The implementation of the electric taxi fleet in the city of Poznan, Poland

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Abstract

Transport is an essential element of socio-economic growth, however, its development, besides the obvious benefits, generates a number of external costs such as congestion, noise, emission of harmful substances into the environment, depletion of non-renewable resources and energy consumption. One of the factors affecting the reduction of the environmental burden from road transport is the replacement of the conventionally-fueled vehicles by other types of powertrains, including the electric drives. The introduction of electric vehicles may become the key element in the sustainable transport strategy development in urban areas, but due to the fact that electric vehicles are still unpopular, the demand for these vehicles should be boosted by the vehicle fleet owners, especially by the companies providing transport services. The introduction of electric taxis requires the construction of an appropriate charging infrastructure, i.e. the selection of the charging station type and the determination of the number and locations of the stations. The paper outlines the progress in the introduction of electric taxi fleets in several cities. The main section relates to the possibility of the implementation of electric taxicabs in the city of Poznan, an agglomeration of 600 thousand inhabitants, located in the western part of Poland. The choice of vehicle and the calculation of the operating costs of a taxicab, as well as the calculation of the charging infrastructure costs have been also presented.
Keywords: electric vehicles, taxicabs, sustainable city, charging infrastructure.

1 Introduction

Transport, despite the fact that it is an inseparable element of social-economic life, generates a variety of nuisances. The limitation of these negative

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consequences is particularly important in highly populated agglomerations, which generate high flow of cargo and increased carriage of passengers. Urban areas are inhabited by over 60% of the European population. All of these areas encounter the same problems caused by road traffic: traffic jams, air pollution, noise, road accidents, health issues, and bottlenecks in delivery systems.

Due to the negative effects of road transport, the European Union recommends the introduction of integrated sustainable urban mobility plans in conurbations with over 100 000 inhabitants [1]. Also in the White Paper on Transport [2], one of ten strategic goals adopted by the European Commission is to halve the use of conventionally-fuelled cars in urban transport by 2030 and phase them out of cities by 2050 and also achieve CO_2-free city logistics in major urban centres by 2030.

An increased number of European cities started to implement the strategy of sustainable transport. The applied solutions aim at shifting the traffic flow from individual transport to public transport by boosting the attractiveness of the latter through improving of its accessibility, traveling comfort and traveling time. Besides, more environment friendly modes of transport are promoted in both public and individual transport.

One of the methods to reduce the environmental burden generated by road transport is the replacement of the conventionally-fuelled vehicles by other types of powertrains, including the electric drives.

Electric vehicles can be a solution to a number of problems that are generated by transport in the city – they generate less noise and less pollution (compared to vehicles fitted with combustion engines). Their significant advantage is also the fact they that are independent of natural deposits of crude oil and other fuels, which reduces the demand for non-renewable fuels. From the point of view of the vehicle users, it is important that the costs of operation (excepted battery renewal) are approximately four times lower compared to conventional vehicles. Electric vehicles are also safer than vehicles fitted with combustion engines due to a lower risk of vehicle explosion during accident, which also reduces the risk of scalding or burning of the passengers [3].

One of the main disadvantages of these vehicles is the need to build a network of charging stations. The problem is to plan their location, number and type. Electric vehicles have a limited range that depends on the capacity of the battery and its service life. The cost of production of the batteries influences the already high cost of electric vehicles compared to conventional vehicles.

Electric vehicles are not a popular mode of transport in Poland. The reason for such low popularity is the vehicle costs and lack of the infrastructure of charging stations. Besides, as opposed to many European countries, future end users, when purchasing an electric vehicle, are not stimulated by any incentive programs.

2 Electric vehicles in the urban policy

When planning the transport policy, city authorities pay particular attention to the greatest possible use of alternative powertrains.

The authorities of Amsterdam want exclusively electric vehicles to be allowed in the city by 2040 [4]. In another European capital – Copenhagen, by 2015 as much as 85% of public vehicles will be electric [5].

