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Promoting environmentally benign electric vehicles

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Abstract

In the last decade a rapidly growing interest in electrification of transport passenger cars could be noticed. The major motivation are the problems related to the use of fossil fuels in the transport sector such as crude oil dependency, greenhouse gas emissions (GHG) and air pollution.
Electric vehicles (EV) are often presented as zero-emission vehicles. However, from a lifecycle CO_2 perspective, EVs are not zero-emissions vehicles. Total emissions are very dependent on the kind of electricity which is used in vehicles.
The core objective of this paper is to analyze costs and emissions of various types of electric vehicles and to provide an overview of policies and strategies for the promotion of electric vehicles in different countries.
Our method of approach is based on lifecycle assessment of GHG emissions of EVs powered by electricity from different energy sources (fossil and renewable energy sources (RES)). The economic performances of EVs are investigated considering investment, operation and fuel costs. The future market penetration of EVs is analyzed considering technological learning and promotion strategies.
The major result of our analysis show, that total GHG emissions could be reduced only in the case that electricity used in EVs is produced from RES. In the case that electricity is produced from fossil energy e.g. coal, total emissions are higher than that of the conventional cars.
The major conclusion of this work is that still a number of barriers exists to be overcome in order to increase market penetration of EVs (e.g. technology maturity, high costs of battery, infrastructure, regulation, etc.). In addition, it is important to ensure that EVs are using electricity from RES to really contribute to the sustainability of transport. The use of CO_2-based taxes could support this. Furthermore, emission-free zones in urban areas are a very important completing policy tool.

Keywords: Electric vehicles; emissions, costs, policies

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1. Introduction

In the last decade a rapidly growing interest in electrification of transport passenger cars could be noticed. The major motivation are the problems related to the use of fossil fuels in the transport sector such as crude oil dependency, greenhouse gas emissions (GHG) and air pollution.

Although the numbers of registrations of new electric vehicles are very low with an average of 0,06 % in the EU, USA, Japan and China, many markets participants believe that there is “no going back” from electric vehicles [1]. However, the most critical factors concerning the market penetration of electric vehicles are technological characteristics (especially maximum operating range and a battery weight), political conditions, and their costs.

Electric vehicles (EV) are often presented as zero-emission vehicles. However, from a lifecycle CO_2 perspective, EVs are not zero-emissions vehicles. Total emissions are very dependent on the kind of electricity which is used in vehicles. The core objective of this paper is to analyze costs and emissions of various types of electric vehicles and to provide an overview of policies and strategies for the promotion of electric vehicles in different countries.

In this paper five types of electric vehicles are analyzed:

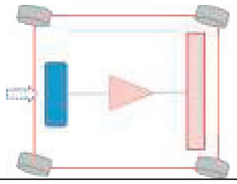
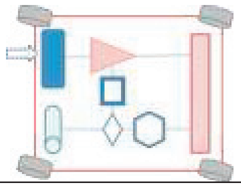
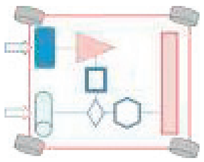
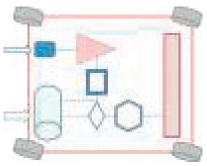
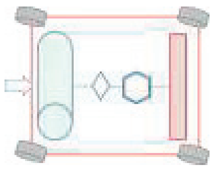
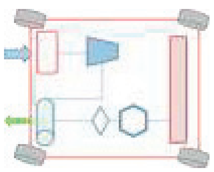
- Battery Electric Vehicles (BEV)
- Hybrid Electric Vehicles (HEV)
- Plug-In Hybrid Electric Vehicles (PHEV)
- Range Extenders (REX)
- Fuel Cell Vehicles (FCV)

The common structure of the electric vehicles analyzed in comparison to conventional internal combustion engine (ICE) vehicles is shown in Table 1.

Current sales of electric vehicles in most important EV markets such as the EU market, the USA and Asian markets (China, Japan and Korea) are shown in Fig. 1. In 2011 from the 51,1 million cars sold only 0,06 % have been electric vehicles. The largest markets for electric vehicles are currently Japan and the USA. The key European markets in 2011 were Germany (with 11386 electric vehicles sold, but without HEV only 2154), France (with 6321 electric vehicles sold, 2630 without HEV) and the United Kingdom (with 13802 electric vehicles sold, 1082 without HEV). The largest number of the total vehicles sold has been hybrid electric vehicle [1].

