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# How Total is a Total Cost of Ownership?

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**Abstract**

In this paper a segmented Total Cost of Ownership (TCO) model is presented for alternative vehicle technologies as well as its extension with external costs related to vehicle ownership and use. Adding external costs to the TCO extends the interpretation of individual ownership to a societal perspective by describing the effect of the technologies on the costs for the society. This extension, called "Total Cost for Society", suggests that battery electric vehicles, plug-in hybrid electric vehicles and hybrid electric vehicles have a lower societal cost than petrol, diesel and compressed natural gas vehicles.
*Keywords: passenger car, electric vehicle, cost.*

## 1 Introduction

One of the most important barriers for battery electric vehicle (BEVs) adoption is the high purchase cost of the vehicles. Consumer mostly consider the substantial initial cost of BEVs above the many other costs involved in car ownership [1]. Since some of these other cost, i.e. fuel, can be quite substantial depending on the car technology, choosing a new car based solely on its purchase price is therefore an incorrect approach for selecting the less expensive option. This is the m§ *Total Cost of Ownership* (TCO) methodology [2] is often used to analyze the competitiveness of BEVs [3]. A TCO aims at describing the full cost of vehicles during the ownership and inform the consumer which vehicle costs less.

[3] review in their article many other articles related to "*Vehicle Cost Analysis*". They cite a total of 29 articles, published since 2010, related to this topic. From these 29 articles, 13 articles apply the TCO methodology for analyzing the difference in cost between different vehicle technologies. This clearly indicates that the TCO is a suitable method for comparing different vehicle technologies.

[4] identifies two distinct types of TCO studies, namely, consumer-oriented TCO studies and society-oriented TCO studies. The difference between the two approaches resides in the author's focus. Consumer-oriented TCO analyses focus mainly on the difference in cost the consumer should pay depending on the various vehicle technologies at his disposal. Examples of such studies are [4, 5]. The particularity of society-oriented TCO studies are the extra relation between the cost of the different vehicle technologies and their societal impact. [6, 7] are two examples of society-oriented TCO studies.

In this paper, a society-oriented segmented-TCO model, developed in the context of the Brussels Capital Region, is presented. The model we present is called a *Total Cost for Society* (TCS), where a TCO analysis is used as tool for discussing the internalization of external costs. Therefore, the amount of taxation in the TCO analysis is calculated and used in combination with the external costs. The combined value enables to extends the interpretation of individual ownership to societal perspectives.

The paper is structured as follows. Firstly, the different methodologies used in this paper are is detailed in section 2. These methodologies comprise a segmented-TCO, an external cost analysis and the

formulation of a TCO-based tax model. Secondly, the results from the TCO, external costs and Total Cost for Society are discussed. Finally, this paper ends with the main conclusions.

# 2 Methodology

Firstly, the assumptions upon which the analysis is based are presented. Secondly, the complete TCO methodology is detailed. The TCO-methodology is based on the work of [4] . Finally, the details of the TCO-based tax model are explained.

## 2.1 General assumptions

A TCO analysis relies heavily on different kind of assumptions. All the assumptions of the TCO presented in this paper are based on characteristics of the Belgian's and Brussels' fleet, since the scope of this research is the Brussels Capital Region in 2015. The main assumptions of these analyses are summarized in Table 1. The average Belgian owns a car for 8 years and 45 days and drives 15.284 kilometers a year [8, 9]. This results in a total mileage of 124.156 km during the ownership of the vehicle. A real discount rate of 0,33% is used for calculating the present value of future costs. This percentage corresponds to the 8-year interest rate for European government bonds [10] . The real discount rate dates from May 4 2015.

