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Total Cost of Ownership and its potential implications for Electric Vehicle diffusion

Jens Hagman[1], Sofia Ritzén[2], Jenny Janhager Stier[3]
[1] *The Royal Institute of Technology*
jenshagm@kth.se
[2] *The Royal Institute of Technology*
ritzen@kth.se
[3] *The Royal Institute of Technology*
jenny@md.kth.se

Abstract
Battery Electric Vehicles have been slow to diffuse on the international as well as the Swedish market. Existing literature have pointed to situational factors such as economical factors, size and performance to be of high importance for car purchasers in their choice of car. In this paper the authors investigates the apparent discrepancy between purchase price and the Total Cost of Ownership between Internal Combustion Engine Vehicles and Battery Electric Vehicles. The Total Cost of Ownership computation reveals that Battery Electric Vehicles can be cost competitive with Internal Combustion Engine Vehicles, a significant finding that could prove to be of importance for the diffusion of Battery Electric Vehicles, although further studies are needed to test car purchasers' knowledge regarding the Total Cost of Ownership analysis.

Keywords: Electric Vehicles, Total Cost of Ownership, diffusion of innovation, sustainability

1. Introduction

In the urgent need for society to decrease its CO_2 emissions, disruptive eco innovations such as Plug-In Hybrid Vehicles (PHEV) and Battery Electric Vehicles (BEV) are of high potential. As now emerging in the mainstream markets they have the potential to decrease CO_2 emissions from transports and hence benefit society at large. Despite its potential, however, electrification of the car fleet has so far only marginally contributed to decreases in CO_2, as represented in the 0,07 % share that PHEV and BEV had of the total Swedish car fleet at the end of March 2014 [1]. In order for this share to increase, it is of high importance to understand the factors that make-up the demand in new car purchases in general and for PHEVs and BEVs in particular. This increased understanding is critical to many actors and can play an important role in engineering design. It refers to a crucial interplay between designers, users and policy makers in a transformation towards a sustainable society. This study will outline an approach to illuminate one of several key factors, one that specifically is determined by users, however need to be managed by designers and businesses delivering new products to the market. The study will specifically focus on BEVs since they are the only mass-market zero emission vehicles on the roads today.

Eco innovations are normally not self-enforcing in their diffusion, illustrated by the low degree of user adoption for solar power and hybrid-electric vehicles in the US [2], [3]. Roy et al [4] identified four barriers for cleaner vehicles. First, high purchase prices and long payback times associated with many low carbon products and systems often act as a major adoption barrier. Second, pioneering low carbon products tend to be engineering-led and hence lack ease and convenience of use. Third, lack of system integration such as refueling infrastructure hinders adaptation of low carbon products. Fourth, the importance of the car as a status symbol is not always present with low carbon vehicles. Extensive research has been conducted on barriers of limited range and performance [5] and charging infrastructure challenges [6], less so on the role of perceived and actual prices for BEVs. Price has been established to be one of the most significant factors in the diffusion process. In a study conducted in the Netherlands, the total share of consumers that was willing to pay extra for cleaner engines was estimated to be between 2-5% compared to 60-65% that are willing to pay extra for a more powerful engine [7].

The general consensus within the industry, press and the public seems to be that BEVs are significantly more expensive than Internal Combustion Engine Vehicles, (ICEV), which following the results of previous works would then negatively affect its diffusion [8]. The purpose of this study is to explore if BEV really are more expensive compared to equivalent ICEV when considering the Total Cost of Ownership (TCO) and the results potential implication on the diffusion of BEVs. The next section will touch upon existing literature regarding Technological Diffusion, factors that influence car choice, the Energy Paradox and TCO. It will be followed by sections that will present the result of the factors that make up TCO and the computed TCO model for the sample cars that is referred to in this study. The paper is closed with a discussion and conclusion sections.

