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Possibilities of Applying Electrically Powered Vehicles in Urban Freight Transport

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Abstract

The negative environmental impacts from urban freight transport and deliveries to a large extent are derived from the fact that conventionally fuelled vehicles are mainly used for transporting goods. Many countries, including all those in the EU, have implemented regulations aimed at setting high technical parameters for conventionally fuelled vehicles in order to reduce their negative impacts, however, in the long term it seems to be insufficient. This, combined with the issue of oil resources depletion, leads to the need to search for alternative forms of delivery transport. One such solution is electric vehicles. These are becoming more and more popular, nevertheless, but they are mainly used in passenger transport. This article analyses a selected range of electrically powered freight vehicles and points out possibilities of applying such vehicles to make deliveries in cities.

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Keywords: urban freight transport; alternative drives; electric vehicles; environmentally friendly transport;

1. Introduction

Within an hour, a single car turns 6000 litres of oxygen into fumes. In comparison, within the same time a medium-size deciduous tree produces 1200 litres of oxygen, and a human consumes 30 litres (www.green-cars.pl). A 10 kilometre car drive emits 2 kilograms of CO_2 into the atmosphere (ec.europa.eu). Apart from carbon dioxide emissions, the increase in the number of vehicles leads to a rise in emissions of nitrogen oxides as well air pollution with fine dust resulting from abrasive wear of brake pads, tyres and road surfaces. In the West Pomeranian Province,

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the yearly emissions from the regional roads amount to: 49 457 Mg of carbon oxide, 14 113 Mg of nitrogen oxides, 45 Mg of sulphur oxide (www.wios.szczecin.pl). In view of the growing significance of the issues connected with saving energy resources and promoting environmentally friendly transport systems, solutions based on alternative sources of energy are becoming more and more important.

It is possible for a reduction in the pollution produced by urban freight transport to be obtained by applying alternative drive vehicles. Particularly useful in this respect are electric vehicles, as they not only produce less pollution, but also operate more quietly. Taking into account the restrictions that are more and more frequently imposed on freight vehicles traffic, as well as taxes and fees charged by local self-governments, application of electric vehicles may contribute to a reduction in delivery costs in cities, which may account for up to 40% of total transport costs. A good example in this respect is in Norway where preferential tax rates for purchasing electric vehicles have made Norway the leader in the area of transport based on alternative sources of energy.

2. Description of alternative propulsion methods for motor vehicles

Alternative propulsion systems for motor vehicles include mainly (Buczaj 2006; Rogall 2010; Szmidt 2011; Maj 2011):

- gas-powered drives (Figure 1), which compared to traditional drives produce 18% less greenhouse gases and generate ca. 3 dB less noise; while their major drawbacks include greater fuel consumption, limited possibilities of filling up the tank and lesser sufficiency, as gas fuel is more difficult to store; at the moment it is the most popular alternative for vehicle powering, moreover, the studies on gas fuels are at the most advanced level. As for gas fuels applied for motor vehicles propulsion, the following are mainly used:
  - Liquefied Petroleum Gas (LPG), which is a liquefied mixture of gases, mainly propane and butane; the first systems to use this type of gas mixture were made in Italy as a result of petrol fuel shortages after the outbreak of WWII; the systems are based on the concept of a reducer that adjusts the pressure so that appropriate fuel-air mixture is formed; compared to petrol fuels LPG is characterised by a higher octane rating which, depending on the propane-butane contents ratio, ranges from 100 to 110 octanes, however, compared to petrol the gas mixture shows ca. 30% less caloric value per unit volume, therefore, fuel consumption in case of using LPG is greater by 20-30% compared to using petrol; an advantage of this solution is the possibility to use it as an alternative fuel in the standard petrol engine;
  - Compressed Natural Gas (CNG) is produced by compressing natural gas under pressure of 20-25 MPa; the works on applying CNG for propulsion were advancing in parallel with the works on LPG; to be used as a fuel to power vehicles, CNG in the liquid form must be contained in a tank, and then it is evaporated in a reducer, mixed with air and moved into the engine combustion chamber; compared to petrol fuels CNG has the octane rating of ca. 130 and its boiling point is lower than in the case of LPG; the advantage of this fuel is the fact it mixes with air easily, which decreases the risk of explosions in case of leaky systems; it is considered to be a clean fuel (pollutants emissions are ca. 3 times lower compared to diesel power engines);
- biofuels – in this case IC engines are modified in such a way so that instead of petrol or diesel they use ethanol being the result of biomass fermentation; at the moment the USA are the leader in biofuels use, as half of the maize grown there is intended for bioethanol production; their application is characterised by poor effectiveness of land resources use, resulting in a disadvantageous environmental balance; biofuels mainly include:
  - first generation biofuels including biodiesel produced from rapeseed and waste, pure vegetable oil, bioethanol produced from sugar beetroot, sugar cane, cereal or potatoes;
  - second generation biofuels where the production technology makes it possible to utilise whole plants as biomass, not just some of their parts;
  - biogas, obtained as a result of anaerobic fermentation of biomass or biowaste;
- hydrogen drives, where hydrogen is the fuel; there are two major ways of obtaining energy in solutions of this kind:
  - hydrogen combustion takes place in a typical piston engine combustion chamber; it is very effective in terms of energy, however, it involves a serious problem connected with liquid hydrogen storage in a vehicle tank (compared to its gaseous form, liquefied hydrogen takes up 900 times less volume, however, it consumes huge

