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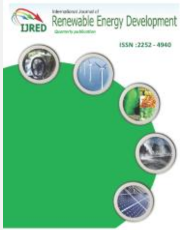

Financial Measures for Electric Vehicles: Supporting the Integration of Renewable Energy in the Mobility Sector in Germany

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ABSTRACT: Electric vehicles (EV) are able to support the transition of sectors towards sustainability. The operation of these vehicles with renewable energies saves local and global emissions. Furthermore, fluctuating renewable energies can be integrated in existing energy systems by using electric vehicles for grid services. Thus, implementation of advantages requires market establishment of electric vehicles. The article provides a review on potentials of market development by comparing and studying costs of electric and conventional vehicles as well as effects of financial measures on costs of EV. These cost comparisons are based on market data and predictions of cost developments for private consumers in Germany. Costs are analysed by an economic model of Total Cost of Ownership (TCO), aiming to display financial proportionality between vehicles in different years of acquisition (2010 to 2030). In a further step, external financial measures are analysed and integrated in the cost model as one possibility to enhance and secure the market introduction. Findings demonstrate that higher costs of acquisition of electric vehicles cannot be compensated by lower costs of operation. While mobility costs of conventionally vehicles stay constant or even increase during the considered years, mobility costs of electric vehicles significantly decrease especially in the upcoming years. In all cases mobility costs of electric vehicles exceed costs of conventional vehicles, but differences are reduced from 19€ct in 2010 to 3€ct in 2030. Cost decreases of the battery have high influence on the increasing financial comparability of EV. Concerning financial measures especially a differentiation of energy prices and a compensation of grid services can help to decrease total costs of EV and to manage a shift from fossil energy resources to electricity in the mobility sector. The existing tax exemption for EV compensates only a little fraction (about 6%) of the cost difference. This highlights the importance of research on incentive schemes to support market integration of EV and thereby the integration of renewable energies in the mobility sector. This integration is supported by the possibility of storing surplus fluctuating renewable energy in the batteries of EV.

Keywords: Electric Vehicle Taxation, Energy Prices, Grid Services, Incentive Schemes, Renewable Energy Development, Sustainable Mobility

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1. Introduction and Motivation

Private mobility displays an elementary function of today's economic and private life, but major challenges increasingly demand the transition of systems towards sustainability. Technical advances, regulations and emission caps were used in the past in all end-use sectors to reduce energy consumption. But still, the mobility sector in Germany is responsible for 19% of

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overall greenhouse gas emissions (Umweltbundesamt 2011) without significant decreases in the past. In addition, the mobility sector is nearly completely dependent on mineral oil (Arbeitsgemeinschaft 2009), renewable energies are integrated in the mobility sector only in a very little amount.

Electric vehicles (EV) have the potential to lower emissions, support the integration of renewable energies in the mobility sector with the diversification of energy resources and furthermore contribute to the transition of the mobility sector into an environmental friendly system (Granovskii *et al*. 2006; Ernst *et al*. 2011). The operation of vehicles with electricity reduces local and global emissions if the electricity is generated from renewable resources. By this, EV display a relevant technology for the transition of the mobility and energy sector. To implement the advantages of this technology, the German Government favours the integration of EV (German Federal Government 2009). Furthermore, financial measures - as one form of incentive schemes - are one possibility to support the market integration by reducing the total costs of EV. Comparable or lower costs in comparison to conventional vehicles represent one of the most important conditions for the purchase of electric vehicles (Sommer 2011). However, the advantages of EV can only be realised if EV can successfully be integrated into the market.

This situation leads to the research questions: Which financial measures can efficiently support the market integration of EV in Germany for private consumers by the reduction of costs? Which impacts on the costs of vehicles and on the integration of renewable energies are linked to these measures?

Effects of the grid integration of EV on energy supply structures have been examined in the research project NET-ELAN (Linssen *et al*. 2012). With reference and in this context, this research focuses the effects of financial measures on the cost structures of EV and the integration of renewable energy resources in the mobility sector.

In the first part of this article costs of vehicles are analysed, summarised and presented with an economic model. The next step provides an overview of financial measures from various actors considering the type and the goal. The focus is put on measures that also support the integration of renewable energy. In the following, selected financial measures are integrated in the analysis of costs of EV. By this, the cost-effect can be investigated for the total costs as well as the type of costs in the lifetime of a vehicle. Finally, the last chapters summarise and discuss the results, followed by a conclusion and outlook.

By displaying concrete effects of financial measures for EV this article provides an analysis of possibilities to support the integration of EV in combination with the integration of renewable energies in the mobility sector. Although this analysis is conducted for Germany it is relevant for several countries as EV play an important role for the transformation of mobility sectors.

