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How expensive are electric vehicles?

A total cost of ownership analysis.

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Abstract

This paper presents a total cost of ownership (TCO) model for three different car segments. The goal is to investigate the cost efficiency of electric vehicles compared to conventional vehicles. All costs that occur during the expected vehicle's lifespan are included: purchase cost, registration tax, vehicle road tax, maintenance, tires and technical control cost, insurance cost, battery leasing cost, battery replacement cost and fuel or electricity cost. Results are shown per vehicle segment and illustrate the share of all cost components. We find that current electric vehicles are only cost attractive within the premium car segment.

Keywords: Total cost of ownership, electric vehicles

1 Introduction

Due to their higher energy efficiency rate, electric vehicles (EVs) can play a substantial role in the energy reduction and greenhouse gas emission goals of the European 20-20-20 objective. However, current EVs sell at higher prices compared to the conventional petrol and diesel vehicles. This price surplus can burden their market introduction.

Within the decision process of a new car, financial factors are regarded as very important [1]. For fleet managers, price is even the most important factor [2]. However, consumers should not only look at the initial purchase cost of the vehicle as many other costs occur during the ownership of a car. Electric vehicles have the advantage that the price of driving the vehicle is lower due to cheaper electricity cost and the higher rate of efficiency of the motor. However, consumers tend not to consider the present value of these fuel savings [3]. Therefore, this paper presents a total cost of ownership (TCO) analysis in order to investigate the cost effectiveness of hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), compared to conventional internal combustion engine vehicles (petrol and diesel). Only when the TCO of an electric vehicle becomes cost efficient, consumers will take these cars into consideration. However, other factors (styling, looks, driving sensation, relationship with the car dealer, influence from friends and family…) that cannot be included in this economic analysis also influence the final purchase decision of the consumer [1], [4].

In this article, a state of the art of other TCO studies on electric vehicles is given and the innovative character of our approach is elaborated. Next, the methodology behind TCO analyses is explained, including the assumptions and limitations of the model. This section also includes the scope of the research and all the input parameters. Next, the results of the TCO analyses are shown and sensitivity analyses are performed. Finally, conclusions are drawn.

2 State of the art of TCO analyses and improvements by our model

Comparing different TCO studies should be done with care as analyses have different assumptions, input parameters and research scope [5], [6]. Literature reveals many TCO studies on electric vehicles, especially since 2008, when several car manufacturers launched their plans of mass production of electric vehicles. TCO analyses can be divided into two main categories: consumer oriented studies and society oriented studies. In the first group, the consumer point of view is considered. The costs that are perceived by the consumers are incorporated and different vehicle technologies are compared. Society oriented TCO studies have a broader scope: next to the consumer costs, externalities (emissions, noise…) and the associated external costs of EVs are included.

TCO literature reveals that BEVs are still a very expensive alternative, even though they have the most positive impact on the environment out of the studied vehicles. Due to their limited range, BEVs are only viable for commuting and other short distance trips. This could change if battery prices would drop or when fuel prices for conventional vehicles would increase (significantly). HEVs have a TCO that differs little from conventional vehicles, while having the same driving distance and offering a lower impact on the environment. In a few studies, fuel cell electric vehicles (FCEVs) were included, but these vehicles indicate a very high TCO, and prospects are uncertain as a large price drop for fuel cells is not expected for the upcoming years.

The TCO model developed in this article is consumer oriented and distinguishes from revealed literature because of the following aspects:

- Detailed TCO, including all costs consumers face when purchasing a vehicle (often ignored cost parameters in literature are battery replacements, residual value and depreciation difference between vehicle technologies);
- Input parameters are based on up-to-date vehicles that are available for today's customers (instead of out-of-production [7] or fictitious vehicle models [8], [9]);
- Results are given per vehicle segment, in which different models are included per vehicle technology;
- Sensitivity analyses are conducted per vehicle segment.