amounts of heat, which means the tank must be cooled down to -253°C, which in practice means that the vehicle may not be left unused for more than a few days, otherwise the hydrogen heats up, converts into gas and escapes into the atmosphere, since hydrogen in the gaseous form can even permeate storage tank metal walls;
  - using fuel cells that produce energy as a result of oxidising the fuel constantly supplied from outside; in the case of hydrogen cells we observe the same phenomenon that takes place when hydrogen and oxygen bind to produce water molecules, the resulting energy in the form of electric current is transferred directly to the engine; apart from hydrogen the fuel cells can also use methanol, natural gas or petrol, however, in that case CO_2 emission is unavoidable;
- hybrid drives where a traditional engine is combined with an electric one; currently three basic types of solutions are used:
  - serial drive, where the IC engine operates all the time within an optimum rotation range, driving the generator which in turn supplies power to the electric motor that propels the vehicle wheels, while any excess power is stored in the battery;
  - parallel drive (most often used), where both the IC engine and the electric one propel the wheels of the vehicle; in this solution the engines may operate together or one at a time; depending on the changing road conditions; during a slow journey in the city the vehicle uses only the electric engine, and when more power is needed (e.g. to gain greater speeds on a motorway) the IC engine is turned on; if need be, the electric engine is powered by the battery which becomes a power generator when it is powered by the IC unit or when braking;
  - serial-parallel drive, combining the features of both solutions;
- electric drives using only battery powered electric engines, which theoretically are the best of the existing drives.

Figure 1. Gas-powered EFV (electric freight vehicle) used in Parma to make deliveries in the historic city centre.

Despite the continuous advances in alternative sources of energy for motor vehicles it is hard to determine unambiguously the best solution. The least advantageous solution seems to be application of biofuels, as the only benefit they offer is gaining independence from petroleum.

Table 1 shows the key benefits and drawbacks of the presented drives.

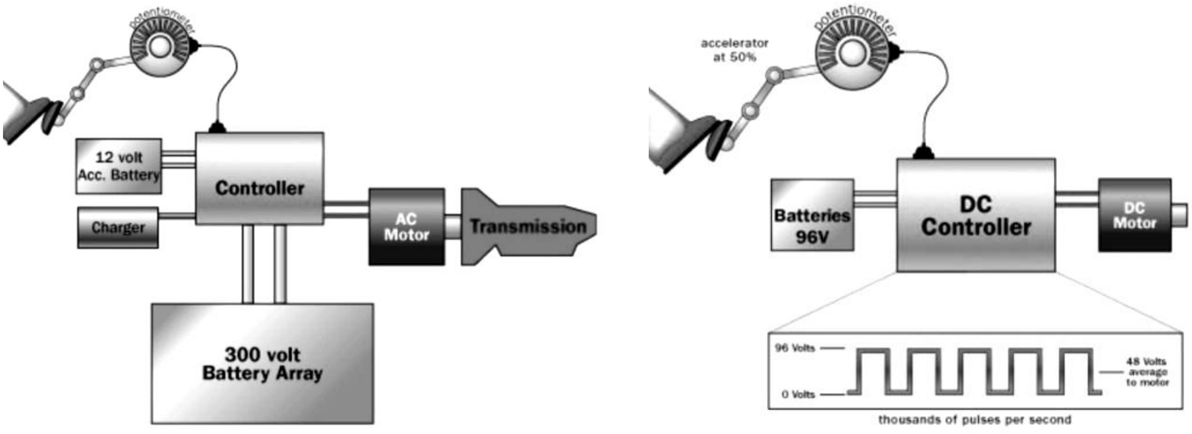
Table 1. Assessment of electric vehicles in terms of sustainable mobility proposals. Source: own study based on (Buczaj 2006; Rogall 2010; Szmidt 2011; Maj 2011).

Type of drive	Benefits	Drawbacks
Gas-powered drive	• may be applied as an alternative fuel in standard petrol-fuelled motors • lower emission of greenhouse gases compared to traditional drives • less noise compared to traditional drives	• more fuel consumption compared to traditional drives • limited possibilities of filling up the tank and lesser sufficiency • low boiling point, which leads to problems in winter when the motor is cold • LPG does not mix well with air • LPG is heavier than air, therefore in case of leaks it may gather under the vehicle
Biofuels	• gaining independence from petroleum	• unfavourable energy balance compared to petrol (ethanol provides 2/3 of the energy petrol would produce) • very disadvantageous impacts in ecological terms (degradation of the environment connected with the increasing areas used for crops growing, substantial use of environmentally harmful fertilisers, irrational utilisation of plant produce) • negative effects for the public – increased food prices caused by limiting the areas used for growing food crops
Hybrid drive	• serious decrease in fuel consumption per distance unit • significant limitation of emissions of harmful pollutants found in fuel • decreasing the noise level	• considerable weight and dimensions of the vehicle, due to the sophisticated structure as well as the battery weight • high price due to the design
Hydrogen drive	• total elimination of harmful emissions, the only product is water • practically unlimited natural resources of hydrogen	• problems with maintaining hydrogen in liquid form in a tank • safety considerations – leaking hydrogen makes an explosive mixture with air, showing a relatively low ignition point • total lack of hydrogen supply infrastructure (exception: USA and Japan – Tokyo)
Electric drive	• elimination of heavy elements such as gearbox and clutch (constant torque available at any range of engine rotations) • very low CO_2 emissions (the motor itself produces no emission, however, the electric power to charge the battery comes from power plants that do produce emissions • very low noise level • extremely easy to operate • may be charged from a standard electrical outlet	• very unfavourable ratio of battery charging time to the distance covered before recharging • considerable battery weight • price (particularly in the case of batteries with better charging parameters – requiring less time to charge)