Table 1: General assumption TCO

| Assumption | Value | Reference |
|---|---|---|
| Duration ownership vehicle | 8 years and 45 days | [9] |
| Yearly mileage | 15.284 km / year | [8] |
| Total mileage | 124.156 km | / |
| Real discount rate | 0.33% | [10] |

Various different vehicle technologies are assumed in this TCO analysis. Conventional petrol (P) and diesel (D) vehicles are assumed as well as alternative vehicle technologies such as hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEV) and compressed natural gas vehicle (CNG). In total 45 vehicles are selected: 9 petrol vehicles, 9 diesel vehicles, 6 CNG vehicles, 3 PHEVs, 7 HEVs and 12 BEVs.
These vehicles are divided into three segments, namely, the city car segment, the medium segment and the premium segment. Those segments are defined based on the vehicle's size, the boot space and the power of the motor. The results of the TCO will be presented for each of the three segments. In total there are 13 vehicles in the city car segment, 22 vehicles in the medium car segment and 10 vehicles in the premium segment.
When constructing a TCO analysis, different costs at different points in time are assumed. Therefore, future costs need to be calculated using a discounted formula approximating the value of money in time, namely, the present value formula [4]. Following formula is applied when facing future one-time costs [11]:

$$PV = A_t * \frac{1}{(1+r)^t} \tag{1}$$

and in the case of recurring costs, following formula is applied instead:

$$PV = A_0 * \frac{(1+r)^t - 1}{r * (1+r)^t} \tag{2}$$

Where,

- $PV$: Is the present value
- $A_t$: Is a one-time cost at time t
- $A_0$: Is a recurring cost
- $r$: Is the real discount rate presented in 1
- $t$ : Is time expressed in years

## 2.2 TCO Calculations

There are three distinct cost categories in a TCO analysis for passenger car, namely, costs at the time of purchase, operational costs and non-operational costs [4]. These costs will be detailed in next subsections.

### 2.2.1 Purchase Costs

The **initial purchase cost** that are considered in this TCO include VAT but exclude any kind of reduction or promotion and also exclude extra vehicle options. The costs were retrieved on the dealers' websites.

Table 2: Depreciation rates per vehicles technology

| Technology | Depreciation rate |
|---|---|
| P | 84,5% |
| D | 82,7% |
| HEV | 83,4% |
| BEV | 78,6% |
| PHEV | 82,4% |
| CNG | 78,1% |

Since the vehicles depreciate over time, it is important to consider their depreciation rate in the analysis. The percentages in Table 2 represent the residual values of the different vehicle technologies after one year. The percentages of the petrol, diesel and HEV are retrieved from [4] , while the other depreciation rates are determined using the same methodology (via exponential regression). The data used in this exponential regression comes from [12]. The values for CNG vehicles and some BEV vehicles are only available for the first three years, therefore their depreciation rate is less certain. Table 2 summarizes the depreciation rates per vehicle technology.
The **registration tax** is a one-time tax due at the time the vehicle is bought. This tax is determined for vehicles registered in the Brussels Capital Region based on the engine's power, the fiscal horsepower, and the engine's displacement [13].
The **charging infrastructure** is another one-time cost that can be spent when buying a new BEV or PHEV. In this analysis we use the prices of Electrabel's "CarPlug" charging pole [14]. The pole itself costs €999 and a standard installation costs €351 for a total of €1.300.

### 2.2.2 Operational Costs

The **fuel costs** for petrol (1,5959 €/l) and diesel (1,4158 €/l) correspond to the average maximum prices from 2014 according to the Belgian Federation of Petroleum [15]. The **electricity costs** are calculated based on trimestrial reports from Brugel in 2014 [16]. The subscription we consider is the standard subscription for households in the Brussels Capital Region, namely, *Electrabel Customer Solutions Easy Indexé*. For an average Brussels household (consumption of 3.500 kWh per year), the cost of electricity is equal to 0,1809 €/kWh. The reference price for CNG that is considered in this paper is equal to 0,87 €/kg. This was the price for one kilogram CNG on May 25th 2015 [17].

## 2.3 Non-operational Costs

The **road tax** is a yearly recurring cost that depends on the vehicle's fiscal horsepower [18].

