Journal of
MECHANICAL and ENERGY
ENGINEERING

ISSN: 2544-0780 | e-ISSN: 2544-1671
Vol. 2(42) | No. 1 | April 2018 | pp. 59-66
DOI: 10.30464/jmee.2018.2.1.59

ELECTRIC VEHICLES: PROBLEMS OR SOLUTIONS

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(Received 8 March 2018, Accepted 30 March 2018)

Abstract: This paper discusses the current directions of vehicle developments, as well as the barriers and opportunities for using electric vehicles instead of conventional vehicles. There is also mentioned a problem of the battery charging system. Compared to refueling gasoline powered vehicles, charging of battery electric vehicles takes considerably more time, which renders a single-purpose charging infrastructure inconvenient. However, an objective of this article is also to investigate the future market prospects of various types of EVs, with the economics of EVs in comparison to conventional cars. Only if the final driving costs can be considerably reduced will EVs gain significant market shares.

Keywords: urban transport system, electric vehicles, costs, effectiveness

1. INTRODUCTION

Currently, transport has a significant impact on economic growth for every countries. Effective and ecological vehicles can help to achieve lower prices for goods production and distribution [16, 19]. It allows one to get new procurement markets where the goods become available to the most of societies. These relations between goods production, distribution, as well their usage, are connected with a fuel consumption by vehicles [17]. Vehicles are very important for the most of people by their society status, independence and for their activity.

Most of these vehicles are equipped with an internal combustion engine (*ICE*) like a spark ignition (*SI*) or compress ignition (*CI*) engine. The engines of these vehicles are fueled by hydrocarbons fuels. The mechanical energy needed for vehicle's movement comes from fuel combustion. It causes air pollution due to exhaust gases emissions which contains carbon dioxides, carbon monoxides, hydrocarbons, sulfur dioxides, nitro oxides and particulate matters. Today, political decisions (mainly *EU* and *EPA*) point to an increase in restriction, from an ecological point of view, turn to combustion engines, where many automotive factories have some problems to fulfill these requirements. The right way to make transportation effective, ecologic and economic, is purposing fully electric or plug-in hybrid vehicles. These vehicles extremely decrease air pollution and noise emission.

2. PERFORMANCE OF POWERTRAIN SYSTEMS

Vehicle's performance results from their construction, technology of production and materials used. This is mainly connected with the mains the of designing targets – low mass, low production price and high incomes for the manufacturers. These strongly different criteria help to achieve more efficient vehicles – but the results are not so clear.

In the most of cases, vehicle performance is connected with such usable parameters as: torque (M_o) and effective power (N_e) and brake specific fuel consumption (*BSFC*).

These parameters are often presented as a speed characteristic for the engine full load (*TWO* – throttle wide open).

The example of engine speed characteristics was presented in Fig. 1.

The torque as an engine usable parameter is needed to achieve the vehicle's maximum acceleration. It covers all road situations connected with the vehicle's movement stages like; start, constant speed, acceleration and the vehicle's ability to pass a hill (with or without the trailer).

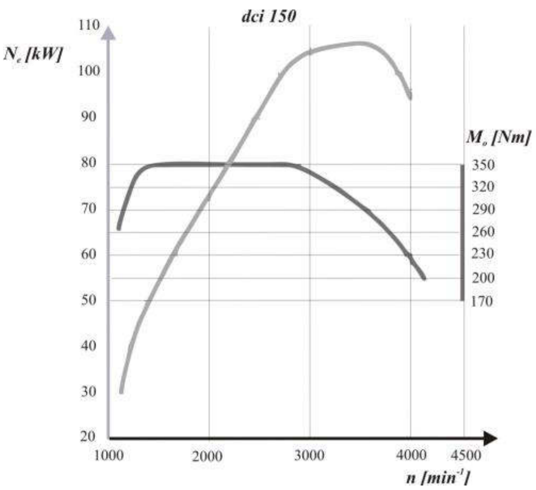

Fig. 1. The speed characteristic of *M9R DI CI* engine manufactured by *Renault-Nissan*: full load, n – engine's crankshaft velocity N_{emax} 110 kW/3700 min^{-1}, M_{omax} 350 Nm / 1400-2800 min^{-1}