3. Details of electric drive

Over the recent years, electric and hybrid vehicles have become particularly popular. In the case of electric vehicles, the energy necessary for their operation usually comes from the mains or is produced by the vehicle engine and stored in its batteries (Rogall 2010). They can be powered by the following (www.pg.gda.pl/~jarguz/e-pojazdy.htm):

- 3 phase AC motors (Figure 2a):
  - asynchronous squirrel-cage motors,
  - asynchronous with trapezoidal electromotive force (Brushless DC Motor – BLDC),
  - asynchronous with sinusoidal electromotive force (Permanent Magnet Synchronous Motor – PMSM),
  - synchronous switched reluctance motors;
- direct current (Figure 2b):
  - electromagnetic induction commutator motors,
  - permanent-magnet commutator motors..



a) b)

Figure 2. Electric motor diagram: a) AC motor, b) DC motor. Source: auto.howstuffworks.com/electric-car2.htm.

In terms of sources of energy, electric vehicles may be divided into the following categories (www.greenweal.eu):

- battery-powered, where batteries may be charged with power from outside or may store power from different sources, applying:
  - lead-acid batteries (historically the oldest ones, invented back in 1858), consisting of several series-connected lead-acid cells; generating electromotive power (EMP) at the level of 2.1 V (the whole battery generates EMP being the sum of individual cell EMPs); since the battery internal resistance is small, large currents flow is possible (for this reason lead-acid batteries are applied for IC engine starting in cars); the major drawbacks of this solution include a relatively high weight and the risk of electrolyte leaking;
  - nickel hydride batteries, which are characterised by a lower efficiency (ca. 65% compared to the traditional lead-acid ones), however, they are much lighter and offer a much longer service life (properly used nickel hydride batteries may serve for exceptionally long periods – e.g. the batteries used in hybrid cars last for ca. 10 years over a distance of 160,000 kilometres); however, their capacity falls down considerably in low temperatures, thus their efficiency is relatively low, additionally they show a high level of self-discharge; they require a special charging cycle;
  - Zebra batteries are based on melted aluminium chloride and sodium chloride as electrolytes ($NaAlCl_4$); the technology is sometimes referred to as “hot salt technology” due to the need to heat the battery up before use; they are characterised by considerable durability (up to several thousand charging cycles); the drawback of this solution is the need to heat up the battery before use and to keep it in a specified temperature (ca. 270° C), which is connected with additional costs; another drawback is the low power density (at the level of 120 Wh/kg);
  - lithium ion or lithium polymer batteries – they have very advantageous efficiency parameters, however, their production involves very harmful components and they are relatively expensive; the traditional lithium ion battery is based on two electrodes: one made from porous carbon and the other from metal (cobalt, lithium) oxides; they produce 3.6 V per single cell; the technology makes it possible to accumulate twice as much energy compared to nickel hydride batteries; they show no memory effect or “lazy battery effect”; a drawback of this battery type is a short life cycle (from several hundred to several thousand charging cycles) and impairment of its parameters over time; in most modern electric cars different variations of this battery are applied, based on, inter alia, phosphates, titanium, spinel (magnesium aluminium mineral), which helps increase their efficiency and life span,
- powered directly from the mains by means of current collectors (pantographs), e.g. trams and trolleybuses,
- powered with solar energy via photovoltaic cells (the latest developments include 3D photovoltaic cells),

- applying flywheels, e.g. girobus,
- driven by electric power generated directly by the IC engine,
- using the energy from regenerative braking or shock absorbers, and
- using the energy generated by fuel cells (e.g. hydrogen cell).

A significant limitation in using solutions of this kind is the still insufficient performance of the vehicles as well as the lack of appropriate infrastructure for battery recharging. In this respect, hybrid vehicles are more useful, since they combine IC and electric drives. This enables the users to use both alternatives depending on the needs and possibilities. The usually distinguished types include (Rogall 2010):

- microhybrids and mild hybrids (conventional hybrid vehicles) where electric power is produced by IC engines and stored in a battery, which makes it possible to cover short distances using only the electric drive, and due to the smooth engine running and regenerative braking the fuel consumption may be decreased by 5-25%;
- plug-in hybrids (full or strong hybrids) are the ones where the electric power is not produced by the engine, but it is charged from the ordinary mains and stored in highly efficient batteries;
- solar vehicles, showing a considerable compatibility with the principles of sustainable mobility, have a relatively small weight, while the propulsive power is supplied by solar cells being part of the vehicle structure.

4. The comparative analysis of selected electric freight vehicles (EFV)

Usefulness of electric vehicles in urban freight transport is demonstrated first and foremost by their appropriate technical parameters, regarding not only delivery making in cities (such as e.g. appropriate carrying capacity), but also ensuring adequate operating time (the travel range before recharging, and the battery charging time). Many among the various solutions appearing on the market already have the parameters that make them ready to be practically applied.