In Belgium it is required that every vehicle is at least insured with the civil liability **insurance** in order to insure any damage done to another vehicle. For new cars an omnium insurance, which is complementary to the civil liability insurance, is preferred. This omnium insurance also insures the driver's vehicle. The cost of an omnium insurance depends on various characteristics, such as age, type of car and mileage per year. The insurances were retrieved using the Touring Insurances website [19]. In this analysis an omnium insurance is considered for the first three years and afterwards a civil liability insurance is preferred.

Lebeau et.al. [4] assume a battery life of 6 years for the battery packs of BEVs. This implies a lifetime equal to 91.704 km given the assumption of 15.284 km driven per year. The **battery pack** must be replaced after those 6 years or 91.704 km. If the battery pack is still under the warranty of the manufacturer, then no costs are charged. Otherwise the cost of replacing the battery pack is approximated by charging €160 per kWh. This value of €160 is based on the article of Nykvist et.al. [20] that determines that market-leading manufacturers sold one kWh of battery for approximately $300 in 2014 and that the cost of one kWh showed an annual decrease of 8% since 2007. We assume that $300 was still the cost of

one kWh at the beginning of 2015 and that this cost will evolve to approximately $180 ( €160) in 2021 given the annual decrease of 8%. PHEV battery packs are also considered for battery replacement. The residual value of the vehicle increases linearly when the battery is replaced.

The **battery leasing** option is offered by some manufacturer. In exchange of a recurring monthly leasing cost, the manufacturer takes care of the battery replacement for free when the battery's capacity drops below a predefined percentage, usually 80%.

Maintenance are crucial costs during the lifetime of the vehicle. They include the replacement of worn out components such as brakes, filters or oil. Two kind of **maintenances** are identified depending on the vehicle's mileage, namely, small and large maintenances. Small maintenances are performed after 20.000 km and large maintenances after 40.000 km as in [4]. The maintenance prices are specific to each model and are retrieved online from [21]. [22] suggests that the cost of maintaining an BEV is 35 % cheaper than conventional vehicles. Therefore, the maintenance costs of BEVs are 35% lower than the mean of the maintenance costs of conventional cars. The maintenance cost of CNG vehicles and hybrid vehicles is assumed to be equal to the maintenance costs of conventional vehicles [23].
Another aspect of the maintenance is the **replacement of tires**. The tires need to be replaced every 40.000 km. The tires and their cost are determined using the websites [24, 25]. A total of €56 is added for the replacement and balancing of the tires [4].
After four years of lifetime, the vehicles must pass an annual **technical control**. This annual inspection costs €33,80 [26].
Finally, this TCO also comprises less obvious costs, namely, fines and parking fees. According to the Household Budget Survey from 2014 [27], Belgian households spent on average €69 for fines and €31 for parking fees. Since 76,78% of all infractions committed by Belgians during 2013 are related to violations of the traffic code [28], the average amount of fines a Belgian pays per year for traffic violations are estimated to be €52,98 with the assumption the percentage of infractions concerning traffic are equivalent in 2014.

## 2.4 External Cost Calculations

In this paper, the impact calculations for external cost comprise a non-exhaustive list of externalities: climate change, air pollution, noise, accidents, congestion and infrastructure. The total external cost is thus a summation of these externalities. In order to calculate the impact of each above mentioned externalities, a scenario representing a typical driving pattern needs to be defined.

### 2.4.1 External Cost Scenario

The scenario that is defined for the calculation of the external costs is based on the driving motives of Belgian drivers, since the scope of this study is the Brussels Capital Region. Several travel motives are identified in the BELDAM study [29]. The average amount of traveled km per trip is given for each motive. Those mean distances are based on different modes of transport but since the car has the biggest share for almost every motive, it is assumed that these average travel distances are representative for car drivers. In this paper the different travel motives are grouped into three main categories: Commuting and work-related trips, recreative trips and other trips (comprising shopping, services such as the doctor, picking up people,...). Those three categories represent the three behaviors that define the scenario that is presented below. The share of the total km driven for each behavior is reported in Table 3 and is determined based on the average distances per trip for each motive belonging to the specific category.