Japan is the first county in which a vehicle with an alternative powertrain – HEV – has become available on the passenger car market. In 2002 there were at least three different hybrid models on the passenger car market [6]. The HEV have been on sale in the USA for over ten years, and today sales have grown to almost 3% of total light-duty vehicles. Over 1,6 million HEVs have been sold over the past six years [7].

Table 1. Classification of various types of electric vehicles investigated in this paper [2]

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 [3].
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. (e.g. Toyoty Prius Plug-In, Ford C-MAX Energy)
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 [4]. (e.g. Chevrolet Volt, Opel Ampera)
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 [5]. An average range between 80-150 km [1] (e.g. Nissan Leaf, Mitsubishi iMiev, Renault Twizy, Volvo C30 Electric)
H2 Electricity 	FCV – Fuel cell vehicles use hydrogen as a fuel to produce electricity in a fuel cell. If connected to electricity grid, FCVs can provide electricity for emergency power backup during a power outage. [3] (e.g. Honda FCX Clarity)
Symbols: ICE Tank Battery Generator Electro motor Power convertor Fuel cell H2-Tank Transmission	

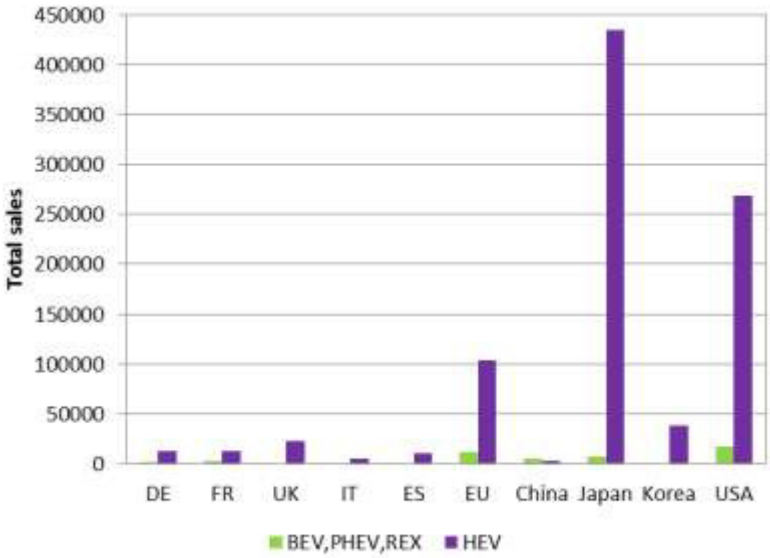


Fig. 1. Sales of electric vehicles in 2011(only Japan in 2010) [1]

Hydrogen vehicles are currently in the demonstration stage and only about 650 FCV are on the road worldwide, of which approximately 200 are buses, see Fig.2.

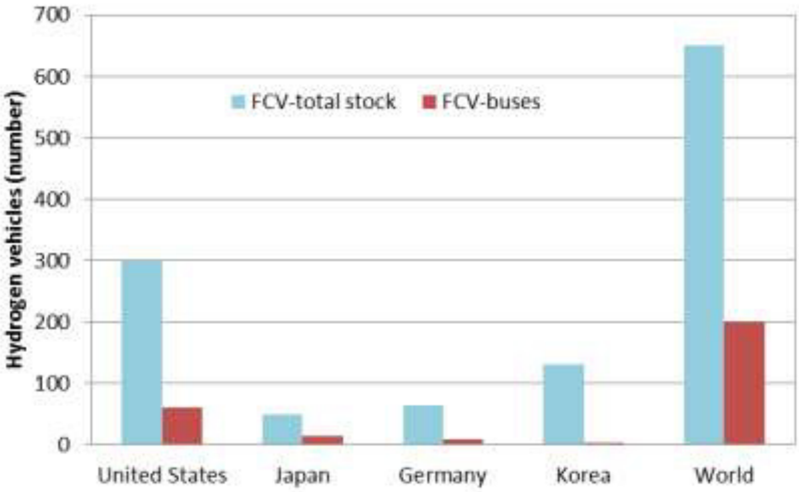


Fig. 2. Total stock of hydrogen FCV in today's leading countries and worldwide (based on [8,9])

In spite of some very optimistic expectations regarding electric vehicles (e.g. [10]), there are also some doubts about the quick introduction of electric vehicles (e.g. [11]). According to Perdiguero and Jimenez [12] the main reasons for the slow introduction of electric vehicles are following obstacles:

- Costs – the costs of the battery will remain one of the main obstacles to the adoption of the electric vehicles
- Charging infrastructure – existing charging network is very limited. Charging points installed in homes are relatively inexpensive (ca. 200 EUR) but slow. More rapid charging requires an investment of several thousand euros. Additional problem is missing harmonization of standards.
- Consumer acceptance
- The evolution of other technologies

These barriers can be overcome with different supporting policy measures, but they are also sensitive on some exogenous factors such as increases in fuel prices, economic crisis, efficiency improvement of conventional ICE vehicles, etc.