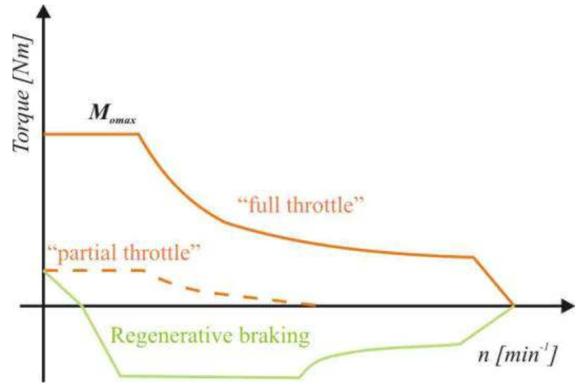

Fig. 2. Theoretical curve of torque for an electrical engine with regenerative braking mode [13]

An effective power is needed to achieve the vehicle's maximum velocity and for balancing for movement resistance (N_r). For normal road-load vehicle's movement condition, it can described by Equation (1):

$$N_r = (f_t Q + 0{,}5 \rho_a c_x A v^2) v. \qquad (1)$$

Both of the aforementioned parameters (power and torque) for *ICE* are resulting from the pressure of exhaust gases due to the fuel combustion. On the basis of this, the production of power by *ICE* is connected with air pollutants. Additionally, the environmental impact of *ICE* is connected with noise emission, too.

Each *ICE* can be characterized by comparable parameters like: specific emissions, volumetric power rate, brake specific fuel consumption, overall engine effectiveness, etc. Currently, a modern combustion engine should be characterized by high overall effectiveness (more than 0.40), high effective power rate (e.g., per engine mass, per cylinder) and ultra-low specific emission [20]. The *ICE* today is not taken into account for the future as the main vehicle's power source, especially for urban areas.

As it was shown in Fig. 1, the engine torque for *ICE* does not start from 0 engine speed. It means that we need the clutch, gearbox and final drive to transfer of the torque and rotary speed to the wheel. Quite a different situation is in the case of the electric engine. For this type of machines, the torque is available with the minimum rotary speed. The example of torque characteristic of electrical engine was presented in Figure 2.

On the basis of Figure 2, we can state that electrical engine has much better torque characteristic than *ICE*. It resulted from the availability of the maximum torque even for zero rotary speed. Moreover, an electrical engine can be used for an energy production during the braking phase [6], when normally (with *ICE* engine) a kinetic energy is lost.

Today, two kinds of barriers can be observed which influence the driver's decision as to what kind of vehicle they should to buy [15]. The first of these is the vehicle range. For the most of passenger *BEV*s (battery electric vehicles), its range starts from 100 km up to 400 km for one charging (Fig.3). The second barrier is connected with the *BEV*'s price. For the most of cases, the price of *BEV* is almost two times higher than that of the conventional vehicle.

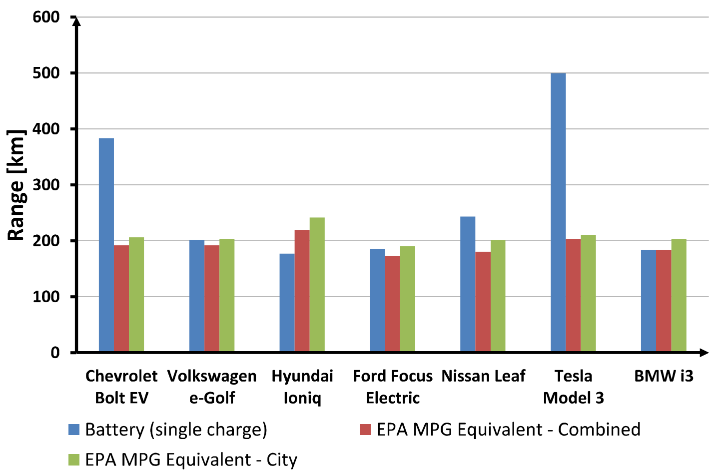

Fig. 3. Range of electric vehicles – data dedicated to the vehicle's model 2018

Next to the *BEV*s today we can meet hybrid electric vehicles (*HEV*s). These vehicles are a combination one of the *ICE* engine (most often *SI*) and electric engine [8]. The powertrain of these vehicles can work with a few different regimes; as fully electric, partially electric and conventional drive mode. Besides of these, *HEV*s can operate in a regenerative braking mode. *HEVs* can usually be categorized on the basis of the type of powertrain as series, parallel, and combined.

