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Recent Developments in Electric Vehicles for Passenger Car Transport

Amela Ajanovic

***Abstract*—**Electric vehicles are considered as technology which can significantly reduce the problems related to road transport such as increasing GHG emissions, air pollutions and energy import dependency.

The core objective of this paper is to analyze the current energetic, ecological and economic characteristics of different types of electric vehicles.

The major conclusions of this analysis are: The high investments cost are the major barrier for broad market breakthrough of battery electric vehicles and fuel cell vehicles. For battery electric vehicles also the limited driving range states a key obstacle. The analyzed hybrids could in principle serve as a bridging technology. However, due to their tank-to-wheel emissions they cannot state a proper solution for urban areas.

Finally, the most important perception is that also battery electric vehicles and fuel cell vehicles are environmentally benign solution if the primary fuel source is renewable.

***Keywords*—**Costs, fuel intensity, electric vehicles, emissions.

I. Introduction

ELECTRIC vehicles (EVs) are considered as technology which can significantly reduce the problems related to road transport such as increasing GHG emissions, air pollutions and energy import dependency. Especially urban areas could benefit from low to zero tailpipe emissions of battery electric vehicles (BEV) as well as reduced noise. Comparing to conventional internal combustion (ICE) vehicles, electric vehicles are more efficient at least on the tank-to-wheel (TTW) basis. However, EVs are still not a mature technology. The major crucial issues are high investment costs, immature battery technology, unsecure source of well-to-wheel emissions and interaction with the electricity generation [1].

The core objective of this paper is to analyze the current energetic, ecological and economic characteristics of different types of electric vehicles.

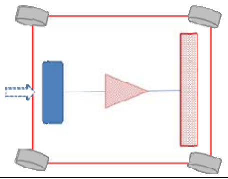
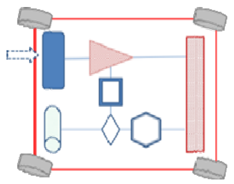
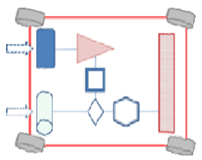
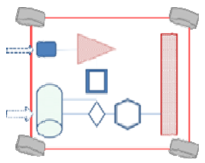
We distinguish the following six different types of electric vehicles:

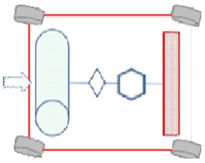
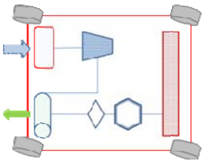
- Full battery electric vehicles (BEV): these vehicles have only an electric engine
- Hybrid electric vehicles (HEV): it is an ICE vehicles by an electric engine (battery is charged by regenerated energy during braking)
- Plug-in-hybrid electric vehicles (PHEV): these vehicles have an ICE and an electric engine (battery can be charged externally)
- Range extender vehicles (REX): these vehicles have a full size electric engine and a small ICE which can be used to charge battery. Battery can be also charged on the grid.
- Fuel cell vehicles (FCV): these vehicles have a fuel cell and an electric engine. Battery is charged by energy from hydrogen.

The common architectures of these electric vehicles are shown in Table I.

Dr. Amela Ajanovic is with the Vienna University of Technology, Energy Economics Group, Vienna, Austria (phone: + 43 1 58801 370364; fax: +43 1 58801 370397; e-mail: ajanovic@eeg.tuwien.ac.at).

TABLE I
CLASSIFICATION OF VARIOUS TYPES OF ELECTRIC VEHICLES INVESTIGATED IN THIS PAPER

Architectures of electric vehicles	Types of electric vehicles
Fossil fuel 	ICE – Conventional internal combustion engine is taken as reference technology. Although ICE vehicles are old and mature technology, they have much lower energy efficiency than electric vehicles.
Fossil fuel 	HEV – Hybrid electric vehicles are propelled by ICE and an electric motor/generator in series or parallel configuration. The ICE allows the vehicles an extended driving range, while the electric motor increases efficiency by regenerating energy during braking and storing excess energy from the ICE during coasting [2].
Fossil fuel Electricity 	PHEV – Plug-In Hybrid vehicles are largely refueled by electricity grid, so they contribute to the independency from oil. Electric range is between 30-60 km.
Fossil fuel Electricity 	REX – The electric drive capabilities of electric vehicles with Range Extender are even further enhanced, permitting purely electric driving. The vehicle's range is great enough to meet average daily mobility requirements (ca. 80 km). If required, electrical energy can be generated on board with the Range Extender [3].