2. Environmental assessment of electric vehicles

Electric vehicles gain increasing attraction in the context of long-term emission targets. They could enable transport sector to reduce greenhouse gas emissions and local air pollution. However, electric vehicles could be more or less environmental friendly technology depending on the carbon-intensity of power generation. Due to this it is important to analyze whole well-to-wheel (WTW) emissions.

Fig. 3a shows current CO_2 emissions per 100 km driven for the whole energy supply chain (as well as for well-to-tank (WTT) and tank-to-wheel (TTW) part) and for various types of EV in comparison to conventional gasoline and diesel cars. Power of all analyzed cars is 80 kW.

The lowest CO_2 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.

It is obvious that with all kinds of EV CO_2 emissions in TTW part are reduced. The TTW-emissions in 2050 are lower because the fuel intensity (kWh/100 km driven) decreases. Regarding fuel intensity it is assumed that all currently known efficiency improvements are achieved until 2050. Due to these improvements less kWh fuel input per km are necessary and this leads also to decreasing WTT-emissions. Moreover, efficiency of power plants, especially from fossil fuels, will improve. 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 [2].

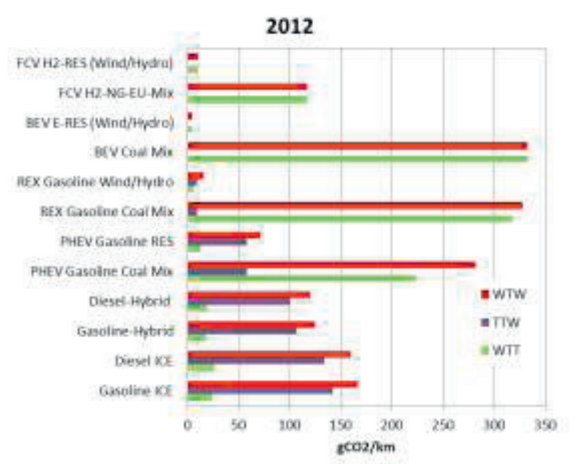


Fig. 3a. CO_2 emissions per km driven for various types of EV in comparison to conventional cars (power of car:80kW)

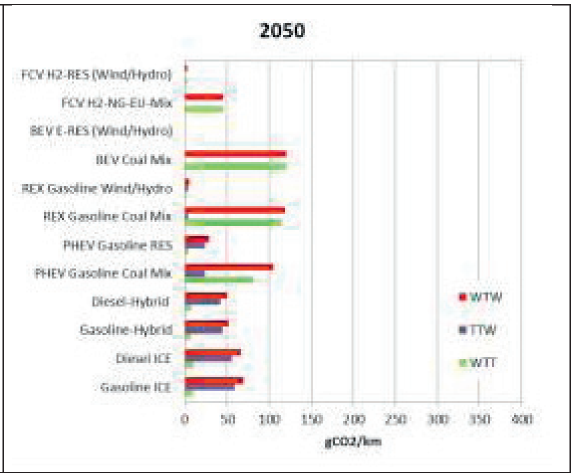


Fig. 3b. CO_2 emissions per km driven for various types of EV in comparison to conventional cars (power of car:80kW)

Considering different average grid mixes, well-to-wheel GHG emissions of electric vehicles are up to 70% lower compared to conventional vehicles but could be worse (10-20% higher) when electricity is based on coal-fired power plants. Assuming current average European energy supply would reduce GHG emissions by more than 50% [13].

3. Economic assessment of electric vehicles

One of the most critical factors concerning the market penetration of electric vehicles are their costs, especially battery costs. Today's costs of a Li-Ion battery system are about 600-800 €/kWh. The battery costs for an electric vehicles can add 6000-16000 € to the cost per vehicles [13].

