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Promoting Electric Vehicles for Sustainable Urban Transport: How to Do It This Time Right

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Abstract—In recent years various types of electric vehicles has gained again increasing attention as an environmentally benign technology in transport. Especially for urban areas with high local pollution this Zero-emission technology (at the point of use) is considered to provide proper solutions. Yet, the bad economics and the limited driving ranges are still major barriers for a broader market penetration of battery electric vehicles (BEV) and of fuel cell vehicles (FCV). The major result of our analyses is that the most important precondition for a further dissemination of BEV in urban areas are emission-free zones. This is an instrument which allows the promotion of BEV without providing excessive subsidies. In addition, it is important to note that the full benefits of EV can only be harvested if the electricity used is produced from renewable energy sources. That is to say, it has to be ensured that the use of BEV in urban areas is clearly linked to a green electricity purchase model. And moreover, the introduction of a CO2-emission-based tax system would support this requirement.

Keywords— Electric vehicles, economics, policies, history.

I. Introduction

In recent years battery electric vehicles (BEV) has gained again increasing attention as an environmentally benign technology in transport. Especially for urban areas with high local pollution this Zero-emission technology (at the point of use) is considered to provide proper solutions. Many countries (e.g. Spain) and cities (e.g. Oslo) has announced in recent years that they have high expectations on this technology. In other countries like Austria and Germany so-called model regions have been implemented which shall contribute to gaining experience on the practical handling of operating this technology.

However, looking at history it is not a new set of expectations that emerged with respect to BEV. By 1900 in the USA more EV than gasoline vehicles were in operation. In the 1970s after the first oil crisis there was a first wave of revivals of EV, [1]. Another resurgence took place at the early 1990s, this time mainly because of growing concerns regarding climate issues. However, these first trys for a take-up of BEV were not successful, mainly because of the high prices of the batteries and the still limited driving ranges of the cars.

The core objective of this paper is to investigate how to do it this time right. We analyze the current benefits and barriers of BEV in passenger transport for the efforts of a city to head towards a sustainable urban transport system. We analyse what are the prospects and what are the major impediments and put this analysis in a historical context. We try to extract what has changed in recent years compared to the former hypes of a re-introduction of EV. Yet the major goal is to identify which policies are proper to provide the right incentives. Moreover, we analyze whether different other types of EV like hybrids and fuel cell vehicles could be more promising. This analysis has been conducted within the EU-funded project ALTER-MOTIVE (www.alter-motive.org), [2].

In addition, to improve the energy efficiency of passenger cars continuously is one of most important instruments for combating increasing GHG emissions and climate change. Beside the technical improvements of conventional internal combustion engine (ICE), it is also important to improve the efficiency of alternative automotive technologies (AAMT) such as battery electric vehicles (BEV), fuel cell vehicles (FCV), and hybrid cars (HEV). These AAMT allow us also to use new, alternative and more environmental friendly fuels such as electricity and hydrogen from RES, see. Yet, the limited operating range, technical immaturity and particularly high costs are still the most important barriers for a broad market breakthrough of AAMT vehicles.

II. Waves of History

The history of electric vehicles (EV) can be categorized in three major phases: (i) Increasing popularity (about 1890-1920); (ii) Decline (after 1920); (iii) attempts for revival (after 1970).

EV had their historical high-time by the turn to the 20th century in the U.S. until about 1920. The electric passenger car was far more successful in the U.S: than in Europe [4]. At 1900 electric cars outsold all other types of cars. The nationwide registration of vehicles by 1900 was 936 gasoline, 1575 electric and 1681 steam in 1900 [1], [3]. In the major metro areas – New York, Boston and Chicago – EV outnumbered gasoline vehicles (GV) even by two to one [4], [5]. The major advantages of BEV over their competitors were that they didn't have the vibrations, smell and noise associated with gasoline cars, [1]. The range issue was not dominating at that time because the only good roads at that time were in

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cities, and most traffic was due to urban commuting. Hence, EVs in the time between 1890s to 1920s consistently served urbanized areas, rather than rural households [4]. This was a perfect situation for EV and their limited range. But also the first hybrids emerged at about 1916.