3 Methodology, scope and assumptions

The costs associated with owning a vehicle occur at different moments in time. Hence, it is necessary to calculate the present value of all occurred costs. The present value methodology makes use of a discount rate, which can be defined as the interest rate reflecting the investor's time value of money [10]. It can be either a real discount rate (excluding inflation) or a nominal discount rate (including inflation). It is recommended to use the real discount rate for TCO calculations as it eliminates complex accounting for inflation within the present value equation. To calculate the present value of future one-time costs, the following equation is used [10]:

$$PV = A_t \times \frac{1}{(1+r)^T} \qquad (1)$$

To calculate the present value of future recurring costs, we use [10]:

$$PV = A_0 \times \frac{(1+r)^T - 1}{r\,x\,(1+r)^T} \qquad (2)$$

Where:

PV = Present value
At = Amount of one-time cost at a time t
A0 = Amount of recurring cost
r = Real discount rate
T = Time (expressed as number of years)

In general, the total cost of ownership is calculated in three steps:

1) Analysis of every stream of (periodic) costs;
2) Calculation of the present value of the one-time and the recurring costs;
3) Division of the present value by the number of kilometres during the vehicle lifetime in order to produce a cost per kilometre.

The TCO is a function of different parameters, some of which are related to the vehicle technology: purchase cost, registration tax, vehicle road tax, maintenance, tires and technical control cost, insurance cost, battery leasing cost, battery replacement cost and fuel or electricity cost. All these parameters are elaborated further in section. For the calculation of the TCO, a dynamic computer simulation model was developed, which allows to immediately calculate the impact of a change in input parameters.

The scope of this research is Flanders, the Flemish speaking part of Belgium. All the input parameters are based on the existing values for Flanders as from January 2013. Three vehicle segments are analysed: small city, medium and premium cars. In every vehicle segment, a selection of cars is made including different vehicle technologies: petrol, diesel, hybrid, plug-in hybrid and battery electric. This selection is based on the vehicle's size, boot space and engine power. Also, the bestselling vehicles in each segment are included.

In Belgium, the average lifetime of a vehicle is 14.1 years [11]. However, the average Belgian consumer owns his vehicle for 7 years before selling it [11]. The average annual mileage is 15,000 kilometres per year, resulting in 105,000 kilometres during these 7 years. A real discount rate of 1.18 per cent [12] is used. This is the 7 year annual nominal Euro area interest rate for governmental bonds for which all issuers have a triple-A rating, dating from January 2, 2013.

This analysis does not take into account technical improvements on the conventional cars and EVs (some studies [13] claim that the current efficiency is already close to what is achievable), improvements in fuel efficiency, nor the inflation.

The input parameters can be divided into three main groups: the purchase costs (initial purchase price and vehicle registration tax), the fuel operating costs (petrol, diesel or electricity) and the non fuel operating costs (yearly road tax, insurance cost, maintenance and tires costs, costs for the technical control, and possible battery costs).

The **initial purchase price** of a vehicle in this TCO analysis includes the VAT (value added tax, 21 per cent in Belgium), but excludes possible reductions or promotions by the car dealer. All prices are retrieved online [14] and are of January 2013.

Current sales prices of EVs are still higher than similar conventional vehicles. This is mainly due to the expensive battery pack, but also to the absence of economies of scale [8], [13], [15]. The production costs of a vehicle can halve when production figures increase from 10,000 a year to 500,000 a year [16]. Moreover, current PHEVs have even higher initial purchase costs, because of the presence of a battery pack, a conventional internal combustion engine and an electric engine [6]. On the other hand, PHEVs benefit from cost savings because of downsizing of the installed conventional engine [17].

Vehicles depreciate over time. The loss of value due to depreciation is the highest in the first years of the vehicle's lifespan. Depreciation rates not only vary according to the fuel or drive train, they also vary according to brand image, mileage, vehicle class… Calculating the residual value of EVs is currently still very controversial [5]. Table 1 depicts the annual depreciation rates used in this analysis per vehicle technology, which are calculated through exponential regression based on available data from the past 7 years [18]. Residual value data for BEVs and PHEVs is only available for the last 2-3 years, entailing a higher uncertainty for these vehicle technologies.

