

Costs and Willingness-to-Pay for Electric Vehicles

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Abstract Electric vehicles are hardly competitive against conventional vehicles with combustion engine today. A reason is the high cost which do not seem to match the value consumers attribute to using electric vehicles over conventional ones. In order to target the differences that exist between the costs of the electric cars and the users' willingness-to-pay (WTP), a parameter-based model has been set up. Using data from Singapore, we calculate the costs of a mid-range electric car and the users' WTP for it and confirm the assumption that the WTP is significantly lower than the costs. This difference is influenced by various technical, economic and regulatory parameters which can potentially be targeted to raise the WTP and reduce the costs. For the case of Singapore, modifying regulatory parameters like tax reductions for electric vehicles seem most suitable at today's vehicle costs, as vehicle taxes make up a large percentage of the purchase price. Modifying technical vehicle specifications like the battery capacity or the costs for them within a reasonable range does not yet equalise the costs and WTP.

1 Introduction

Compared to conventional vehicles with internal combustion engine, electric vehicles have the potential to locally reduce greenhouse gas and noise emissions. Especially in urban areas, these advantages can help to improve the quality of life, for example regarding the air quality issues of some Chinese cities today [7]. For Singapore, also the emissions over the entire life cycle of an electric vehicle are lower than of a comparable gasoline one for an accumulated mileage of more than 100,000 km. This includes the emissions of the vehicle and battery production, of the electricity production as well as of the fuel production and combustion [22].

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However, zero-emission battery electric vehicles (BEVs) do not sell well today. An important reason is that they are relatively expensive to buy, although the total cost for buying, using and reselling them may be lower than the one of conventional vehicles due to low electricity costs in comparison to fuel costs per kilometre. Another reason is the limited flexibility of a BEV as its range is typically significantly lower than the one of comparable gasoline or diesel cars, and the charging time to “refill” the battery is usually in the range of hours depending on the charging power [28]. This makes BEVs only usable for short distances and cases where enough time for charging can be guaranteed. In addition, compared to the network of petrol stations, the charging infrastructure network is not yet well developed which also reduces the flexibility of the BEV users.

Despite the technical inconveniences of BEVs or the missing infrastructure, costs are often decisive. In particular, this leads to the question about the amount of the total costs of BEVs, and under which circumstances this amount can be lower than the actual willingness-to-pay (WTP) of people for those environmentally friendly cars.

Therefore, a model has been set up which allows comparison of the costs of BEVs and the customers’ WTP for them. The purpose is to quantify the “gap” between the costs and the WTP and to find possibilities to reduce it. The comparison is based on a range of parameters which have an effect on the WTP of potential customers, on the total cost of ownership (TCO) of the electric vehicles or on both of them. Varying these parameters can affect the gap.

The objective is to identify promising parameters which allow to minimise the gap effectively. For this analysis, we use TCO and WTP data from Singapore in order to show the potential of the approach. The results can be a basis for subsequent work which should aim at a refinement of the approach and at the feasibility of measures to change the identified parameters in order to reduce the gap.

2 Total Cost of Ownership of Electric Vehicles

There is no general definition of the TCO [6]. It has to be applied according to the use case. For this analysis, the TCO is split into three main components [3, 19]: the acquisition costs, the operating costs and the end-of-life value of the car. For this study, a former TCO model presented in [10] has been modified and integrated into a combined TCO-WTP model.

As this study was conducted in Singapore, the acquisition costs of cars include a range of parameters which are specific for this city. Most of them are taxes which are imposed on the open market value of a vehicle and which make cars in Singapore relatively expensive. An important tax is the certificate of entitlement (COE) which a potential car buyer has to obtain in a bidding system [13–15]. The purpose of the COE is to limit the traffic volume on the streets in Singapore in order to limit traffic congestions [10].

