Electrifying light commercial vehicles for city logistics? A total cost of ownership analysis

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Different measures are considered by the authorities to tackle the negative impacts of city logistics. Among them, battery electric vehicles are seen as a promising solution, but high purchase cost represents an important barrier to their adoption. However, these vehicles benefit also from low operational costs. This different cost structure between electric and conventional vehicles makes therefore a comprehensive cost analysis necessary for fleet managers who want to assess the real competitiveness of the vehicles. Hence, we developed a total cost of ownership model to assess the competitiveness of quadricycles and light commercial vehicles for freight transport companies. This paper presents the results for 7 battery electric vehicles, 5 diesel vehicles and 3 petrol vehicles. The results of a sensitivity analysis explored also the possible measures that can support their competitiveness.

The model shows that battery electric vehicles have a better competitive position than petrol vehicles but they do not compete yet with diesel vehicles. A sensitivity analysis shows however that their total cost of ownership can become lower than diesel vehicles depending on their utilization, future market conditions or government support. Still, electric quadricycles appear to be currently an affordable solution for transport operators to adopt electric vehicles since their total costs of ownership is lower than diesel light commercial vehicles.

Keywords: Battery Electric Vehicles, City logistics, Total Cost of Ownership.

1. Introduction

Freight transport is expected to increase in cities the coming years because of converging trends: the current urbanization process generates more freight volumes in cities, transport is increasingly fragmented due to the success of light commercial vehicles (LCVs) and distances are stretching out due to the delocalisation of logistics platforms in the periphery (Dablanc and Rakotonarivo, 2010; Browne et al., 2010). Even though that growth should support the development of the urban economy, it might also increase the environmental burden of freight transport in cities. Freight vehicles are already responsible for about one fourth of CO_2 emissions, one third of NO_x emissions and half of particulate matters generated by the transport sector in cities (Dablanc, 2011). Recognizing the need to find solutions, the European Commission has given the objective of reaching free CO_2 city logistics in major urban areas by 2030 (EC, 2011).

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A wide range of logistics concepts, regulations and technologies have been developed to fulfil the city logistics carbon free target (Quak, 2011). Among them, battery electric vehicles (BEVs) are considered to be an answer to the negative impacts listed above (Crainic et al., 2004; Van Mierlo & Maggetto, 2005). Browne, Allen & Leonardi (2011) have shown the positive contributions related to the use of BEVs in an urban consolidation centre. Their analysis showed an important reduction in terms of CO_2 and congestion on the whole urban area. The logistic concept analysed showed also that the limited driving range of BEVs is not problematic. This constraint is easily controlled by the structured and time-based environment of the logistics chain. Besides, the frequent use of the vehicles in city logistics makes the low running costs of BEVs particularly interesting to reduce transport costs. Indeed, BEVs benefit from both lower energy prices and a more efficient energy consumption compared to conventional vehicles (Martensson, 2005).

However, purchase cost tends to be the most important criteria in the vehicle choice of fleet managers (Nesbitt and Sperling, 2001). A survey conducted by Van Amburg and Pitkanen (2012) confirms this behaviour since fleet managers consider the high purchase cost of a BEV as the main barrier for switching from a conventional vehicle. 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 vehicles makes such an analysis particularly important: estimating the breakeven points where BEVs become competitive with conventional vehicles should be therefore clarified.

Previous research on the competitive position of BEVs has overlooked the segment of freight vehicles. Most of the attention has been instead on the passenger vehicles (Lebeau, 2013; Turcksin, 2011). Literature reveals only a few studies. Feng and Figliozzi (2012, 2013) approached the question by developing a fleet replacement model considering an electric and a conventional truck. The results show that electric trucks are competitive only with high utilisation: the breakeven point is estimated around 45,000 kilometres per year per truck. The market position of electric trucks was further investigated by Davis and Figliozzi (2013), who integrated four models to evaluate the optimal routing parameters, the energy needed for operating the deliveries, the range constraints and the associated ownership costs. The results illustrate that electric trucks become more competitive when more customers are served, the energy costs increase and when longer distances are travelled. On the other hand, the competitive position decreases with lower purchase costs for diesel trucks and reduced payload. As a result, Davis and Figliozzi (2013) conclude that electric trucks are viable in an environment where daily distances approach 160 kilometres, low speeds and congestion are present, stops are frequent and where authorities are supporting electric vehicles with tax incentives or technological breakthroughs. The planning horizon of the vehicle should also be beyond 10 years. These results are partly confirmed by Lee et al. (2013) who conducted a total cost of ownership analysis comparing an electric and a conventional truck in an urban environment (with frequent stops and low average speed) and in a suburban environment (with less frequent stops and higher average speed). In the urban environment, they found that the BEV has a TCO of 22% less than the conventional truck while, in a sub-urban environment, the TCO of the BEV was 1% more than the conventional vehicle.