Electricity 	BEV–Battery electric vehicle uses chemical energy stored in rechargeable battery packs. BEVs use electric motors and motor controllers instead of internal combustion engines for propulsion [4].
H2 Electricity 	FCV–Fuel cell vehicles use hydrogen as a fuel to produce electricity in a fuel cell. Wen connected to electricity grid, FCVs can provide electricity for emergency power backup during a power outage. [2]
Symbols: ICE Tank Battery Generator Electro motor Power convertor Fuel cell H2-Tank Transmission	

In spite of improvements on electric vehicles, publicity and supporting policy measures, they are still niche products. In Europe share of electric vehicles is about 1% of the passenger car market today [5]. The highest market share of gasoline HEV in Europe in 2011 was in the Netherlands, 2,7% of total passenger car sale. This high share can be attributed to generous financial incentives for low-emission cars starting in 2007. The situation of full BEV is even worse. In Europe the highest market share of BEV is 0,3% in Denmark [6].

II. Energetic Performance

The use of EV could contribute to GHG reduction in transport sector, to increasing energy supply security and to reduction of fossil fuel consumption. However, energetic performances of EVs are diverse depending on the type of EV and kind of electricity used.

The energetic WTT-performance of various types of fuels for EVs in comparison to gasoline and diesel are depicted in Fig. 1. The total energy input required to produce one kWh of energy used in cars is split up in fossil and renewable energy. Lowest primary energy input is needed in case of BEVs, REX and PHEV if they are powered by electricity produced from RES like wind or hydro power. In this case we can notice also significant reduction of used fossil energy. In the case that we are using fossil energy, e.g. coal, for electricity production, total WTT energy balance of conventional gasoline and diesel vehicles is better than by EVs.

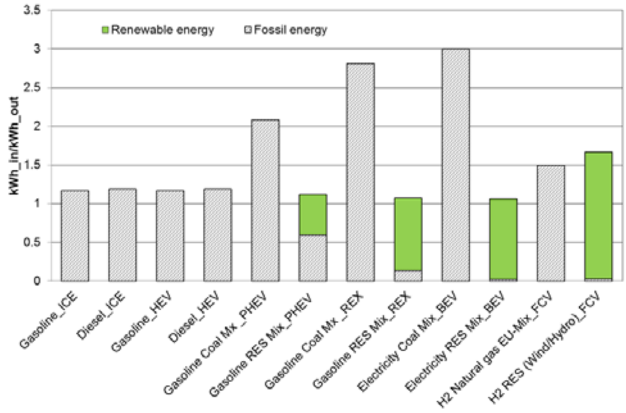


Fig. 1 Energetic WTT-performance of various types of fuels for EVs in comparison to gasoline and diesel cars (2010) (source: [7,8])

Fuel intensity per 100 km driven for various types of EVs is given in Table II in comparison to gasoline and diesel cars. (Power of all cars is 80 kW.)