2. Perspectives from literature

2.1 Technological diffusion

This study is concerned about the adoption of the BEV technology on an aggregate scale, often called technical diffusion. Kemp & Vopli [9] describe technological diffusion as the adoption of a technology by a population over time. Technological diffusion describes the aggregate of adoption decisions. Diffusion analysis does not seek to find answers as to why a particular unit (firm or consumer) has adopted an innovation at a particular time in any detail but concerns itself with the adoption decisions of a population of potential adopters. Rogers' work from 1962 [10] on diffusion of innovations is one of the foundation blocks of modern diffusion research. He describes diffusion of a particular innovation as a gradual process largely dependent on five factors: *Relative Advantage, Compatibility, Complexity, Trialability and Observability*. Several schools of diffusion have followed, such as the epidemic model and the probit model. The epidemic model builds on the premise that what limits the speed of usage is the lack of information available about the new technology, how to use it and what it does [11]. The probit model follows from the premise that different actors, with different goals and abilities, are likely to want to adopt the new technology at different times [11].

2.2 Factors that influence car choice

In order to understand what drives technological diffusion for BEV it is important to investigate the factors that influence car-purchasing behaviors, which are numerous both for fleet and private buyers. Lane et al [3] divide them into situational factors and psychological factors. Situational factors include: economic and regulatory environments, vehicle performance and applications and the existing fuel/road infrastructure. Psychological factors include: for private drivers – attitudes, lifestyle, personality and self-image; and for fleet drivers – risk-perception, corporate culture, and company image. Other studies have found that private car purchases are predominantly driven by situational factors such as price, fuel economy, comfort, size, practicality and reliability [12]. Car-buyers are hence according to the literature driven by a mix of logical (situational) and emotional (psychological) factors where logical factors seem to be of larger significance in their choice of car.

2.3 Fuel economy and the Energy Paradox

Fuel economy constitute one of the situational factors and have been found to be an important factor during the decision making process [3], [12]. However, it seems to be the case that most car buyers place little effort in comparing fuel economy between different vehicles during the decision-making process [13]. As a consequence, many consumers will consistently undervalue fuel economy savings that in turn leads to lower adoption rate of "Eco Innovations" then theoretical market theory would predict, in the literature this phenomena is called the Energy Paradox [13, 14, 15].

Several possible explanations for the energy paradox have been suggested, including imperfect information, bounded rationality, limited mathematical skills, principle agent problems, and heterogeneity of consumers' preferences as explained by Green et al [14]. Lane et al [3] suggest that consumers of all types have a very low knowledge base regarding the potential impacts of low carbon and fuel-efficient vehicles. This can be attributed to greater importance of other factors in the car purchasing process. As Lane et al p.1089 conclude, "Although it appears that fuel economy influence car choice, other non-environmental issues (cost, performance, styling, image etc) continue to play a more crucial role" [3].

2.4 Total cost of ownership (TCO)

TCO is defined by Ellram (1995) as a purchasing tool and philosophy, which is aimed at understanding the true cost of buying a particular goods or service from a particular supplier [16]. TCO is a useful calculation for consumers and firms alike to assess the direct and indirect cost associated with a purchase. TCO is important since the purchasing price of most capital goods is not the only cost associated with its use and ownership. Traditionally have TCO been mostly used by firms, tools for consumers have so far been limited. Hence are there reasons to suspect that consumers have limited knowledge regarding the TCO concept that potentially could lead to uneconomical car purchases decisions. This is also interesting in perspective of the epidemic model [11], addressing that new technology may not be used due to lack of information for users.

Previous vehicle TCO analyses have concluded that BEVs can be cheaper to own compared to their ICEV competitors [18], [20]. The electric drive train has lower service and maintenance costs, better fuel economy and lower taxes compared to ICEV but significantly higher purchase price. Hence the relevance for investigating TCO relation to the purchasing process for BEV rather than just fuel economy or purchasing price. Costs to include in such analysis are maintenance costs, insurance, interest, taxes, fuel costs and depreciation [18].
The US based Consumer Report could be claimed to be the leading authority with regards to vehicle TCO, with annual updated calculations and ongoing information regarding the different cost structure between vehicles. Figures 1 indicates the relative size of each cost for the average new car in the US over a 5-year ownership and have been added for illustrational purposes.