These studies consider however a limited selection of vehicles to describe the competitive position of BEVs. Often, the analyses compare one electric with one conventional freight vehicle. Also, the scope of the analysed vehicles covers the freight vehicles with a gross vehicle weight of more than 3.5 tonnes. However, these heavy good vehicles (HGVs) only represent 12% of the trips in city logistics, while 88% of the trips is done with LCVs (PORTAL, 2003). Given the expected growth of the LCVs (Zanni & Bristow, 2010), that segment deserves a detailed analysis. Hence, the objective of this paper is to extend the previous competitive analyses of BEVs to the segment of LCVs. Consequently, the main research questions addressed in this paper are:

1. What is the competitive position of electric LCVs according transport companies compared to their conventional counterparts?

2. What are the breakeven points for electric LCVs to be competitive at current market conditions and future market conditions?

3. What are the minimum levels of market interventions needed in order for electric LCVs to be competitive?

We developed a total cost of ownership (TCO) model for LCVs with a gross vehicle weight of maximum 3.5 tonnes. We analysed the costs from 7 BEVs, 5 diesel vehicles and 3 petrol vehicles available on the Belgian market. As we are interested in city logistics, we used as case study the institutional context and the geographical scope of the Brussels-Capital Region. After detailing the methodology, the paper presents the results of the model in order to solve the first research question. Then, the different breakeven points are identified through a sensitivity analysis in order to answer the two last research questions. They allow to extend the results to other urban contexts than the one of the Brussels-Capital Region.

2. Methodology

Owning and operating a vehicle is associated with costs that occur at different moments in time. To compare these costs across time, the TCO methodology uses the financial formula of the present discounted value. This way, the present value of every cost can be summed to obtain the full cost of one alternative. The TCO 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*"(Ellram, 1995, p. 4). To calculate the present value of future one-time costs, the following formula is used (Mearig et al., 1999):

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

Where:

PV = Present value

A_t = Amount of one-time cost at a time t

I = Real discount rate

t = Time (expressed as number of years)

The financial formula of the present discounted value is divided into three parameters: (1) the period of time over which these costs occurred, (2) the discount rate applied on future costs to actualize them and (3) the costs of ownership. This section describes how these parameters were collected. Finally, once the present values are calculated, the sum of the actualized costs related to the use of a vehicle is divided by the number of kilometres driven during the ownership period in order to get the TCO of each vehicle per kilometre.

2.1 Period of ownership:
Because of the intense competition in the logistics sector, transport operators tend to operate their vehicles as long as possible in order to limit investments (Dablanc, 2007). According the data of the Belgian technical control (GOCA, 2015), the average end life of the LCVs in Belgium is 9.89

years. The period of ownership used in the TCO model is therefore 10 years. But the sensitivity analysis will investigate how the TCO change with different ownership periods.

2.2 Discount rate:

The discount rate can be defined as "*the rate of interest reflecting the investor's time value of money*" (Mearig et al., 1999, p. 6). By actualizing the future costs with the discount rate, the TCO considers that paying tomorrow is preferred than paying today. The discount rate reflects the return that the money spent in a more expensive vehicle could have brought if it was invested in the financial markets. In order to eliminate the additional return for the risk, the discount rate is often based on long-term interest rate of state bonds. Since we consider a period of ownership of 10 years, we use the Belgian long-term bounds at 10 years which showed a rate of 1.15% in July 2015 (ECB, 2015).