The following analysis encompasses 29 electric vehicles that may be put to use in delivery making in city areas (Table 2). The solutions include proposals made by manufacturers dealing with production of traditionally powered vehicles, as well as vehicles produced by companies specialising exclusively in electric vehicle manufacturing. Some of them are already available on the market, whereas the others are still in the testing phase. Among the analysed electric vehicles, the ones that may be used for the purposes of urban deliveries include (www.samochodyelektryczne.org):

- MegaVan (www.megavan.org) – a vehicle produced by the British company Mega which has long been operating on the automotive market; a fully charged battery makes it possible for the vehicle to drive up to 150 km at the maximum velocity of ca. 60 km/h; its carrying capacity of up to 600 kg makes it possible to use it for the purposes of last mile deliveries and supplying small shops or the HoReCa (Hotel, Restaurant, Catering) sector; it may be additionally equipped with a tipper, a net for picking up litter and emptying municipal dustbins; it is an environmentally friendly vehicle, cheap, inexpensive to maintain; used mainly in Great Britain and also in France, Belgium, Holland, and Germany.
- Nissan e-NT400 Concept (newsroom.nissan-europe.com) – it is a conceptual vehicle manufactured by the company ATLAS Concept, based on the IC version of Nissan Cabstar; it applies the Nissan Leaf drive and lithium-ion batteries ensuring a travel range of up to 140 km and the maximum velocity of 90 km/h; the vehicle carrying capacity amounts to 600 kg.
- e-Wolf Omega 0.7 (www.ewolf-car.com) – this vehicle is manufactured by the German company e-Wolf which specialises in production of electric vehicles intended for different purposes; apart from the Omega 0.7 the company also offers passenger cars (as well as racing cars); the Omega 0.7 has the max. carrying capacity of 620 kg; the motor is powered with unique ceramic lithium batteries that ensure the highest safety standards and can be charged from the standard home electric mains; the vehicle travel range before recharging is over 150 km, while the maximum velocity is up to 110 km/h (in the economic mode – 90 km/h).
- Renault Kangoo Express Z.E. (www.renault.pl/samochody-nowe/samochody-elektryczne/kangoo-ze/kangoo-ze-2013/prezentacja-ogolna) – this electric freight vehicle is manufactured by Renault; this model has been available

on the automotive market since 2011 and it is the only vehicle of this type sold directly on the Polish market; it guarantees quiet engine operation, there is no need to change gear, it offers low operation costs and zero pollutants emissions; since the batteries are placed centrally under the floor, its loading capacity is comparable to the IC engine version (ca. 650 kg); access to the cargo compartment is made easy thanks to the double-leaf, asymmetric back door and the sliding side door; batteries are charged via a socket located under a flap in the front of the vehicle, next to the right-hand headlight; the travel range before recharging is up to 160 km, at the maximum speed of 130 km/h.

- Peugeot Partner Electric Van (www.peugeot.co.uk/news/new-peugeot-partner-electric-van) – in 2012 Peugeot presented its Partner Electric Van – an EV model which entered the serial production in the first half of 2013; electric freight vehicles of this make are practically no different from their IC counterparts, offering the identical total carrying capacity of 690 kg; the electric motor is located under the bonnet, it is a result of cooperation with Mitsubishi; placing the lithium ion battery under the floor made it possible to avoid the need to decrease the cargo space; the velocity reached by the vehicle does not exceed 130 km/h, while the travel range before recharging is up to 170 km.
- Ford Transit Connect Electric (www.trans-west.com/ford-transit-connect-EV.htm) – this vehicle is manufactured by Ford Motor Company; it is perfectly suited for applications requiring frequent stopping, which is a specific feature of deliveries made in city areas; the total carrying capacity does not exceed 700 kg; the motor is powered with state-of-the-art lithium ion batteries that may be charged using the standard home electric mains, the travel range before recharging is up to 129 km, at the maximum speed of ca. 121 km/h.
- Mitsubishi i-MiEV Cargo (www.mitsubishi-cars.co.uk/innovation/imiev-cargo.aspx) – the Japanese company Mitsubishi presented the vehicle for the first time at Tokyo Motor Show 2009; it was designed on the basis of the passenger version of i-MiEV; the travel range before recharging is up to 160 km, at the maximum speed of 140 km/h; the vehicle carrying capacity is up to 700 kg.
- Streetscooter Work (www.spijkstaal.com) – it’s an electric freight vehicle manufactured by the Dutch company Spijkstaal Elektro B.V.; it is equipped with lithium ion batteries; it enables covering not very long distances (depending on the version, its battery set makes it possible to drive a distance of up to 80 km) at the maximum speed of 85 km/h; it is currently used by, inter alia, Deutsche Post, DHL; its carrying capacity is ca. 700 kg.
- Piaggio Porter electric-power (www.piaggioporter.co.uk/electric.htm; www.piaggio.wanicki.pl/ content.php?body=article&name=piaggio-porter-electric-power&lang=pl) – it is a very quiet (in its case the noise emission in dBA is close to zero, for the sake of comparison, the mean calculated for similar vehicles powered with diesel engines is 74 dBA) electrically powered freight vehicle which is very popular in Europe; it is used by municipal services (e.g. city cleaning services, greenery maintenance services) as well as the police, fire service, medical service, municipal police; it is also applied by private companies providing short-distance, courier or postal delivery services, including parcel deliveries; the vehicle carrying capacity is up to 750 kg, the maximum velocity is 57 km/h, while the travel range before recharging is up to 110 km; the batteries applied in the vehicle enable accelerated charging which takes up only 2 hours.
- Opel Vivaro e-concept (www.motonews.pl/opel/news-7359-debiut-opla-vivaro-econcept.html) – a conceptual electric freight vehicle produced by Opel; the maximum travel range before recharging reaches 100 km, the carrying capacity is 750 kg; the maximum speed the vehicle can reach is ca. 110 km/h.
- Volkswagen e-Co-Motion (www.caranddriver.com/news/volkswagen-e-co-motion-concept-photos-and-info-news) – it is an urban delivery van developed by Volkswagen; the model may be equipped with one of three types of batteries, depending on the users’ needs: the 20 kWh basic module makes it possible to travel a daily distance of up to 100 km, the 30 kWh batteries enable travelling for ca. 150 km a day, while the highest capacity module provides a travel range of ca. 200 km; the vehicle carrying capacity is 800 kg, while its maximum velocity is 120 km/h.
- Electric delivery van 1000 (www.spijkstaal.com) – this is another vehicle made by the company Spijkstaal Elektro B.V.; it is produced in two versions: the shorter one, ensuring the maximum carrying capacity of 830 kg and the longer one, which makes it possible to carry up to 965 kg of cargo; the travel range before recharging is 118 km, and the maximum speed only 40 km/h, which makes it a solution suitable mainly for making deliveries in the core city centre.