Vehicle technology	Annual depreciation rate
Petrol	0.845
Diesel	0.827
HEV	0.834
BEV	0.720
PHEV	0.773

Table 1: Depreciation rates per vehicle technology

The **vehicle registration tax** (VRT) has to be paid once, when purchasing the vehicle. In an attempt to green the vehicle fleet, as from April 2012, the amount due for citizens living in Flanders is calculated on the basis of the CO2 emission, the EURO norm, the age of the vehicle and the presence of a diesel particulate filter [19]. Before that date, the calculation was done based on cylinder capacity and kW. The amount of the VRT cannot be lower than €40 or higher than €10,000. When the EURO norm of the vehicle is unknown, it will be defined according to the date of the first registration of the vehicle. PHEVs and BEVs are exempted from the vehicle registration tax in Flanders. An online simulator provided by the Flemish government enables calculating the VRT figures that are used in this TCO analysis [20].

The **fuel or electricity costs** are based on the average prices in 2012 for petrol (€1.7076 / litre), diesel (€1.5318 / litre) and electricity (€0.21 / kWh). The figures origin from the Belgian Federation for Petroleum [21] and the Flemish Regulator of the Electricity and Gas market [22] and include VAT. The fuel and electricity consumption is based on the New European Driving Cycle (NEDC). Studies show that these consumption figures tend to underestimate the real consumption of the vehicles by 15-20 per cent [23], [24]. In this analysis, since all consumption values are NEDC values, vehicles can still be compared and conclusions can be drawn.

The **yearly road tax** in Belgium depends on the fiscal horsepower (fiscal hp) of the vehicle, which is in relationship with the displacement (cylinder capacity) of the engine of the vehicle.

In Belgium, **insuring** your vehicle is obligatory. Drivers must pay the civil liability premium, which insures all damage done to another vehicle in collision. For new cars, consumers prefer to take a complementary omnium insurance, which also insures the vehicle of the person driving the car. The omnium premium is based on different parameters: driver's age, domicile, bonus-malus… and depends on the actual value of the car of the driver. In the TCO model, the omnium insurance is taken during the first three years, after which the civil liability premium is taken.

The **battery pack** of BEVs has a limited lifespan. In this study, the battery pack is **replaced** according to the expected lifetime of the lithium-ion battery pack. Quantitative studies [25] show that the expected number of cycles for lithium-ion batteries before their capacity drops below 80 per cent is around 1,000 cycles. If consumers fully charge their batteries 3 times per week, this totals to 156 charges per year, or a battery lifetime of approximately 6 years. Linking this with our assumption of a yearly mileage of 15,000 kilometres per year, this amounts to a battery lifetime of 90,000 kms. These values are in between those used in other TCO studies, in which a battery lifetime of 75,000 kms [26] or 8 to 10 years [27] is considered. Next, we look at the warranty given by the manufacturer. This warranty is linked to a certain mileage or to a certain amount of years. If the battery change is covered within the warranty period, no costs are added. When replacing the battery pack, we consider a price of €400 per kWh, which is the expected cost for lithium ion batteries in 6 years [28]. Today, the average cost is between €600 per kW [17], [26], [27] and €900 per kWh [9]. The battery for HEVs and PHEVs is not expected to be replaced. If the battery pack of the BEV is changed during the TCO analysis, the residual value of the vehicle increases. The residual value of the battery pack is linearly calculated based on its replacement value.

Some car manufacturers sell their electric vehicles without the battery. Customers are obliged to sign a contract for **battery leasing**. Here, the manufacturer guarantees a battery change if the battery capacity would drop under 80 per cent of its original capacity. In the TCO calculation, the monthly battery leasing costs is regarded as a recurring cost.

The **maintenance costs** depend on the vehicle type and annual mileage. Maintenance costs include the costs for all the small and large maintenances throughout the vehicle's lifespan. These costs are necessary to keep the vehicle operational. They include oil replacements, brake replacements, etc. Reports [29] claim that small maintenances should take place after 10,000 kms and large maintenances after 30,000 kms. However, after consulting several car dealerships, in this TCO, these figures are respectively 20,000 kms and 40,000 kms. The maintenance prices are retrieved online [14] and are specific for every model. In general, the maintenance costs for BEVs are lower compared to ICE vehicles. Since BEVs have less moving components, they face less temperature stress and do not need oil and filter replacements [30], [31]. Also, due to the possibility to recuperate energy whilst braking, the braking pads will last longer [17]. We assume a maintenance cost for BEVs of 65 per cent of a similar conventional vehicle [32]. Other studies are more prudent and use a reduction of 20 per cent in maintenance costs BEVs [5]. As for the maintenance costs of hybrid cars, they are considered to be the same as those for ICE cars [33].