Table 3: Share of the total km driven per behavior

| Behavior | Average distance per trip | Share of total driven kilometers |
|---|---|---|
| Commuting and work-related | 24,17 km | 54,6% |
| Recreative | 11,61 km | 26,2% |
| Others | 8,51 km | 19,2% |
| Total | 44,29 km | 100% |

The scenario upon which the calculations are based is defined is the follows:

- Commuting and work-related trips:
  - During daytime
  - Share metropolitan motorway and main roads: 80% and 20%
  - Share peak and off-peak: 20% and 80%
- Recreative trips:

  - During daytime
  - Share metropolitan motorway, main roads and small roads: 20%, 30% and 50%
  - Share peak and off-peak: 5% and 95%

- Other trips:
  - During daytime
  - Share metropolitan motorway and main roads: 30% and 70%
  - Share peak and off-peak: 10% and 90%

### 2.4.2 Climate change

The external climate change costs are determined based on the fuel and electricity consumption using a well-to-tank approach. Table 4 summarizes the well-to-tank emissions of $CO_2$ per unit of fuel/electricity. A total amount of kilograms $CO_2$ emissions are derived using these emissions and the NEDC-based consumption values of fuel and electricity for each vehicle. Finally the external climate change costs are determined by multiplying the total emissions with the external climate cost per kg $CO_2$ (0,09 €/kg according to [30]).

Table 4: Well-to-tank emissions

| Fuel/electricity | $CO_2$ emissions | Reference |
|---|---|---|
| Diesel | 3,200 kg $CO_2$/liter | [31] |
| Petrol | 2,800 kg $CO_2$/liter | [31] |
| CNG | 3,070 kg $CO_2$/kg | [31] |
| Electricity (BE mix) | 0,187 kg $CO_2$/kWh | [32] |

### 2.4.3 Air pollution

As opposed to the external climate change cost, the up- and down-stream costs are not considered for air pollution, since those are hard to isolate for electric vehicles. The external air pollution costs are thus calculated based on the total mileage of the vehicles during the ownership period (see Table 1). The values (in €/km) for the marginal external air pollution costs per km are referenced in Table 5. The marginal external costs depends on vehicle technology, the engine displacement, the EURO-class and the type of road.

Table 5: Marginal external air pollution costs in €/vkm for Belgium. Based on [30]

| Vehicle | Engine | EURO-Class | Urban | Motorway |
|---|---|---|---|---|
| Diesel | 1,4-2,0l | EUR 5 | 0,0084 | 0,0041 |
| Diesel | >2,0l | EUR 6 | 0,0061 | 0,0022 |
| Petrol | <1,4l | EUR 5 | 0,0034 | 0,0008 |
| Petrol | 1,4-2,0l | EUR 5 | 0,0033 | 0,0008 |
| Petrol | 1,4-2,0l | EUR 6 | 0,0033 | 0,0008 |
| Petrol | >2,0l | EUR 6 | 0,0033 | 0,0008 |

### 2.4.4 Noise

Analogous to external air pollution costs, external noise costs are determined based on the total mileage of the vehicle and the marginal external noise costs. The marginal external noise costs are determined by the time of day, the area and traffic density type. In the above described scenario, the time of day and the area are always defined as daytime and urban. Therefore, the main difference in external noise cost is determined by the traffic density. This cost is equal to €0,0105/vkm for dense traffic and to €0,0255/vkm for thin traffic [30]. For BEV and CNG vehicles different values are assumed. BEVs are assumed to emit no noise and CNG vehicles to emit only 50% of the noise generated by conventional vehicles because those vehicles have significant lower noise levels.

### 2.4.5 Accidents

The marginal external accident costs are defined solely on the type of road. Since the scenario takes place in an metropolitan setting, only motorways and urban roads are of importance. The marginal external accident costs for motorways is €0,003/vkm and €0,004/vkm for urban roads.

### 2.4.6 Congestion

The marginal external congestion costs depend on the area (metropolitan in the Brussels' case), the road type and the type of traffic. Free flow is assumed when the traffic is off-peak. When in rush hours, the average of near flow capacity and over capacity is assumed. The total external congestion cost is calculated by multiplying the marginal cost per km with the total mileage of the vehicles.

