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# Electric versus conventional vehicles for logistics: A total cost of ownership

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## Abstract

Today, different measures are investigated to solve the challenge of a sustainable urban freight transport. Among them, electric vehicles are often viewed as an interesting solution but the purchase cost of these vehicles is commonly seen as a barrier to their adoption. However the different cost structure between electric and conventional vehicles makes an analysis of every cost particularly needed if fleet managers want to assess the real competitiveness of the vehicles. As a result, we developed a total cost of ownership model to assess the competitiveness of light commercial vehicles in the Brussels-Capital Region. This paper presents the results of the total cost of ownership analysis on 8 battery electric vehicles, 5 diesel vehicles and 2 petrol vehicles. The results of a sensitivity analysis of the model are also presented.

The electric vehicles were found to be competitive with conventional vehicles in the category of the quadricycles and the light commercial vehicles with a payload lower than 1,000kg: five out of six battery electric vehicles had a cost lower than the conventional vehicles of their category. The situation is inverted for the battery electric vehicles with a payload above 1,000kg where the costs are always higher than the conventional vehicles because of the expensive purchase and battery costs. Since battery electric vehicles are found to be a viable solution for some parts of the logistics, the next challenge should be to convince the fleet managers of the benefits of battery electric vehicles.

*Keywords: Electric vehicles, Total Cost of Ownership, Competitiveness analysis*

## 1 Introduction

In transportation research, electric vehicles are considered as a solution for a sustainable transport [1]. In particular, battery electric vehicle (BEV) offers an interesting alternative to conventional vehicles in different logistics applications like in intermodal networks, in urban freight transport and in night distribution [2–4]. Indeed, the different properties of electric vehicles fit particularly well in these logistics environments. First, the typical short distance trips with multiple stops make the BEV’s limited range irrelevant. This BEV specific boundary is easily controlled by the structured and time-based environment of the logistics chain. Second, within the situation of frequently accelerating and stopping, the energy consumption of BEVs is more efficient compared to internal combustion engine vehicles [5]. Third, the zero emissions of BEVs contribute a lot to the welfare of the facilities, the urban environment and the image of the organisation operating the electric vehicle. Finally, the frequent use of electric light commercial vehicles in combination with relative low operational costs is an important advantage over conventional vehicles that can outweigh the high purchase prices of battery electric vehicles.

However, adopting BEVs remains difficult for fleet managers. The main barrier for switching to an electric vehicle is the high purchase cost [6]. But when deciding on the purchase of a vehicle, a rational fleet manager should consider every cost related to the vehicle choice, and not only the purchase cost. The difference of cost structure between electric and conventional commercial vehicle makes such an analysis particularly important. Hence, assessing to what extent the trade-off between low operating costs and high purchase costs makes the BEVs competitive with conventional vehicles is critical. Hence, the paper presents the results of a competitiveness analysis between diesel, petrol and electric vehicles in the market of urban commercial vehicles.

We developed a total cost of ownership (TCO) model for the commercial vehicles with a gross vehicle weight of maximum 3.5 tonnes in the Brussels-Capital Region. We analysed the costs from 8 electric vehicles and 7 conventional vehicles available on the Belgian market. The paper presents a competitiveness analysis of the different drive trains and the sensitivity of the different assumptions of the model. The results of the sensitivity analysis are used to estimate the impact of expected market evolutions on the competitive position of electric commercial vehicles.

# 2 Methodology

## 2.1 The Total Cost of Ownership (TCO)

Owning and operating a vehicle is associated with costs that occur at different moments in time. To be able to compare these costs across time, the total cost of ownership methodology uses the financial formula of the present discounted value. This way, every cost can be included in one cost indicator to describe the full cost of one alternative. The total cost of ownership is defined as *"a purchasing tool and philosophy which is aimed at understanding the true cost of buying a particular good or service from a particular supplier"* [7]. It gives the total discounted cost of owning, operating and maintaining an asset over a limited period of time. It is used to compare competing investments and evaluate the most profitable alternative.

To calculate the present value of future one-time costs, the following formula is used [8]:

$$PV = A_t \times \frac{1}{(1+I)^t} \qquad (1)$$

Where:
PV = Present value
At = Amount of one-time cost at a time t
I = Real discount rate
T = Time (expressed in 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.