The discount rate can be either real (excluding inflation) or nominal (including inflation). We prefer in our analysis the real discount rate because it eliminates complex accounting for inflation over the future costs. We extract from the interest rate the 1.1% of expected average inflation between 2014 and 2020 in the euro zone (Federal Planning Bureau, 2015) to find a real discounted rate of 0.05%.

2.3 Costs of ownership:

The costs for each vehicle were retrieved from the standard vehicle versions by contacting the manufacturers, the distributors, the car dealers, the insurance companies and the regulatory bodies. The selection of BEVs took into account the diversity of the market supply: we included vehicles from different segments according the European vehicle classification (European Commission, 2007, 2002), with different gross vehicle weight and different business models (battery leasing and purchasing). When different battery packs are available, we considered always the option that allows a minimum range of 70km. To be able to compare the BEVs with conventional vehicles, the most similar versions of the selected BEVs were also analysed (5 diesel and 3 petrol vehicles).

The TCO analysis considers all costs associated with the use of the vehicle, except for the investments in charging infrastructure as they should be diluted according to the size of the fleet. The following costs streams are considered: annual car inspection, fuel (and electricity) costs, "maintenance, repair and tyre replacements" (MRT), insurance, vehicle purchase costs, battery costs, governmental support, fiscal incentives and road taxes. All costs are excluding VAT. They are detailed in Table 1 and in the following sub sections. The following sub sections describe also the assumptions applied on these costs.

Fuel and electricity costs

According GOCA (2015), LCVs drive on average 147,281 kilometres on 10 years. But that distance depends on their age as shown in Figure 1. That variation will be considered in the sensitivity analysis. In order to calculate the running costs, the model uses the following energy prices (excl. VAT): €1.542/l[5] for petrol, €1.281/l[6] for diesel and €0.1636/kWh[7] for electricity. Energy costs are assumed not to increase more than inflation. Hence, the TCO model does not simulate changes in fuel prices since we use the real discount rate. Though, the effect of different fuel prices on the TCO of conventional vehicles is investigated in the sensitivity analysis given the depletion of oil resources in the future. The influence of electricity prices will also be estimated.

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[5] Source : www.petrolfed.be (price of "petrol 95 oct", Consulted on 5th of July, 2015)
[6] Source : www.petrolfed.be (price of "diesel 10ppm", Consulted on 5th of July, 2015)
[7] Source : average of electricity prices in 2014 from Electrabel for a SME with a consumption of 50.000kWh per month (Brugel, 2014).
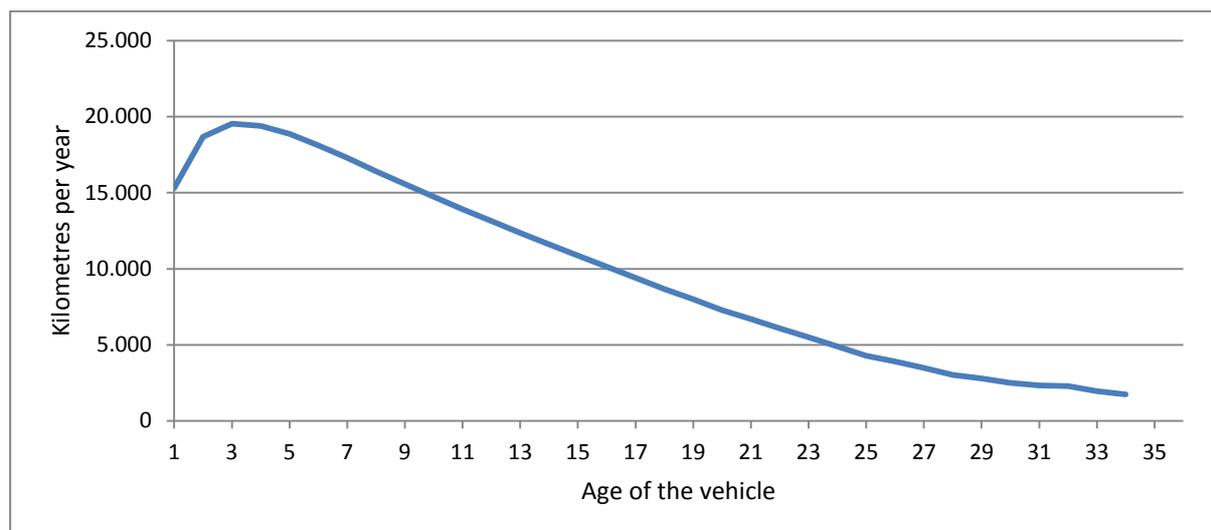
Figure 1. Average kilometres driven per year by LCVs according their age (Source: GOCA, 2015)