Table 6: Marginal external congestion costs in €/vkm for Belgium. Based on [30]

| Road type | Free flow | Near capacity | Over capacity |
|---|---|---|---|
| Motorway | 0,0000 | 0,3192 | 0,7338 |
| Main roads | 0,0111 | 1,6853 | 2,1617 |
| Other roads | 0,0297 | 1,9019 | 2,8930 |

### 2.4.7 Infrastructure

The calculation of the external infrastructure costs are similar to the calculation of the other externalities (except for climate change). The marginal external infrastructure costs depend on the type of road. The cost per vkm is equal to €0,0024 for motorways, €0,0033 for other trunk roads and €0,0082 for other roads [30].

## 2.5 From TCO to Tax Model

By calculating the extend of the vehicle taxes it is possible to combine them with the external costs calculations and thus internalize the external costs given the TCO results. This TCO-based tax model is an important building stone for extension from TCO to TCS.

There are three kind of taxes that are incorporated in this assessment: the vehicle specific taxes, the VAT and the excises.
The vehicles specific taxes such as the registration tax, the road tax, the fines and the parking fees are completely integrated without any reduction.
In Belgium the VAT is usually equal to 21%. Some goods or services have a VAT inferior to 21%, for example electricity had a VAT of 6% in 2015. The VAT of the installation of the charging pole has also a VAT of 6% if it is installed in a private house that is older than 5 years [14]. Thus all components of the TCO are subjected to a VAT of 21% except for electricity and for the charging pole installation.It is also important to observe that the initial purchase cost is taxed instead and not the depreciation of the vehicle.

The excise, special excise and energy taxes of fuels and electricity in transport applications are summarized in Table 7. Those excises are fully integrated in the tax model derived from the TCO results.

Table 7: Excise, special excise and energy taxes in Belgium in €/l [33]

| Energy | Excise | Special excise | Energy taxes |
|---|---|---|---|
| Petrol | 0,2454146 | 0,360191 | 0,0286317 |
| Diesel | 0,1983148 | 0,2183561 | 0,0148736 |
| Electricity | 0 | 0 | 0,001914 |
| CNG | 0 | 0 | 0 |

# 3 Results

In this section the results of the TCO, external cost calculations and the internalization of the external costs to the TCO are presented.

## 3.1 Results TCO

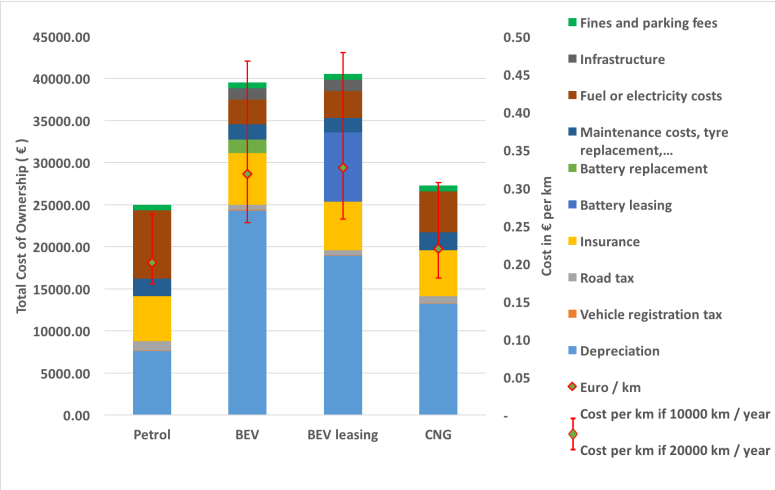



Figure 1: TCO results for the city car segment

The TCO results for the city car segment are depicted in Figure 1. The TCO value is denoted by the left y-axis and the cost per km in € is indicated by the right y-axis. Petrol vehicles are clearly the most competitive vehicles in this segment (0,20 €/km), although the TCO of CNG vehicles is rather close to the TCO for petrol vehicles (0,22 €/km). BEVs, both with and without leasing of battery, are not competitive in this car segment (respectively 0,33 and 0,32 €/km). The big difference resides in the depreciation cost that is much higher for BEVs even if their operational costs are lower.
The error-bars show the deviation in cost per km when driving 10.000 km or 20.000 km per year instead of 15.284 km. It is clear that the BEV technology shows the most variance in costs depending on the distance driven. This means that BEVs will become more competitive when used more intensively.