The next generation of *HEV*s are vehicles able to charge the battery from the outside charging system. These vehicles were assessed as *Plug-in HEV*s (*PHEV*). The standard range of fully electric mode is between 30 to 60 km.

Some manufacturers (e.g. *Opel, Chevrolet*) have elaborated a range extended electric vehicle (*REX*s). These vehicle normally are operated on fully electric mode but they are equipped with *ICE* for charging the battery and to extend the range.

The last type of the electric vehicle are fuel cell vehicles (*FCV*). These vehicles are operated like standard *BEV*s but electric energy is produced on board by the vehicle's power system from hydrogen. This type of energy production allows one to achieve a higher vehicle's range (Fig.4) taking to account only full electric mode.

Electric vehicles (*EV*) should fulfil all the demands of the urban and suburban traffic. Today *EV*s can be: small passenger cars or the second family car, the family car or the intermediate car segment, the high class segment, commercial delivery vans, trucks, minibuses and urban buses; but also electric bicycles and scooters. It covers most of transport activities (goods and passengers).

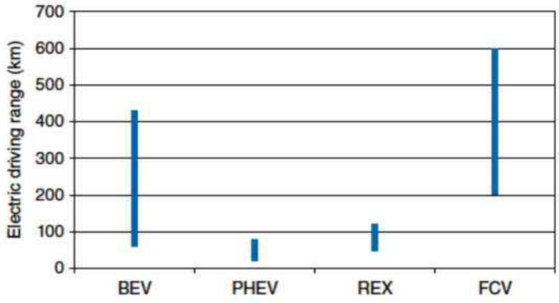

Fig. 4. Electric mode range of various types of electric vehicles [1]

Currently, transport policy expects that in the close future, the number of *ICE* vehicles will be extremely minimalized. It can be shown by the limitation fuel consumption by greenhouse gas (*GHG*) emissions. The example of this limitation for commercial vehicles was presented in Figure 5. These values is assessed on the basis of medium road emissions for all vehicle types produced by manufacturers. For passenger cars, the target of *GHG* emission limitation is about two times lower (*2020 95g CO_2/km*, *2025 80 g CO_2/km*).

The directions of political and environmental decisions presented in Figure 5 let us state that electrification of vehicles will be resulted from a decrease in prime energy consumption. Instead of conventional fuels, there can be used fuels from the recovery energy sources, where mainly electric energy looks to be the solution [12]. However, we can use gas fuels as a waste product but most of petrochemical installations use a different kind of primary food for its technical processes. So there is a social problem connected with the strategy fuel-or-food production.