TABLE II
Fuel Intensity per 100 km Driven for Various Types of EV in Comparison to Gasoline and Diesel Cars (Power of Car: 80 kW) (source: [7,8])

	Liter/100 km (gasoline or diesel)	**kWh/100 km (total)**
Gasoline ICE	6.182	53.8
Diesel ICE	5.097	50.8
Gasoline-Hybrid	4.637	40.3
Diesel-Hybrid	3.823	38.1
PHEV Gasoline Coal Mix	3.09	44.1
PHEV Gasoline RES	3.09	44.1
REX Gasoline Coal Mix	0.62	36.3
REX Gasoline Wind/Hydro	0.62	36.3
BEV Coal Mix	-	34.4
BEV RES (Wind/Hydro)	-	34.4
FCV H2-NG-EU-Mix	-	31.0
FCV H2-RES (Wind/Hydro)	-	31.0

Energy consumption per kilometer driven is dependent from size of cars. Cars with higher power have also higher fuel intensity. Current energy use per 100 km driven for various types of EVs in comparison to gasoline and diesel cars is shown in Fig. 2 depending on power of car.

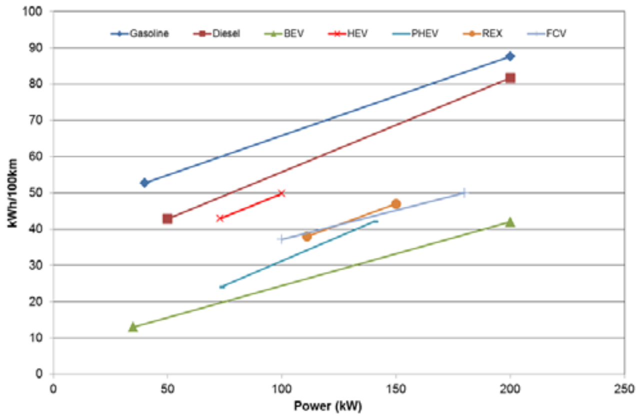


Fig. 2 Energy use per 100 km for various types of EV in comparison to gasoline and diesel cars depending on power of car (2010 – 2012) (source: own investigations from magazines and internet sites of vehicles)

III. Ecological Assessment

Many countries have been establishing subsidy schemes or tax allowance programs to increase the attractiveness of electric vehicles for consumers (see e.g. [9-12]). The promotion of electric vehicles is based on the fact that they are a promising technology for the reduction of air pollution and GHG emissions from transport sector. Electric vehicles have the highest engine efficiency of existing propulsion systems and zero tailpipe emissions. However, the electricity used in vehicles can be produced from different primary energy sources. This is the reason that the consideration of total well-to-wheel (WTW) emissions of electric vehicles can lead to very different assessments.

In this context it is important to consider – in addition to the driving performance (tank-to-wheel (TTW)) – also the emissions in the well-to-tank (WTT) part of the fuel supply chain. Fig. 3 shows CO_2-emissions per 100 km driven for the whole energy supply chain and for various types of EV in comparison to conventional gasoline and diesel cars. Power of all analyzed cars is 80 kW.

The lowest CO2 emissions are in the case of BEV powered by electricity from renewable energy sources (RES) – wind or hydropower – and FCV powered with hydrogen produced from RES. By these EVs TTW emissions are zero. The embedded emissions of car production and scrapage which are in the range from 2 to 2.8 tons CO_2 per car for all analyzed vehicles are not shown in Fig. 1.

It is obvious that with all kinds of EV CO_2 emissions in TTW part are reduced. Yet, for urban areas only BEV and FCV can be considered as proper because of their zero TTW emissions. HEV are less recommendable. However, in the case that electricity produced from fossil energy – coal – is used in EV, total WTW CO_2 emissions are even higher than of conventional vehicles.

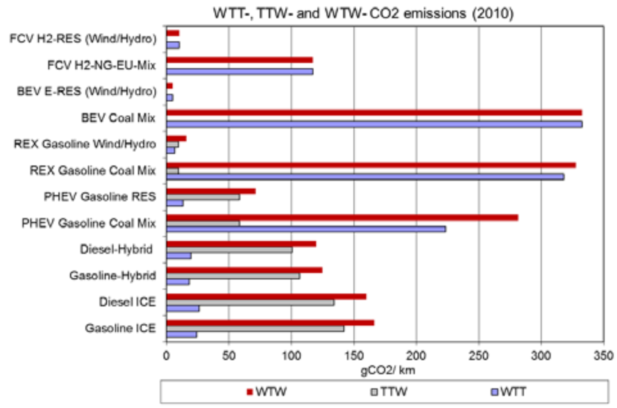


Fig. 3 WTW-balance of CO_2-emissions per 100 km driven for various types of EV in comparison to gasoline and diesel cars (Power of car: 80 kW) (source: [7,8])

The major advantages of EV can only be achieved in the case that electricity and hydrogen are produced from RES. In other cases EV could just contribute to the reduction of the local air pollution.