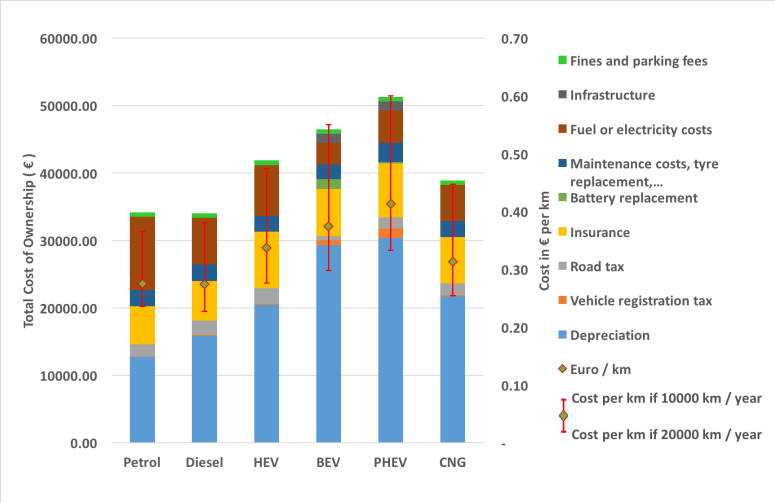



Figure 2: TCO results for the medium car segment

Figure 2 illustrates the results for the medium car segment. In this segment, the difference between BEVs and conventional vehicle technologies such as petrol and diesel is smaller than for the city car segment. The difference between these technologies is of 0,09 - 0,10 €/km since BEVs have a cost per km equal to 0,37 €/km and petrol and diesel vehicles have a cost per km of respectively 0,28 €/km and 0,27 €/km. This difference was equal to 0,12 - 0,13 €/km in the city car segment. The medium car segment is thus more interesting for buying a BEV than the city car segment when comparing with the alternatives in the same segment. CNG vehicles are still competitive (0,31 €/km) in this segment but less than in the city car segment (a difference of 0,03 - 0,04 €/km instead of 0,02 €/km with respect to conventional

vehicle technologies). HEV vehicles are an interesting option that is a little bit more expensive than CNG vehicles, while PHEVs are the most expensive cars with a cost per km equal to 0,41 €/km. PHEVs and BEVs have still too much depreciation costs to compete with the other alternatives.

The conclusion is slightly different in the premium car segment (Figure 3). The HEVs are the most competitive cars with a cost per km of 0,63 €/km. Diesel and petrol vehicles are close with costs per km of 0,64 €/km and 0,67 €/km respectively. It is also in this segment that BEVs are the most competitive with a cost per km equal to 0,73 €/km. This is partly due to the fact that BEVs do not have costly road taxes, that the battery replacement is covered by their warranty and that the depreciation cost is not as bad as in the other segments. An important observation is that if the vehicles would drive more than 20.000 km, the cost per km would be almost equal for all technologies.

