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ENERGY ECONOMICS IN PASSENGER CAR TRANSPORT

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ABSTRACT

Rapidly increasing use of fossil fuels especially in the transport sector leads worldwide to problems such as local air pollution and greenhouse gas emissions. There is a growing need for transition towards low-carbon transport system. The core objective of this paper is to provide an appraisal of the long-term developments in passenger car transport from an economic and environmental point of view. The method of approach is based on dynamic economic assessments and scenario developments based on policies implemented and price developments. The major conclusion is that to increase future relevance of alternative automotive technologies it is necessary to continue research and development, to realize potential technological learning, especially for batteries and fuel cells. However, significant uncertainty regarding penetration of electric vehicles is how fast cost reductions will take place due to technological learning. Moreover, policy design will play a crucial role for the future technology and energy mix.

1. INTRODUCTION

Rapidly increasing use of fossil fuels especially in the transport sector leads worldwide to problems such as local air pollution and greenhouse gas emissions (GHG). There is a growing need for transition towards low-carbon energy systems. In opposite to all energy sectors, in which energy consumption was stable or decreasing over the last decades, in the EU in the transport sector, in spite of policies implemented, GHG emissions have been continuously increasing until 2007. Slight decrease in recent years was mostly due to economic crises; see Fig. 1.

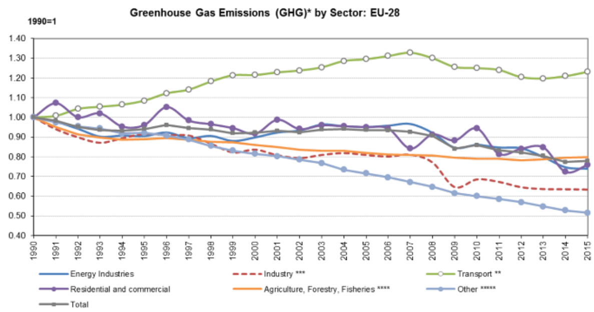

Fig.1 Greenhouse gas emissions in the EU by sectors [1]

Currently, in the EU-28, transport is responsible for about 23% of the total GHG emissions, see Fig. 2. The largest amount of these emissions is caused by road transport, especially passenger car transport (61%).

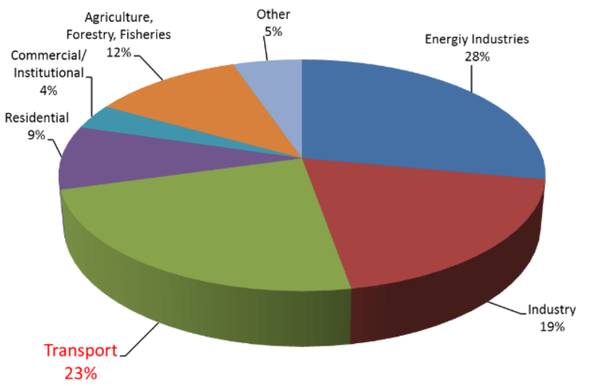

Fig. 2 Greenhouse gas emissions by sector: EU-28, shares of total emissions in 2015 [1]

The major challenges for the European energy and climate policy in the EU is to implement effective policies and measures with which is possible to reduce energy consumption in the transport sector, to reduce local air pollution as well as to mitigate global warming, see Fig. 3.

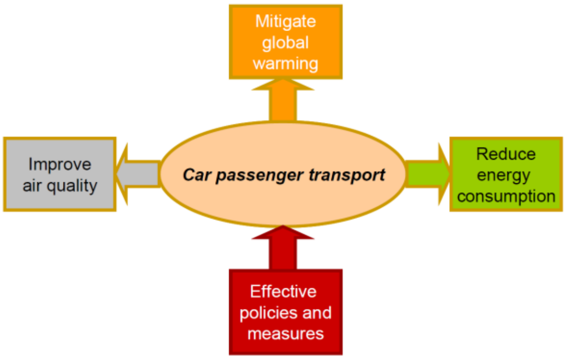

Fig.3 The challenges for the EU climate and energy policy [2]

Over the last decade, the major focus in the transport sector was on improvement of energy efficiency, increasing use of alternative fuels and electrification of mobility.

The core objective of this paper is to provide an appraisal of the long-term developments regarding the electrification of passenger car mobility from an economic and environmental point of view.

2. METHOD OF APPROACH

For the economic assessment we have calculated total costs of passenger car mobility in dependency on investment cost (IC), specific number of vehicle kilometres driven per year (skm), capital recovery factor (α), fuel/energy price (P_f), fuel/energy intensity of vehicles used (FI), and operating and maintenance costs ($C_{O\&M}$).

$$C_{km} = \frac{IC \cdot \alpha}{skm} + P_f \cdot FI + \frac{C_{O\&M}}{skm} \qquad (1)$$

A dynamic economic assessment is based on technological learning and scenario developments based on policies implemented and price development.