Tires are expected to be changed every 40,000 kms [34]. The type and prices of the tires was found online [35], [36]. Also included are the costs for replacing the 4 tires at the car dealership. Here, we include €32 to replace the tires and €24 for balancing.

Every vehicle in Belgium has to be inspected on the **technical control**. During the first 4 years, no costs are expected. After that period, the car has to be inspected on an annual basis. The cost for this inspection amounts to €32.80 (€29.10 for the normal inspection and €3.70 for the environmental inspection) [37]. All prices include VAT.

4 Results

In this section, the results of the TCO analysis for the reference or business as usual scenario in the three vehicle segments are elaborated.

Figure 1 illustrates the TCO results for the small city cars. The left y-axis shows the total cost of ownership (in €), while the right y-axis shows the cost per kilometre (in €/km). The difference between conventional ICEVs and BEVs is clear: small petrol cars range from 0.18 – 0.23 €/km, small diesel cars range from 0.19 – 0.21 €/km, BEVs range from 0.30 – 0.36 €/km. As expected, the share of the depreciation cost for BEVs within their TCO is significantly higher compared to petrol and diesel cars: this share equals on average 59% (BEVs), 34% (petrol) and 44% (diesel). However, fuel and electricity costs shares are lower for the selected BEVs: 8% (BEVs), 38% (petrol) and 25% (diesel).

The results for the medium car segment are depicted in Figure 2. Here, results are more promising for the analyzed EVs: the difference in TCO with conventional and EVs is lower compared to the small city car segment. Ranges go from 0.27 – 0.33 €/km for petrol cars, 0.28 – 0.31 €/km for diesel cars, 0.27 – 0.38 €/km for hybrids, 0.39 – 0.42 €/km for BEVs and 0.45 – 0.50 €/km for PHEVs. For this segment, buying a BEV with a battery leasing contract is more cost efficient than buying the car with the battery. Also, the share of depreciation between all vehicle technologies is more uniform: 43% for petrol vehicles, 51% for diesel vehicles, 53% for hybrids, 55% for BEVs and 70% for PHEVs. Results illustrate that the investigated BEVs are closing in on conventional vehicles. However, if consumers wish to combine the eco-efficiency of BEVs with the driving range of conventional vehicles, PHEVs are still a costly option.

For the premium car segment, the results are depicted in Figure 3. For this segment, other factors like brand perception, image and looks play a more important role than in the other two vehicle segments. Comparable cars from the three best selling manufacturers are investigated, each with three different vehicle technologies: petrol, diesel and hybrid. The BEV is represented by the Tesla Model S, which is available in 3 settings, depending of the capacity of the battery pack: 40 kWh, 60 kWh or 85 kWh. Results show that the investigated BEVs for this segment are cost efficient compared to the conventional technologies. Costs per kilometre range from 0.53 – 0.67 €/km for petrol cars, 0.52 – 0.66 €/km for diesel cars, 0.59 – 0.72 €/km for hybrids and 0.58 – 0.79 €/km for BEVs. Even the BEV model with the largest battery pack (85 kWh, expected driving range of 480 km) is cost comparable with the HEVs. It must be noted that battery replacement costs for the 3 BEVs after 6 years are covered by the warranty given by Tesla (7 years, 160,000kms). If the vehicles are used for a longer period, consumers should be aware that expensive replacement costs could occur.