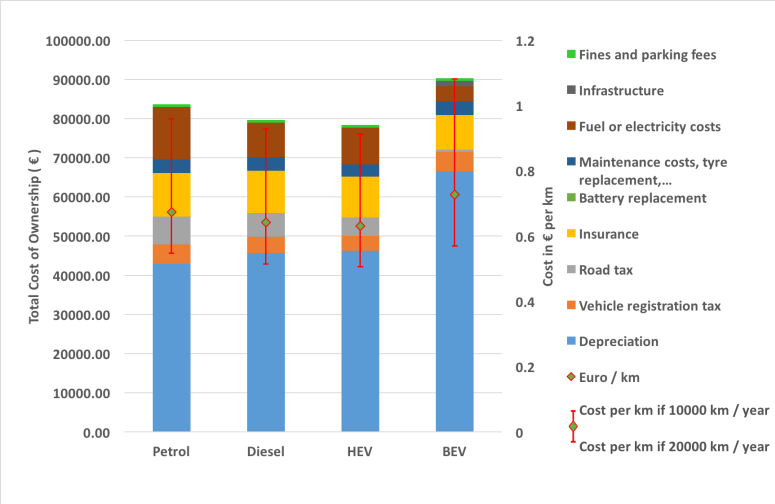


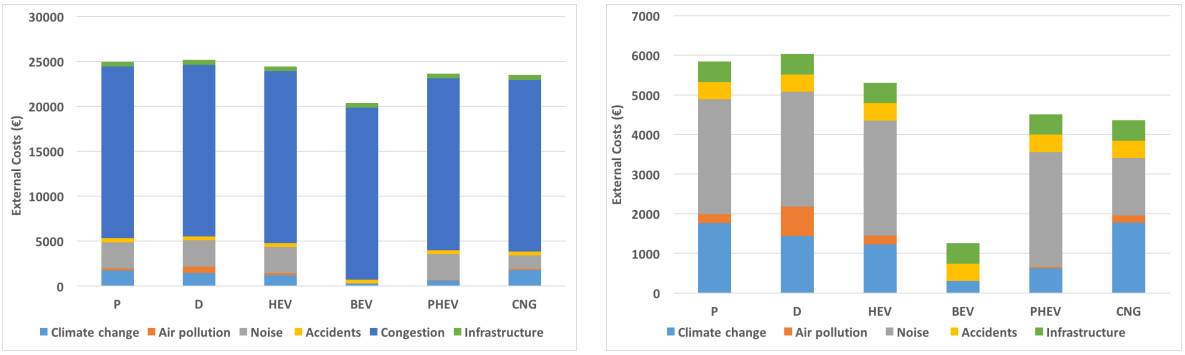

Figure 3: TCO results for the premium car segment

## 3.2 Result External Costs

Since the conclusions of the results for the different segments are similar, only the medium car segment will be detailed. The analysis is split in two parts, an analysis including congestion costs and an analysis excluding congestion costs. It is clear from Figure 4a that the congestion cost are quite high (approximately €19.000). This is typical for the setting of Brussels. Brussels is a city with a huge amount of congestion, therefore it is not unusual to have such high external congestion costs. It is thus easier to exclude congestion costs from the analysis in order to generalize the results and notice differences in the external costs between several vehicle technologies.
The main differences in external costs reside in the climate change, air pollution and noise costs. It is clear that BEVs have the less significant external costs, approximately €1.250 when excluding congestion costs. This is almost five times smaller than the external costs for diesel and petrol vehicles (around €6.000 without congestion costs). Notice that air pollution and noise are equal to zero in this analysis. This is an underestimation since the up- and down-stream costs are not taken into account for air pollution and that even if electric vehicles have a silent motor, they emit a little bit of noise as well when they are on the road.
The reasons why PHEVs and CNG vehicles have lower external cost are different, even if both technologies have lower external costs than petrol, diesel and HEVs. PHEVs have less impact on the climate change cost due to reduced $CO_2$ emissions, but have the same impact as diesel petrol and HEV vehicles on the external noise cost due to the combustion engine. On the other hand, CNG vehicles have a much higher climate change cost and a much lower noise cost than PHEV vehicles. Diesel, petrol and HEV are the vehicle technologies with the highest external costs, namely, between €5.000 and €6.000 when excluding congestion costs and almost €25.000 when including congestion costs.