2. Material and Methods

2.1.Current State of Research

Recent studies have examined the economic efficiency of electric vehicles in comparison to conventionally driven vehicles (Ernst *et al*. 2011; van Vliet *et al*. 2011; Sharma *et al*. 2012; Lin *et al*. 2013). The battery plays an important role for the economic assessment and causes additional costs for electric vehicles. As a general result, costs of electric vehicles are exceeding the costs of conventionally driven vehicles today and in the near future. Also social external costs resulting from emissions of vehicles depending on the energy used for operation are considered in the studies of (Funk & Rabl 1999; Granovskii *et al.* 2006). External costs for emissions are large and significant. But due to high costs, also the internalisation of external costs would not give a clear advantage to electric vehicles. Furthermore, incentive schemes and political support schemes for EV have been analysed (de Haan *et al*. 2009; Mueller & de Haan 2009; Kley *et al.* 2010) using literature analysis and agent-based modelling. The effects of incentive schemes are dependent on the design of the incentive scheme and the reaction of the consumer.

As an extension to the existing research, this article combines the economic assessment of electric vehicles with the analysis of incentive schemes by direct integration into the economic model. Financial measures from various actors involved in the context of EV are considered - like car manufacturers or electricity producers - in addition to incentives from the government. By this, the effect on the costs of vehicles is directly visible.

2.2.The Analysis of Costs of Vehicles

EV compete with efficiency increasing internal combustion engine vehicles (ICE) in the market. In this context, it is important to know which costs are related to EV in comparison to ICE and if additional financial measures are needed to support the market integration of EV. For this, the method of Total Cost of Ownership (TCO) is used. All costs during the lifetime of EV are compared to costs of ICE with gasoline engines in the compact class. Furthermore, different years of acquisition (2010, 2015, 2020 and 2030) are considered to display impacts of cost developments. The analysis of vehicles in an economic context is referring to (Linssen *et al*. 2012).

2.2.1. *The Method of Total Cost of Ownership*

TCO include all costs over a given lifetime of a product. This analysis is focusing on mobility costs (MC) to display the complete costs of vehicles in relation to their driving performance (equation 1). One-time costs are distributed equally over the whole lifetime by an annuity factor (equation 2). All costs are displayed in €2010. The calculation is conducted after the following formula 1:

$$MC\left[\frac{€}{km}\right]=\frac{(CSC+CNC)*a+FC+VC}{Tkm} \qquad \textbf{(1)}$$

with the annuity factor:

$$a=\frac{(1+r)^{T}*r}{(1+r)^{T}-1}. \qquad \textbf{(2)}$$

2.2.2. *Vehicles*

For EV the electric drive consists of the main components battery, electric engine and power electronics. The energy needed for the engine and all auxiliary consumers is supplied by a battery charged from the grid. The analysis exclusively considers battery electric vehicles (BEV) as electric vehicles. Hybrid electric vehicles that combine an electric drive with a combustion engine are not considered. BEV display the most efficient type of vehicles to reduce emissions and the dependency on mineral oil in the mobility sector. ICE are represented by an actual conventional gasoline vehicle that is available on the market today.

In the analysis, BEV have an assumed driving range of 120km as a result from a comparison between consumer preferences, real needs and reasonable costs (infas & DLR 2010; Sommer 2011). Additionally, it is assumed that this driving range is sufficient for all daily trips of the users of BEV. Hence, all daily distances can be provided without a loss in utility for the consumer. The electric drive train contains a battery with a capacity of 25kWh in 2010, derived from calculations based on the assumed driving range. The electric engine is assumed to have a drive power of 50kW; energy consumption is calculated according to the vehicle design.

Data for the conventional driven vehicle including vehicle design, energy consumption and costs are taken from ADAC data base (ADAC 2013). For 2010 the reference vehicle in the compact class follows the data of a Ford Focus with drive power of the combustion engine of 77kW.

2.2.3. *Assumptions*

The calculation is carried out for private costs of consumers regarding different points in time to display and account for cost developments within time. In the following, the years 2010, 2015, 2020 and 2030 are considered as years of acquisition. Value added and energy taxes are included in the assumed costs. A total lifetime of 11 years is assumed with a yearly driving performance of 11,700km (Bundesministerium für Verkehr Bau und Stadtentwicklung (BMVBS) 2013). A discount rate of 5% for costs is additionally assumed to meet the loss in value of money in time.

2.2.4. *Costs of Acquisition*

Costs of acquisition follow the assumptions of (Blesl *et al.* 2009) and are displayed in Table 1. The battery of BEV has to be purchased by the consumer of the vehicle. Cost developments of 850€ in 2010, 450€ in 2015, 325€ in 2020 and 250€ in 2030 are assumed in this analysis, following average values of an extensive literature analysis (Anderman 2009; Biere *et al.* 2009; Hackbarth *et al.* 2009; Richter & Lindenberger 2010; The Boston Consulting Group 2010).

General cost increases of 0.4% per year for standard components of vehicles are considered (car body, combustion engine and drive train). These cost increases account for improvements in efficiency in the components. At the same time improvements in the electric engine as well as battery technology and efficiency are expected, resulting in smaller battery capacities, sizes and costs. Consequently, a cost decrease of 35% for the electric engine and of 70% for the power electronics is assumed until 2030 (Blesl *et al.* 2009).