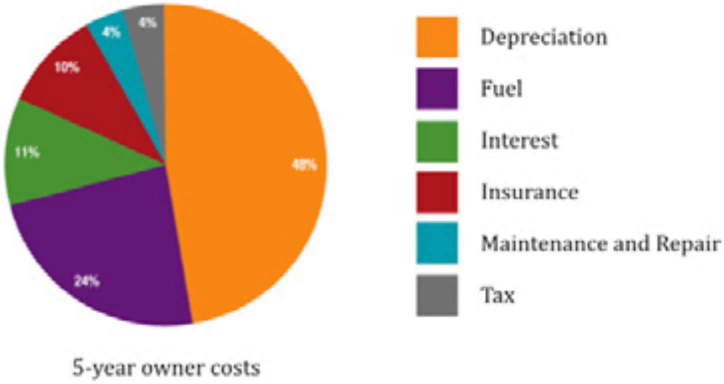

Figure 1 – Total Cost of Ownership for the typical newly bought car in the US [19].

3. Research gaps

It has been shown above that price plays a significant role for diffusion of eco innovations such as BEVs. Up-front price is however not the same as the total cost of buying and owning a car. This paper explores if TCO are significantly different between BEVs and ICEVs, and its potential impact of the diffusion of BEVs. The theoretical context is provided from previous work in diffusion theory and the energy paradox.
This article explores the answers to the following questions:

1. How should a TCO model be defined and what costs and considerations does it need to include?
2. Is BEVs TCO competitive with conventional cars for the average user?
3. What is the potential impact of question 1-2 on the diffusion of BEVs and how can it be used in the development of new vehicles?

The purpose of this study is to point out the direction for further potentially useful studies regarding the price and the TCO aspect of the diffusion of BEVs and its usage in product development.

4. Methodology

The TCO model constructed in this study contains individual factors that each have been defined, analyzed and computed into the TCO result. Extensive use of industry and government data, phone and email exchanges with leading automobile authorities and modeling in Excel have made the TCO model possible.

In this study the TCO model will be used to compare cost of ownership between one BEV, two equivalent ICEVs and one hybrid petrol electric vehicle in a Swedish market setting. Since the TCO model is aimed to illustrate the relative differences and to be comprehensible for the average car buyer, the authors will for simplicity reasons assume a 0% discount rate.

Existing theoretical and empirical literature will be used in order to explore the relevance of the TCO model towards the diffusion of BEVs in Sweden.

5. Results

5.1 Cost factors to include in the TCO model

In order for a TCO model to be of relevance it is of great importance to identify and compute the necessary cost categories for the product or service in question. The cost of buying and owning a vehicle entails several different costs categories that fortunately have been defined by previous literature and automobile authorities [18], [19], these studies did not however bring up its potential implications for diffusion. The following section will in detail explain the individual cost categories that make up vehicle TCO and its relevance to the purpose of this study.

5.1.1 Depreciation

Depreciation rate is the difference between the initial price and the second hand price of a product after a period of time. Depreciation is often the biggest cost in the vehicle TCO analysis as illustrated by figure 1 and consequently of great importance for new car buyers. Depreciation is a complex process dependent on factors such as: vehicle features (color, equipment, ect) brand perception, fuel prices, maintenance costs, quality scores, government regulations and other less quantifiable values. A general rule of thumb in the Swedish car market is a 50% depreciation rate after 3 years ownership, with a 10% annual depreciation rate in subsequent years.

Of the new generation of BEVs one of the few that have been on the market for at least 3 years is the Nissan Leaf on the US market. The authors have therefore conducted a depreciation analysis for Nissan Leaf SV, bought in California in 2011 as seen in table 1 below. Although affected by significant tax rebates the authors conclude that the Nissan Leaf have a depreciation rate of 19 %, considerably lower than expected. Due to the uncertainties in making depreciation estimates for BEVs on the Swedish market (due to limited local historical depreciation data, local market differences, uncertainties regarding future developments of price, performance and battery lifespan) the authors will assume a more conservative depreciation rate of 50 % when the tax rebate or government subsidy have been included.

