far have been higher prices of electric vehicles than internal combustion cars, however, experts expect that the prices will level out over the next decade.

One of the most important factors determining the choice between an electric vehicle and an internal combustion car are the operating costs (one vehicle or one vehicle-kilometre per year). Electric vehicles are much cheaper to maintain and have lower failure rates. It is estimated that the cost of fuel required to cover 100 km by an electric vehicle is lower by about 25–30% than in the case of an internal combustion car. For example, the average fuel consumption of VW Golf 1.0 TSI is approx. 4.9 L/100 km and the average fuel price of e95 is PLN 5.01, which gives the cost of driving 100 km at the level of about PLN 24.55, while the electric equivalent of VW eGolf consumes 12.7 kWh/100 km, which with the average price of 1 kWh of approx. PLN 0.55 gives PLN 6.99 for 100 km. The cost of driving 100 km by an electric car is 28.5% of the cost of travelling by an internal combustion car[2].

Electric vehicles give the opportunity to save money while using them and then in subsequent repairs by reason of a their fairly simple design and less complicated parts. A breakdown of features of the popular VW Golf model with three types of drives in Table 7 shows that the maintenance costs are the lowest in the electric version.

Table 7. Cost of repairs and maintenance checks of VW Golf (PLN)

	VW eGolf	VW GOLF 110HP 1.2 TSI	VW Golf 1.6TDI 105 HP
Service	Electric engine	Gasoline engine	Diesel engine
Periodic check every 30 000 km with oil change	–	1387.88	1454.08

[2] Prepared on the basis of the manufacturer's data, VW (https://www.volkswagen.no/no.html) and average energy prices available at https://zaradnyfinansowo.pl/ceny-pradu/ https://www.e-petrol.pl/notowania/rynek-krajowy/ceny-stacje-paliw [Accessed 25 June 2018].

	VW eGolf	VW GOLF 110HP 1.2 TSI	VW Golf 1.6TDI 105 HP
Air filter replacement including filter	–	336.02	350.04
Fuel filter replacement including filter	–	–	455.78
Periodic check without oil change	870.78	677.28	677.28
Dust filter replacement including filter	222.28	222.28	222.28
Timing belt replacement every 210,000 km	–	3592.62	3954.54
Oil change including oil and filter	–	1021.90	2346.56
Replacement of front brake pads and disks	2236.97	2209.45	2321.11
Replacement of rear brake pads and disks	2022.48	2158.55	2022.48
Replacement of spark/glow plugs	–	863.15	

Source: (own study based on data from the website of VW in Norway, prices converted from NOK according to the average exchange rate of the National Bank of Poland, where NOK 1 = PLN 0.4637; the exchange rate of 3.7.2018)

Another advantage of electric vehicles is their lower failure rate, as they do not have expensive and complicated Common Rail fuel supply systems which are very sensitive to low quality fuels and expensive to repair as is the case with replacement of e.g. a dual-mass flywheel in the turbocharger. This is the reason why the EV is a good solution for short distances and in city traffic. The cost of periodic checks is also cheaper as there is no need to change oil or the fuel filter.

Table 8. Costs of owning and using selected models of internal combustion cars

Make/Model	Fiat Panda	Skoda Fabia	Volkswagen Golf	Ford Mondeo
Number of doors	4d	5d	5d	4d
Engine version	Fresh	Classic	Trendline	Ambiente
	1.2 ECO 69HP	1.2 TSI 105 HP	1.6 TDI 90 HP	2.0 TDCI 115 HP
Purchase price	27 990	43 400	70 450	90 600
Registration fees	180.5	180.5	180.5	180.5
Check cost	198	198	198	198
Cost of insurance	6700	7200	12000	15000
5 years				
Mileage: 1 year/5 years	15 000/75 000	15 000/75 000	15 000/75 000	15 000/75 000
Average fuel consumption (combined cycle l/100km)	4.9	5.3	4.5	5.9

Make/Model	Fiat Panda	Skoda Fabia	Volkswagen Golf	Ford Mondeo
Cost of fuel: 1 year/5 years	3601/18 007	3895/19 477	3105/15 525	4071/20 355
Cost of periodic checks up to 5 years of use	1700	3600	6000-8000	4000
Other expenses	1800	1800	1800	1800
e.g. car wash				
Total cost of owning a car	56 575	75 855	106 153-108 153	132 133
– 5 years of use				
Cost of owning a car per month	943	1264	1769-1802	2202
Loss of value (%)	37.4	41.3	40.4	36.6
Value of car	10 468	17 924	28 462	33 160
after 5 years				

Source: (Krupiński, 2011).