Costs for infrastructure are considered as a one-time payment of 800€ for the charging of the vehicle at home and additional costs. Charging at home displays a very important factor of a future charging infrastructure (Biere *et al.* 2009).

2.2.5. *Fixed Costs of Operation*

Fixed annual costs are assumed to account for 3% of the purchase price (Blesl *et al.* 2009). Maintenance costs are dependent on the driven km (California Air Resources Board (CARB) 2000) and account for 3.6€ct/km (reference vehicle) and 2.4€ct/km (BEV).

2.2.6. *Variable Costs of Operation*

Costs for electricity and fuel follow the calculations of the energy scenarios of (ewi, gws, prognos 2010). This reference displays quite moderate price developments of electricity with 0.234€/kWh in 2010, 0.236€/kWh in 2015, 0.238€/kWh in 2020 and 0.243€/kWh in 2030 as well as fuel with 1.42€/l in 2010, 1.46€/l in 2015, 1.51€/l in 2020 and 1.68€/l in 2030. Values for 2010 refer to (BMWI 2011).

2.3. *Overview of Financial Measures for Electric Vehicles*

Financial measures can influence the TCO - and by this the economic efficiency - of EV and support their market integration. The German Government supports

Table 1
Total Costs of Acquisition (€) for Different Years

	2010		***2015***		***2020***		***2030***	
	Ref. Vehicle	**BEV**	**Ref. Vehicle**	**BEV**	**Ref. Vehicle**	**BEV**	**Ref. Vehicle**	**BEV**
Battery	-	20,995	-	10,125	-	6,825	-	4,725
Car Body	16,165	16,165	16,490	16,490	16,825	16,825	17,510	17,510
Comb. Engine + Drive Train	2,310	-	2,355	-	2,405	-	2,505	-
Tank	125	-	125	-	125	-	125	-
Electric Engine	-	925	-	845	-	765	-	600
Power Electronics	-	1,020	-	825	-	665	-	310
Total Costs of Acquisition	18,600	39,105	18,970	28,285	19,355	25,080	20,140	23,145

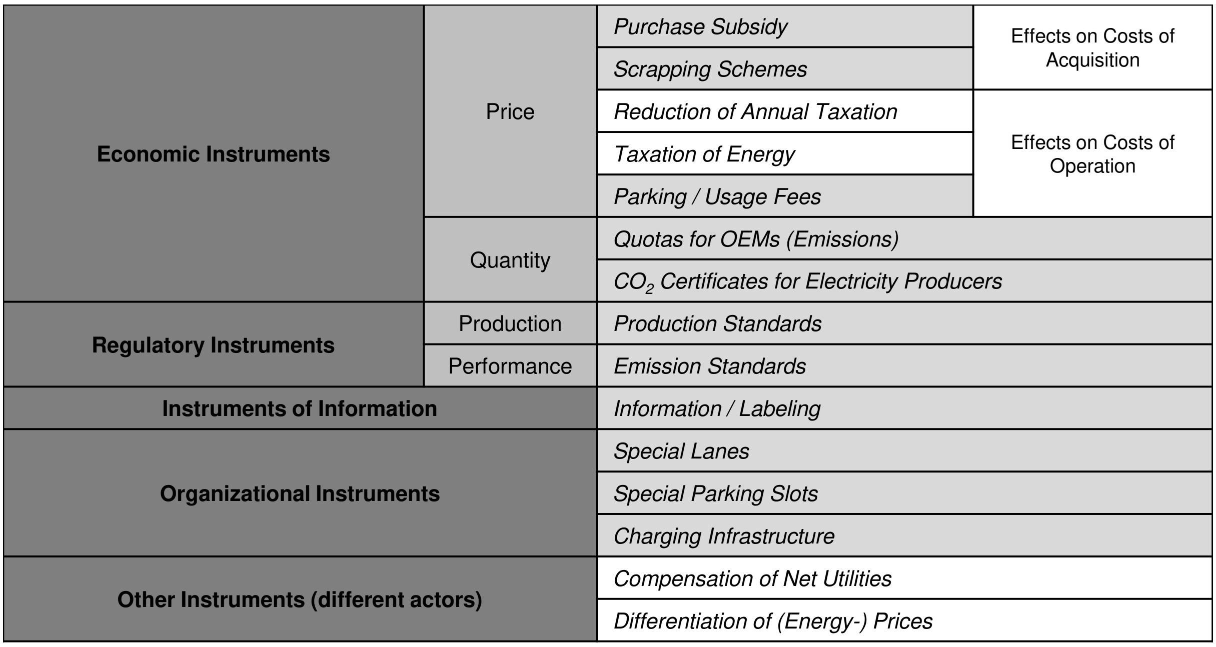

Fig. 1 Overview of Incentive Schemes

the market integration of EV with the aim to establish 1 million EV in the market until 2020 and 6 million vehicles until 2030 (German Federal Government 2009). A variety of research projects and demonstration activities are in operation by now. Furthermore, the annual taxation of vehicles has been reformed in 2009, including special conditions for EV. However, in contrast to other (European) countries, no financial measures for the purchase of vehicles are in operation in Germany today.