Maintenance, repair and tyre replacements (MRT)
The costs for MRT are based on the estimates of van Vliet et al. (2010). They recognise that maintenance and repair increase with the age of the drivetrains, so they consider that petrol engines have an MRT cost of 3.8€/100km for the first 60,000km, which increases to 4.3€/100km afterwards. On the other hand, they consider that the MRT cost of diesel engine remains constant over time with 4.3€/100km. Estimating the MRT cost for BEVs is more challenging, since the data are still limited nowadays. However, it is assumed that these costs are lower compared to conventional vehicles since they do not have an internal combustion engine: BEVs have less moving components, they face less temperature stress and they do not need oil and filter replacements (Fischer et al., 2009). According Davis and Figliozzi (2013), the MRT costs of the BEVs are half of the conventional cars. Hence, the model considers a MRT cost of 2.15€/100km for BEVs.

Insurance costs
The insurance costs are calculated by the insurance company AXA in 2014 using the following criteria. The vehicle belongs to a company based in Brussels (postcode 1000). It is operated "frequently", mainly by a driver of 30 years, having a driver license for 10 years and with no accidents in the last 5 years. The insurance is limited to the civil liability. No cost difference as such is applied between electric and conventional vehicles. The differences in the insurance premiums between the vehicles depend on the power of the motors. Still, every vehicle with a power of less than 25kW have the same insurance premiums.

Vehicle purchase costs
The vehicle purchase cost reflects the depreciation of the vehicle during the period of ownership: the purchase price is reduced by the residual value that can be retrieved as a capital gain realised on fixed asset. We considered an annual depreciation rate of 18.57%[8] on the value of the diesel and petrol vehicles. For battery electric vehicles, we used a higher depreciation rate which is set at 24.43%[9]. This faster depreciation of BEVs is explained by the less mature market of second hand BEVs and by the fast development of BEV supply observed these last years. Let us note that

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[8] This is an average of the annual depreciation rates of the company LeasePlan between the Kangoo 1.5dci, Caddy 1.6tdi, Trafic 27 2.0dci L1H1, Transporter 2.0tdi swb, Master 35 2.3 dci L3H3, Crafter 35 2.0tdi lwb.
[9] This is based on the Kangoo ZE annual depreciation rate of the company LeasePlan.

Table 1. Input parameters of the vehicles

	Vehicle name	GVW (kg)	Capacity (m³)	Motor type	Battery type	Purchase cost (€)	Battery cost *purchase (€) **leasing (€/month)	Battery warranty	Urban Consumption (l/100km or kWh/100km)	Insurance (€/year)
	Ligier Flex	755	2,3	Diesel	N.A	11,649	N.A	N.A	5	828.16
	Mega d-truck (fourgon)	1,000	2,8	Diesel	N.A	12,374	N.A	N.A	4.2	828.16
	Mega e-Worker (fourgon court - 11,5kWh)	1,640	2,7	BEV	Lead Acid	20,075	2,961*	4 years	15	828.16
	Goupil G3-2 (L) (fourgon standard; 11,5kWh)	2,075	2,8	BEV	Lead Acid	20,370	3,248*	4 years	19.5	828.16
	Alke ATX210E (van box - 8,7kWh)	1,500	2,7	BEV	Lead Acid	21,500	2,115*	1 year	13.8	828.16
	Renault New Kangoo Express	1,920	3	Petrol	N.A	13,950	N.A	N.A	7.2	1129.62
	Renault New Kangoo Express	1,950	3	Diesel	N.A	13,600	N.A	N.A	5.2	941.06
	Renault Kangoo ZE	2,126	3	BEV	Li-ion	21,150	from 73**	N.A	15.5	871.92
	Peugeot Partner	1,960	3,3	Petrol	N.A	12,940	N.A	N.A	8.3	1047.91
	Peugeot Partner	1,960	3,3	Diesel	N.A	13,960	N.A	N.A	5.8	941.06
	Peugeot Partner Electric	2,225	3,3	BEV	Li-ion	26,000	6,000*	8 years / 100.00km	17.6	903.35
	Nissan NV200	2,000	4,2	Petrol	N.A	14,100	N.A	N.A	8.8	1104.48
	Nissan NV200	2,000	4,2	Diesel	N.A	15,400	N.A	N.A	5.7	1010.20
	Nissan e-NV200	2,220	4,2	BEV	Li-ion	25,652	From 73**	N.A	16.5	1098.20
	Nissan e-NV200	2,220	4,2	BEV	Li-ion	31,550	6,000*	5 years / 100.000km	16.5	1098.20