Table 1 – Depreciation Nissan Leaf SV - 2011

	Price in 2011	Price in 2014	Depreciation	Depreciation rate
Nissan Leaf SV	$21 100*	$17 113**	$3 987***	19 %****

* Base price: $33 600. Federal tax refund: $7 500. California state rebate: $5 000.
$33 600 - $7 500 - $5 000 = $21 100. Based on information received in an email conversation with the California Center for Sustainable Energy.
** Mean from sample of 39 used Nissan Leaf SV 2011 with an average of 27 041 miles on the meter, national US average is 36 000 miles after 3 years, retrieved from cars.com on the 16/4 2014. Standard Deviation of the sample: $1 626. A 68% confidence interval yields that 68 % of the sample is between: $15 487 and $18 739.
*** $21 100 - $17 113 = $3 987
**** $3 987 / $21 100 = 19 %

5.1.2 Fuel costs

Fuel economy make up the key concept in previous studies concerning the energy paradox, [14], [15]. Fuel cost is calculated by the straightforward formula: *Fuel consumption * Fuel price.* The authors will use fuel consumption estimates provided by each car manufacturer, although it is often assumed that the actual fuel consumption is higher than these fuel labels suggest. Table 2 below illustrates gasoline, diesel and electricity prices used in this study.

Table 2 – Average fuel prices 2013 -2014

Gasoline Sek/l	Diesel Sek/l	Electricity Sek/kWh
14,48 Sek*	14,45 Sek**	1,79 Sek***

* Mean from Swedish monthly average consumer gasoline prices Feb 2013 and Feb 2014 from http://www.okq8.se/pa-stationen/drivmedel/. Std Dev: 0,21
** Mean from Swedish monthly average consumer diesel prices Feb 2013 and Feb 2014 from http://www.okq8.se/pa-stationen/drivmedel/. Std Dev: 0,18
*** Mean from biannual 2013 consumer electricity prices for households consuming between 2500 - < 5000 kWh annually, extracted from http://www.scb.se/sv.

5.1.3 Interest

The authors assume based on interviews with leading car authorities that most car buyers finance at least part of their car purchase with a car loan or a private bank loan that are paid back in regular installments. In this study will the authors assume that the purchaser provide a 20% down payment with the reminder of the purchasing cost financed by a 36 month loan with a 6 % annual interest of which 30 % is tax deductible, effective interest rates are hence 4,2 %. Compounded interest payments will be calculated according to the commonly used formulas below.

Monthly payment formula

$$c = \frac{rP}{1-(1+r)^{-N}} = \frac{\Pr(1+r)^{N}}{(1+r)^{N}-1}$$

c: Monthly payment
r: Monthly interest rate
N: Number of monthly payments
P: Amount borrowed

Total interest paid formula

$$I = cN - P$$

I: Interest paid over the lifetime of the loan
c: Monthly payment
N: Number of monthly payments
P: Amount borrowed

5.1.4 Insurance

Individual car insurance premiums are determined by a host of different car and owner specific factors. Car specific factors include: performance, safety ratings, weight, car value and other factors. Owner specific factors include: number of accident free years, age, gender, address and other factors. In this comparative study we want to isolate the car specific factors and will hence use the same owner profile when calculating the insurance cost per vehicle. In order to get accurate quotes rather than estimates will the authors use one of the co-authors personal information to extract quotes: Male, 29 years of age, 11 accident free years and living in urban Stockholm. All quotes are extracted from one of the major insurance companies in Sweden, Trygg Hansa.

5.1.5 Maintenance and repair

Most new cars come with warranty that covers any malfunctions during the first three years of ownership. Repair costs should hence be none or small during the first three years. Warranties are however only valid if the owner complies with the vehicle specific service intervals. Service costs are calculated by adding the by the manufacturers estimated service cost during the ownership. BEVs have fewer moving parts that need no oil or filter change and less brake pad tear due to its strong regenerative braking. Service cost should hence be lower for BEVs compared to an ICEV. Other maintenance costs such as tire and windshield wiper changes are to be considered equal between BEVs and ICEVs and are for simplicity reasons not included in this study.