Incentive schemes can be set by the government, but also from other actors in the context of electric mobility. E.g. financial measures from electricity producers or OEMs can support EV by offering special prices and tariffs. In addition to financial measures, incentive schemes can appear as non-monetary incentives. Referring to (Kley *et al.* 2010) Fig. 1 summarises possible incentive schemes exemplarily and shows selected applications. Hatched regions are analysed regarding their effect on the TCO of EV in the following chapter.

3. Result and Discussion

3.1.Total Cost of Ownership of Vehicles

The calculated results of TCO in the given frame of analysis for the selected vehicles point out that differences between BEV and ICE arise in different areas. In the costs of acquisition differences between BEV and ICE occur on the one hand due to lower costs for the engine for the BEV but high additional costs for the battery – resulting in financial disadvantages. In contrast, BEV can mainly obtain financial advantages in the area of variable operation costs due to higher efficiency of the electric engine and lower costs for electricity.

Fig. 2 illustrates the costs structures of considered vehicles. Percentages of costs are divided into costs of acquisition, additional battery costs, fixed and variable costs of operation. In general, battery costs are part of the costs of acquisition. Here, battery costs are displayed separately to particularly highlight the high share in the TCO for BEV.

In all cases costs of acquisition including battery costs account for the highest share. For the reference vehicle costs of acquisition display 54% in 2010, increasing up to 65% in 2030 – resulting from technical development and necessary improvements in efficiency of standard components of vehicles. Nevertheless, acquisition costs of BEV exceed the costs of conventional vehicles in all cases and constantly account for 72% to 74%. Proportionally higher costs of acquisition of BEV can nearly be explained completely by additional costs for the battery. Therein, the share of battery costs decreases significantly over the years (39% to 14% of the total costs), leading to decreasing importance of battery costs for electric vehicles. For operation costs, fixed costs stay mainly constant for both vehicles, while on the other hand especially in variable costs BEV enhance cost savings against ICE due to higher efficiencies of the electric engine and lower costs for energy. In 2010 variable costs of operation account for 26% for ICE and only 8% for BEV. As the share basically stays constant for BEV during the considered years, the share of variable operation costs for ICE decreases up to 14% in 2030. Although energy related cost increases are considered in the model, increasing costs of acquisition and increasing efficiencies of the engines overtake rising energy costs – resulting in constant or decreasing shares of variable costs. In summary, cost structures of BEV approximate to cost structures of conventionally driven vehicles mainly due to the decreasing role of battery costs. This trend forms the initial situation for decreasing total costs of BEV and thereby financial comparability.

Looking at mobility costs (Fig. 3) it can be seen that lower costs of operation of electric vehicles cannot compensate higher costs of acquisition in comparison to the reference vehicles today (in 2010) and in the next years (until 2030).