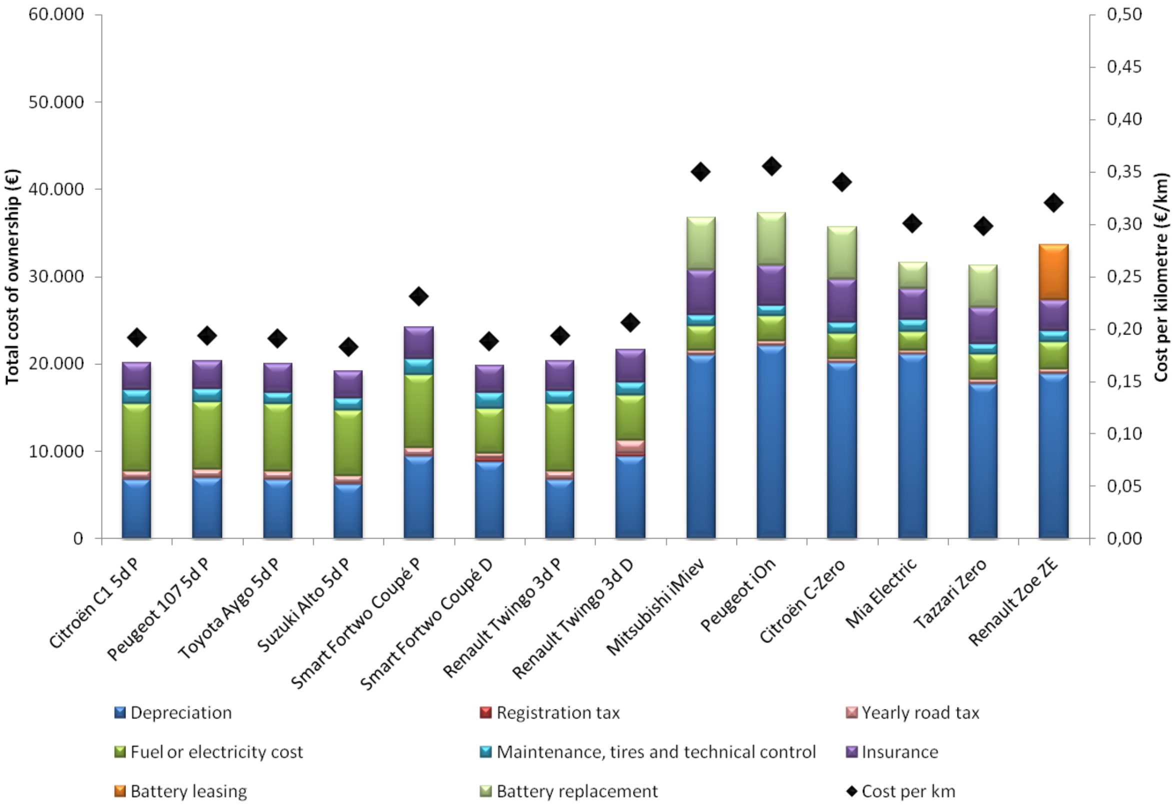

Figure 1: TCO results for small city cars

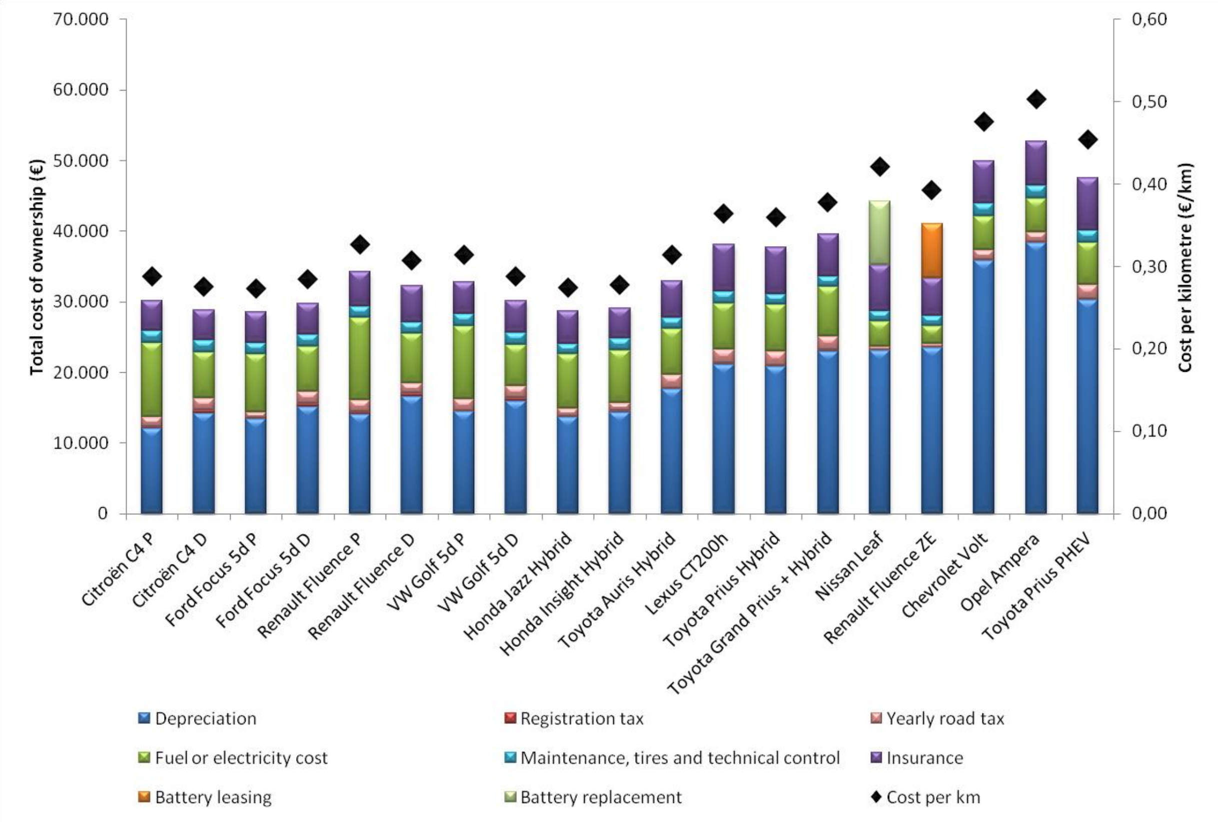

Figure 2: TCO results for medium cars

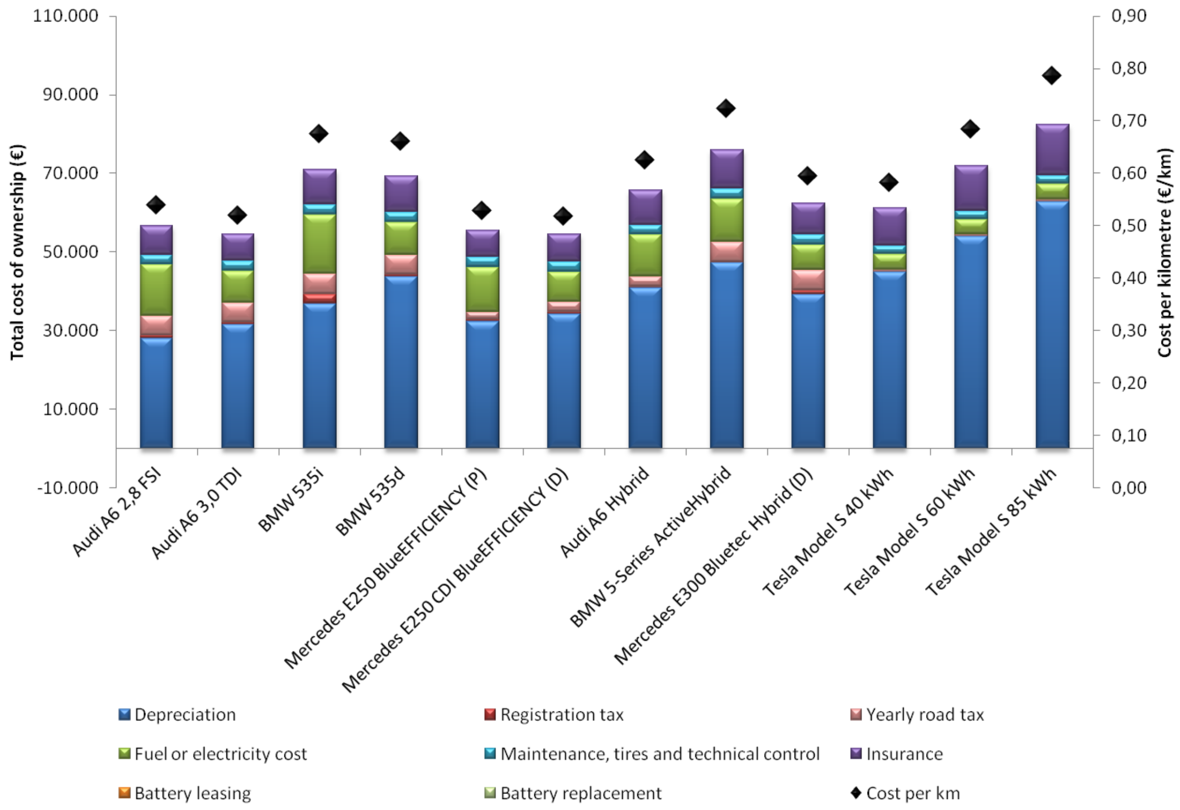

Figure 3: TCO results for premium cars

5 Sensitivity analyses and scenarios

In the TCO model, several input parameters contain a degree of uncertainty: the discount rate, the maintenance costs for electric vehicles, the annual mileage and the ownership duration.

The general TCO model takes into account a discount rate of 1.18 per cent on an annual basis. Sensitivity analyses are conducted for discount rates of -40% to +40% from the BAU discount rate. The TCO (in €/km) decreases as the discount rate increases, because all future costs have a lower present value. Results show that for all three vehicle segments, BEVs and PHEVS induce a lower impact from the change in discount rate compared to ICEVs, as these vehicles have higher initial sales prices that do not need to be discounted. BEVs without a battery leasing contract show the largest difference, as these are the most expensive cars in the study.