For the environmental assessment we have considered whole energy supply chain (Well-to Wheel) including different primary energy sources used for fuel or energy production, see Fig. 4. The method of approach is based on life-cycle-analyses.

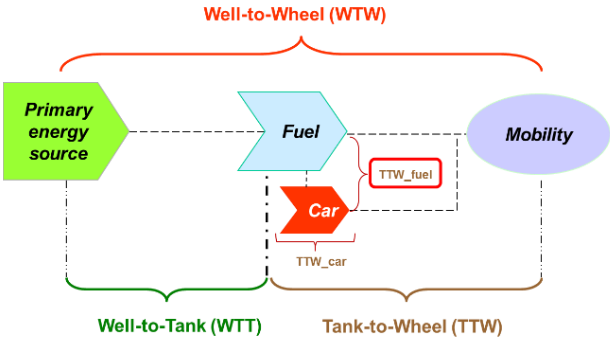

Fig.4 Energy supply chain

We have analysed five types of electric vehicles (Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs), Plug-In Hybrid Electric Vehicles (PHEVs), Range Extenders (REXs), and Fuel Cell Vehicles (FCVs)) in comparison to the conventional internal combustion engine vehicles powered by fossil fuels. All types of EVs analysed have different level of electrification (see Fig. 5), and could more or less contribute to the reduction of GHG emissions and local air pollution.

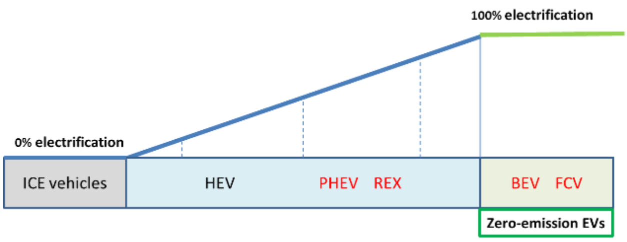

Fig.5 Level of electrification of EVs (based on [3])

3. BATTERY

One of the major challenges for the future development of e-mobility is further development of batteries regarding price development, energy density, and weight.

Different types of EVs need different battery capacities, see Fig. 6. Currently in the majority of the BEVs battery capacity is between 20 and 80 kWh.

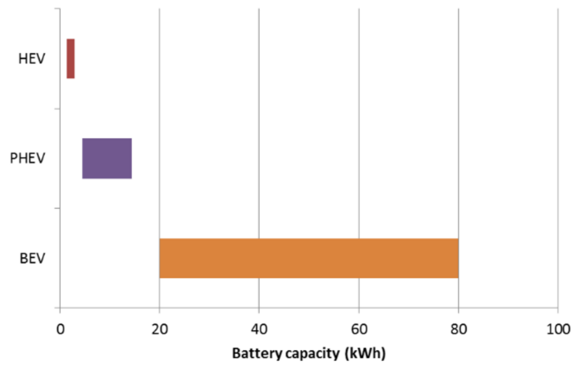

Fig.6 Battery capacity of EVs [4]

With the increasing battery capacity we can also increase driving range of vehicles. Figure 7 show relation between battery capacity and driving range for PHEVs and BEVs.

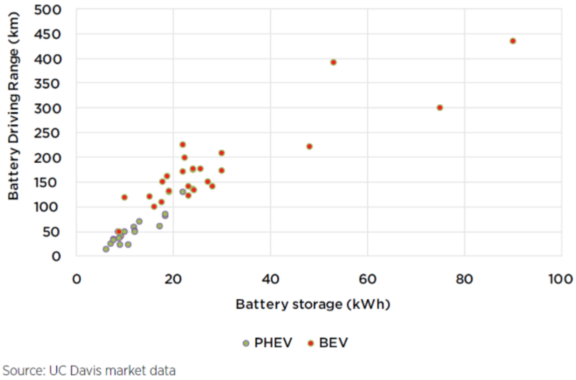

Fig.7 Battery capacity of EVs [5]

However, the problem is that with increasing battery capacity increase also battery weight making cars less efficient.

Although, the limited driving range of EVs is often seen as a barrier, the fact is that daily travel need in the most of cities could be covered by all types of EVs, see Fig. 8.