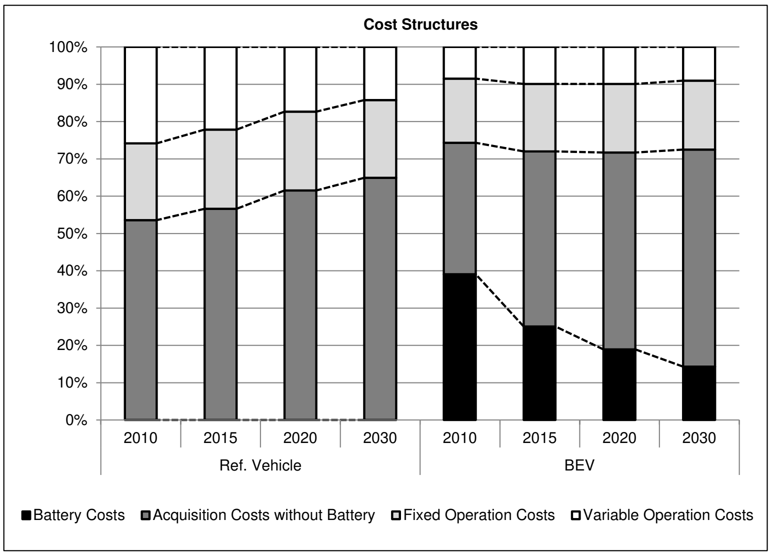

Fig. 2 Cost Structures of Vehicles

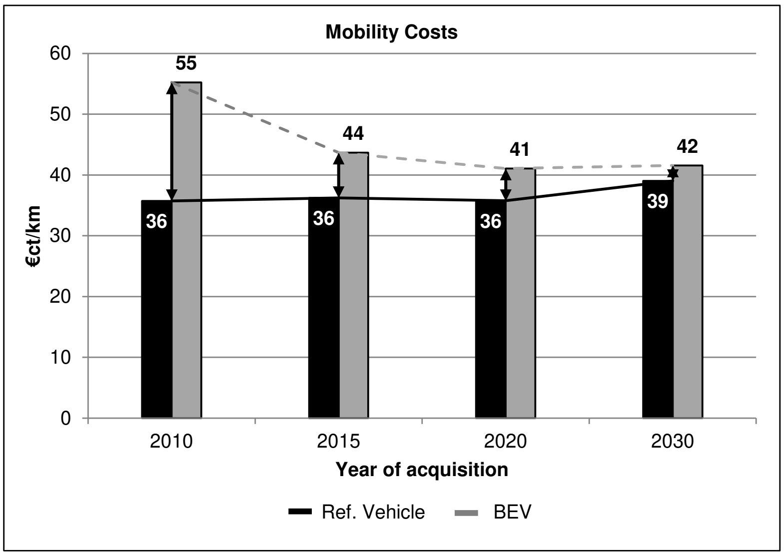

Fig. 3 Mobility Costs of Vehicles

Mobility costs of the reference vehicle stay constant between the years of acquisition 2010 and 2020. Higher costs for vehicle components and energy are offset by increasingly efficient engine technologies and decreasing fuel consumption. Especially cost increases of the engine and car body lead to an increase of mobility costs in 2030. In contrast, clear decreases of costs are visible for BEV between 2010 and 2020, resulting from efficiency increases and cost decreases of the new components like battery, electric engine and power electronics. The largest decrease arises between the acquisition years 2010 and 2015. This also clarifies the importance of battery cost developments for the economic assessment of BEV. Again, in 2030 increases of costs for the car body and for the operation of vehicles due to higher prices for gasoline and electricity influence and increase the TCO of vehicles. For the considered BEV, mobility costs rise slightly by 1€ct/km in 2030. For vehicles in general it may be assumed that this increase is the bigger the smaller the degree of electrification. In summary, within the given assumptions mobility costs of BEV exceed mobility costs of ICE for all considered years of acquisition. But as especially battery costs decrease, mobility costs of BEV approximate to mobility costs of ICE. In 2030, mobility costs of the considered BEV exceed the mobility costs of ICE by only 3€ct/km. Further improvements of the financial comparability can be expected for future years.

3.2. Impact of Financial Measures on the TCO of Vehicles

The analysis of costs has shown that additional measures are necessary to support the economic comparability of EV to ICE and by this achieve the advantages of electric mobility including the integration of renewable energy into the mobility sector. Here, the measure of external financial support for electric vehicles is considered. The impact of financial measures is demonstrated by the specific calculation of an example within the TCO analysis. This article thereby analyses and considers the impact on TCO of:

- the taxation of vehicles,
- a compensation of grid services,
- a differentiation of energy prices.

The article focuses on this selection of financial measures to especially consider incentive schemes that not only support the market integration of EV, but also promote a reduction of emissions as well as the integration of renewable energy resources in the mobility sector. Of course, other financial measures - like e.g. buying incentives - are possible to support the market integration of EV. After the calculation of TCO the impact of a buying incentive is easy to calculate. The TCO summed up over the whole lifetime is reduced by the amount of the buying incentive. Thereby, the used energy for the operation of EV is not necessarily considered. The above-mentioned financial measures are more complex to analyse and their impact on TCO and mobility costs is not immediately visible.

For the analysis 2015 is considered as the year of acquisition. This year seems reasonable as costs of EV and ICE should be comparable to this time to manage a market integration of EV and reach the goal of 1 million EV until 2020. The analysis of TCO results in additional costs of acquisition of 12,753€ for the BEV in comparison to the reference vehicle. On the contrary, the sum of fixed and variable costs of operation results in a cost advantage of 2,660€ for the lifetime of 11 years. Consequently, a cost difference of 10,093€ remains for the BEV. If costs of the BEV and the reference vehicle should be approximated, a compensation of this amount is necessary for the BEV. During the lifetime this compensation results in 918€ per year.

3.2.1. Taxation of Vehicles

Annual vehicle taxation has been reformed in July 2009. It includes a component for new vehicles considering the CO_2-emissions during operation (Gawel 2011). By this, fixed costs of operation are influenced. The taxation of vehicles displays the only financial incentive for BEV for private consumers in Germany until now. By this, not only electric vehicles enjoy tax privileges, also small and low-emission vehicles receive a financial advantage. For vehicles with a gasoline combustion engine, annual taxation consists of a basic amount of 2€ for each $100cm^3$ of cylinder capacity plus a CO_2 component of additional 2€ for every gram (g) CO_2 above limitation values. These values amount 120g CO_2 per km in 2010 and 2011, 110g CO_2 per km in 2012 till 2013 and 95g CO_2 per km from 2014. The taxation of BEV depends on weight. Partial amounts account for 11.25€ for every started 200kg until a vehicle gross weight of 2,000kg, between 2,000kg and 3,000kg for 12.02€ per every started 200kg and between 3,000kg and 3,500kg for 12.78€ for every started 200kg. All partial amounts are summed up and discounted by 50% for BEV. Additionally, for the first five years after initial purchase (for the first ten years after initial purchase between 18 May 2011 and 31 December 2015) BEV benefit from a complete tax exemption of annual vehicle taxes.