## 2.2 Assumptions of the model

Given its definition, the TCO equation can be divided into three variables: (1) the costs of ownership, (2) the period of time over which these costs occurred and (3) the discount rate applied to future costs to actualize them.

### 2.2.1 Period of ownership

The distribution of the end life of the commercial vehicles in Belgium is shown in Figure 1. As the average end life of the vehicles is 12.47 years [9,10], a period of 12 years of ownership is used in the TCO model.

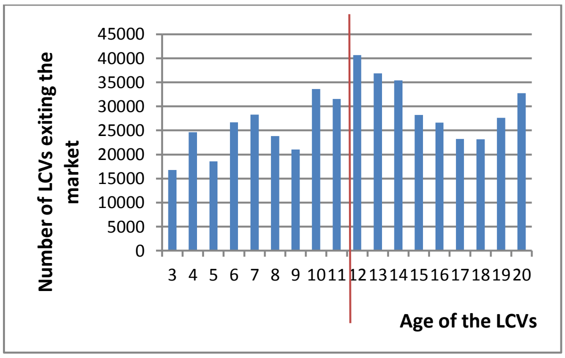


Figure 1: Number of commercial vehicles exiting the market in function of the age of the vehicles in Belgium (Source: own setup based on the new registration of commercial vehicles in Belgium between 1991 and 2008 (FEBIAC, 2011) and the remaining vehicles registered at the car inspection in 2011 (GOCA, 2011)).

### 2.2.2 Discount rate

The discount rate can be defined as *"the rate of interest reflecting the investor's time value of money"* [8]. It can be either a real discount rate (excluding inflation) or a nominal discount rate (including inflation). However, the real discount rate eliminates complex accounting for inflation within the present value equation. As a result, this study uses the real discount rate. It is based on the long-term interest rate of state bonds to eliminate the risk factor of the financial markets. For this TCO calculation, we use the Belgian long-term bounds at 10 years as reference for the real discount rate of 2.54% [11]. We extract from the interest rate the 2% of expected inflation in Belgium [12] to find a real discounted rate of 0.54%.

### 2.2.3 Cost of ownership

The analysis of the cost of ownership considers every cost associated to the use of the vehicle. Only investments in charging infrastructure are not included since they will be diluted according to the size of the fleet. The following costs flows are considered: road taxes, governmental support and fiscal incentives, battery, maintenance, car inspection, insurance, fuel (and electricity) and purchase costs. All costs are excluding VAT. The following assumptions of the model are applied to these costs:

1. Based on the data from the Belgian car inspection (GOCA, 2011), commercial vehicles were found to drive an average of 185,145kms in 12 years, which represents 15,429kms per year and a daily distance of 58kms.
2. The insurance costs were calculated for a company with a frequent use of the vehicle, based in Brussels (postcode 1000) with no accidents in the last 5 years. The insurance is limited to the civil liability[1]. No cost difference as such is applied between electric and conventional vehicles but differences in the power of the motors may generate a variation in the insurance premiums between the different drive trains.
3. Maintenance costs include costs for small and large maintenance. They are different between conventional and electric vehicles. Maintenance costs of BEVs are more limited than conventional since they do not have an internal combustion engine: they have less moving components; they face less temperature stress and do not need oil and filter replacements [13]. As a result, the maintenance costs of BEVs are estimated to be half of the conventional [14] which gives a cost of 4.3€/100km for conventional vehicles and 2.2€/100km for BEVs [15].
4. As the vehicle is assumed to be sold on the second hand market, its residual value is retrieved. The analysis considers an annual depreciation rate of 18.57%[2] on the value of the diesel, petrol and hybrid vehicles and an annual depreciation rate of 24.43%[3] on the value of electric vehicles.
5. In order to have a clear idea of the cost structure, the costs of the new battery included in the initial purchase costs are deduced from the purchase costs and affected to the battery costs. As battery prices are expected to fall in the future, we tested the sensitivity of such a change on the TCO.
6. The lifetime of the batteries differs according the kind of batteries. The lead-acid batteries and sodium-nickel chloride are the least performing with a lifetime of respectively 500 and 1,000 cycles [16]. The longest lifetime is attributed to Lithium iron phosphate batteries with 1,500 cycles [17]. Once the number of cycles is reached, the model considers that the battery is replaced by a new one. Since the BEVs are assumed to be charged once a day during 260 days a year, BEVs with a lead acid battery are replaced after 2 years, BEVs with sodium-nickel chloride are replaced after 4 years and lithium-ion batteries are replaced after 6 years. If the manufacturer provides a warranty on the battery, the replacement is then assumed to take place only once the warranty is over. However, it is important to mention that the number of cycles is based on the standardized lifecycle methodology. Indeed, the performances can change to a large extent depending on many factors such as the depth of discharge, operating temperature and the charging method [17].
7. The support for electric commercial vehicles in the Brussels-Capital Region is of 25% for large firms, 35% for medium firms and 45% for small firms on the investment costs with a maximum of 5,000€ [18]. Since most of the firms in urban freight transport are small [19], the TCO model considers a 45% support. The efficiency of the subsidies in supporting