The range of the total costs of BEVs is very broad. The costs of EVs (REVA NRX City, Nissan Leaf, Think City, Tesla Roadster) are between 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%.

The total costs of mobility comprise:

- Capital costs for vehicles
- Operation and maintenance costs (O&M)
- Fuel costs - running costs (e.g. electricity costs, fuel costs)

These costs for various types of EVs in comparison to gasoline and diesel cars are shown in Fig. 4 in Euro per 100 kilometers driven. In 2012 the largest part of the total costs for all categories of vehicles are capital costs, especially in the case of FCV and BEW. Due to technological learning effect, mainly regarding the batteries and the fuel cells the capital costs especially of BEV and FCV decrease remarkable until 2050 (see also [14]).

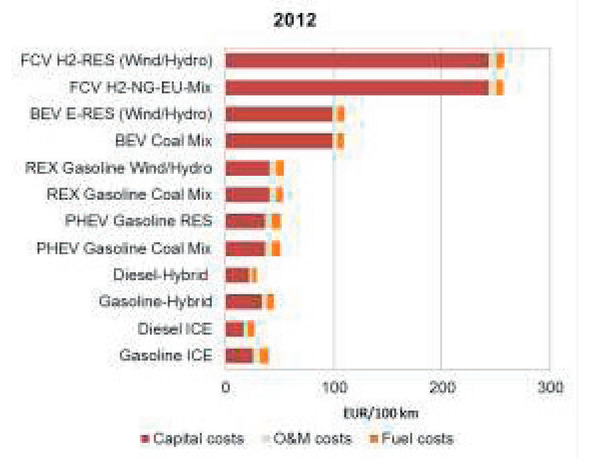


Fig. 4a. Total current costs of mobility with electric vehicles in comparison to conventional ICE vehicles

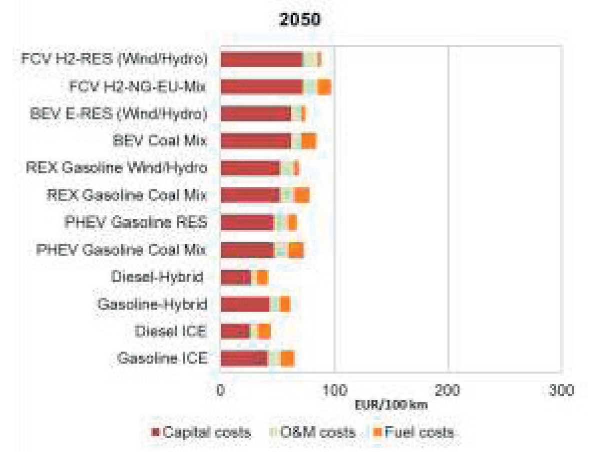


Fig. 4b. Total future costs of mobility with electric vehicles in comparison to conventional ICE vehicles

The fuel cost of fossil-based vehicles increase up to 2050 because of higher fuel prices and additional taxes on CO_2. The major finding of Fig. 4b is that due to technological learning and efficiency improvements, by 2050 all investigated vehicles will be in much more narrow cost-range than today.

Obviously currently, EVs have higher costs than conventional vehicles. If a more rapid market penetration of electric vehicles is intended by policymaker, subsidies and incentives are necessary to foster their market introduction.

4. Policies for promotion of electric vehicles

To make electric vehicles more competitive to conventional vehicles various supporting measures have been implemented. According to Heike and Kilian [1] major monetary measures are:

- Financial incentives
- Tax relief
- Exemption from tolls
- Free parking
- Free recharging stations

Important non-monetary parameters are:

- Use of bus lines
- Charging time/Charging options
- Entry to city center and zero emission zones
- Social/ecological benefits

Depending on the objectives and time horizon different policy measures (e.g. tax incentives, grants, purchasing incentives, etc.) can be used to promote electric vehicles. An overview on the current financial incentives and taxation in European countries in comparison to the USA and some Asian countries are given in Table 2.