- Mercedes Vito E-CELL (www.mercedes-benz.pl/content/poland/mpc/mpc_poland_website/pl/ home_mpc/van/home/vans_world/blueefficiency/technologies/e-cell.0002.html) – Mercedes-Benz has added Vito E-CELL to its assortment, the model is intended for businesses where freight vans are used mainly in cities, covering short distances (e.g. fleet managers, public institutions, delivery companies, courier and express mail services); the maximum speed of the vehicle does not exceed 80 km/h, the carrying capacity is 850 kg, the travel range before recharging is up to 130 km.
- Mitsubishi MINICAB-MiEV (www.mitsubishi-motors.com/en/products/minicab-miev) – Mitsubishi Motors Corporation started production of their electric freight vehicles in 2011; the model Mitsubishi MINICAB-MiEVc is a minicar-class commercial electric vehicle, has been developed using the technologies, experience and know-how which made it possible to produce an ecological, highly economical vehicle with carrying capacity up to 900 kg, characterised by high performance and reliability; its travel range before recharging is up to 150 km, at the maximum speed of ca. 80 km/h.
- Toyota EV Truck (www2.toyota.co.jp/en/news/13/03/0301_2.html) – the electric truck is a result of cooperation between Toyota Motor Corporation and Hino Motors; it has a carrying capacity of up to 1000 kg; as the small-size traction drive is located in the front, and the lithium ion battery set is placed under the cargo space, the cargo compartment is more than 40 cm lower than in the IC counterpart, which makes reloading significantly easier; the maximum velocity of the vehicle is 60 km/h; the carrying capacity is up to 1000 kg.
- Boulder DV-500 (boulderev.com/models_500.php) – this is the first electric truck put on the market by the company Boulder Electric Vehicle; it comes with different body types, its carrying capacity amounts to more than 1400 kg, and since its travel range is 160 km and the maximum speed exceeds 120 km/h, the vehicle draws a lot of attention.
- Renault Maxity (www.pvi.fr) – this is another proposal from Renault, prepared in cooperation with the company PVI; the lithium ion batteries provide travel range up to ca. 100 km, the electronically restricted maximum velocity is 70 km/h; and the maximum carrying capacity is nearly 1900 kg.
- Navistar eStar (www.samochodyelektryczne.org/navistar_estar.htm) – this is an electric truck manufactured by the companies Modec and Navistar International Corporation for the US market (it is used mainly by FedEx courier company), and also in Great Britain and France; the vehicle is equipped with Zytek's E-Drive; its carrying capacity is ca. 2000 kg, its travel range before recharging is 160 km, while its maximum velocity is up to 80 km/h;
- Modec (www.samochodyelektryczne.org/modec.htm) – it’s a compact van developed for the needs of Tesco the British supermarket chain; it is also used in Holland; the vehicle applies lithium batteries and it is available in many configurations (inter alia a truck, a pick-up truck, cooling truck); the maximum carrying capacity is 2000 kg; the travel range is ca. 160 km, at the speed up to 80 km/h;
- MT-EV WIV (freightlinerchassis.com) – this van is popular in the USA (it is used by, inter alia, General Services Administration – the unit responsible for supplying the administrative and military organisations), developed by Freightliner Custom Chassis Corporation and Morgan Olson; equipped with a set of Tesla Motors batteries, which ensure a travel range of up to 160 km, at the maximum velocity exceeding 100 km/h; the carrying capacity is ca. 2000 kg.
- EVI Walk-In Van (www.evi-usa.com) – this vehicle was developed by Electric Vehicles International (EVI) in cooperation with Freightliner Custom Chassis Corporation; it is equipped with Valence Technology lithium ion batteries which ensure a travel range of nearly 190 km, at the maximum speed of 100 km/h; its carrying capacity is 2000 kg.
- EVS Edison (www.smithelectric.com) – this electric vehicle is manufactured by Smith Electric Vehicles US Corporation; its carrying capacity is up to 2300 kg, its maximum velocity is 80 km/h, and fully charged batteries enable a travel range of 160 km.
- Boulder Delivery Truck 1000 (boulderev.com/models_1000.php) – this electric truck model was designed by the American company Boulder Electric Vehicle; it is equipped with a set of lithium ion batteries providing a travel range of 160 km and a longevity of ca. 500 000 km; the vehicle maximum speed is 120 km/h; with the carrying capacity of up to 2700 kg.