The decline of BEV started when in the 1920s a better network of roads outside the cities emerged, bringing with it the need for longer-range vehicles. Moreover, ICE vehicles were technically and economically – see next chapter – improved while the electric car stagnated. E.g. the need for the hand crank was eliminated by 1912 with the invention of the electric starter.

Afterwards, EV has virtually disappeared from the driving scene also in urban areas.

The first wave of revival started in the 1970 triggered in California after the first oil crisis and because of increasing concern about emissions. It led to the recognition "that gasoline vehicle emissions would have to be reduced sharply if the nation was to continue to rely on the automobile as the foundation for its transportation. In 1970, the "Muskie Act", the cClean air Act was passed" [4]. This first try to revie the EV led to increased research mainly by Toyota and Mitsubishi regarding hybrid vehicles. Resurgence took place at the early 1990s, this time mainly because of growing concerns regarding climate issues. However, these first try for a take-up of BEV were not successful, mainly because of the high prices of the batteries and the still limited driving ranges of the cars. Another major reason was from our point-of-view wrong incentives. E.g., in the 1990s the prevailing political approaches were subsidies, e.g. lower registration taxes and the attempt to build up a plug-in infrastructure. Yet the financial incentives did not provide a broad increase in customers' Willingness-to-pay and lack of infrastructure was obviously not the main problem. If we discuss the prospects we also have to look at the reasons why the EV has been virtually distincted at the end of the 1920s: limited range and expensive cars, mainly due to the battery.

III. Economic Assessment

Aside from the unfavorable technical problems of batteries and driving ranges another major problem was the development of economics. The major changes occurred between 1900 and 1920 [1], [3] and where rather attributed to favorable developments regarding the gasoline car. First the discovery of Texas Crude oil reduced the price of gasoline remarkably and made it affordable for average customers. Second, the emerging mass production of gasoline vehicles by Henry Ford made these vehicles widely affordable in a range of $500 to $1000 [1]. Yet, the prices of the less efficiently produced EV did not decrease.

This situation did actually not change up to now. In the following we analyze the fuel costs and the total costs of conventional vehicles as well as of BEV, HEV and FCV.

To evaluate the economics we compare the transport service costs per 100 km driven and per car and year. In this context different driving distances play a role. Our formal economic framework starts with calculating the total driving costs C_{drive} per year [7] and [9]:

$$C_{drive} = IC\ \alpha + P_f FI\ skm + C_{O\&M} \quad [€/car/year] \qquad (1)$$

The costs per km driven C_{km} are calculated as:

$$C_{km} = \frac{IC \cdot \alpha}{skm} + P_f \cdot FI + \frac{C_{O\&M}}{skm} \quad [€/100\ km\ driven] \qquad (2)$$

where:

IC……investment costs [€/car]
α……..capital recovery factor
skm…..specific km driven per car per year [km/(car.yr)]
P_f…….fuel price incl. taxes [€/litre]
$C_{O\&M}$…operating and maintenance costs
FI……..fuel intensity [litre/100 km]

The fuel price depends on the cost of fuel C_f, and possible VAT, excise and CO_2 taxes:

$$P_f = C_f + \tau_{CO_2} + \tau_{VAT} + \tau_{exc} \qquad (3)$$

The average fuel costs of service mobility in EU-*15 per 100 km driven* in passenger cars in 2010 are depicted in Fig. 1. It can be seen that virtually all types of BEV, HEV and FCV have cheaper fuel costs than gasoline cars. Diesel is relatively cheap mainly because of its better fuel intensity.