this annual depreciation rate is not applied on the battery costs but only on the vehicle purchase costs. When the battery costs are included in the initial purchase costs, they are deduced from the purchase costs category and affected to the battery costs category.

Battery costs

The batteries have a limited lifetime in transport applications. Once they reach 80% of their initial energy capacity, they need to be replaced. Old batteries could be used in second life applications but, since this market is not developed yet, it is not clear if such batteries can be valorised. As a result, the TCO analysis does not consider a residual value for BEV batteries but the sensitivity analysis will investigate the influence of such effects.

The lifetime of the batteries can change to a large extent depending on many factors such as the depth of discharge, operating temperature and the charging method (Omar, 2012). But in order to estimate their number of cycles, we used figures based on the standardized lifecycle methodology. These figures differ according to the type of batteries. The lead-acid is the least performing battery with a lifetime of 500 cycles (Van den Bossche et al., 2006). Lithium-ion batteries have a longer lifetime that can be estimated to 1,500 cycles (Omar, 2012). Once the number of cycles is reached, the model considers that the battery is replaced by a new one. Since batteries are assumed to be charged once a day during 260 days a year, lead acid batteries are replaced after 2 years and lithium-ion batteries are replaced after 6 years. Replacement costs are assumed to be in charge of the customer only once the warranty provided by the manufacturer is over. As we could not find the cost of the battery of the Peugeot Partner, we used the same cost as the e-NV200 since they have both the same type of battery (Lithium Ion of about 24kWh). Replacement costs are however not supported by the customer if the battery is leased. Instead, a monthly fee covers the costs of battery.

Regional subsidies

The Brussels-Capital Region introduced a financial support for electric commercial vehicles, which consists of 20% for large firms, 30% for medium firms and 40% for small firms on the investment costs with a maximum of 5,000 euros (Moniteur belge, 2009, 2013). Since most of the firms in city logistics are small (Dablanc, 2011), the TCO model considers a 40% support. In order to evaluate the effectiveness of the government support, the sensitivity analysis will investigate the effect of different levels of subsidies.

Fiscal incentives

The Belgian fiscal system allows deductibility from corporate income taxes up to 120% for BEVs on every cost related to the use of the vehicle. Conversely, every cost related to a conventional vehicle supports a deductibility rate ranging from 50% to 100% depending on their CO_2 emissions (Fisconetplus, 2012a). However, that fiscal system does not apply for vehicles that are designed for the transport of goods. In that case, deductibility rate remains at 100% for every type of vehicles. Hence, the model does not make a difference between electric and conventional vehicles from a fiscal point of view. But the sensitivity analysis will explore the influence of that system on the results.

Road taxes and car inspection

The segment of the quadricycles is exempted of road taxes and car inspection cost. Conversely, LCVs have to annually be inspected and pay road taxes. These taxes depend on their gross vehicle weight (SPF finances, 2015). No differences are however made between electric and conventional vehicles. The sensitivity analysis will explore the impact of an exemption of road taxes for BEVs.

A distance based road pricing scheme is also being discussed in the Region. That scheme should be implemented in Belgium by 2016 for heavy goods vehicles but nothing is planned yet for light commercial vehicles. Still, the sensitivity analysis will investigate the effect of such a system on the competitive position of BEVs when they are exempted of such a scheme.