- ZeroTruck (zerotruck.com) – this electric truck is based on Isuzu N-Series, and was designed by the American company Electrorides; the vehicle uses Dow Kokam lithium ion batteries; its maximum speed is up to 90 km/h, the travel range – up to 160 km before recharging; the carrying capacity is 2800 kg.
- EVI Medium Duty (www.evi-usa.com) – this is an electric truck manufactured by the American company Electric Vehicles International (EVI), depending on the capacity of applied batteries it provides a travel range from 100 to 180 km; in the latest version, the Valence Technology 99 kWh lithium ion batteries allow covering a distance of up to 145 km, at the maximum speed of 96 km/h; the carrying capacity is 3000 kg.
- Renault Midlum EV (corporate.renault-trucks.com) – this is an electric truck prototype developed by Renault in cooperation with the companies PVI and IFP Energies; it was tested in two versions: with a carrying capacity of up to 3000 kg (in this case the travel range was up to 140 km) and up to 5500 kg (which meant a smaller travel range – up to 100 km); the applied lithium ion batteries ensure the maximum speed of 90 km/h.
- Mule M100 (www.balqon.com) – that's the name of an electric truck manufactured by Balqon; the applied lithium ion batteries set enables covering a distance of up to 160 km (without cargo the distance increases even up to 240 km), at the maximum speed of 110 km/h; this truck borrows many components and solutions previously applied in the Nautilus E-30 truck tractor.
- EVS Newton (www.smithelectric.com) – another vehicle manufactured by Smith Electric Vehicles US Corporation; in March 2009 the company was the first to present an electric truck featuring the highest carrying capacity in the world at that time, amounting to over 7000 kg; the serial production was commenced in 2010 in Kansas City, Missouri; the maximum velocity is 100 km/h, the travel range before recharging is 128 km.
- E-FORCE (eforce.ch) – this electric truck is one of the largest electric freight vehicles (its gross vehicle weight is 18 tonnes); it was designed on the basis of Iveco Stralis by the Swiss company FORCE ONE in cooperation with the companies Designwerk and Brusa Elektronik; the two-part set of lithium ion batteries enables a travel range before recharging of up to 300 km, at the maximum speed of 87 km/h; the carrying capacity of the vehicle is 10000 kg.

Table 2. The comparative analysis of selected parameters of the analysed electric freight vehicles. Source: own study.

Name	Manufacturer	Carrying capacity [kg]	Max. velocity [km/h]	Travel range [km]	Battery charging time [h]	Price [PLN]
MegaVan	Mega	600	60	150	6	55,000
Nissan e-NT400 Concept	ATLAS Concept	600	90	140	9	No data
e-Wolf Omega 0.7	e-Wolf	620	110	150	8	260,000
Renault Kangoo Express Z.E.	Renault	650	130	160	7	98,000
Peugeot Partner Electric Van	Peugeot	690	130	170	9	76,500
Ford Transit Connect Electric	Ford	700	121	129	6	62,750
Mitsubishi i-MiEV Cargo	Mitsubishi	700	140	160	7	No data
Streetscooter Work	Spijkstaal Elektro B.V.	700	85	80	5	70,000
Piaggio Porter electric-power	Piaggio Porter	750	57	110	8	95,750
Opel Vivaro e-concept	Opel	750	110	100	8	No data
Volkswagen e-Co-Motion	Volkswagen	800	120	200	7	No data
Electric delivery van 1000	Spijkstaal Elektro B.V.	830/965*	40	118	No data	No data
Mercedes Vito E-CELL	Mercedes	850	80	130	5	No data
Mitsubishi MINICAB-MiEVc	Mitsubishi	900	80	150	6.5	96,640
Toyota EV Truck	Toyota Motor Corporation/ Hino Motors	1000	60	No data	8	No data
Boulder DV-500	Boulder Electric Vehicle	1400	120	160	8	No data

Renault Maxity	Renault/ PVI	1895	70	100	8	No data
Navistar eStar	Modec/ Navistar International Corporation	2000	80	160	8	153,000
Modec	Modec	2000	80	160	8	126,250
MT-EV WIV	Freightliner Custom Chassis Corporation/ Morgan Olson	2000	104	160	7	No data
EVI Walk-In Van	Freightliner Custom Chassis Corporation/ Electric Vehicles International	2000	100	184	6	No data
EVS Edison	Smith Electric Vehicles US Corporation	2300	80	160	7	No data
Boulder Delivery Truck 1000	Boulder Electric Vehicle	2700	120	160	12	302,000
ZeroTruck	Electrorides	2800	90	160	12	No data
EVI Medium Duty	Electric Vehicles International	3000	96	145	12	No data
Renault Midlum EV	Renault/ PVI/ IFP Energies	3000/5500*	90	140/100*	8	No data
Mule M100	Balqon	4000	110	160	10	No data
EVS Newton	Smith Electric Vehicles US Corporation	7400	80	160	7	274,580
E-FORCE	EFORCE ONE AG./ Designwerk/ Brusa Elektronik	10000	87	300	6	No data

In terms of carrying capacity, most of the contemplated vehicles may be useful for deliveries to smaller entities (shops, hotels and restaurants). It must be noted that electric freight vehicles are often used to make deliveries in restricted zones and cover relatively short distances, therefore their operation parameters seem to be sufficient. The mean velocity at the level of 93 km/h absolutely satisfies, and even exceeds, the needs of urban freight transport. However, a major drawback is the battery recharge time which is from 5 up to as many as 12 hours.

Undoubtedly, the greatest obstacle to applying electric vehicles is their relatively high price. They are usually more expensive than their traditionally powered counterparts. On the other hand, though, we can expect that businesses will be able to use different forms of support in purchasing vehicles of this type. This may mean tax relief as well as subsidies from local governments. A good example in this respect is Norway experiencing a substantial increase (the highest in Europe) in the number of electric vehicles.

5. Usefulness of electrically powered vehicles in urban freight transport

Application of electric vehicles in urban freight transport is connected with the basic advantages of using electric drive, which include: (www.nytimes.com):

- possibility to produce energy from any sources,
- lack of gaseous or solid pollutant emissions into the atmosphere,
- lack of noise emissions,
- higher energy efficiency compared to traditional drives,
- cheaper production of drives, their maintenance and operation,
- providing energy independence,
- low operation costs depending on the vehicle velocity and the price of 1kWh (the costs of driving the distance of 100 km is PLN 2-5), and
- the existing electric power distribution network is the best developed part of the infrastructure.