The introduction of electric vehicles in the cities is the simplest when starting with entire fleets. This could be vehicles used by municipal organizations, public administration or taxi operators. Electric vehicles are particularly useful in taxi operations, because cabs are used mainly in the city and the time spent at the taxi stand can be used for battery charging. In cities with a large number of taxis such as Tokyo, conventionally powered taxis generate 20% of the air pollution. The introduction of electric cabs is therefore a good solution to reduce the exhaust emissions and it popularizes the idea of electric transport among the citizens.

Electric taxi fleets have been introduced in several cities and some other cities are introducing or planning to introduce the clean fleet concept.

Amsterdam-based Taxi Electric was the first private taxi company to switch to a fleet of 100 percent electric taxis in November 2011. It started with 10 Nissan Leaf's and now it operates a fleet of 25 Nissan Leaf's and 10 Tesla S models. The company's electric vehicles has now amassed 2 million km in taxi operations. In October 2014 also the Schiphol airport has inaugurated a new fleet of 167 Tesla S taxis, giving it the largest fleet of all-electric taxis of any airport in the world. The taxis are operated by two companies – BBF Schipholtaxi and BIOS-groep – who shuttle passengers to and from the airport with zero emissions.

The City of Amsterdam's municipal government finances part of the cost of purchasing the taxis through a subsidy that is available for electric transport offering 10000 euros toward every new electric taxi [4]. The electric taxis can be recharged at special taxi charging points located throughout the city or at regular charging stations. A total fleet of 3000 taxis operates in Amsterdam, around 2500 taxis are active during the working week and this number rises at the weekend. The Dutch capital is striving to have 450 electric taxis active in the city in 2015 [4]. In Rotterdam, Taxi Centre, which is one of the biggest taxi operators in the Netherlands, is also switching to electric taxis and has put into service two BYD e6 models, following successful test operations. The trials of the BYD e6 taxi have demonstrated that the car has sufficient range to cover a typical day's operating cycle on a single charge and can be recharged quickly during breaks when required. The company plans to extend its fleet of emissions free pure electric taxis to 25 by 2015. The City of Rotterdam has now 500 charging stations, all supplied with green electricity from renewable sources.

The largest fleet of electric taxis is used in Beijing. In the capital of China a total of almost 46 000 taxis are registered. In order to reduce the exhaust emissions, the Beijing authorities decided to solve the problem by introducing a fleet of electric taxis. In 2011 there were 50 electric vehicles in the streets and in January 2014 this number grew to 1150 [6]. To encourage purchase and use of electric taxis the authorities of Beijing came with an incentive program by co-financing the purchase in the amount of approximately 370 euros monthly [6]. Beijing anti-pollution drive also calls for setting aside more than 10% of the

city's parking spaces for electric vehicles. The objective is to convert Beijing's 46000 taxis into electric vehicles until 2017–2018. In another Chinese city of Shenzhen, in May 2010 first 40 taxis were introduced. In 2013 the fleet grew to 800 electric taxis and it is forecasted to grow to 2200 vehicles. The owner of the fleet is Pengcheng Electric Taxi Company – a joint venture between Shenzhen Bus Group and BYD Automobile (manufacturer of electric BYD e6 models). An average daily mileage of a taxi is 360 to 500 km. This means the vehicles must be charged twice per day (a three-hour stop).

Smaller fleets of electric taxis have also been introduced in other cities worldwide.

In January 2014, electric taxis were introduced in the largest city of Switzerland – Zurich. The iTaxi operator initially launched 10 Nissan Leaf vehicles and, another 10 vehicles extended the fleet in mid 2014 [7]. The project 'Initiative of green taxis for Zurich' was launched in the beginning of 2013 by Global Shapers and Nissan Europe during the World Economic Forum in Davos. By 2015 the aim is to have 15% of Zurich's total taxi fleet operating on electricity. To support this, a network of fast charging stations will be developed so that the batteries of the electric taxis can be charged from 30 to 80% of capacity in just 15 minutes.