3. Results

Based on the TCO model developed for quadricycles and light commercial vehicles (LCVs) in the Brussels-Capital Region, the cost structure of the different vehicles is shown in Figure 2. The results are consistent with the current market observation as diesel vehicles have a lower TCO compared to petrol vehicles, mainly due to lower fuel costs. This difference explains the market dominance of diesel vehicles within the Brussels-Capital Region. Diesel owns indeed a market share of 93% of the registered freight vehicles in the Region (Lebeau & Macharis, 2014).

3.1 Competitive position of BEVs

The competitiveness position of BEVs is more intermediate in their respective segments. In the light commercial vehicle segment, the results in Figure 2 show that the TCO of battery electric vehicles is located between the TCO of diesel and petrol vehicles. Still, battery electric vehicles can sometimes have a lower TCO than diesel vehicles. That is the case when we compare the Electric Kangoo ZE with the diesel NV200. But when we compare the diesel and electric versions of the Kangoo, diesel remains the most competitive vehicle. Conversely, BEVs might have a higher TCO than petrol vehicles. That is the case when comparing the Electric e-NV200 with the petrol Kangoo. But the electric e-NV200 remains more competitive than its petrol counterpart. From a financial point of view, BEVs can therefore be more interesting than petrol vehicles for light commercial vehicles. Still, diesel vehicles remain today the most competitive technology in that segment.

That observation can also be confirmed in the segment of quadricycles. Diesel vehicles are also more competitive than BEVs. However, it is interesting to notice that electric quadricycles have a lower TCO than diesel LCVs. Even though these vehicles cannot really be compared because of different performances, they might represent an affordable option to transporters that want to adopt BEVs. The limited power of quadricycles might indeed not be an important drawback in city logistics compared to their environmental benefits.

3.2 Cost structure of BEVs

When analysing the cost structure of the BEVs with the conventional vehicles in Figure 2, we observe that the main cost advantage of the BEVs over conventional vehicles (and especially petrol vehicles) is their lower operational costs. Diesel and petrol are entailed with high fuel prices and larger MRT costs while BEVs benefit from low maintenance, low electricity prices and efficient energy consumption. These advantages are however reduced by the more important purchase costs. BEVs are indeed entailed with a faster depreciation than conventional vehicles. Also, the low maturity of the market of BEVs does not ensure a competitive market and economies of scale which might explain the higher initial purchase costs for these vehicles (battery excluded).