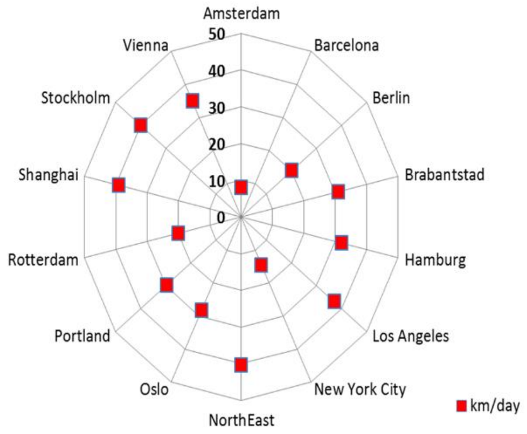

Fig. 8 Average driving range in cities [6-8]

Battery size is also related to the costs. Figure 9 shows development of the lithium-ion battery prices in period 2010-2016. Significant cost reductions have been reached over the last years but further reductions are necessary to make EVs economically competitive with the conventional cars.

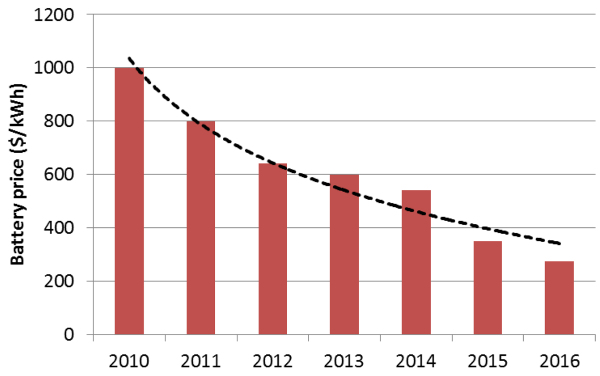

Fig. 9 Development of the lithium-ion battery prices (based on [9])

3. ELECTRIC VEHICLES: ECONOMIC AND ENVIRONMENTAL ASSESSMENT

Due to supporting policies implemented by many governments all over the world, the number of electric vehicles is slightly increasing. HEVs are mostly used type of EVs (see Fig. 10) since they are very similar to conventional cars. However, for the future of the special interest are rechargeable EVs with the higher level of electrification, see Fig. 5.

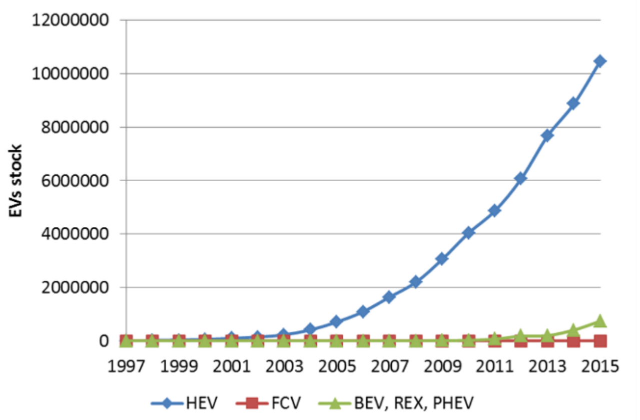

Fig. 10 Electric vehicles stock [10]

Battery electric vehicles and fuel cell vehicles are seen currently as most environmentally friendly option for passenger car transport in the future.
However, only if electricity and hydrogen are produced from renewable energy sources, BEVs and FCVs could considerably contribute to the reduction of GHG emissions, see Fig. 11. Total environmental benefits of EVs are very dependent on the available primary energy sources used for electricity and hydrogen production.

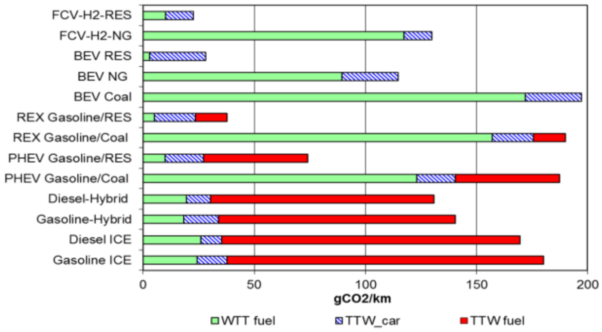

Fig. 11 CO_2 emissions per km driven for various types of electric vehicles in comparison to conventional cars (based on [11])

For faster market penetration of electric vehicles further cost reductions are necessary, especially in the case of FCVs and BEVs, see Fig. 12.

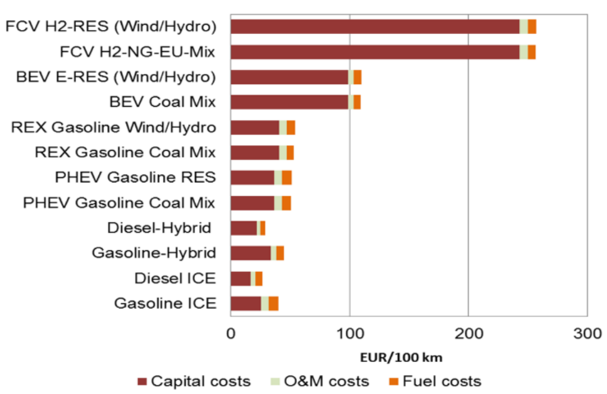

Fig. 12 Mobility costs of EVs in comparison to conventional cars (based on [12])

Over the last years some cost reductions have been already reached, and further technological learning can be expected in the future, see Fig. 13.