[1] Data collected from the insurance company Axa.

[2] This is an average of the annual depreciation rates of the company LeasePlan between the Kangoo 1.5dci, Caddy 1.6tdi, Trafic 272. 0dci L1H1, Transporter 2.0tdi swb, Master 35 2.3 dci L3H3, Crafter 35 2.0tdi lwb.

[3] This is based on the Kangoo ZE annual depreciation rate of the company LeasePlan.

the competitiveness of BEVs was assessed in the sensitivity analysis.

8. The Belgian fiscal system allows a deductibility from corporate income taxes of 120% for electric vehicles on every cost related to the use of the vehicle. Conversely, conventional vehicles support a deductibility rate ranging from 50% to 100% depending on their CO2 emissions [20]. A rate of 75% is always applied on fossil fuels. Hence, the influence of the system on the competitiveness of the BEVs varies in function of the total of the costs associated to the use of the vehicle and in function of the corporate tax rate applied to the company operating the vehicle. More the corporate tax rate and the total cost of the vehicle are elevated, stronger is the impact of the fiscal system. The model uses a rate of 24.98% which is commonly used for companies with a profit between 1 and 25,000 euros [21]. However, a sensitivity analysis was conducted to test the influence of a higher corporate tax rate on the TCO of the vehicles.
9. Fuel and electricity costs are assumed not to increase more than the inflation. Because we use the real discount rate, the TCO model does not simulate change in fuel prices. The prices excl. VAT is €1.64/l4 for petrol, €1.42/l5 for diesel and €0.15/kWh6 for electricity. However, the effect of increasing fuel prices was tested and the results are presented in the sensitivity analysis given the uncertainty of oil prices in the future.

## 2.3 Scope of the market research

The supply of commercial electric vehicles is less developed than for passenger car. Nevertheless, a total of 8 electric vehicles were selected based on the availability of the commercial information. Also, the selection paid attention to keep the diversity of the market supply by showing a range of vehicles from different vehicle categories according the European vehicle classification [22,23], with different payloads (from 450kg to 1,700kg) and different business models (battery leasing and purchasing). To be able to compare as accurately as possible the electric commercial vehicles with conventional vehicles, the most similar version of the selected BEVs were chosen. As a result, 5 diesel vehicles and 2 petrol vehicles were included in the analysis. The costs considered by the TCO model of the different models were retrieved from vehicle users and by contacting directly the manufacturers, the distributors, the car dealers and the regulatory bodies.

# 3 Results

Based on the TCO model for commercial vehicles in the Brussels-Capital Region, the cost structure of the different vehicles is shown in Figure 2. The vehicles are divided into three groups according the European classification (European Commission, 2002, 2007):

1. the quadricycles (L6 & L7) that can be driven without a driving license and do not support any road tax or car inspection cost;
2. the light commercial vehicles (LCV) N1 with a payload less than 1,000kg;
3. the light commercial vehicles (LCV) N1 with a payload equal or superior to 1,000kg.