General maintenance costs for BEVs are assumed to be 65 per cent of the costs of conventional vehicles within the same segment. However, as BEVs have only recently entered the market, no figures are available in current literature. In this sensitivity analysis, the maintenance costs for BEVs range from 45% (-30% to BAU) to 85% (+30% to BAU). Off course, this sensitivity analysis only impacts the TCO of BEVs (with or without battery leasing contract). Results show small impacts on the TCO when the maintenance costs increase of decrease, ranging from -0.52% to +0.52%. This entails that the lower maintenance costs should not be regarded as a major advantage for BEVs.

The annual mileage is presumed to be 15,000 km a year. A change in mileage ranging with 33% of the BAU scenario is investigated (10,000 km – 20,000 km). As expected, the higher the annual mileage, the lower the TCO (in €/km). For BEVs, the effect is bigger (in both sides) as these vehicles have lower running costs.

Identical results are shown for the sensitivity analysis for the ownership duration. While the parameter used in the TCO BAU model was 7 years, results are calculated for 3, 5, 9 and 11 years. The annual mileage is kept on 15,000 km a year. Again, BEVs induce larger impacts from changes in ownership duration, which is linked with the total mileage of the vehicle's lifetime.

Next, several scenarios are investigated: an increase in fuel prices, a decrease in battery prices and an up-front subsidy for BEVs. These scenarios are realistic changes in economic parameters that could occur in the near future.

If fuel prices would increase with 4 per cent (above inflation), the TCO for petrol, diesel, hybrid and plug-in hybrid vehicles would increase. The effect is the largest for petrol cars, as these vehicles consume the most fuel and as petrol prices are higher than diesel prices. The TCO for PHEVs increases only marginally, as part of the driving distance is covered by electricity, which in this scenario remains at the same cost level. However, the result of this sensitivity analysis indicate only marginal increases in cost efficiency for EVs compared to conventional vehicles, in each of the three segments.