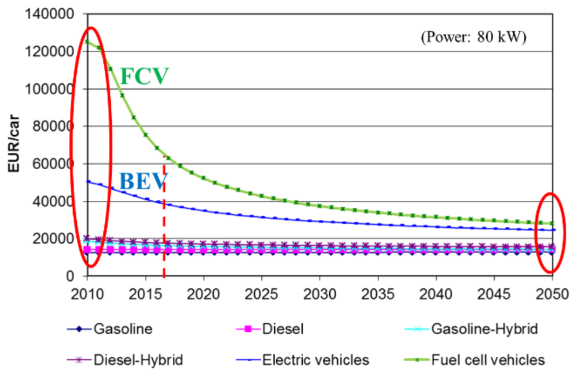

Fig. 13 Cost reduction due to technological learning (based on [12])

In the case of such developments future difference in mobility costs between EVs and conventional cars could be much lower, see Fig. 14.

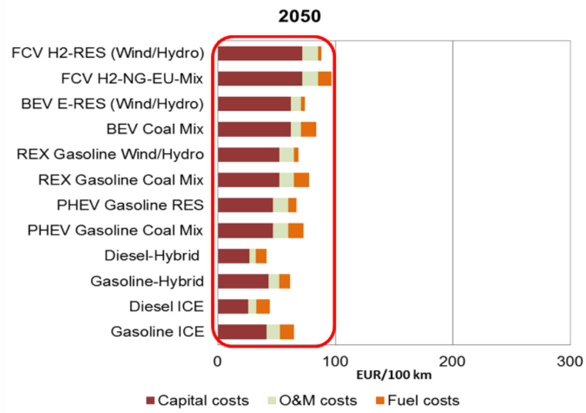

Fig. 14 Mobility costs of EVs in comparison to conventional cars, in 2050 (based on [12])

4. CONCLUSIONS

Electrification of mobility is recognised as a possibility for the reduction of GHG emissions from the transport sector. A broad portfolio of monetary and non-monetary measures has been implemented with the goal to make EVs more attractive.
However, in spite of all policies and measures provided, the electrification of passenger car transport has been relatively slow.
Between 1973 and 2015 total electricity consumption increased significantly (from 440 Mtoe to 1737 Mtoe) but the lowest increase was in the transport sector, see Fig. 15.

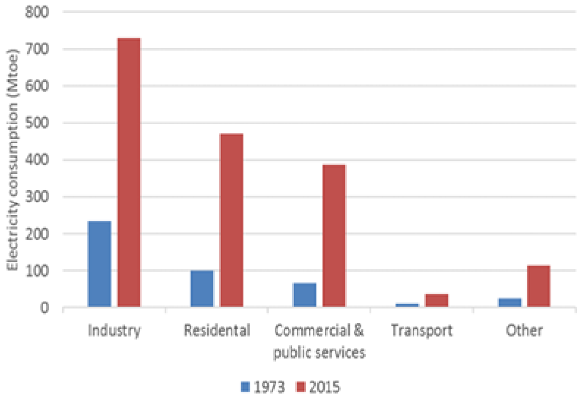

Fig. 15 Electricity consumption by sector [13]

To increase future relevance of alternative automotive technologies it is necessary to continue research and development, to realize potential technological learning, especially for batteries and fuel cells.

The major uncertainty regarding BEV and FCV is how fast cost reduction due to technological learning will take place. Finally, CO_2 costs (e.g. taxation) will play a crucial role for the final future fuel mix. For example, Oslo (in Norway) is a city with one of the highest penetrations of BEVs in the world. One major reason is that – due to different incentives – the driving costs of conventional cars are very high compared to rather cheap electricity costs for BEVs drivers.

Nomenclature

BEV battery electric vehicle
$C_{O\&M}$ operating and maintenance costs
E-RES electricity produced from renewable energy sources
EV electric vehicles
FCV fuel cell vehicle
FI fuel/energy intensity
GHG greenhouse gas
HEV hybrid electric vehicle
H_2*-RES* hydrogen produced from renewable energy sources
IC investment costs
ICE Internal combustion engine
NG natural gas
P_f fuel price incl. taxes
PHEV plug-in hybrid electric vehicle
RES renewable energy sources
REX range extender electric vehicle
skm specific km driven per car per year
TTW Tank-to-Wheel
WTT Well-to-Tank
WTW Well-to-Wheel

Greek Letters

α capital recovery factor

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