Table 1 Key specifications and costs of the analysed vehicles [1, 2, 4, 5, 11, 12, 14–17, 20, 21, 27–29]

General settings and assumptions		
Year of purchase	(Beginning of) 2013	
Discount rate	3 %	
Annual mileage	18,200 km	
Usage period	7 years	
Main vehicle specifications		
	Volkswagen Golf	Volkswagen e-Golf
Fuel/electricity consumption	7.5 L/100 km	16.5 kWh/100 km
Engine/motor power	103 kW	85 kW
Battery capacity		24.2 kWh
Main TCO components in USD (rounded values)		
	Volkswagen Golf	Volkswagen e-Golf
Purchase price	130,276	157,195
Thereof OMV	23,321	33,448
Thereof COE	59,699	64,166
Thereof ARF	26,278	40,433
Thereof CEVS rebate	−11,989	−15,986
Operating costs	49,129	38,540
Thereof fuel/electricity costs	14,521	4,134
End-of-life value	−30,749	−43,333

All values are taken from the given sources or are calculations and estimations based on them

OMV Open market value, *COE* certificate of entitlement, *ARF* additional registration fee, *CEVS* carbon emissions-based vehicle scheme

The operating costs include insurance premiums, maintenance costs, cost for fuel or electricity, an annual vehicle tax as well as average parking costs. In addition, some other cost components may increase the operating costs, for example using toll roads.

The end-of-life or resale value is estimated to be relatively high because the high acquisition costs lead to an increased resale value after 7 years of usage, including tax returns. For example, as the COE is valid for 10 years, it increases the end-of-life value of the vehicle if it is sold or deregistered after only 7 years [15]. The end-of-life value is given as negative costs, assuming that the user can earn money by selling the car at the end of the 7-year usage period.

A detailed breakdown of the different components of the acquisition costs is shown in Table 1.

Emissions are important for the calculation of the vehicle cost as well. In the case of Singapore, the tax rebates (CEVS) are granted depending on the vehicles'

tank-to-wheel emissions encouraging car buyers to make their decision for more environmentally friendly cars. Emissionless electric vehicles are granted the maximum rebate on the purchase price of almost 16,000 USD [15] (Table 1).

3 Willingness-to-Pay for Electric Vehicles

The willingness-to-pay (WTP) can be defined as the maximum price which a consumer would be willing to spend for a product (e.g. [24]). In this case, the WTP is the amount of money a potential customer is willing to spend for buying a BEV.

In order to estimate this WTP, a consumer survey in Singapore was conducted. Participants were asked to rank a range of mobility-relevant attributes according to how important they are to them when travelling around in Singapore. The attributes which were more important to the respondents were then used in a second web-based survey in which 914 Singaporeans were asked about their WTP for vehicle-related parameters which are characteristic of the particular mobility attributes [10]. Table 2 shows the mobility attributes and vehicle parameters selected for this study.

In order to quantify the WTP, the method of a choice-based conjoint analysis was used in the survey. This approach allows to estimate utility values for different levels of the parameters listed in Table 2. Using the purchase price (premium) as one of the parameters, monetary WTP values were calculated for each parameter level. This survey design does not allow to estimate a large number of WTP data points per parameter. Hence, the WTP curves were extrapolated following the law of diminishing marginal utility using a simple logarithmic function [9, 18].

Figure 1 exemplarily shows the Δ WTP for the mobility attribute “flexibility”, described by the parameter “driving range”. The Δ WTP is the price premium a consumer is willing to pay on top of the purchase price of a comparable

Table 2 Mobility attributes and parameters

Mobility attributes	BEV parameters	Parameter unit
Time savings	Time to fully charge the battery	hours
Reliability and certainty	Distance to next available charging station	km
Convenience	Availability of home charging	Yes/no
Cleanliness	Amount of inner-urban pollution reduced	% Relative to conventional vehicle
Flexibility	Maximum driving range on a single charge	km
Costs	Reduction of operating costs	% Relative to conventional vehicle
Costs	Purchase price premium	Fixed monetary amount relative to conventional vehicle

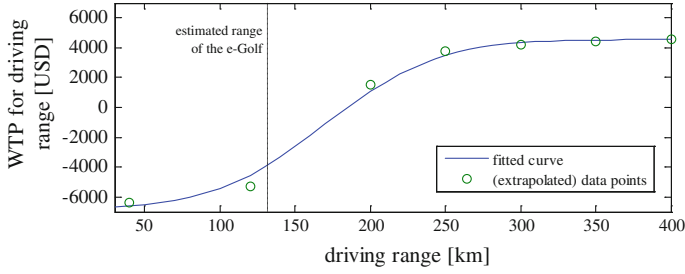


Fig. 1 Example of a ΔWTP curve for driving range

conventional vehicle (Volkswagen Golf). Ideally, as described by [8] for the US, the WTP for driving range is negative for ranges which are less than most of today's conventional cars. According to the data collected in Singapore, consumers already value ranges of above 200 km positively. This difference is certainly related to the different survey design, but is certainly also influenced by the relatively short distances within the limited area of Singapore, so that lower ranges are considered sufficient for the daily usage of electric cars.