Under the given assumptions the annual vehicle taxation of the BEV accounts for 56€ per year. However, even the tax exemption only compensates a fraction of the required amount of 918€/year required to approximate TCO of BEV to the TCO of the reference vehicle. If the approximation of TCO should only be managed by the annual vehicle taxation, a complete tax exemption for BEV in combination with a tax increase for the reference vehicle to 862€ is needed. This measure seems unrealistic as it contradicts to the vehicle tax reform in 2009. Although the preferential treatment in the annual taxation of BEV is until now the only financial measure in operation, it rather has a symbolic character.

Looking at the annual vehicle taxation in a more detailed way, in this context it is interesting that hybrid electric vehicles are not taxed like electric vehicles but like internal combustion engine vehicles instead. For this, the electric driving is considered to exhaust zero grams of CO_2 per km, only CO_2 emissions resulting from the combustion engine are considered for the calculation of the partial CO_2 tax amount. Since the internal combustion engine is very small and CO_2 emissions are usually beyond the limitations, these vehicles face a lower amount of taxation (in most cases even lower than BEV), although CO_2 emissions arise in any case due to the internal combustion engine. Also in these premises, the arrangement of the annual vehicle taxation to support BEV and the reduction and avoidance of CO_2 emissions remains questionable.

3.2.2. Vehicle-to-Grid (V2G)

Other actors in the context of electric mobility (next to the government) can initiate financial measures to support the market integration of BEV. Electric vehicles and especially the batteries of those vehicles offer the possibility to supply services to the grid. BEV can operate as controllable loads by intake and storage of surplus wind and solar energy as well as the feed in of those fluctuating renewable energies into the power grid. A necessary precondition is an attractive compensation of these grid services. It has to be considered that every charging/ discharging cycle reduces the lifetime of the battery and thereby has a negative monetary effect on the TCO of BEV - especially due to the high costs of the battery. Additionally, restrictions regarding the flexible usage of the vehicle may be linked with grid services, as the vehicle has to be connected to the grid at certain times. The compensation of grid services therefore should support the market integration of BEV by giving them a clear financial advantage and also financially account for the losses in charging cycles of the battery and usage of the vehicle.

Regarding the example, the approximation of TCO of BEV to the TCO of ICE by the compensation of grid services requires a compensation of 918€ each year. From a technical viewpoint the compensation of grid services from batteries mainly is expected for minute reserves or secondary balancing services (Heidingsfeld 2012). For 2015 the amount of 918€ cannot be expected under the given assumptions. Calculations point out that an amount between 50€ and 250€ for the compensation of grid services is more realistic (Hennings & Linssen 2010). The problem includes that among other things a market for grid services from the batteries of BEV does not yet exist. This is due to the small number of registered electric vehicles today. A market can only develop if the number of registered vehicles increases. In combination, the compensations from the existing market of grid services are too low to give BEV a clear economic advantage. Looking into the future, the additional use of BEV for grid services offers an interesting opportunity for financial compensation. Furthermore, this opportunity supports the integration of renewable energies in the mobility sector and the power grid. Research is needed in the future to analyse the development of a market especially for BEV as well as to analyse effects of grid services on losses in battery charging cycles and thereby on the TCO.

3.2.3. Differentiation of Energy Prices

A differentiation of energy prices as financial measure to support BEV can be initiated by several actors. On the one hand a differentiation of taxes and fees for gasoline and electricity is made by the government; on the other hand companies from the energy or mobility industry can offer special tariffs or contract conditions for BEV and thereby create incentives for consumers. Energy prices influence the variable costs of operation of vehicles. In the considered example, prices for electricity account for 23.6€ct/kWh and prices for gasoline account for 1.46€/l. With the assumed energy consumption, even the providing of electricity at no charge for BEV in 2015 would not be enough to approximate TCO of BEV to the TCO of the reference vehicle. In 2015 variable costs of operation solely account for 478€ per year for the BEV. Additional 440€ would be necessary for this approximation to fill the yearly gap of 918€. An additional opportunity could be the increase of prices for gasoline. With constant prices for electricity and the assumed energy consumptions, an increase of prices for gasoline of 103% to 2.96€/l would be necessary to balance TCO. Assuming that a price for gasoline of 1.46€ contains a proportion of 0.90€ for taxes and fees, the increase of the price only by measures of the government has to account for 167% of the value to 2.40€/l (plus 0.56€ as price for the energy). For 2015 all displayed measures in the differentiation of energy prices seem unrealistic as the only measure to support the market integration of BEV. Even though a differentiation of energy prices appears to be a promising measure - supported by expected rising prices for fossil energy - it not appears to be the only single measure to achieve an approximation of TCO of BEV and reference vehicles in the next years.

4. Summary and Discussion

The analysis of TCO has shown that combustion engine gasoline vehicles are economically advantageous to EV today and also in the near future. Higher costs of acquisition of BEV cannot be compensated by lower costs of operation. Also the structure of costs changes during the considered years of acquisition. In general, EV are competing against efficiency-increasing conventional vehicles. Along with cost increases for the car body and internal combustion engine especially reference vehicles show decreases in energy consumption. These decreases are offset by higher prices for gasoline, especially in 2030. For financial competitiveness of EV it is important to decrease especially costs of acquisition and further improve the battery, electric engine and vehicle design. The behaviour of future consumers is determining the economic success of electric vehicles. To ensure successful market integration, costs have to be decreased and the loss in utility of EV by limited driving ranges has to be as small as possible. This is influenced by the developments of infrastructure and battery technology.