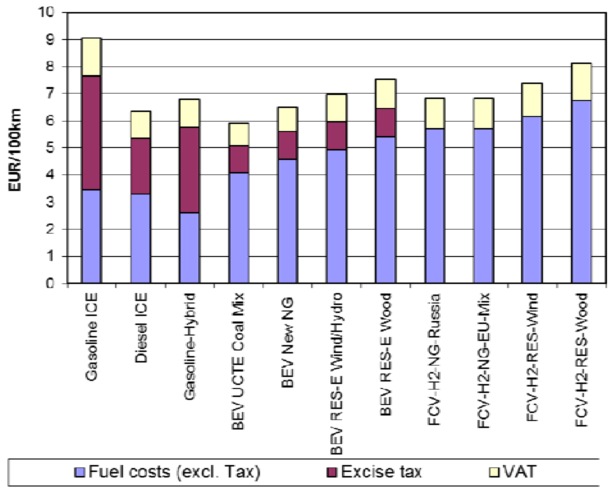

Fig. 1 Fuel costs of service mobility per 100 km driven in passenger cars in 2010 (Average of EU-15)

The fuel costs *per year* of service mobility in passenger cars in EU-15 in 2010 are shown in Fig. 2. Again, it can be seen that virtually all types of BEV, HEV and FCV have cheaper fuel costs than gasoline cars, given the same driving range. Diesel is relatively expensive mainly because of its higher driving range.

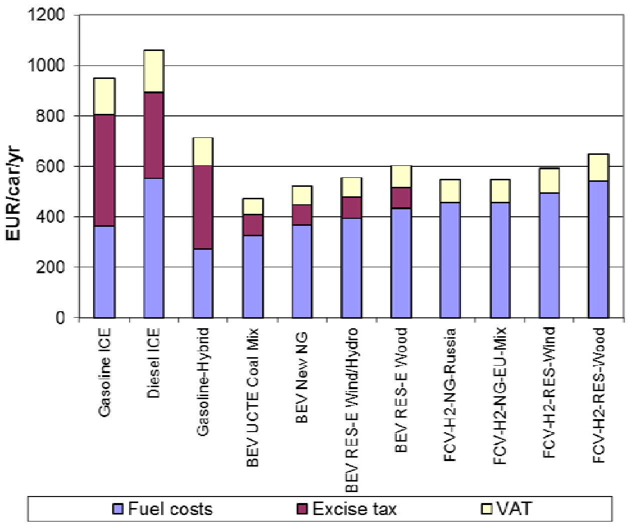

Fig. 2 Fuel costs per passenger car and year in 2010 (Average of EU-15)

Fig. 3 illustrates the cost structure of total costs of service mobility per 100 km driven of different types of cars in 2010. We can see that the advantages of alternative powertrains regarding lower fuel costs are more than compensated by higher capital costs in 2010. In this Fig. 3 diesel is cheapest because the capital costs are distributed over a higher number of specific km driven per car per year, see (2).

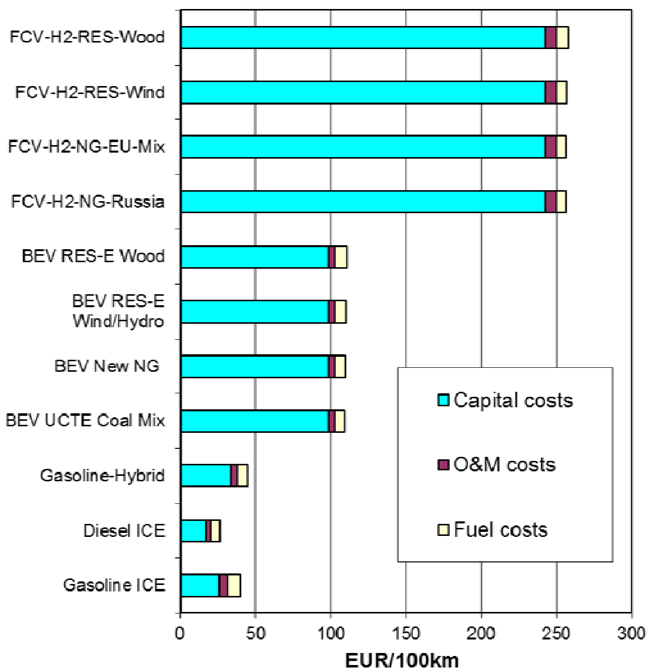

Fig. 3 Total costs of service mobility per per 100km driven in passenger cars in 2010 (Average of EU-15)