Table 2. Financial incentives & taxation for promotion of electro-mobility (based on [1,13])

Country	Financial incentives & taxation
Germany	2009-2011: 500 million Euro provided to promote electromobility (out of the second rescue package). Introduction of a vehicle tax waiver for the period of 10 years for vehicles producing ≤ 50g of CO2.
France	Consumers receive a 5,000 Eurocheck by the French government for buying a vehicle producing ≤ 60g of CO2. In 2011 the French Ministry of Environment coordinated the delivery of 50,000 electric vehicles to 20 large private and public companies. No company car tax applies for EVs and Hybrids.
UK	Point-of-purchase grants of 2,400-6,000 Euro for private and business fleet buyers from January 2011 onwards. Several vehicle taxes for new cars are calculated based on CO2 emissions (in g/km), resulting in low taxes for EVs.
Italy	No annual ownership tax for five years from the date of first registration. After five years, 75% reduction of the tax applied to comparable petrol vehicles.
Spain	Several local governments grant tax incentives of 2,000-7,000 Euro for the purchase of EVs and other ecofriendly vehicles.
Austria	In Austria the fuel consumption tax is CO2 based. As a result alternative fuelled vehicles attract a € 500 bonus whereas cars emitting more than 180 g/km pay a penalty of € 25 for each gram emitted in excess of 180 g/km (160 g/km as from 1st January 2010).
Greece	In Greece electric and hybrid cars are exempted from the special consumption tax and from the yearly circulation taxes. Furthermore they are excluded from circulation restriction in metroploitain areas, where these are applied.
Norway	Electric cars are exempted from registration tax, VAT and annual car tax. Furthermore drivers of electric cars are allowed to use bus-lanes. Also they are exempted from congestion charges and parking fees on public parking places.
Sweden	Electric and hybrid cars are covered by a green car rebate which allocates SEK 10,000 to individuals who buy a new green car. Furthermore the taxation system is CO2 based. The annual circulation tax consists of a SEK 360 base rate plus SEK 15 for each gram CO2 emitted above 100 g/km. For alternative fuel vehicles, the tax is SEK 10 per gram emitted above 100g/km. The Stockholm congestion charge exempts hybrid and electric vehicles.
USA	Financial incentives & taxation in USA are provided by individual states. E.g. **California**: Purchase subsidies of $2,500 for BEVs and PHEVs and $1,500 for electric motorcycles and NEVs. The city of Riverside provides local residents with purchase subsidies for both new and used hybrid vehicles worth $2,000 and $1,000 respectively; **Hawaii:** Purchase subsidies covering 20% of the vehicle price (max. $4,500); **Illinois**: Purchase subsidies of 80% (max. $4,000) of the price for alternative fuel vehicles; **Oklahoma:** Subsidies covering 50% of either the price premium of EVs and PHEVs or the conversion costs of conventional vehicles; **Colorado**: Income tax credit of 75% (max. $6,000) of the price premium of BEVs or PHEVs; **Louisiana**: Income tax credit covering 50% of the cost of purchasing or converting to a hybrid electric vehicle; **New Jersey**: Exemption from sales tax for zero emission vehicles; **Michigan**: Exemption from personal property taxes for EVs and PHEVs; **Washington D.C**.: Exemption from excise tax for alternative fuel and fuel efficient vehicles. Reduction of vehicle registration fees. Exemption from time-of-day and day-of-week restrictions and commercial vehicle bans.
Japan	Purchase price reductions of up to 16000 dollars (ca 12000 Euro) off the retail price of electric vehicles. No acquisition and weight tax accruement until March 2013, reduction on road tax.
Korea	2009-2012: Government initiative “Green New Deal” (30 billion Euro) to reduce CO2 emissions. Share allocated to the promotion of low carbon vehicles is 1.4 billion Euro. Tax reduction for purchasing an EV: 5% reduced consumption tax, 7% reduced acquisition tax, discount of up to 20% on governmental automobile bond purchases. In absolute terms: ca. 800-3000 Euro.

In Europe use of electric vehicles is promoted by various regulations such as:

- Directive 2009/28/EC which states that 10% of the energy used in transport must be provided by renewable sources by 2020;
- the EC regulation 443/2009 which imposes reductions in average emission levels for vehicle manufactures, setting objectives of 130 gCO_2/km for 2015, and 95 gCO_2/km for 2020;
- the European strategy (COM,2010; 186 final) which establishes as priorities the development of electric vehicles that are at least as safe as conventional ones, a European standard for charging points, a public charging network, a smart grid and research programs for the safe recycling of batteries [12].

In the USA a goal is to put one million electric vehicles on the road by 2015. This should be reached through the tax credits, investments in R&D and competitive programs to encourage communities to invest in infrastructure supporting electric vehicles [15].