However, it is important to stress some limitations and impediments which must be overcome to increase interest in the offered solutions. They can be broken down into three basic groups:

- economic difficulties, including in particular:
  - costs of purchasing the vehicles themselves,
  - costs of producing the energy for recharging the batteries,
  - costs of batteries utilisation;
- safety concerns, resulting from:
  - the fact that many a time traffic participants fail to hear approaching electric vehicles, which leads to collisions and accidents,
  - risk of battery self-ignition,
- operational barriers, mainly connected with:
  - long time needed for battery recharging,
  - the fact the full potential of electric drives is not fully achieved yet.

Table 3 presents the assessment of electric vehicles in terms of sustainable mobility proposals.

Table 3. Assessment of electric vehicles in terms of sustainable mobility proposals. Source: Rogall 2010.

Proposals	Impact
Environmental aspects	
1. Climate protection	Very large contribution, if the electric power comes from renewable energy sources.
2. Boundaries of nature's tolerance	Moderate contribution, maybe smaller vehicles.
3. Using renewable resources	Counteracts competition for biomass, since it does not use it as fuel.
4. Using non-renewable resources	Considerable contribution because of smaller consumption of raw materials in vehicle production.
5. Health risks	Very large contribution due to negligible emissions of harmful substances and considerable decrease in noise.
Economic aspects	
1. Economic effects	Slightly downward trend, since EVs are usually somewhat smaller, may be compensated by competitive advantages.
2. Meeting the needs	Small change compared to the current situation.
3. Cost-effectiveness, counteracting the concentration	Appropriate prices, still expensive batteries.
4. Dependence on raw materials supplies	Considerable contribution, as import of raw materials is only necessary for production.
5. Technical effectiveness, competition for use	Very large contribution, since the energy and resources productivity (per tkm or pkm) is much higher than in the case of IC vehicles.
Social and cultural aspects	
1. Social tolerance	Acceptability uncertain at the moment, it will probably increase due to the growing fuel prices and discussions on climate concerns.
2. Long-term reliability of supplies	Better perspectives for the future due to gaining independence from resources subject to depletion.
3. Integration with the existing structures	Need for large investments.
4. Preventing conflicts	Very large contribution due to considerable limitation of imports.
5. Safety	Uncertain impact.

Additionally, the impediments limiting the possibilities of applying all types of electric vehicles include (Allen et al. 2007):

- higher operating costs of applying electric vehicles,
- small capacity of batteries,
- no infrastructure (appropriate battery charging stations and charging points), and
- low reliability and a large number of defects during the operation of the vehicles.

It should be noted that EV purchases are currently most often financed with public funds. Private operators will be inclined to replace their fleets if: they notice benefits for their companies, an appropriate number of alternative fuel stations is provided, there are marketing benefits for the company, the given company is in any way connected with environmental protection, appropriate vehicles are available (Allen et al. 2007). Many a time operators are forced to apply solutions of this kind by way of administrative decisions which in specified areas (e.g. historic city centres) prohibit vehicles other than those with alternative drives.

Summing up, the key difficulties in effective use of electric vehicles in urban freight transport are derived from four basic problems:

- high prices of vehicles and batteries,
- long time needed for battery recharging,
- shrinking travel range of the vehicles as the batteries get worn out, and
- scarce infrastructure for battery recharging.

The latter problem becomes particularly important in the context of deliveries in cities.

6. Infrastructure requirements for developing electric freight transport in cities

The fundamental challenge faced by cities in the context of stimulating development of transport based on electric vehicles application is providing appropriate infrastructure for batteries recharging. It is a prerequisite without which even decreasing the vehicle purchase or operation costs will not contribute to an increased interest in EVs.

Four basic strategies of battery recharging may be distinguished, in view of the power supply location:

- charging at the place of residence,
- charging at the place of work,
- charging in urban public spaces, and
- charging on the travel route between cities.

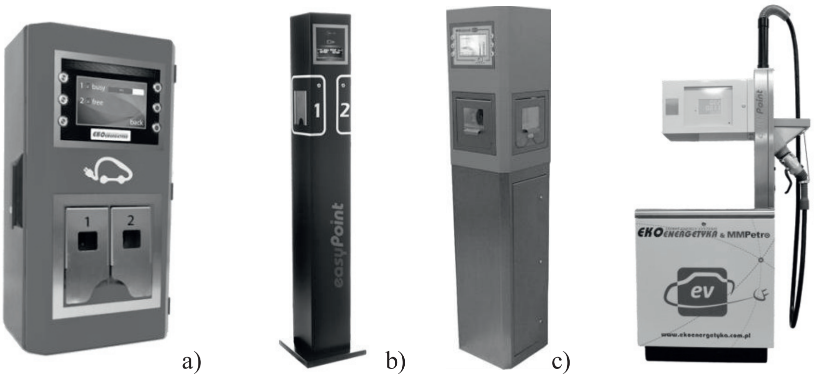
These strategies mainly relate to passenger cars. In the case of urban freight transport, and particularly in the case of deliveries, vehicles are charged mainly in their depot locations (base). However, due to the nature of their tasks, it is important that batteries can be recharged in the course of the work, i.e. in a public space. In this case two solutions may be considered – providing power supply sources by the deliveries recipients or providing a generally accessible urban infrastructure. In this context, the key factor is the battery recharge time, which is related to the technical solutions applied (Table 4).