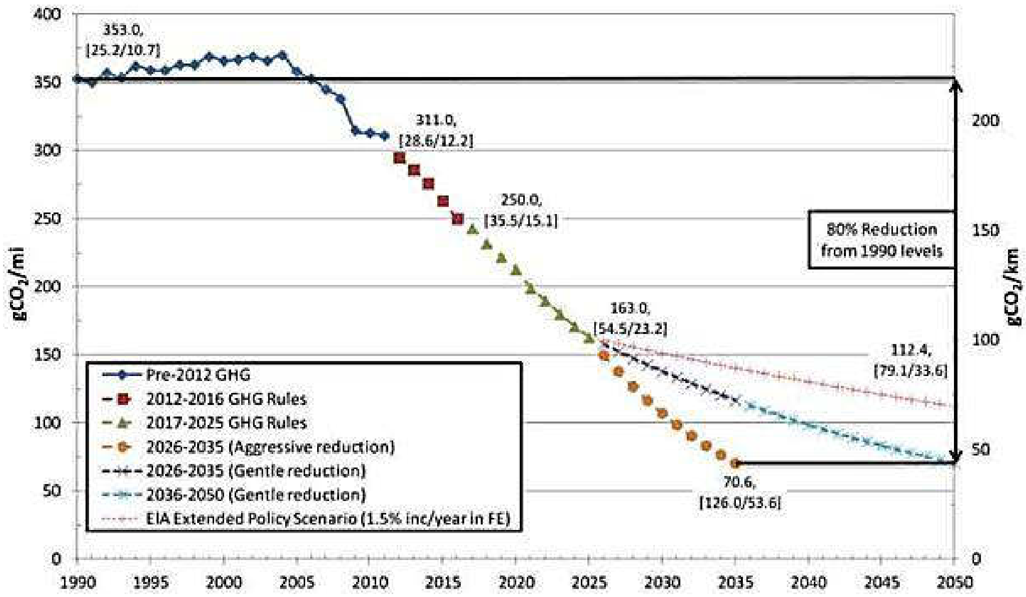

Fig. 5. Past and future greenhouse gas (GHG) standards and projections for the car and truck combined new light-duty vehicle fleet. The Energy Information Administration (EIA) reduction scenario is based on the extended policy scenario in the 2012 Annual Energy Outlook and is extrapolated out to 2050 past 2035, which is the final year of EIA forecasting [14]

The situation of vehicle electrification needs to rebuild the energetic system of all countries [3]. This is a one of the critical problem which is the result of the need to charge the battery system in *BEV* and probably it should be quite a new power system (different electrical parameters). Most of countries do not possess a power infrastructure which can be directly switched to feed *BEV* charging system.

Moreover, charging of *BEV* during a working day is not stable for each day, which must be coordinated. This problem was presented in [5], where the authors presented a mathematical model for the *BEV*s charging system. As an overall energy demand function to charge each vehicle ($E_v{}^{dem}$) was a described as:

$$E_v^{dem} = \Delta t \cdot \sum_{p,t_v} P_{v,p,t_v} \,. \qquad (2)$$

Some examples the results of their work were presented in Figures 6 and 7.

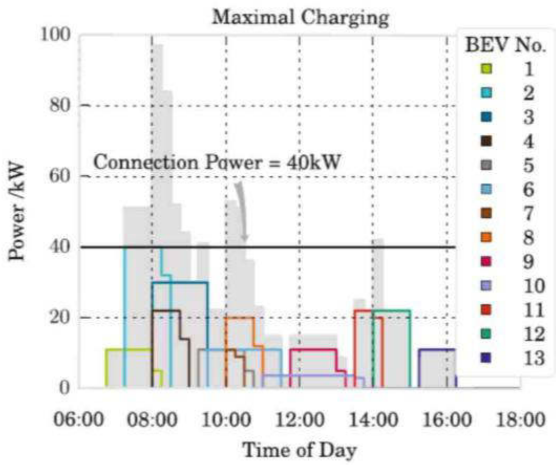

Fig. 6. Workload of a charging infrastructure occupied by the *BEV*s for uncoordinated simultaneous charging of all electric vehicles with their respective maximum powers would lead to a massive conflict with the overall power limit of the infrastructure [5]

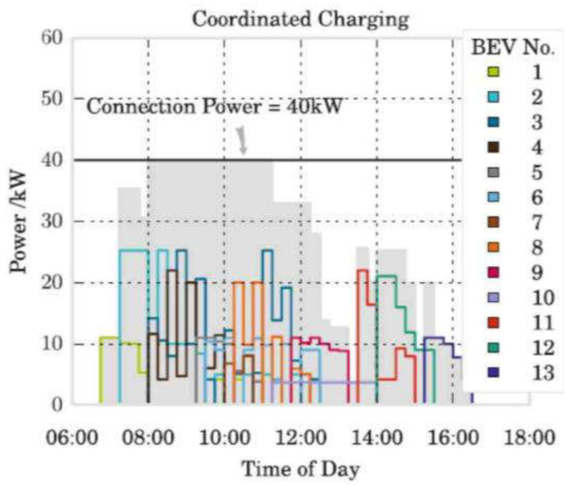

Fig. 7. Workload of a charging infrastructure occupied by the *BEV*s for coordinated charging mode [5]

The author's of work [5] have been showed, that the coordinated charging not only ensures the power limits of the infrastructure and at the grid connection but accounts for all restrictions of the BEVs as well. So there is a strong need to build power supply system which will be able to fulfill changes in demands on parameter of charging band. It should be done during a few next years due to the increase in the numbers of *BEVs* (Fig. 8) and *PHEV*s (Fig.9).