5.1.6 Taxes and subsidies

The Swedish transport energy policy is based on CO_2 emissions per kilometer. Vehicles that emit under 50 grams of CO_2 per kilometer are qualified for a 40 000 Sek cash premium from the government, this subsidy has been in place since the 16th of January 2012, [16] Transportstyrelsen (2014). The annual vehicle tax for the vehicles in this study will be extracted through the use of registration number on Transportstyrelsen's online tax calculator.

5.2 Selection of sample vehicles

In this study it is expected that the result will only be of relevance for car buyers that have access to charging and have range expectations within the range of a typical BEV (not claiming that BEVs always are perfect substitutes for ICEV). Chosen vehicles share similar size, equipment and performance. For illustrational purposes have the authors included a gasoline and a diesel version of one of the most sold cars in Sweden, the Volvo V40, together with the popular Toyota Prius Hybrid and the newly introduced BMW i3 (BEV). Table 3 below illustrates key data points for each model.

Table 3 Vehicle descriptions

Volvo V40 D3 - 2014	Volvo V40 T4 - 2014
List price: 244 000 Sek Horsepower: 150 hp Fuel type: Diesel Fuel consumption (mixed): 4,3 l/100km Carbon dioxide emissions: 114 g/km	List price: 240 000 Sek Horsepower: 180 hp Fuel type: Gasoline Fuel consumption (mixed): 5,5 l/100km Carbon dioxide emissions: 129 g/km
Toyota Prius - 2014	**BMW i3 - 2014**
List price: 273 000 Sek Horsepower: 136 hp Fuel type: Gasoline/Electricity Fuel consumption (mixed): 3,9 l/100km Carbon dioxide emissions: 89 g/km	List price: 339 000 Sek Horsepower: 170 hp Fuel type: All-electric Fuel consumption (mixed): 12,9 kWh/100km Carbon dioxide emissions: 0 g/km

5.3 The computation Total Cost of Ownership (TCO) of sampled vehicles

Table 4 below states the computed values based on assumptions given on previously discussed factors above.

The conditions for the TCO analysis are:

- *Length of ownership: 3 years*
- *Annual km driven: 15 000 km*
- *Owner: Male, 29 years old, living in Stockholm*

It needs to be noted that all costs are shown in Swedish crowns and percentages in brackets indicate each TCO categories share of TCO for each vehicle.

Table 4 – Total Cost of Ownership

	Volvo V40 D3	Volvo V40 T4	Toyota Prius	BMW i3
Depreciation	122 000 (67,9%)	120 000 (65,8%)	136 500 (70,1%)	189 500* (103%)
Fuel cost	27 961 (15,6%)	35 838 (19,6%)	25 412 (13,1%)	10 391 (5,6%)
Interest	12 897 (7,2%)	12 685 (7%)	14 430 (7,4%)	15 804 (8,6%)
Insurance	9 909 (5,5%)	8 343 (4,6%)	8 643 (4,4%)	8 241 (4,5%)
Maintenance and repair	3 564 (2%)	3 564 (2%)	9 792 (5%)	0** (0%)
Taxes and subsidies	3 264 (1,8%)	1 800 (1%)	0 (0%)	- 40 000 (-21,7%)
TCO	**179 594**	**182 230**	**194 777**	**183 936**
TCO per month	**4 989**	**5 062**	**5 410**	**5 109**

* Depreciation rate without the government subsidy. Percentage over 100 % of the total reflect the large effect of the government subsidy.
** All new BMW have free service for the first 3 years of ownership, BMW only have a 2-year warranty but the i3 will in this study assumed to not suffer any technical malfunction during the third year of ownership.
() Percentage of the particular TCO factor in relation to TCO of that vehicle.