Owners of internal combustion cars do not calculate the costs of ownership and maintenance of the car rationally. In addition, in an urban area, where the number of parking spaces is limited, and the public transport is generally available, it often seems unnecessary to own a vehicle and pay the costs related to its maintenance.

The most important thing in the Smart City concept is that all transport services should be integrated and generally available. A solution that can integrate automobiles with the public transport system is Car-sharing, where a fleet of vehicles is made available to users for a charge. The operators are various enterprises, public agencies, cooperatives, associations or groups of individuals. Owing to this system, electric vehicles can be used more effectively and their owners may have additional benefits. This system allows reducing the costs of owning a vehicle. This may be one of the important arguments for the society to open up to electromobility, and that the approach to vehicle ownership should change even if a little bit only and that an integrated transport system should be used. The service of renting private cars as a common mode of transport is currently introduced in Norway under the name of HYRE. Hyre is a Norway-based company that is in the process of developing a new generation of car sharing services. It is creating a platform that will make it easier and more convenient to share the car than it is today, both for those renting and those owning cars. All cars in Hyre will be available for rent[3]. Vehicles that are made available for rent by private owners are visible in a mobile application with which the vehicle is opened, closed and started. The private owner, having met the specified technical conditions for vehicles not older than 5 years and with a mileage up to 120,000 km, may have a special system for opening and starting the vehicle that is integrated with mobile applications. The owner himself determines when the vehicle is available for rent. The interested person checks the available vehicles in his/her area and can rent them, for example, for an hour or two. The owner

[3] Information from Hyre website, https://www.hyre.no/om-oss [Accessed 28 June 2018].

gets paid for renting his/her vehicle. The HYRE service is one of the solutions for a better use of private vehicles. People who have an electric car and do not use it much can have some additional earnings. This can also convince users to resign from having a car, as it is possible to rent a car in an easy and convenient way only for the time when we need it.

The most well-known and popular service now is carpooling, in other words, sharing a car when travelling. The best known system in Poland is blablaca.pl. The service in the case of electric vehicles can work at both extra-urban and urban distances. The surveyed users of electric vehicles indicate that nearly 45% of the respondents cover a distance between 30 and 70 km per day, which is shown in Table 5. It can be concluded that users use vehicles to travel to work from non-urban and urban areas. The fact that respondents in 64% cases travel alone (Table 2) shows that the vehicle is not used effectively. This is worth being taken into account when offering carpooling services in shared commuting to work and improve the efficiency of using private cars with a benefit for the environment. All means of transport should be available in an integrated transport management system. Users of the means of transport should have access to applications with specified means of transport in order to be able to choose the one that best suits their needs. New services will allow the choice of the means of transport to be adjusted to the needs of residents, also reducing the demand for parking spaces in increasingly congested urban agglomerations. Moreover, the budgets of cities will show savings on sound-absorbing screens.

Conclusions

The use of technical, economic and environmental advantages of electric vehicles in implementing the Smart City idea requires public acceptance by city residents. This acceptance is conditioned by adapting the features of these vehicles to the transport needs of their users. The surveys conducted and the above described selected results of these surveys show that there is little convergence between the features of the contemporary mobility of city residents (average occupancy rate in cars, medium distances covered and frequency of travels) and the operating properties of electric vehicles. Replacing internal combustion cars with electric ones will not result in increasing their average occupancy rate during the travel and traffic jams will not be less severe. The environmental benefits and lower energy consumption by electric cars are of lesser importance for their users than the purchase price of the vehicle. The benefits of owning electric vehicles can be appreciated by entrepreneurs and users who decide to make their vehicles available in services of the Hyre or Car-sharing type, by reason of lower maintenance costs, lower failure rates and predominance of fixed costs over variable expenses in the case of electric cars.

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