By PHEV and REX CO_2 balances are dependent from the share of electricity in total energy consumption. In Fig. 3 it is assumed that by PHEV and REX share of electricity is 50% and 90%, respectively.

IV. Economic Assessment

The most crucial aspect for the acceptance of electric vehicles is economics. To make EVs more attractive they have to be competitive on the market with conventional vehicles. The successful market introduction of electric vehicles is highly dependent on the battery technology as well as costs of battery. Fig. 4 shows current investment costs of seven different BEVs and costs of battery depending on the power of car. The range of the total costs of BEVs is very broad. For vehicles shown in Fig. 4 costs are in the range from about 20.000 to 100.000 Euro for the power range from 13 to 185 kW, respectively. Depending on the power of car share of battery costs in total costs of vehicles is between 23% and 58%.

Average investment costs of all analyzed types of electric vehicles of the same power (80kW) are shown in Fig. 5 in comparison with conventional gasoline and diesel vehicles. It is evident that currently all electric vehicles have higher investment costs than conventional ICE vehicles, but highest costs are for FCV and BEV.

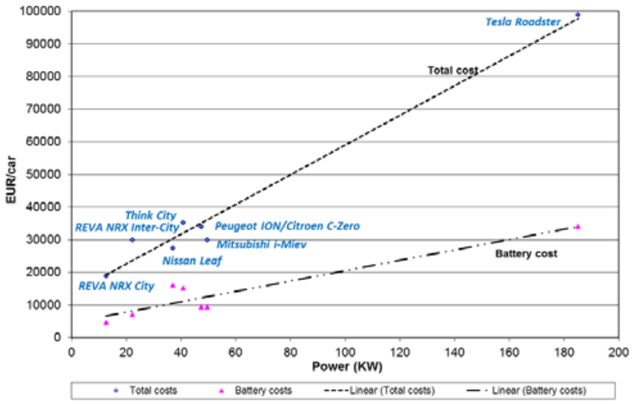


Fig. 4 Total investment and battery costs of BEV depending on power of car in 2012 (source: own investigations from magazines and internet sites of vehicles)

Costs of vehicles are very dependent on the power of car. The relation between investment costs for vehicles and their power is shown in Fig. 6 for the models currently available on the market. Since FCVs are still not on the market, numbers given in Fig. 6 are assumptions based on the literature (see e.g [13]).

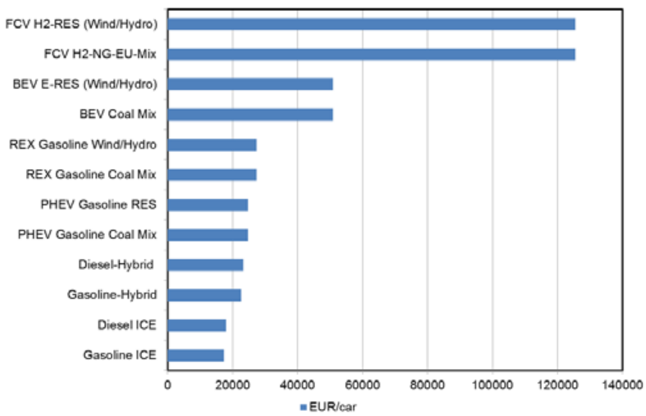


Fig. 5 Investment costs of various types of fuels for EV in comparison to gasoline and diesel cars in 2012