Based on the ΔWTP values for the different parameters, the total WTP for an electric vehicle WTP_{BEV} is calculated by summing up all ΔWTP values for parameter configurations of this BEV and the purchase price of the reference conventional vehicle:

$$WTP_{BEV} = \sum \Delta WTP_{BEV,i} + C_{\text{purchase,ref.vehicle}}$$

with $\Delta WTP_{BEV,i}$ being the purchase price premiums regarding the parameters i of the electric vehicle (Table 2) and $C_{\text{purchase, ref. vehicle}}$ the acquisition costs (purchase price) of the conventional reference vehicle. In theory, WTP_{BEV} of a potential customer for an electric car has to be equal or higher than its acquisition costs so that the car can be sold.

In this survey design, only the acquisition costs can be easily compared to the WTP for a BEV, as the WTP is the total amount a person would be willing to spend to buy an electric vehicle, and not both to buy and use it for several years. This fact seems to make the comparison incomplete because only a part of the TCO is taken into consideration, whereas the customer would have to come up for all costs when using the car, and not only for the acquisition costs. However, the comparison of the WTP and acquisition costs already takes into account the operating costs of a car which are one of the parameters used in the WTP survey (Table 2). Hence, a modification of the statement about the operating costs of a vehicle configuration in the survey would also affect the respondents' answers. Higher operating costs are generally perceived as a disadvantage.

This implicates that the consumers take into account an implicit discount rate when weighing the low future operating costs against the high acquisition costs. Verboven [25] shows for similar trade-offs between different vehicle types that this

implicit discount rate is close to the market rate. This supports the assumption in our approach that the discount rates on the side of the TCO and WTP can be considered as equal.

4 Combination and Comparison of WTP and TCO

Both the TCO and the WTP data are combined in a parameter-based model. The goal is to compare the values of the acquisition costs and the WTP for electric and conventional vehicles and to specify the difference between both values (“gap”) using parameters which describe the TCO, the WTP or both of them.

The parameters can be classified in different categories. Vehicle-related or technical parameters include the electric motor or engine power, the battery capacity of the BEV or the fuel and electricity consumptions. Many cost values like battery costs, the motor/engine production costs as well as margins are attributed to the vehicle manufacturer. Taxes, incentives or registration fees which have a significant impact on the TCO of vehicles in Singapore are summarised in a third category.

Some of these parameters influence either the TCO or the WTP. However, the parameters which have an impact on both are considered most interesting. For example, a lower battery capacity decreases the purchase price of a vehicle, but also changes the WTP as the range of electric vehicles is an important aspect for potential customers.

Based on the estimated values of the TCO and the WTP, a cost “gap” between both values is calculated as follows:

$$C_{\text{gap}} = C_{\text{BEV}} - \text{WTP}_{\text{BEV}}$$

with C_{BEV} being the acquisition costs of the electric vehicle and C_{gap} the monetary difference between the consumers WTP_{BEV} for the electric vehicle and its purchase price.

Ideally, WTP_{BEV} surpasses C_{BEV} resulting in a negative C_{gap} . However, for the case of Singapore, we confirmed the assumption that this is generally not the case today. We analysed the example of a Volkswagen Golf, which is also available as an electric version. The costs of this car are shown in Table 1. Figure 2 displays the acquisition costs and the WTP for both versions in Singapore. The WTP for the conventional Golf is assumed to be as high as the acquisition costs because it has already been sold in Singapore at this price (in reality, the WTP can be equal or higher than the costs), whereas the WTP for the e-Golf is estimated based on the survey data.