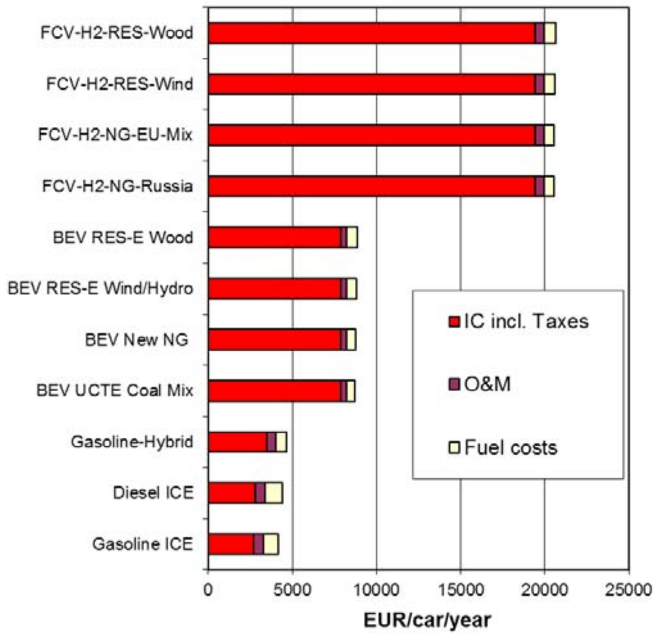

Fig. 4 Total costs of service mobility per passenger car and year in 2010 (Average of EU-15)

The total costs of service mobility per per passenger car and year in 2010 (Average of EU-15) are depicted in Fig. 4. Again, we can see that the capital costs dominate the cost comparison.

IV. Results from Historical Policy Analyses

In the project ALTER-MOTIVE cited above (see also [2]) an important issue was to analyze the effect of policies (top-down and bottom-up) implemented by national governments or at EU-level. The recommendations for policy makers derived from these comprehensive analyses of innovation and fiscal policies are:

Policy measures to support the introduction of any alternative technology need to be well-timed according to their current technological status. Therefore, the technology status should be carefully analysed before the introduction of measures. As sometimes the technological development and learning curve move ahead fast, close technology monitoring and flexible policies are suited best.

Each of the technologies discussed above requires a tailor-made approach, but also different framework conditions in the EU member states need to be considered in the choice of the policy instruments. For example, due to the specific economic importance of car manufactures in Germany the development of more efficient cars such as electric and fuel cell vehicles plays an important role in designing polices.

With respect to the considered technologies the major perceptions are (see also [2], [6] and [8]):

Hybrid electric vehicles: Main barrier are high vehicle costs in comparison to conventional vehicles. Support measures that bring the costs of vehicles down are successful, especially measures that make the private use of company cars (lease) more attractive.

Fuel cell vehicles based on Hydrogen: The main barriers are the initial cost of fuel cell vehicles (consumers) and high upfront investments in infrastructure (industry). The costs of vehicles can be brought down by (i) R&D and learning-by-doing in demonstration projects and (ii) reaping scale advantages of mass production. This requires support for R&D and demonstration projects on the one hand and direct support to bring down the costs of the first batches of vehicles on the other hand. Infrastructure investments can be triggered by implementing measures that offer a viable long-term perspective to fuel providers, but also by more direct measures such as investment subsidies and accelerated depreciation. Locally initiated hydrogen implementation projects (bottom-up) provide first experiences with technology and grow out into corridors (links) to other hydrogen application centres. With limited availability of hydrogen passenger cars, public transport buses or niche applications can be a starting point.