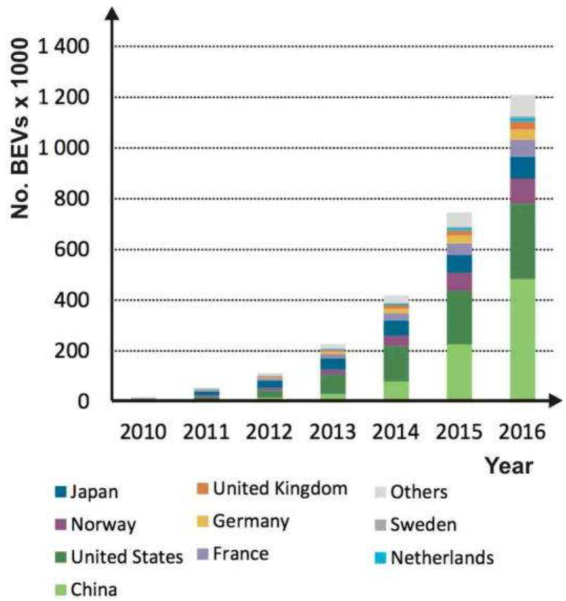

Fig. 8. The increase in BEVs from 2010 to 2016 by leading countries [10]

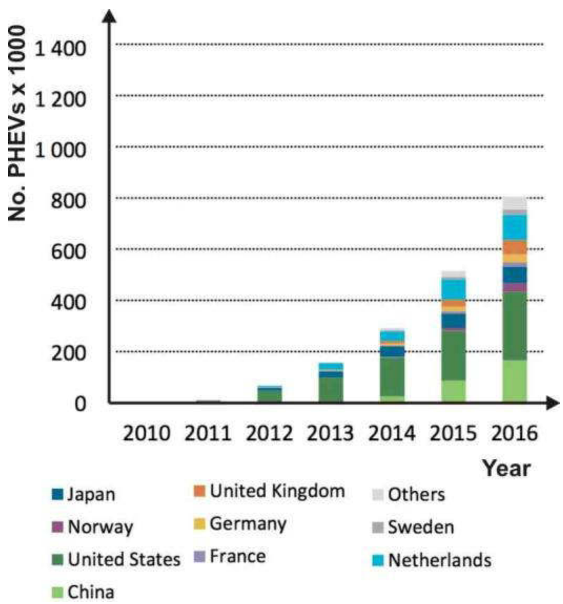

Fig. 9. The increase in PHEVs from 2010 to 2016 by leading countries [10]

3. EFFECTIVENESS OF EV

One of main coefficient which is considered in relation to effectiveness *EV*s is connected with their energy chain called tank-to-wheel (*TTW*). This coefficient shows how effective is the vehicle powertrain system and its movement resistance, how much energy is lost by these reasons. So this parameter could by comparable with other vehicles. Some examples of the comparison of *TTW* coefficients were presented in Figure 10.

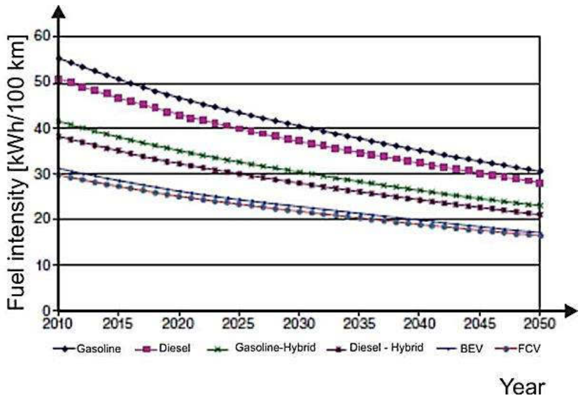

Fig. 10. Graph for fuel intensity of new passenger cars per 100 km driven for various types of *EV*s in comparison to gasoline and diesel cars characterized by representative power 80 kW by 2010-2050 [1]

On the basis of the data presented in Figure 10, we can state that during next forty years coefficient *TTW* should be more than 30% lower. It can be solved by two ways – by a decrease in movement resistance and an increase in the effectiveness of the powertrain system. But both of these problems can developed by an implementation of a new (maybe still unknown) technology or/and materials. Today, a serious problem is connected with energy density represented by the battery [4, 7], its charging [9, 18] parameter (time and electric current) and the battery's costs.

Next parameter which is taken into account to calculate overall *EV* effectiveness is connected with primary energy production - electrical or hydrogen. This parameter was assessed as a well-to-tank (*WTT*) and it shows how much primary energy input is required to produce 1 kWh of electricity used in vehicles. In the many cases, the total energy input required to produce one kWh of electric energy used in cars is split into fossil and renewable energy. In the case of many countries, still the most important are fossil fuel power stations (e.g. Poland).