## 3.3 Internalization of External Costs with the TCO-based Tax Model

As in previous subsection, only the medium car segment is considered. Given the TCO-based tax model depicted in Figure 5 and the previously discussed external costs, a number of observations can be formulated. Combining the tax incomes and the external costs enables to compare the different societal impacts of the various vehicle technologies. In this analysis the congestion costs are included such that a more




(a) Including congestion costs

(b) Excluding congestion costs

Figure 4: External costs results for the medium car segment

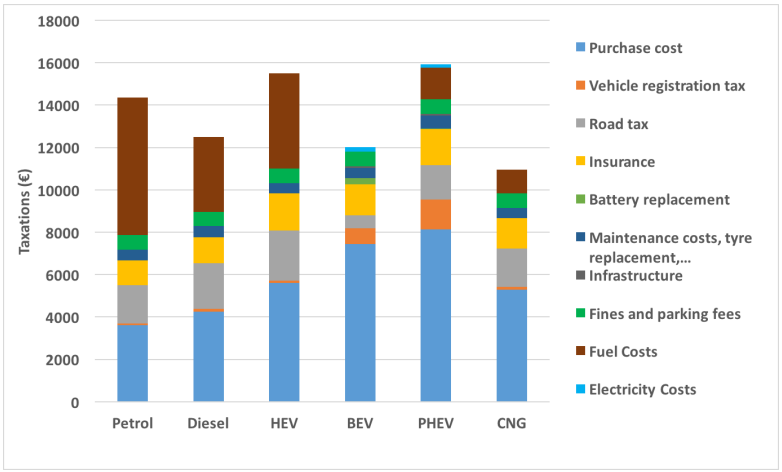



Figure 5: TCO-based tax model results for the medium car segment.

realistic Total Cost for Society (TCS) can be obtained. It is important to mention that it is assumed that the tax incomes from the TCO reduce directly the external cost generated by the vehicle, even though normally tax incomes are grouped and redistributed where needed. Nevertheless, this direct comparison enables to investigate which technology has a bigger impact on the society.

First, the two most taxed vehicles are the HEV and PHEV. Those two vehicle technologies are heavily taxed mainly due to the higher initial purchase price. The taxation of fuel does also play a part in the high taxation of the HEV technology. When taking Figure 4b into account it is noticeable that PHEV vehicles are also vehicles that do not generate the most external costs. This means that buying a PHEV has in fact a good impact on the society by on one hand generating a great amount of tax incomes and on the other hand having a moderate impact on the external costs. The TCS for PHEVs is around €7.700. The HEV vehicles have a smaller societal impact (TCS of €8.900) than PHEV vehicles since their external cost is one of the biggest.
Secondly, BEVs have also a great societal impact with a TCS of €8.350. Even though those vehicles are not heavily taxed, besides the VAT on the higher initial purchase price, their external cost is so low in comparison with the other vehicle technologies that it has still a big societal impact. CNG vehicles look like they are in the same situation as BEVs (smaller tax incomes and moderate external costs), but in fact the TCS is much bigger than expected with a TCS of approximately €12.500.
Finally, petrol and diesel vehicles have big TCS values, €10.600 and €12.600 respectively, which indicates that both technologies have worse societal impacts than in example BEVs or PHEVs .

# 4 Conclusion

Several analyses have been conducted in this paper. Firstly, a segmented-TCO has been presented. Three car segments are defined, namely, the city, the medium and the premium car segments. The main con-

clusion of this segmented-TCO analysis is that BEV and HEV become more competitive in higher cost segments. The cost per kilometer is reduced from 0,12 €/km to 0,07 - 0.09 €/km between the city car segment and the premium car segment for BEVs.
Secondly, an external cost analysis is conducted. A first observation is that the congestion costs are incredibly large. This is the result of the scope of this analysis being the Brussels Capital Region, a region known for its high congestion degree. The results show that the BEV technology generates the lowest amount of external costs.
Finally the different analyses are combined. A TCO-based tax model is formulated and combined with the external costs analysis, in one methodology that assesses the societal impact of buying a car depending on its technology. This methodology, called Total Cost of Society, indicates that the BEV, PHEV and HEV technologies are more profitable for the society since they generate less costs (€7.700 - €8.900) than petrol, CNG and diesel vehicles (€10.600 €12.600).

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