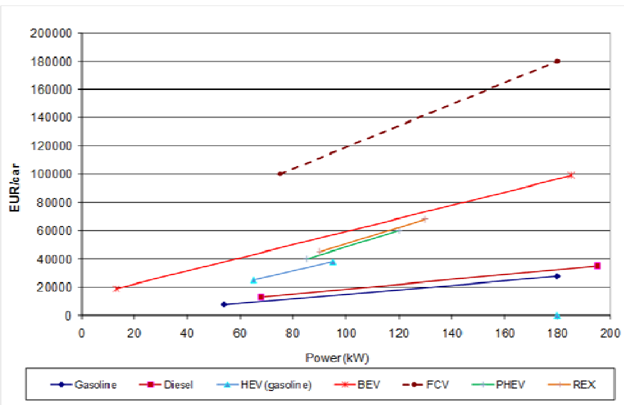


Fig. 6 Investment costs of EV in comparison to gasoline and diesel cars depending on power of car (year 2012)

It is also important to analyze total fuel costs for various types of EV. Fig. 7 depicts current fuel costs of mobility with various types of EV per 100 km driven in comparison to gasoline and diesel cars. The total fuel costs are divided in fuel costs without taxes, excise tax and value add tax (VAT).

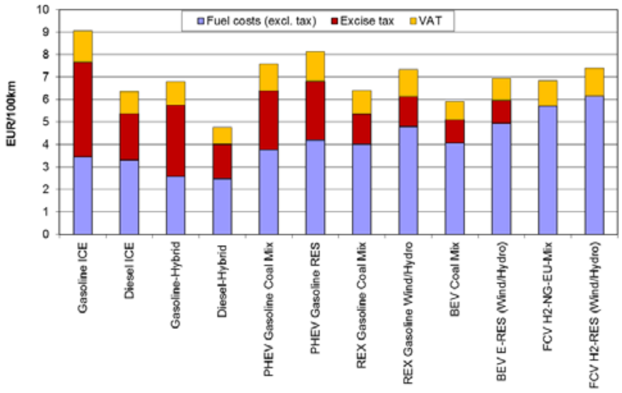


Fig. 7 Fuel costs of service mobility for various types of EV comparison to gasoline and diesel cars in 2010

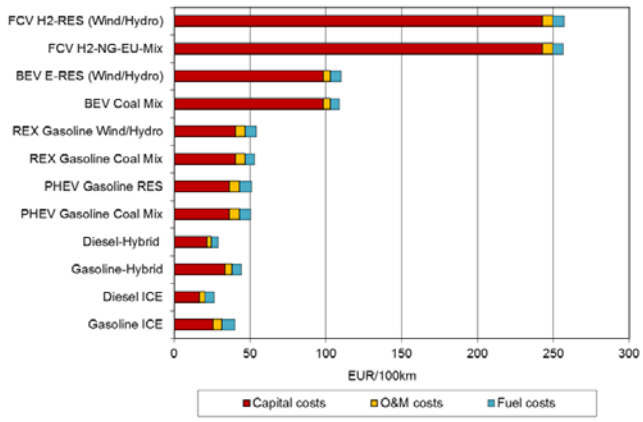


Fig. 8 Total costs of service mobility of various types of EV in comparison to gasoline and diesel cars

Total costs of service mobility are dependent from capital costs of cars, fuel costs and operating and maintenance costs. Total mobility costs of various types of EVs in comparison to gasoline and diesel cars are shown in Fig. 8 in Euro per 100 kilometers driven. The analyzed diesel cars are cheapest mainly due to a higher driving range than gasoline cars.

V. Conclusions

The major conclusions of this analysis are: The high investments cost are the major barrier for broad market breakthrough of BEV and FCV. For BEV also the limited driving range states a key obstacle. The analyzed hybrids could in principle serve as a bridging technology. However, due to their TTW emissions (see Fig. 3) they cannot state a proper solution for urban areas.

Finally, the most important perception is that also BEV and FCV are environmentally benign solution if the primary fuel source is renewable.

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