The results for diesel vehicles compared to petrol vehicles are consistent as they reflect the real market facts. The diesel vehicles have higher purchase costs but lower fuel costs which, within logistics operations, entails in a lower total cost of ownership. This is the reason why today's market for light commercial vehicle is primarily dominated by diesel vehicles.

When analysing the competitiveness position of electric vehicles, the results do not give a straightforward answer. Indeed, the cheapest and the most expensive vehicles are both electric vehicles (the Goupil G3 with 18 cents/km and the IVECO Ecodaily with 80 cents/km). However, a trend emerges from the TCO results: when the payload of the investigated vehicles gets higher, the electric alternatives become less competitive.

In the category of the quadricycles, the most expensive vehicles are internal combustion engine vehicles (Alke petrol with 35 cents/km and diesel with 32 cents/km). The relatively small batteries of the electric vehicles in this category do not

[4] Source : www.petrolfed.be (price of "Petrol 95 oct 10ppm", Consulted on 1st of May, 2013)

[5] Source : www.petrolfed.be (price of "Diesel 10ppm", Consulted on 1st of May, 2013)

[6] Source: www.brusim.be (price for a professional customer based in 1000 Brussels, with a single rate meter and a total consumption of 10.000kWh a year, Consulted on October 9, 2011)

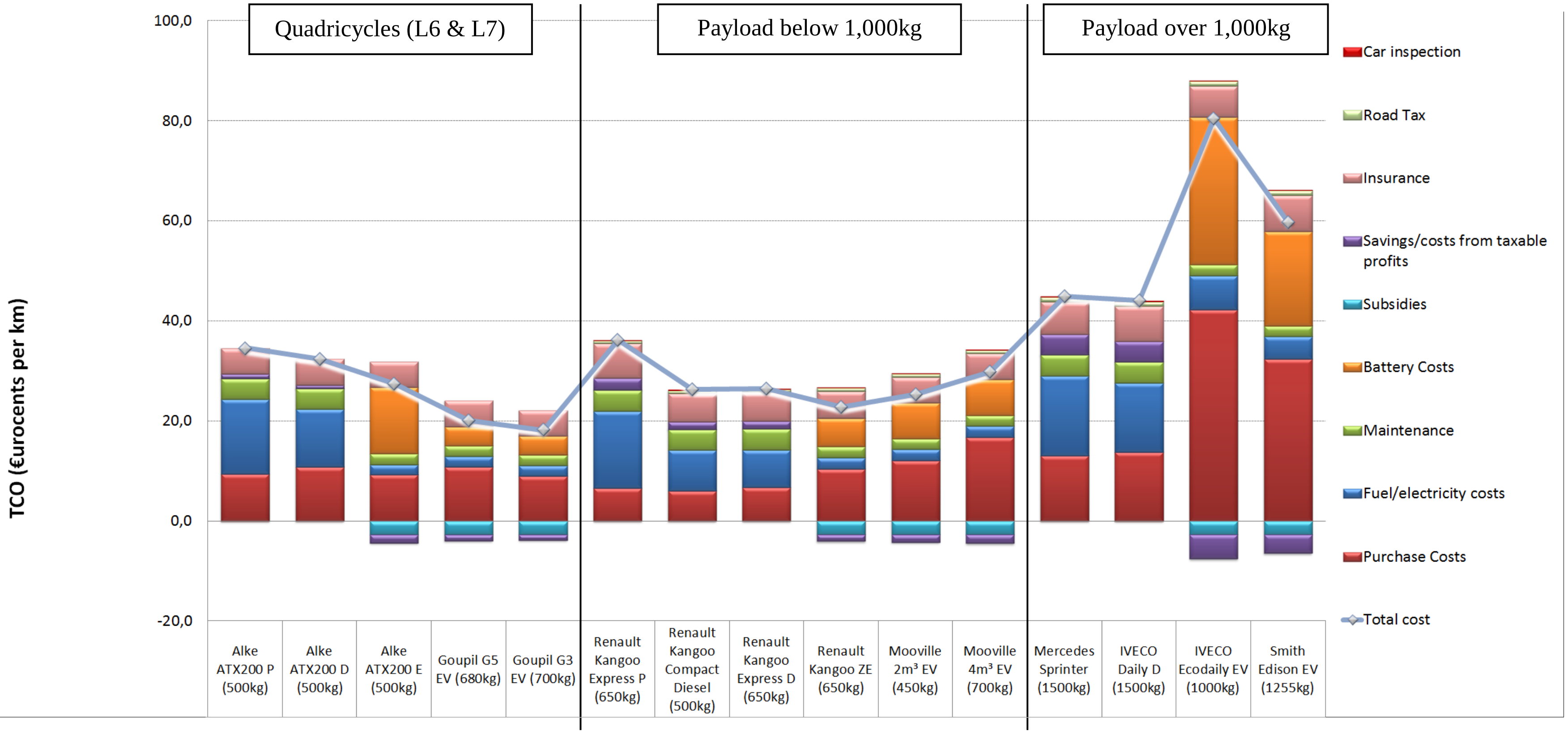


Figure 2 : Total cost of ownership for diesel, petrol and battery electric commercial vehicles (own setup)

penalize their competitiveness. On the contrary, they allow saving on fuel costs. Because of the simplicity of the electric motor, BEVs can also save on maintenance cost compared to conventional vehicles. As a result, the electric version of the Alke ATX200 receives a lower TCO than its conventional counterparts. But the 4 years of warranty that covers the batteries of the Goupil G5 and G3 gives the best competitive position in the category of the quadricycles. The TCO of the Alke ATX200 supports indeed a more frequent replacement of the batteries due to the short lifetime of the lead-acid batteries.
In the light category of the N1 vehicles, the observations are similar: every BEV presents a lower total cost of ownership than the conventional vehicles of the category, except for the Mooville 4m³, the heaviest vehicle of the category. The most relevant comparison in this category though is within the Kangoo's vehicle family of Renault where the electric version receives a TCO of 3 cents/km lower than the diesel versions and 9 cents/km lower than the petrol version. Also, the battery leasing of the Kangoo protects the vehicle user against replacement costs of batteries. This way business model of Renault allow to save in the TCO 2 cents/km from the battery costs compared to the Mooville business model where batteries need to be replaced after 3 years (lifetime of their battery is 800cycles according the manufacturer).