Also in Tokyo, in April 2010, a 90-day switchable-battery electric taxi demonstration project was launched, using three Nissan Rogue crossover utility vehicles, converted into electric cars with switchable batteries. The initial three-month field test was continued until late November 2010. The main advantage of this project was assistance in battery charging based on quick swap of discharged batteries with fully charged ones in the vehicle. A point of quick battery swap was built especially for electric taxis enabling the replacement of a discharged battery with a fully charged one under a minute. The battery swap stations were created with a view to extending the vehicles' range without wasting time for charging, particularly since typical Tokyo's taxi mileage reaches 300 kilometers daily. Independently of the project realized by Nissan and Better Place, in 2010 Hinomaru Limosine Company (taxi operator) launched two Mitsubishi iMiEV operated under the name of ZeRO TAXI [8].

The Nissan Corporation has continued an extensive policy of launching electric taxis in cities. It frequently participates in pilot projects organized in various cities and makes their electric vehicles available to serve as taxis for a specified period of time [9]. The concern also supports cities in building battery charging infrastructure. In collaboration with the authorities of New York and the cab owners in 2013, Nissan launched a pilot project in which they provided six Nissan Leaf electric vehicles and 3 charging stations. They were tested and evaluated by the cab drivers and the city authorities for their suitability to an electrified fleet of New York taxis. Beside New York, other pilot projects were launched in Mexico and the Brazilian cities of Rio de Janeiro and Sao Paulo. In Mexico, the pilot project was launched in 2011. The project assumed 70 electric taxis nationwide – 20 in Mexico City and 50 in the state of Aguascalientes. In Rio de Janeiro the project was launched in March 2013 when two electric taxis appeared in the streets and by the end of the year this number grew to 15. In

2012 electric taxis were also introduced in the streets of Sao Paulo. Initially there were two vehicles and the number will grow to 10.

There are more cities that are preparing for the launch of their electric taxi fleets such as Paris (currently there are 11 electric taxis and by 2018 almost 2000 are planned), Oslo (as much as 1000 units are to be used by the end of 2015) or Barcelona and London (have signed letters of intent with Nissan for testing of the e-NV200 electric vehicles). BYD car maker said it has received orders from a Taiwanese taxi association for more than 1500 electric e6 cars.

Table 1: Electric taxi fleets.

City	Existing fleet (number and car model)	Plans
Aguascalientes, Mexico	50 Nissan Leaf	–
Amsterdam, The Netherlands	25 Nissan Leaf, 177 Tesla S	450 electric taxis in 2015
Beijing, China	1150 BYD e6	100% of taxi fleet by 2017–2018
Bogota, Colombia	45 BYD e6	–
Brussels, Belgium	50 BYD e6	–
Hong Kong, China	45 BYDe6	3000 electric taxis in 2015
London, UK	20 BYD e6	All new taxis from 1 January 2018 100% of taxi fleet by 2020
Mexico City, Mexico	20 Nissan Leaf	–
New York, USA	6 Nissan Leaf	30% of taxi fleet (without time frame)
Oslo, Norway	10 Tesla S	1000 electric taxis in 2015 100% of taxi fleet by 2023
Paris, France	11 Tesla S	2000 electric taxis by 2017–2018
Rio de Janeiro, Brazil	15 Nissan Leaf	–
Rotterdam, The Netherlands	2 BYD e6	25 electric taxis in 2015
Shenzhen, China	800 BYD e6	2200 electric taxis in 2015
Tokyo, Japan	2 Mitsubishi iMiEV	–
Trondheim, Norway	6 Nissan Leaf	–
Warsaw, Poland	13 Ford Mondeo	–
Zurich, Switzerland	20 Nissan Leaf	15% of taxi fleet in 2015

3 The use of electric vehicles in Poznan

Poznan, with its population of over 550000, is the fifth largest city in Poland, and together with the neighbouring suburban area, it makes up an agglomeration inhabited by nearly one million people. Currently in Poznan, only several electric vehicles are used and practically there are no charging stations. Outside of the city centre there are two charging stations installed near large shopping malls – one in the south and the other in the north of the city. What is more, there are no incentives to purchase electric vehicle in Poznan at all. The charging stations are not subsidized either. No infrastructure and lack of incentive programs virtually blocks the sales of electric vehicles in Poland.