According to the data, the WTP for the Volkswagen e-Golf is approx. 18,500 USD lower than the purchase price of the conventional Volkswagen Golf, and significantly lower (approx. 45,500 USD) than the estimated purchase price of an e-Golf in Singapore. In general, this relationship seems reasonable as an e-Golf can

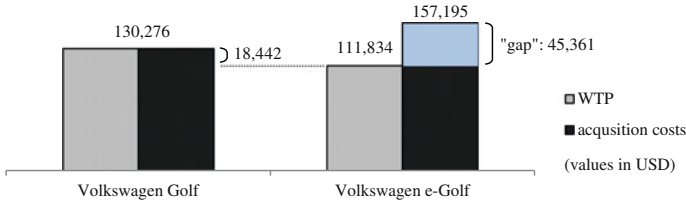


Fig. 2 Estimated WTP for and acquisition costs of an electric and conventional Volkswagen Golf in Singapore

certainly be regarded as less convenient as a conventional Golf considering the currently available infrastructure, the short range of about 130 km (Fig. 1) and the long charging time. The absolute height of these values may be questionable, but regarding the high vehicle prices in Singapore including vehicle taxes which are a lot higher than the gap of 45,500 USD, these numbers are within an acceptable range.

Consequently, the question arises which parameters are mainly responsible for the gap, and which possibilities exist to change them so that C_{gap} decreases. Therefore, the three categories described above were distinguished: technical vehicle-related aspects, parameters which have to be attributed to the vehicle manufacturer, and governmental or regulatory aspects. Changing the electric vehicle specifications like battery capacity or electricity consumption in a way that costs are reduced and the WTP of potential customers increases fall under the first category. In this case, the gap could be reduced by trying to modify the BEV technically in order to lower its costs and increase its attractiveness for potential customers at the same time, resulting in a higher WTP. Parameters of the second and the third category focus directly on the costs rather than on technical vehicle aspects. On the side of the manufacturer, costs of the vehicle or vehicle components can be reduced for example by technological progress or high-volume production.

In Singapore, regulatory levers seem to be most promising regarding the enormous vehicle taxation. Exempting BEVs from only one of the major vehicle taxes ARF or COE can make the vehicle purchase price of a Volkswagen e-Golf drop by at least 40,000 USD which would almost eliminate the gap. In contrast, the sensitivity of the gap to changes of technical vehicle parameters is comparatively low.

However, targeting vehicle taxation is not considered as a long term strategy, but rather as an incentive in order to motivate users to get in touch with the new technology. In addition, as the price of COE is determined in a bidding system, future COE prices are not directly controllable by the government which makes it more difficult to prioritise electric vehicles through the COE system. This uncertainty weakens the effect of those regulations or at least narrows the possibilities of governmental interventions to other taxes like the ARF. This aspect should be addressed in future studies.

5 Conclusion

A consumer's "WTP is an unobservable construct" [26]. Measuring it can only be an attempt to come as close as possible to the true WTP [26]. Regarding this fact and the situation that electric vehicles are a new product today which potential users are hardly very familiar with, collecting reliable WTP data is a major challenge of this approach. In addition, the TCO can also only be estimated using plausible assumptions about vehicle usage and future price developments. Hence, the approach described in this paper is considered to be suitable to get a rough overview of the suitability of electric vehicles for selected markets or users. An exact comparison of costs of cars and WTP for them will not be possible. However, validating the stated WTP data by additional interviews, experiments or observed WTP data will be useful.

Regarding the model, the parameters which are used to estimate and compare the costs and WTP of electric cars have to be synchronised in order to be able to simulate the effects that certain technical and regulatory changes have on both costs of the electric vehicles and the consumers' WTP for it. This can help to understand a BEV in its environment and to tailor the measures to introduce BEVs in selected markets. The example of Singapore may be a special case regarding the vehicle costs in this city state, but it still seems to be a promising market for electric vehicles where short distances and inner-urban traffic conditions prevail, which are generally more favourable for BEVs than for conventional vehicles.

At long term, it is certainly economically more viable to focus on measures which help to increase the attractiveness of BEVs for consumers on a technical or infrastructure level than trying to push the costs below a certain level by giving for example tax incentives. Advertising lower operating costs of BEVs may also fail. According to [23], people usually make their opinion about the acquisition costs of private vehicles in a different way than estimating future expenses and payback periods as they do not have the basic building blocks to make a calculated decision. However, at short term, incentives can be helpful to let more people get in touch with the new technology.

Acknowledgments The work presented was financially supported by the Singapore National Research Foundation under its programme "Campus for Research Excellence and Technological Enterprise" (CREATE).

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Sustainable Automotive Technologies 2014

Proceedings of the 6th ICSAT

Denbratt, I.; Subic, A.; Wellnitz, J. (Eds.)

2015, IX, 237 p. 134 illus., 103 illus. in color., Hardcover

ISBN: 978-3-319-17998-8