In the heavier category (with a payload more than 1,000kg), the competitiveness of electric vehicles is inverted. The expensive TCO of the electric models highlights the challenge for the introduction of BEVs within this category of vehicle. The difference between the diesel and electric vehicles is indeed large, varying between 15 and 34 cents/km. Figure 2 illustrates that the main part of the TCO for the heavy electric LCVs consists of the elevated purchase costs and battery costs. However, the Lithium iron phosphate battery of the Smith Vehicle needs to be replaced once compared to the sodium-nickel chloride battery of the IVECO Ecodaily that has a lifetime requiring one more replacement in 12 years. This results in a better competitive position for the Smith Electric Vehicle.

# 4 Sensitivity analysis

In this analysis, the different assumptions of the TCO model were tested to evaluate the sensitivity of the results. The battery cost, the fuel prices, the corporate tax rate, and the level of subsidies were analysed. Figure 3 provides an overview of the results.
Different studies forecast that the cost of batteries for EVs will lower in the upcoming decades. These could be divided by two in 2020 [24,25]. When simulating the effect of battery prices cut by half in the model, the TCO model shows that the biggest impact is on the BEVs with a frequent replacement of the battery and on BEVs with large batteries. The TCO of the BEV from Alke is reduced of 6 cents/km. However the BEVs from Goupil remain the most competitive of the category since they also profit of a reduction of 2 cents/km from the falling battery costs. The Moovilles have a reduced TCO of about 3 cents/km. But the main impact is on the BEVs from IVECO and Smith given their large battery: their TCOs are reduced respectively of 14 and 10 cents/km.
Conventional vehicles might also be impacted by market changes. The total cost of ownership model considered an equivalent inflation on every product. However, fuel prices might grow faster than the other prices given the scarcity of the oil reserves. Hence, a sensitivity analysis on the effect of rising fuel prices has been conducted to evaluate its impact on the competitiveness of electric vehicles. A scenario where prices of diesel and petrol converge to 2 euros per litre is simulated in the total cost of ownership model. The results show that the TCO of the conventional vehicles in the two first categories of vehicles increases between 3 and 5 cents/km while the TCO of the electric commercial vehicles does not change from the base scenario. In the category of vehicles with a payload above 1,000kg, the TCO of the diesel IVECO daily and Mercedes Sprinter increases respectively of 6 and 7 cents/km. Though, these vehicles remain more competitive than their electric version. But when the effect of falling battery costs and increasing fuel prices are combined, the competitive position change: the Smith Electric vehicle becomes less costly than the Mercedes Sprinter of 2 cents/km and is as competitive as the IVECO daily. On the other hand, the electric IVECO Ecodaily remains more expensive with a TCO higher of 15 cents/km. The government has economic instruments to influence the market. It can use either fiscal measures or subsidies. Regarding fiscal measures, the TCO model considered a company with profits of less than 25,000euros. However, a company making profits higher than 90,000euros in Belgium would have to support a tax rate of 35.54% instead of 24.98%. Within the Belgian fiscal system, the impact is especially interesting for the heavy LCV