The lowest level of used primary energy is needed in the case of electricity produced from renewable energy sources (wind or hydro power stations) — which can be used by any *EV*s. The example of *WTT* analysis was presented in Figure 11.

Both parameters *WTT* and *TTW* can be taken together. In this case, parameter *WTW* (well-to wheel) will describe all the energy processes which are required to achieve the vehicle's movement, which has an impact on total CO_2 emission [11].

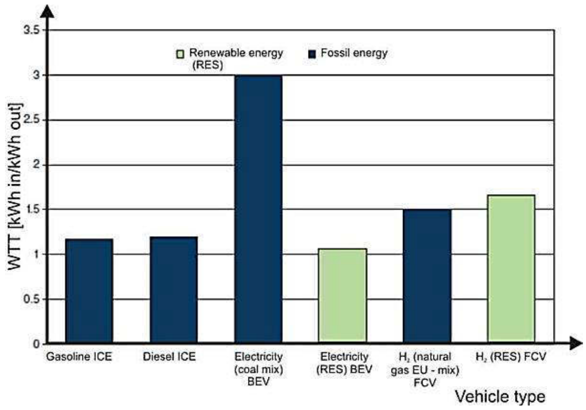

Fig. 11. Energetic well-to-tank performance of various types of fuels [2]

On the other hand, the most popular *HEV*s can reduce *GHG* emissions only slightly, because they are fully driven by fossil fuels. Much better environmental impact can be reached with *BEV*s and *FCV*s, however total emissions in the *WTW* chain are very dependent on the primary energy used for electricity generation.

4. ECONOMIC ASPECTS OF EVS

One of the most crucial aspects in the social acceptance of EVs is economics. For a wholesale usage of EVs, it is important that they must be economically competitive with conventional ICE vehicles. It seems to be the only right way to implement these vehicles in the future. One if the main problems of this is connected with the battery. Some automakers sell this battery with the car, other (e.g. Renault) only rent the battery. So this a different market policy, which is depend on local conditions and market demands. Figure 12 presents a relation between *BEV*s and battery prices. Currently, battery prices are 23-58% of BEVs total costs.

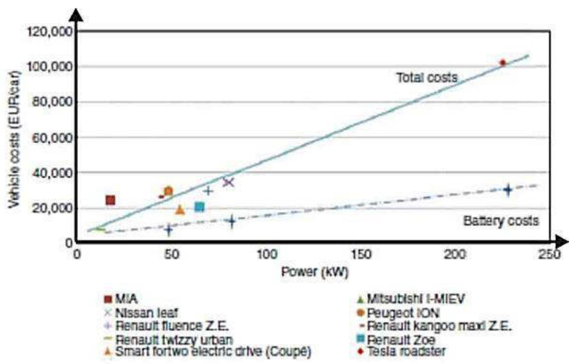

Fig. 12. The investment costs of EVs related to power of car [1]

The total costs of mobility (K_{cm}) involve the costs of vehicles, operation and maintenance costs and energy costs. These costs can be calculated as:

$$K_{cm} = K_i \cdot a + E_{tc} \cdot \rho_f \cdot b_c + K_{OOT} \text{ (€/car/year)}. \quad (3)$$

As an example of an economic evaluation of different types of vehicles and fuels, the mobility costs per 100 km driven were calculated and presented in Figure 13.

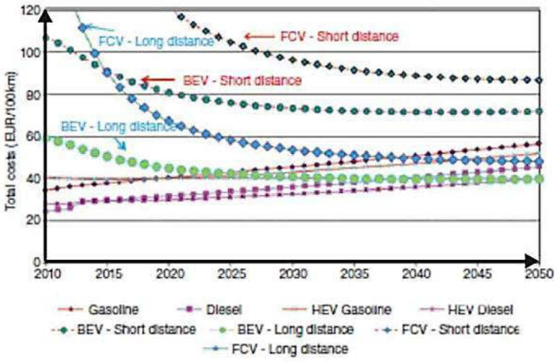

Fig. 13. Different scenarios for the development of the total costs of mobility of various types of vehicles [1]