Battery electric vehicles: Main barriers are high initial vehicle cost (in particular for batteries) and limited driving ranges. Support should aim to lower cost through battery R&D and demonstration projects (learning by doing and volume effects). More experiences are needed regarding what coverage of charging infrastructure is really required (and will be utilized) by end-users. Consumer incentives are suitable to provide a financial relief to reduce initial high vehicle cost, either in form of tax incentives or as a direct subsidy.

V. Reducing CO_2: At Which Costs?

The crucial question is of course "How much do citizens have to pay for achieving these goals?" The most important policy measures for the reduction of CO_2 emissions in passenger road transport according to EU goals for 2020 are fuel tax, standards, registration tax and E-mobility. With an appropriate mix of these measures in an Ambitious policy scenario we can reduce CO_2 emissions in 2020 for about 100 million tons CO_2-eq comparing to business as usual scenario (for further details see [2]).

In the following we give a survey on the costs of various measures to head towards a least-cost approach. Fig. 6 shows the basic principle of a least-cost approach. The different measures are put in a least-cost order including the possible saving potentials up to 2020 for achieving finally 100 million tons CO_2 reduction which corresponds to about 20% CO_2 reduction compared to 2008.

The method of approach of identifying these costs is based on calculation of total costs for society and resulting CO_2 reductions:

- For taxes these costs are the over-all welfare losses for society due to a tax divided by CO_2 savings;
- For the technologies we consider the additional investment costs of the technology and the energy cost reduction for the customers (purchasers of cars) respectively the increased producer surplus if the technology is produced in the region;
- For alternative fuels we have to consider the additional production costs minus the increased producer surplus if the technology is produced in the region.

For the last two categories it is furthermore important to consider the technological learning effect. Moreover, we have assumed that 75% of the value chain of new technologies is produced within the EU countries and hence these additional costs are converted into producer surplus.

The CO_2 reduction effects and the corresponding costs of the measures considered in the above categories for the aggregate of EU-15 countries are depicted in Fig. 5.

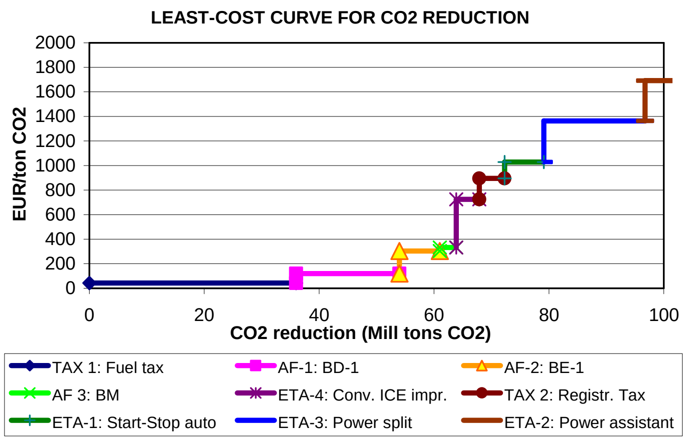

Fig. 5 Least-cost curve for CO_2 reduction in passenger car transport in the EU-15 in 2010

The major result of this analysis is that the costs of taxes up to 36 million tons CO_2 reduction at a price of about 40 EUR/ton CO_2 are cheapest for society. So reducing especially the vkm driven and valuing the corresponding welfare loss has the first priority. Next cheapest is switch to biofuels first generation – biodiesel, bioethanol and biogas (BM). This implies that by 2020 biofuels save at least 70% CO_2 compared to fossil fuels. Based on this pre-condition these biofuels in our scenario save 28 million tons CO_2 at costs between 180 and 350 EUR/ton CO_2. Measures of technical efficiency improvements – starting with start/stop automatics, over electric power assistants (mild hybrids) to power splits (full hybrids) and efficiency improvements of the classical gasoline and diesel engine – are in the range of about 1000 to 1500 EUR/ton $_{CO2}$. The most expensive measures are to promote fuel cell cars and battery electric vehicles with saving costs above 2000 EUR/ton CO_2. This is the reason why neither BEV nor FCV show up in this figure for least-cost reduction of 100 million tons $_{CO2}$. Also BF 2nd generation are not among the least-cost solutions up to 2020 and do, hence, not show up in Fig. 6.