The effect of selected financial measures to support the market integration by reducing costs of EV is displayed by an application example of the TCO-analysis. Analysed measures of different actors point out that the reduction of annual vehicle taxation for EV cannot solely achieve a financial advantage. A coordinated mix of measures - addressing costs of acquisition as well as costs of operation - appears to be the most promising measure for the balancing of TCO of EV and ICE. Thereby, a combination of the differentiation of energy prices and the usage of EV for grid services offers a promising possibility to support EV in the future. Furthermore, the combination of these measures supports the integration of renewable energies in the mobility sector as well as the power grid and reduces emissions from gasoline.

In the long run, electric mobility can only be successful if it evolves in the market without incentive schemes. Innovations in technology, production and costs have to be attained to achieve market success. Nevertheless, financial measures can help to overcome the first years of market integration of EV. Summarising, the development of electric mobility should go hand in hand with further development of renewable energy resources in Germany. Financial measures should always consider and aim at the support of the market integration of EV and the integration of renewable energies in combination.

Finally, it has to be mentioned that the research is highly dependent on the assumptions made. Different forms of cost developments can change the results for the costs of vehicles as well as for the effects of financial measures on the costs. Uncertainties in the assumptions of cost developments especially arise for new components of electric vehicles, like the battery or the electric drive. In these cases the choice of optimal technology is not yet finalised and has to be adapted to specific use cases of the vehicle. Certainty can only be achieved by experience yet to be made for the components in question. The level of uncertainty is dependent on the level of experience in production of the respective product. These uncertainties have to be considered in the interpretations of the results. Compared to other successful innovations - like e.g. flat-screen televisions - it becomes evident that costs of innovations often significantly decrease. If this can also be achieved for electric vehicles, market success may become possible at an earlier time point. Costs and availability of resources will also determine the market success of electric vehicles by having an effect on energy prices and on the costs of the electric drive. Next to energy resources, relevant resources in this case are e.g. neodymium for the magnets of the electric engines or lithium for the batteries. While cost increases in the resources for components will aggravate the situation for electric vehicles, cost increases especially for mineral oil will in reverse support electric vehicles. This development favors electric vehicles, as prices for gasoline rise faster than prices for electricity. The costs of disposal, the possibility of recycling of resources and the options for additional use of components (like the battery) after the lifetime of the vehicle will also influence costs of vehicles.

5. Conclusion and Outlook

The transformation of the mobility sector towards sustainability by the integration of renewable energies into this sector with EV can only be managed if electric vehicles evolve in the market. As costs of EV may hinder the market integration, financial measures can support the integration. Thereby, especially a differentiation of energy prices can help to give EV a financial advantage and to manage a shift from mineral oil to electricity in the mobility sector. With the storage of surplus fluctuating renewable energy in the battery of EV, those vehicles support the integration of renewable energies in the mobility sector and furthermore into the power grid. Additionally, a compensation of grid services helps to give EV a financial advantage in the future. A fundamental condition of the transition of the mobility sector towards sustainability is the operation of EV with electricity produced from renewable energy resources.

Besides the analysis of costs and financial measures, further research is needed in the field of production technology to achieve cost decreases within the production of electric vehicles and thereby become independent from external incentive schemes. Furthermore, the behavior of consumers needs further research, especially within the purchase decision. It remains questionable, if cost savings in the operation of vehicles over a long period of time are considered in contrast to the higher purchase price at the time of purchase. Only the overcoming of barriers of purchase decisions for electric vehicles enables market development and success.

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References

ADAC. (2013) Autodatenbank. Retrieved 29.04.2013, from www.adac.de

Anderman, M. (2009) *Value Proposition Analysis for Li-Ion Batteries in Automotive Applications*. 9th Advanced Automotive Battery Conference, Long Beach, USA.

Arbeitsgemeinschaft Energiebilanzen e.V. (2009) Auswertungstabellen zur Energiebilanz für die Bundesrepublik Deutschland 1990 bis 2008. Stand: September 2009. Berlin, Köln.

Biere, D., Dallinger, D., Wietschel, M. (2009) Ökonomische Analyse der Erstnutzer von Elektrofahrzeugen. *Zeitschrift für Energiewirtschaft (ZfE)* 2009(2), 173-181.

Blesl, M., Bruchof, D., Hartmann, N., Özdemir, D., Fahl, U., Eltrop, L., Voß, A. (2009) Entwicklungsstand und Perspektiven der Elektromobilität. Universität Stuttgart, Institut für Energiewirtschaft und Rationelle Energieanwendung, Stuttgart.

BMWI (2011) Entwicklung von Energiepreisen und Preisindizes Deutschland, Energiedaten Tabelle 26. Berlin.