On the basis of the results presented in Figure 13, we can state that context different driving distances play a role in the value of costs per vehicle/km. However, in practice, the mobility costs per km driven also have an impact on the total number of km driven and on the size of vehicles, which influences fuel intensity. In the following, the costs per km driven (K_b) can be calculated as:

$$K_b = \frac{K_i \cdot a}{b_c} + E_{tc} \cdot \rho_f + \frac{K_{OOT}}{b_c} \text{ (€/100 km)}. \qquad (4)$$

The energy total price (E_{tc}) depends on the cost of energy used (E_u), and possible VAT (p_{VAT}), excise (p_{exc}) and/or CO_2 taxes (p_{CO2}). It can be calculated on the basis of:

$$E_{tc} = E_u + p_{CO2} + p_{VAT} + p_{exc} \text{ (€/kWh)}. \qquad (5)$$

The biggest part of the total costs of all the categories of vehicles is capital costs. These costs are especially high in the case of FCVs and BEVs, but their impact on energy costs is relatively lower than others (Fig. 14).

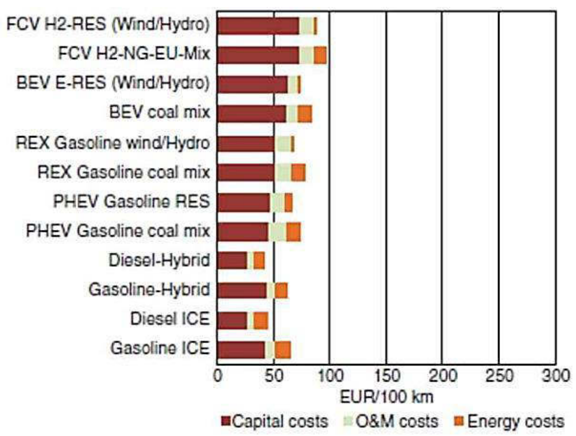

Fig. 14. Structure of total transport costs of various types of EVs in comparison to conventional cars in 2050 [1]

5. CONCLUSIONS

On the basis of the information presented in this article the following conclusions were formulated:

1. *EV*s are going to be an solution for effective and ecological means of transport, especially in urban and suburban areas.
2. Power grid is insufficient for building of *EV*s charging band and this problem should be solved by a system of an intelligent power grid which will be able to predict the charging demand for an optimisation of the power grid operation.
3. The investment costs and *EV*s range constitute a barrier for a wider implementation of *EV*s on the society level.
4. There is observed a strong political and ecological demand for a decrease in ICE vehicles usage by increasing technical and environmental requirements.

Nomenclature

Symbols

a – capital recovery factor
b_c – specific km driven per car per year
c_x – air drag coefficient
f_t – coefficient of rolling resistance
p – power from all power bands, kW
t_v – all times when the vehicle is connected to power bands, s
v – velocity of vehicle, m/s
A – frontal area of vehicle, m^2
E_{tc} – energy (fuel) price including all taxes, €/kWh
K_i – investment costs, €
K_{OOT} – operation and maintenance costs, €
Q – vehicle gravity, N

Greek letters

ρ_a – air density, kg/m^3
ρ_f – the fuel (energy) intensity, kWh/100 km,
Δt – denoting the equidistant width of the discrete time steps, s

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Biographical notes

Piotr Piątkowski received his M.Sc. degree in Mechanics and Mechanical Engineering and as D.Sc. degree in *ICE* Designing and Operation from Koszalin University of Technology, in 2000, 2007 and 2014, respectively. Since 2006 he has been a researcher in the Department of Transport at the Koszalin University of Technology, where currently he works as an associated professor. His scientific interests focus on problems concerning transport processes and its efficiency, transport telematics, vehicle's monitoring and diagnostics. He has participated in 1 international research projects, presenting results of his work at 12 international and 15 national conferences, published more than 70 scientific papers in international and national journals, book chapters, as well as conference proceedings.

Wojciech Puszkiewicz graduated from the Tank and Car Service Training Centre in Pila and received his M.Sc. degree from the Faculty of Mechanical Engineering at the Koszalin University of Technology. He also attended a course for officers at The Military Academy for Land Forces in Wroclaw and completed post-graduate studies at the Higher School of Technology and Economics in Szczecin. Currently, he is a lecturer at the University of Applied Sciences in Pila, an advisor for the carriage of dangerous goods by roads (ADR) and rail (RID), a driving instructor, a vehicle inspector and a lecturer at driver training centres.