For comparison, Norwegian Oslo, which is a city of the population close to that of Poznan (population 600000) already 10 years ago set developing of electric infrastructure as one of its priorities. Today, Oslo has the world's highest number of electric vehicles per citizen. In September 2014 Oslo counted about 15000 electric vehicles and currently 15% of new cars in Norway are electric.

The high number of electric vehicles in Oslo is partly thanks to a number of charging stations. The highly visible charging stations in the city centre reduced anxiety for people worried about a lack of charging facilities. As of mid-2014, the Agency for Urban Environment has established over 1000 charging stations in Oslo (700 public and 300 private) and in 2015 Oslo plans to create additional 400 public charging stations as well as increase the number of private sector applications through the Climate and Environment Fund. Other reason for fast development of electric cars market are the incentives implemented on the national level:

- there is no VAT (25%) on electric vehicles and no "first-time registration fee",
- electric vehicles are allowed to drive in lanes reserved for bus and taxi,
- electric vehicles can drive for free on toll roads and travel for free on the ferries part on the regional road system and they can park for free in all public parking spaces.

The transport policy of the city of Poznan has been aimed at the improvement of road infrastructure, much less attention has been paid to public and bicycle transport, let alone other solutions reducing the negative impact of road transport. Recently, the city authorities have taken steps to develop a strategy for sustainable transport, which is why the implementation of environment friendly solutions, including electric taxis, still stands a chance.

4 Selection of a vehicle

In cities where battery-charging infrastructure does not exist, when implementing electric taxis, the cost of purchase, operation and the cost of installation of a number of charging terminals must be allowed for.

The selection of the vehicle model is impactful on the annual maintenance costs of the fleet and the type of charging station the driver will use. Not every electric vehicle available in the market can be used as a taxi. Only four- or five-

door vehicles should be used for commercial carriage of passengers. The vehicles must also have sufficient luggage space. Out the vehicles available in the Polish market, Renault Fluence, Nissan Leaf, a passenger version of Nissan eNV200 and Renault Kangoo (Table 2) can be used as taxis. In Poland one can also purchase Mitsubishi iMiEV and Peugeot Ion, but these are too small to operate as taxis. Because of their similar price and operating costs of both Renault models, only Renault Fluence was included in the further analysis.

Table 2: Comparative analysis of electric vehicle models available in the Polish market.

Car model	Body*	Battery (kW)	Boot volume (l)	Range (km)	Net price (euro**)
Renault Kangoo	4D	22	1 300	170	20 674
Renault Fluence	4D	22	317	170	21 006
Nissan eNV200	4D	24	2 900	170	26 047
Nissan Leaf	5D	24	330	160	23 823
Mitsubishi iMiEV	3D	16	166	150	21 349
Peugeot Ion	3D	16	166	150	23 023

*3D – three doors, 4D – four doors, 5D – five doors.
** Original prices in Polish zloty, exchange rate 1 euro=4.3 Polish zloty.

From the perspective of a taxi operator, the analysis of the operating costs, including the initial expenditure is of paramount importance. The greatest impact on the operating costs of electric vehicles have: the purchase of the vehicle (depreciation), battery renewal or battery lease and the costs of consumed energy.

Table 3 presents estimated annual costs of operation of three models of electric vehicles (Renault Fluence, Nissan Leaf and Nissan e-NV200) that were compared to the models fitted with diesel engines of similar technical parameters.

The adopted assumptions for the cost analysis are as follows:

- The purchase price is reduced by 15% of the catalogue price for fleet purchase.
- The cost of purchase is included as the cost of depreciation. A 5-year period of depreciation is assumed (at 0.2).
- Annual mileage of the vehicle is 37920 km (one shift, 10 fares daily and average 10.39km/fare).