Yet, most of these technological solutions are still in the early phase of market introduction. Given that a continuous adaptation of these technologies takes place up to 2020 a remarkable cost reduction of these technologies is possible. However, even if this takes place up to 2020 fuel tax will remain the cheapest solution for CO_2 reductions.

The principle of the cost calculations can be visualized by means of the following example. We analyze the costs of hybrid electric vehicles. They save about 0.9 litre gasoline per 100 km. With a driving distance of 12000 km this is 108 litre/car and year or 252 kg CO_2-eq. The corresponding investment costs are 1700 EUR/car or 340 EUR/car/year with a capital recovery factor (C.R.F) of 0.2. Assuming that 75% of this investment contributes to producer surplus of the European companies, the costs are 85 EUR/0.25 ton CO_2-eq, this is about 340 EUR/ton CO_2-eq.

VI. Priorities of Actions Today, Up to 2020 and Beyond

In order to achieve e.g. the GHG emission reduction target of -80% in 2050, the transport sector will need to contribute its share. Most emission reduction potential is expected to come from the de-carbonization of transport fuels (through electric vehicles and hydrogen fuel cells powered by energy from sustainable sources) which represents a big challenge for policy makers in the next decade. Therefore, framework conditions need to be shaped now in order to prepare for a successful market introduction of those innovative transport technologies with high carbon abatement potential.

Derived from the perceptions described above our suggestions for action lead to the following recommendations (see also [2]):

Battery electric vehicles and fuel cell vehicles may to some extent contribute to a relief of over-all CO_2 emissions and may especially in cities contribute to improve air quality.

Yet, the potentials for market penetration of and CO_2 reduction up to 2020 are very limited for all three major technologies (BEV, FCV and HEV). In an optimistic scenario the number of BEV in EU-15 will grow to a stock of about 528.000 cars in 2020 leading to less than 1% CO-reduction (because the overall stock of cars remains at about 200 millions).

In addition, the overall ecological performance of BEV strongly depends on how electricity is generated, how the battery performs ecologically and whether actually conventional passenger cars are substituted or additional transport is triggered.

Regarding infrastructure for E-mobility: In most cities an infrastructure sufficient for the needs of the next years already exist. No further financial public support is needed. There should rather be an agreement between the electricity supply of the industry and (local) policy makers to provide a minimum reliable infrastructure at connection points to public transport, park & ride, airports and other crucial locations. Hence, it is recommended that the electricity supply industry and municipalities design joint roadmaps for an efficient development of infrastructure.

Regarding infrastructure for hydrogen vehicles: Experts - especially from Germany - expect that up to 2020 the market introduction of H_2 based vehicles will have started at least in some parts of Europe. We suggest that based on the model region concept for specific areas road-maps considering infrastructure and market introduction of cars will be developed.

The major result of our analysis is that currently the bad economics and the limited driving ranges are still major barriers for a broader market penetration of BEV and FCV. With respect to cities an important approach is on an international level should be to start the electrification of those car categories with the highest driving distances like taxis. They should world-wide be the first to switch to electric cars. The major reason is, that they will have the best balance between driving range per trip and battery size. Furthermore, the most important precondition for a further dissemination of BEV in urban areas are emission-free zones. This is an instrument which allows the promotion of BEV without providing excessive subsidies.

Another major result is that the full benefits of EV can only be harvested if the electricity used is produced from renewable energy sources. That is to say, it has to be ensured that the use of BEV in urban areas is clearly linked to a green electricity purchase model see also (see also [6], [7], [8], [9]). Hence, in parallel to the market introduction of BEV the corresponding deployment of new renewable electricity capacities must be ensured and proven by certificates. And moreover, the introduction of a CO_2-emission-based tax system would support this requirement.

The most important conclusion for BEV is that providing subsidies for its promotion is wasted money. Urban planning incentives are of much higher relevance for the proper introduction of BEV in urban areas.

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