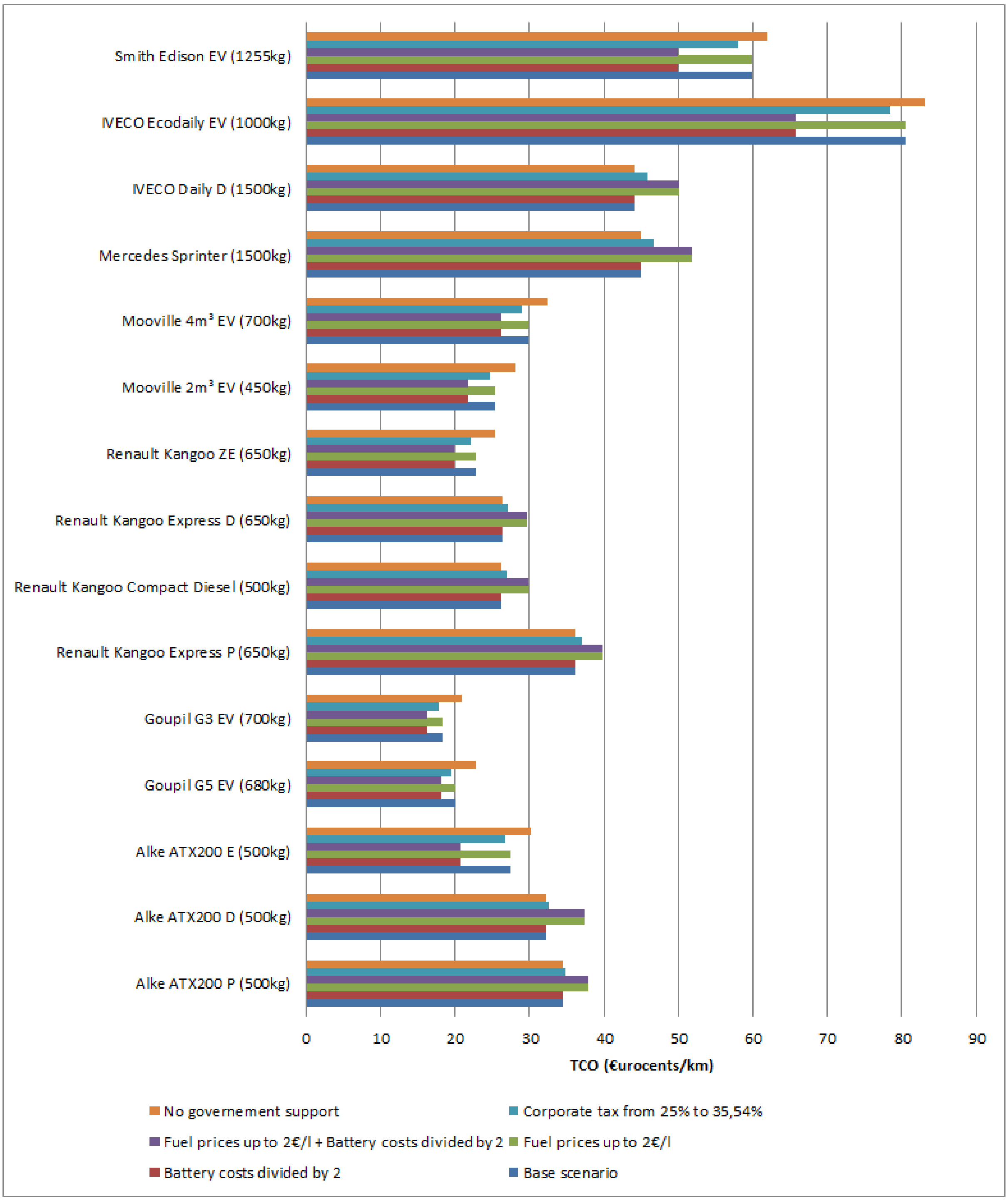


Figure 3 : Sensitivity analysis of the TCO model (source: own setup)

category since more the vehicles of the category are costly, more the fiscal system supports the competitiveness of BEVs: while the BEVs of the last category have a reduced TCO of about 2 cents/km, the diesel vehicles support a higher TCO of 2 cents/km. The effect is more limited on less costly vehicles since BEVs of the two first categories benefit of a reduction of about 1 cent/km while the conventional vehicles have an increased TCO of about 1 cent/km. Since the lighter electric commercial vehicles are already more competitive than the conventional commercial vehicles, a higher tax rate widens the competitive gap between Diesel and electric vehicles. Conversely, the fiscal system reduces the gap between electric and conventional vehicles in the category of vehicles with a payload higher than 1,000kg.
Subsidies are also a way of supporting BEVs but their design does not seem to be efficient. Indeed, the sensitivity analysis revealed that the competitive position of the BEVs with a payload of less than 1,000kg would not be affected if the subsidies were discontinued. The TCO of each BEV increases of 2.7cents/km which does not change the competitiveness position of the vehicles across all the categories: the vehicles from Goupil, Alke, Renault and the Mooville 2m³ remain more competitive in their category than the conventional vehicles while the Moovile 4m³ and the BEVs of Mercedes and IVECO keep a higher TCO than their conventional competitors.

# 5 Conclusion

The results of the total cost of ownership analysis show that electric commercial vehicles with a payload lower than 1,000kg can be more financially attractive than the conventional alternatives. Due to their small battery pack, 5 BEVs out of 6 have a lower TCO than the conventional vehicles. However, the competitive situation is inverted for the commercial vehicles with a payload higher than 1,000kg. The large competitive gap in this category was identified as a critical challenge for the adoption of such BEVs.