Bundesministerium für Verkehr Bau und Stadtentwicklung (BMVBS), Ed. (2013). Verkehr in Zahlen 2012/2013. DVV Media Group GmbH, Hamburg.

California Air Resources Board (CARB) (2000) Staff Report. 2000 Zero Emission Vehicle Program.

de Haan, P., Mueller, M.G., & Scholz, R.W. (2009) How much do incentives affect car purchase? Agent-based microsimulation of consumer choice of new cars--Part II: Forecasting effects of feebates based on energy-efficiency. *Energy Policy* 37(3), 1083-1094.

Ernst, C.-S., Hackbarth, A., Madlener, R., Lunz, B., Sauer, D. U., & Eckstein, L. (2011) Battery sizing for serial plug-in hybrid electric vehicles: A model-based economic analysis for Germany. *Energy Policy* 39(10), 5871-5882.

ewi, gws, & prognos (2010) Energieszenarien für ein Energiekonzept der Bundesregierung. Basel, Köln, Osnabrück.

Funk, K., & Rabl, A. (1999) Electric versus conventional vehicles: social costs and benefits in France. *Transportation Research Part D: Transport and Environment* 4(6), 397-411.

Gawel, E. (2011) Kfz-Steuer-Reform und Klimaschutz. *Wirtschaftsdienst* 2011(2), 137-143.

German Federal Government (2009) German Federal Government´s National Electromobility Development Plan. Berlin.

Granovskii, M., Dincer, I., & Rosen, M. A. (2006) Economic and environmental comparison of conventional, hybrid, electric and hydrogen fuel cell vehicles. *Journal of Power Sources* 159(2), 1186-1193.

Hackbarth, A., Schürmann, G., & Madlener, R. (2009) Plug-in Hybridfahrzeuge: Wirtschaftlichkeit und Marktchancen verschiedener Geschäftsmodelle. *Energiewirtschaftliche Tagesfragen (et)* 59(7), 60-63.

Heidingsfeld, C. (2012) Festelektrolyt-Batterien: Ableitung potentieller Einsatzgebiete auf Basis einer technischen und wirtschaftlichen Bewertung. STE Student Research Report 01/2012. Forschungszentrum Jülich, Institut für Energie- und Klimaforschung - Systemforschung und Technologische Entwicklung (IEK-STE), Jülich.

Hennings, W., & Linssen, J. (2010) Welche Netzdienstleistungen können Elektrofahrzeuge sinnvoll erbringen? VDE Kongress "E-Mobility" 2010, Leipzig.

infas, DLR (2010) Mobilität in Deutschland 2008. Bonn, Berlin.

Kley, F., Wietschel, M., & Dallinger, D. (2010) Evaluation of European electric vehicle support schemes. Working Paper Sustainability and Innovation, No. S 7/2010. Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI), Competence Center Energy Policy and Energy Systems, Karlsruhe.

Lin, C., Wu, T., Ou, X., Zhang, Q., Zhang, X., & Zhang, X. (2013) Life-cycle private costs of hybrid electric vehicles in the current Chinese market. *Energy Policy* 55(0), 501-510.

Linssen, J., Schulz, A., Mischinger, S., Maas, H., Günther, C., Weinmann, O., Abbasi, E., Bickert, S., Danzer, M., Hennings, W., Lindwedel, E., Marker, S., Schindler, V., Schmidt, A., Schmitz, P., Schott, B., Strunz, K., & Waldowski, P. (2012) Netzintegration von Fahrzeugen mit elektrifizierten Antriebssystemen in bestehende und zukünftige Energieversorgungsstrukturen. Advances in Systems Analyses 1. Forschungszentrum Jülich GmbH. Zentralbibliothek Verlag, Jülich.

Mueller, M. G., & de Haan, P. (2009) How much do incentives affect car purchase? Agent-based microsimulation of consumer choice of new cars--Part I: Model structure, simulation of bounded rationality, and model validation. *Energy Policy* 37(3), 1072-1082.

Richter, J., & Lindenberger, D. (2010) Potenziale der Elektromobilität bis 2050 – Eine szenarienbasierte Analyse der Wirtschaftlichkeit, Umweltauswirkungen und Systemintegration. ewi, Köln.

Sharma, R., Manzie, C., Bessede, M., Brear, M. J., & Crawford, R. H. (2012) Conventional, hybrid and electric vehicles for Australian driving conditions – Part 1: Technical and financial analysis. *Transportation Research Part C: Emerging Technologies* 25(0), 238-249.

Sommer, K. (2011) Continental-Mobilitätsstudie 2011. Hannover.

The Boston Consulting Group (2010) Batteries for Electric Cars. Challanges, Opportunities, and the Outlook to 2020. BCG Focus, The Boston Consulting Group (BCG).

Umweltbundesamt (2011) National Trend Tables for the German Atmospheric Emission Reporting 1990-2009. Final version: 17.01.2011. Dessau.

van Vliet, O., Brouwer, A. S., Kuramochi, T., van den Broek, M., & Faaij, A. (2011) Energy use, cost and CO2 emissions of electric cars. *Journal of Power Sources* 196(4), 2298-2310.