- For electric vehicles, an additional cost is the renewal of battery. Two solutions are available: monthly battery lease payments (Renault Fluence) or the purchase of a new one after 160000 km (Nissan Leaf or Nissan eNV200).
- Inspection intervals have been assumed at 20000 km; maintenance service of electric vehicles is 15% cheaper compared to conventional vehicles.
- Net cost of energy is 0.11344 euro/kWh.
- Net cost of diesel fuel 1.0326 euro/l.
- Daily consumption of energy for electric vehicles is 16.59 kWh (15.97 kWh/100 km).
- Daily consumption of fuel for vehicles fitted with combustion engines – 8l/100 km in the urban cycle + 2l/day of stoppage.
- Annual cost of insurance was assumed at 3% of the vehicle value.
- Cost of battery for Nissan Leaf and Nissan eNV200 amount to 10618 euros. With 4.2-year depreciation (resulting from the battery use) the annual cost will amount to 2516.74 euros. Battery lease for the assumed mileage will be 317 euros per month.
- All costs included in the calculation are costs net of VAT.
- All euro amounts were converted at 1 euro = 4.3 Polish zloty.

Table 3: Comparative analysis of the operating costs of electric and conventional vehicles.

	Renault Fluence EV	Fluence Dci 110 HP	Nissan eNV200	Nissan Leaf	Nissan Juke dci110 HP	Nissan Qashqai dci110 HP
Net price (euro)	17 855	10 009	22 139	20 250	10 993	11 152
Depreciation (euro/year)	3 571	2 002	4 428	4 050	2 199	2 230
Insurance (euro/year)	536	300	664	607	330	335
Battery lease (euro/year)	3 804	–	–	–	–	–
Battery exchange (euro/year)	0	0	2 528	2 528	0	0
Service (euro/year)	316	372	316	316	316	316
Cost of fuel or energy per 1 shift (euro)	1.9	10.6	1.9	1.9	10.6	10.6
Total cost per year (euro)	8 912	6 546	8 629	8 188	6 772	6 808

Annual cost of operation of electric taxis, based on the mileage of 37920 km per year, fall between 8188 and 8912 euros. From the compared models of electric vehicles the Nissan Leaf has the lowest costs of operation. Its advantage, similarly to the other model of the Japanese manufacturer (i.e. eNV200) is the possibility of quick battery charging with direct current based on the Chademo standard. The battery of Renault Fluence cannot be charged in this way. Due to similar costs of purchase and operation of both Nissan models, these vehicles appear to be the optimum choice for taxi operators out of all electric vehicles available in the Polish market.

Comparing these costs with the costs of operation of taxis fitted with combustion engines (diesel), the annual cost of operation of Renault Fluence EV is 36% higher than the same model fitted with a diesel engine. The same, costs for Nissan Leaf is 20% higher than other comparable Nissan models fitted with combustion engines.

5 Charging stations

The number of charging stations depends on the forecasted size of the fleet and daily demand for battery charging. When selecting the type of charging station the cost of infrastructure and the charging time (vehicle unavailability in that period) must be considered. Each electric vehicle should be charged at least once per shift i.e. in a one-shift system – once per day and in a three-shift system – three times per day. In practice, the chargings are more frequent but shorter. Poznan currently has approx. 3000 taxis operating in a one-shift system. The charging stations should be located at taxi stands totalling 102 in Poznan.

There are three ways to charge a vehicle: traditional (works fine only in a one-shift system), accelerated (available in any system of shifts) and quick (the best solution for intense vehicle use) [10]. Quick charging stations are too expensive for the one-shift system because the cost of infrastructure is very high and the taxi still remains idle for most of the day (operates an average of 4 hours per shift). These terminals are the only available option in a three-shift system, though the battery manufacturers do not recommend them for frequent use. In a two-shift system one can use both accelerated-charging (22 kW) and quick-charging terminals.

The costs of construction of the infrastructure includes the cost of purchase and fitting of the charging stations as well as the cost of connecting of the system to the power network (with a possible cost of adaptation/modernization of the energy distribution network).

The net cost of purchase of a terminal or station ranges from 756 euros for wall-mounted terminals of the lowest power rating, 7674 euros for accelerated-charging terminals of the power rating of 22 kW to 14651 euros for direct or alternating current quick-charging stations.