To test the sensitivity of the model and estimate the change of the competitive position of the BEVs according to the expected evolution of the market, the paper exposed the results of a sensitivity analysis. The effect of falling battery prices was found to be particularly beneficial for the BEV with large batteries (BEV with a payload above 1,000kg) or with frequent replacement of the batteries (BEV with lead-acid batteries). Also, the effect of rising fuel prices was found to increase the TCO of conventional vehicles. Finally, the effectiveness of governmental support to BEVs was evaluated. The subsidies appeared to be less efficient than the fiscal system for companies in the Brussels-Capital Region. Indeed, subsidies are granted to already competitive electric commercial vehicles and do not bring sufficient support to heavier electric commercial vehicles. However, the fiscal system was found to be better adapted. Its flexibility brings stronger incentives for BEVs with important costs than vehicles BEVs with small ones. As a result, the BEVs with a higher payload receive a bigger support from the fiscal system than from the subsidies while the lighter electric commercial vehicles receive a smaller support from the fiscal system than from subsidies.
Hence, electric commercial vehicles with a payload below 1,000kg can be a viable technological solution to make urban freight transport more sustainable. However, even if a technology is better, actors tend to stick to the old technology as they fear to adopt the wrong one [26]. Hence, the challenge relies in convincing the fleet managers of the benefits and the competitiveness of the identified electric commercial vehicles.


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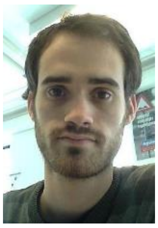

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