Contrarily, a decrease in battery prices from €600 to €400 per kWh (today) and from €400 to €200 per kWh (in 6 years) does have a significant impact on the cost efficiency for BEVs. This decrease impacts both the initial sales price (BEVs, PHEVs) as well as the battery replacement costs (BEVs). It does not impact BEVs with a leasing contract, since the customer does not acquire the battery pack and battery replacements are included in the leasing contract. Results for the small city car segment show that surcosts for BEVs without leasing contract compared to petrol and diesel cars decreases from 67% to 53%. Hence, these vehicles become more cost efficient than BEVs with a leasing contract. However, BEVs are still not cost competitive to conventional cars, but the cost difference between technologies has lowered. Results for the medium car segment illustrate that the TCO difference between BEVs without leasing contract and ICEVs decreases from 43% to 28%, while the difference with HEVs decreases from 29% to 15%. Because of the large battery packs in the electric models for the premium car segment, a decrease in battery prices has a large impact on the final TCO. BEVs become as cost efficient as the popular diesel vehicles in this segment.

Many countries stimulate the purchase of electric vehicles by offering governmental financial subsidies. In Belgium, from January 2009 until December 2012, customers of BEVs were eligible to receive a grant of 30% on the sales price of the vehicle (with a yearly indexed maximum of € 9,190) [38]. Results for governmental subsidies show an even greater drop in surcosts for BEVs (this time including BEVs with leasing contract) in the small city and medium car segment compared to the sensitivity analysis where battery prices drop. Results for the premium car segment are inverse: the effect of the governmental financial subsidy is lower than the decrease in battery prices, because of the very large battery packs. In general, these findings are similar to what can be found in literature [13], [26]: governmental subsidies can make BEVs cost efficient compared to conventional vehicles.

6 Results and discussion

In this study, a total cost of ownership model is created for three different car segments: small city cars, medium cars and premium cars. All costs that occur during the expected vehicle's lifespan are included: purchase cost, registration tax, vehicle road tax, maintenance, tires and technical control cost, insurance cost, battery leasing cost, battery replacement cost and fuel or electricity cost.

Results for the small city car segment indicate that, taken into account the assessed vehicles in the model, BEVs without a battery leasing contract are not cost attractive compared to conventional petrol and diesel vehicles. For the medium car segment, the price difference between technologies is more subtle. However BEVs without a leasing contract and PHEVs are still cost inefficient. If the consumer opts for a BEV with battery leasing, TCO values are within the range of current HEVs. The results for the premium car segment depend largely on the size of the battery pack for the BEVs. When equipped with a 40 kWh battery pack, BEVs are competitive with modern petrol and diesel cars. However, if the consumer opts for an electric driving range of approximately 450 kms, the TCO of the BEV is slightly higher than modern HEVs within the segment. In general, electric vehicles suffer from high depreciation costs (due to the elevated sales price), but benefit from low driving costs. For the medium car segment, BEVs with a leasing contract are more cost efficient.

Since several input parameters of the TCO model contain a degree of uncertainty, different sensitivity analyses were conducted. These include a change in the discount rate, the maintenance costs for electric vehicles, the annual mileage and the ownership duration. Results show that the discount rate has a relatively low impact on TCO values. In general, the higher the share of the initial sales price within the TCO, the lower the effect of a change in discount rate. Lower maintenance costs should not be regarded as a major advantage for BEVs, as sensitivity analyses show relatively small impacts on TCO results (-0.52% to +0.52%) when the maintenance costs change. A change in annual mileage ranging with 33% of the BAU scenario is investigated. As expected, the higher the annual mileage, the lower the TCO (in €/km). For BEVs, the effect is bigger (in both directions) as these vehicles have lower costs for fuel/electricity. Identical results are shown for the sensitivity analysis for the ownership duration. BEVs induce larger impacts from changes in ownership duration, which is linked with the total mileage of the vehicle's lifetime.

Next, several plausible future sensitivity scenarios were elaborated: an increase of fuel prices, a decrease in battery prices and a governmental support for BEVs. Results are shown per vehicle segment. In order to have the largest impact on the TCO for small city and medium cars, governmental subsidies would have to be implemented, followed by a decrease in battery prices. However, BEVs in this segment still remain cost inefficient compared to the conventional models. In the premium car segment, a decrease in battery prices has the largest impact, as the battery packs of the investigated BEVs are relatively large, followed by governmental subsidies. In general, increased fuel prices do not render BEVs cost competitive.

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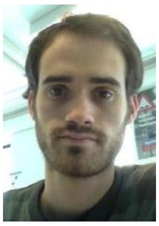

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