The cost of connection to the existing power network depends on the power rating of the charging station. Wall-mounted charging stations up to 6.6 kW do not require special connection to the power distribution network. For the other stations, the net cost of connection to the existing power network is directly

proportional to the power rating of the charging terminal and is 35 euros per 1 kW (as per the rates of ENEA – Poznan electricity supplier [11]). If special power cables are needed suitable for the required power rating, the net cost will amount to 15 euros for each kW and an extra of 8 euros for each meter of the connection. On average, the net cost of connecting of a charging station to the power network is 229 euros for wall-mounted terminals of the power rating of 6.6 kW, 1540 euros for two-socket freestanding terminals of the power rating of 22 kW and 1733 euros for terminals of the power rating of 50 kW.

The greatest share in the cost of development of the infrastructure has the purchase of the charging stations, which accounts for 83% to 85% of the cost. The number of the charging stations that should be built depends on the extent of fleet electrification. Accelerated-charging stations (22 kW) allow charging batteries of some electric vehicles within 2 hours. Freestanding charging stations are usually fitted with two sockets and allow simultaneous charging of 2 vehicles. Given that the taxis are parked for half of the operating time and carry passengers for another half, they should be charged when parked at taxi stand, at which they wait for an average of 4 hours. A single station can, therefore handle up to 8 vehicles per shift (2 sockets x 4 vehicles x 2 hours of charging). Quick-charging stations can handle only one vehicle at a time. For quick-charging stations a charging time of 1 hour for a single vehicle was assumed even though the station can charge the battery to the level of 80% within 30 minutes (1 socket x 8 vehicles x 1 hour of charging). In practice, the quick-charging and accelerated-charging stations can handle the same number of vehicles. Since it is impossible to manage the fleet to optimally use the charging potential of all stations (one needs to allow for a situation when there is no free charging station around due to high demand in city centres) a greater number of stations has to be set up than it would result from simplified calculations. It is important to note that the entire vehicle fleet is not used at a time. If Poznan now has 3000 taxis, then, in a single-shift system, even assuming total fleet electrification, there will not be more than 1000 vehicles in the streets at a time. The cost of construction of the infrastructure (depending on the predetermined number of vehicles per shift and assuming the number of charging stations extended by 20% against the number of vehicles operating in the streets) has been presented in table 4.

Table 4: The cost of construction of the infrastructure depending on the fleet electrification variant.

Number of electric taxis per shift	Number of charging stations (2x22kW or 1x50kW)	Total net cost for 22kW charging stations (euro)	Total net cost for 50kW charging stations (euro)
250	38	349 565	622 581
500	75	689 930	1 228 779
750	113	1 039 495	1 851 360
1000	150	1 379 860	2 457 558

If, on one shift, not more than 250 taxis are used, the net cost of construction of the infrastructure will range from 350000 euros for accelerated-charging stations to 623000 euros for charging stations of the power rating of 50 kW. If full electrification of the fleet is taken into account, the cost of construction of the infrastructure will range from 1.38 million to 2.46 million euros respectively.

6 Conclusions

European cities should reduce the exhaust emission level, as inscribed in the White Paper. To this end the authorities of many cities utilize a variety of available tools to achieve this goal. One of these tools is the implementation of electric taxis. Electric taxis have already been in use in many cities, which allows a reduction of the emission of carbon dioxide and other toxic compounds generated during operation of conventionally-fuelled vehicles. The aim of the green fleet is also to demonstrate that electric vehicles are already a viable, clean alternative to conventional cars and to promote the concept of zero-emission mobility for personal transport.

In cities like Poznan where infrastructure does not exist, the prerequisite for fleet electrification is building of an adequate number of charging stations. The investment project should be financed by the city. Another stage is the purchase of the vehicle fleet. Due to the fact, however, that the costs of operation of electric vehicles are higher than conventional vehicles, the introduction of incentive programs for electric vehicle owners is necessary. The best solution appears to be co-financing of an electric vehicle, as financial incentives are the most effective way to impact on society.

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