For the wide use of electric vehicles comprehensive standards and norms have to be created to ensure the vehicles can be easily used and recharged. This should also avoid market fragmentation and cost reduction (due to economic of scale). As discussed by Reiner et al. [13] major technical issues which need EU-wide harmonization are:

- Standardization (plug, phases, data protocol)
- Cross-national compatibility (re-charging abroad should not be different to recharging at home)
- Safety requirements for recharging/discharging places
- Safety requirements while recharging/discharging the battery, e.g. short circuits
- Charging cable at the car or at the recharging station
- Technical approval body for recharging places
- Periodic inspections & maintenance of recharging places
- Convenient billing systems.

One good example for the successful introduction of EV is Norway. In 2012 the share of EVs in total vehicle sales in Norway was 2,86 %. This is very high compared to other EU countries, e.g. Denmark (0,31%), Portugal (0,07%), Germany (0,12%), Sweden (0,34) or Ireland (0,17) [10]. The main reason for this is a combination of different supporting measures in Norway as shown in Table 3.

Table 3. Supporting measures for electric vehicles in some EU countries [10]

	Norway	***Sweden***	***Denmark***	***Germany***	***Portugal***	***Ireland***
Financial incentives	**Yes**	Yes	Yes	Yes	Yes	Yes
Access to bus line	**Yes**	Limited				
Free parking and no road toll	**Yes**	Limited	Some	Some		
Charging infrastructure	**Yes**	Some	Yes		Yes	Yes

5. Conclusions

The major conclusion of this work is that still a number of barriers exist to be overcome in order to increase market penetration of EVs (e.g. technology maturity, high costs of battery, infrastructure, regulation, etc.). Since HEV have lower costs compared to other types of EVs, they could serve as a bridging technology. However, they have relatively high TTW emissions.

Most important is to ensure that EVs are using electricity from RES to really contribute to the sustainability of transport. For example, the use of CO_2-based taxes could support this. Furthermore, emission-free zones and other non-monetary incentives (free parking, access to bus lines, etc.) in urban areas are a very important completing policy tool. As shown by the example of Norway only a mix of different measures could accelerate the introduction of electric vehicles.

References

[1] Proff H, Kilian D.Competitivness of the EU Automotive Industry in Electric Vehicles. Final Report. 2012.

[2] Ajanovic A.Recent developments in electric vehicles for passenger car transport. World Academy of Science, Engineering and Technology, Issue 75, March 2013, Madrid

[3] Chan C.C, The state of the art of electric, hybrid and fuel cell vehicles. Proceedings of the IEE. Vol.95, No.4, April 2007

[4] Bosch Automotive Technology. Systems for electric vehicles with range extender. http://www.bosch-automotivetechnology.com/en/de/powertrain/powertrain_systems_for_passenger_cars_1/systems_for_electric_vehicles_with_range_extender/systems_for_electric_ vehicles_with_range_extender_1.html (08.02.2013)

[5] Wikipedia: http://en.wikipedia.org/wiki/Battery_electric_vehicle (05.02.2013)

[6] Ahman M. Government policy and the development of electric vehicles in Japan. Energy Policy 34 (2006) 433-443

[7] IEA. Hybrid and Electric Vehicle Implementing Agreement, Hybrid and Electric Vehicles: the Electric Drive Advances, March 2010

[8] OECD. Market Development for Green Cars, 2012.

[9] IEA.Tracking Clean Energy Progress. Energy Technology Perspectives 2012 excerpt as IEA input to the Clean Energy Ministerial, Paris: OECD/IEA, 2012.

[10] Malvik H.V, Hannisdahl O.H, Wensaas G.B. The future is electric! The EV revolution in Norway – explanations and lessons learnd. ECEEE 2013

[11] Kageson P. Reducing CO2 emission from new cars: A progress report on the car industry's voluntary agreement and an assessment of the need for policy instrument. European Federation for Transport and Environment, Brussels, 2005.

[12] Perdiguero J, Jimenez L. Plocy options for the promotion of electric vehicles: a review.IREA.Working paper 2012/8

[13] Reiner R, Cartalos O, Evrigenis A, Viljamaa K. Challanges for a European Market for Electric Vehicles, European Parliament, 2010

[14] Ajanovic A, Haas R. A comparison of technical and economic prospects of battery electric, hybrid and fuel cell vehicles. 2012 Asia-Pacific Power and Energy Engineering Conference. March 2012. Shanghai. China.

[15] Department of Energy. USA. One Million Electric Vehicles by 2015.Status Report, 2011.