6. Discussion

The TCO results in Table 4 shows significant discrepancies between the vehicles compared in relation to their purchasing prices. The BMW i3 have the highest purchasing price but has a TCO similar to the second to cheapest car in the sample, Volvo V40 T4. Volvo V40 D3 has the lowest TCO of the cars in the sample even though it has a higher purchasing price than the Volvo V40 T4. Somewhat surprisingly is that the Toyota Prius is the most expensive car to own in the sample.

As expected the BMW i3 is the cheapest to own in the fuel cost, maintenance and repairs, and taxes and subsidies categories. Surprisingly is the BMW i3 the cheapest car to insure in the sample. Table 4 clearly indicates that purchasing price only directly influences two factors in the TCO; depreciation and interest costs. These costs can nevertheless contribute to a significant part of the total, as seen in the case of the BMW i3 that has depreciation and interest cost making up 111,6 % of TCO. The government subsidy of -21,7 % of TCO consequently has a large effect in bringing down the cost to a competitive level compared to the ICEVs. The authors can conclude that the BEVs can be cost competitive with ICEV on the Swedish market when considering TCO. An interesting finding is that BEVs can even be cheaper compared to Hybrid vehicles such as the Toyota Prius.

TCO is a mind-widening concept in the sense that it through facts contradicts budgeting vehicle purchase by purchasing price, which is the common observed behavior among car buyers. The cost difference between BEVs and ICEVs brings up some interesting scenarios for the future. The largest single contributor to the high purchasing price of BEVs is the cost of the battery that cost significantly more than the drivetrain of an ICEV. Battery prices are expected to decrease in the future, a development that will make BEVs even more TCO competitive, potentially even significantly cheaper than ICEVs in the future. The very low running ownership cost of BEVs also presents a potentially interesting effect on its second hand value. Without the high rate of depreciation and interest cost associated with buying a new BEV, the TCO for a used BEV could be significantly lower than comparable used ICEVs. These are factors that could potentially positively affect the second hand value of BEVs and hence also make new BEVs even more TCO competitive. Limited battery lifetime and cost associated with its replacement could however have a negative effect on the second hand value of BEVs.

If BEVs indeed then are cost competitive with ICEVs and also come with added environmental and societal benefits, why are then BEVs slow to diffuse? Part of the answer certainly comes from the limited range of BEVs and low access to charging infrastructure that do not fit into the lifestyle of some car buyers as discussed earlier in this paper. This study however gives reason to believe that part of the answer is also low awareness and use of comprehensive TCO analysis, i.e. lack of information as addressed by Geroski [11]. Rogers (1962) early findings, [10], further stress the importance of having the true picture as innovation diffusion is largely driven by relative advantage – if advantages are not known the market will stay reluctant. For BEVs and also for PHEVs the diffusion also highly concerns the diffusion factor compatibility, referring mainly to charging possibilities. Regarding compatibility the society has a large responsibility while interestingly for product development and the engineering design area the TCO calculation in this paper reveals an opportunity for companies selling BEVs to inform their potential users. A market situation where competitors compete for reduced resource usage is also a strong sustainability factor.

7. Conclusion

The objective of this study was to illustrate the TCO (Total Cost of Ownership) of four vehicles with different drivetrains but otherwise similar in terms of performance, size and equipment. Previous work on the energy paradox and factors that affect choice of vehicle have confirmed that most car buyers do not place great significance on the operating costs of owning a vehicle. Armed with that assumption, this study concludes that the TCO framework most likely contributes less to the individuals' choice of car than rational economic models would predict. Lack of TCO realization among car buyers might hence be a significantly contributing factor to why BEVs are diffusing so slowly. More studies that preferably investigate the prevalence of TCO analysis among car buyers and their reasoning for using or not using TCO are needed to confirm this, studies that can also consider possible weaknesses in the current calculations relating to assumptions made. Nevertheless this study points out an interesting direction for further studies and the need for easy to access tools in order to compare TCO between different vehicles. Future studies could yield high impact results that could prove valuable for governments that through policy wish to increase the share of BEVs and for vehicle manufacturers that more clearly would like to point to the cost benefits with BEVs in their marketing. Designers have an important role not only in developing new technologies and products but also in informing potential users in order to secure a successful diffusion in a market.

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