Table 4. EV charging levels. Source: own study on the basis of Pateh's own materials. Source: www.pateh.com.pl

Charging level	Charging parameters	Charging manner	Charging time, from 0 to 100%
Level 1 – slow charging	standard charging socket: • 120 V, 12 A – 1.4 kW, • 230 V, 16 A – 3.7 kW,	power is supplied directly from the mains to the vehicle's on-board charger	ca. 16 hours
Level 2 – accelerated charging	available in adapted terminals for EV charging: • 3x230/400 V, 32 A – 22 kW, • 3x230/400 V, 63 A – 43 kW;	power is supplied from the charging terminal to the vehicle's on-board charger	ca. 3-8 hours
Level 3 – rapid charging – direct charging with direct current	available in rapid charging terminals supplied from 400 V AC LV mains: • output voltage 50-600 VDC, max. 250 A, • output power 50 kW;	power is supplied directly to the DC busbar of the battery	ca 20-30 minutes

In view of the effectiveness of urban deliveries, application of the accelerated (level 2) and rapid (level 3) charging seems to be the most advantageous.

Level 2 charging is a solution that is becoming more and more popular mainly due to the affordable price of the devices, besides, they can be easily incorporated in the existing urban space. The chargers applied at this level may be used both directly at the place being the vehicle's base (garage) as well as in a public space. In the first of the aforementioned examples, the devices may be installed e.g. in garages, such as garagePoint produced by Ekoenergetyka Zachód S.C. (www.ekoenergetyka.com.pl) – Figure 3a. This is a modular terminal to be wall-mounted. It makes it possible to install CEE7 and IEC 62196 outlets, which affects the charging speed (slow charging or accelerated charging). The voltage in the sockets is turned on following a successful authorisation by means of a RFID card, connecting to the outlet, then closing and locking the socket flap (due to that the device is provided with a safety feature for the connection and the socket during charging). The terminal is intended for household use and it may also be applied in public spaces in underground car parks.



a) b) c) d)

Figure 3. EV chargers manufactured by Ekoenergetyka Zachód S.C.: a) garagePoint, b) easyPoint; c) smartPoint; d) quickPoint. Source: www.ekoenergetyka.com.pl

In a public spaces, a much better charger will be the one with a housing mounted directly in the ground. Examples of such chargers include easyPoint (Figure 3b) and smartPoint (Figure 3c). The former offers only two CEE7 sockets, thus providing for merely the first charging level. The latter additionally provides the possibility of accelerated charging, therefore its usefulness in public spaces is definitely higher.

Rapid charging (level 3) requires special devices whose main drawback is a relatively high price. Currently, the main functioning rapid charging standard in the world in CHAdeMO, developed in Japan by the consortium involving Tokyo Electric Power Company, Nissan, Mitsubishi, Fuji Heavy Industries and Toyota (www.samochodyelektryczne.org). In Japan, chargers based on this standard, manufactured by Nissan, cost nearly JPY 800,000. An example of a terminal produced in that standard in Europe is quickPoint (www.ekoenergetyka.com.pl) – Figure 3d. It makes it possible to charge the battery up to 80% of its capacity within 20 minutes. Due to their structural design and considerable installation costs, terminals of this kind can be mounted mainly in petrol stations.

7. Conclusion

The authorities in Amsterdam stipulate that 20% of IC cars will have been replaced by EVs by 2020. By 2050, in turn, pollutants emissions resulting from using internal combustion engines will have been totally eliminated in Amsterdam (www.amsterdam.nl). It is estimated that in 2020 the share of electric and hybrid vehicles in total sales of all cars will be from 11 to 52% (polskawue.gov.pl).

An increase in the number of electric vehicles on the roads means a need to develop the infrastructure necessary for recharging their batteries. It is estimated that by 2017 there will be over 2 million charging points in Europe, of which 3% will be the rapid, inductive DC-DC solutions (Strategic… 2011). The value of investments connected with completing the infrastructure necessary for EV charging in Europe will probably amount to EUR 5 billion within the next 7 years. The ratio of cars to charging stations in Europe is now 2.5, however, by 2017 it will drop to 1.8 (Strategic… 2011).

According to the aforementioned analysis, a fully charged battery makes it possible for an EV to cover an average distance of ca. 145 km. Battery charging time ranges from 5 to 12 hours, but putting rapid chargers on the market will make it possible to shorten the time to 15-20 minutes (www.motofakty.pl), which is particularly important in the context of transport tasks in urban freight transport. Additionally, providing charging stations that are easy to use will make it possible for users to charge batteries during each stop (e.g. in the course of delivery). This will lead to limiting the need for additional stops in the course of the journey, which is the case with traditional filling up.

The aforementioned factors will make EVs more attractive for the purposes of deliveries in cities. The vehicles' operation parameters already make it possible to use them effectively. However, for the urban freight transport to function properly it is necessary to provide integrated networks of charging terminals in cities, so that any places with limited access to power supply sources are eliminated. The report by Frost & Sullivan entitled "Strategic Technology and Market Analysis of Electric Vehicle Charging Infrastructure in Europe" says that there has recently been a significant progress in that regard, and in accordance with the forecasts the number of public chargers provided on the initiative of the governments will exceed 2 million by 2017, while seven West European countries will spend EUR 700 million over the next 7 years (Strategic… 2011). The aforementioned report additionally emphasises the possibilities of developing inductive systems of vehicle battery charging, which may play a key role for freight transport, providing possibilities of rapid charging during short stops connected with deliveries.

Therefore, it seems that as a result of the requirements of the European Union regarding sustainable transport development and the world-wide trends connected with popularity of alternative sources of energy, in the near future the dynamics of urban freight transport development based on using alternatively powered vehicles, in particular using electric motors, will grow and playing a more and more important role.

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