Battery costs reduce further the advantage from the low operational costs of the BEVs. Different business models are being proposed by the manufacturers regarding these costs, namely the "battery ownership model" and the "battery leasing model". In the battery ownership model, the customer purchases the battery with the vehicle and supports the risks of replacement costs once the warranty on the battery is over. This model is mainly used in the quadricycles segment where lead acid is the standard battery. The battery ownership model is also used sometimes for light commercial vehicles. However, the standard battery in that segment is Lithium Ion which is
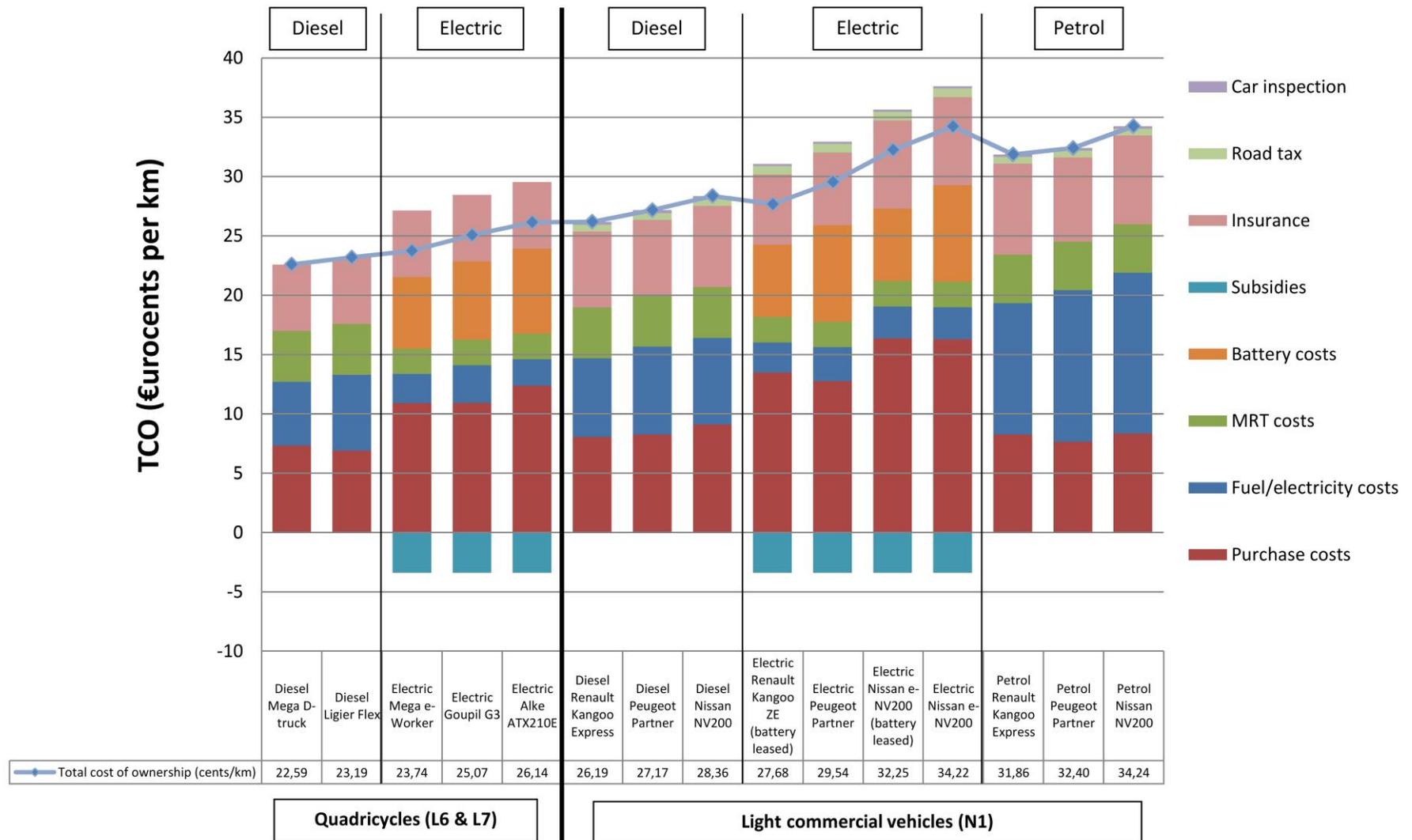
Figure 2. Total cost of ownership for diesel, petrol and battery electric vehicles

more expensive but has a longer lifetime than lead acid. The customer faces therefore more important one-time costs with lithium Ion than with lead-acid batteries. In order to avoid the burden of a few important costs events, manufacturers propose also in that segment the battery leasing model. In that case, the battery is owned by the manufacturer and costs of battery are spread for the customer monthly through a renting system. When comparing both models in the light commercial vehicle segment, Figure 2 shows that the battery leasing model reduces the TCO compared to the battery ownership model. However, the sensitivity analysis on the years of ownership brings in the next section more insights into the impact of these two business models on the TCO.

3.3 The role of authorities

When the different costs are aggregated, Figure 2 shows that the battery costs and high purchase costs of BEVs offset their low running costs advantage compared to conventional vehicles. However, the authorities of the Brussels-Capital Region provide a subsidy of maximum 5.000 euros to the purchase of freight electric vehicles. These incentives are shown to support effectively the competitive position of BEVs: the TCO of the battery electric vehicles is triggered down thanks to the subsidies. As a result, BEVs become more competitive than their petrol versions. A slightly better support however might improve further the competitive position of BEVs with diesel vehicles. The sensitivity analysis in the next section will show the subsidy levels required to support the competitiveness of BEVs compared to diesel vehicles.

4. Sensitivity analysis

The results shown in the previous section are however limited to the context of the Brussels-Capital Region. The assumptions developed in the methodology section might also differ according to the transport operator or market changes. In order to generalize the findings, the authors relaxed these assumptions in a sensitivity analysis where we collected more insights on the evolution of the competitiveness position of BEVs. A first section of this sensitivity analysis show how the competitive position of BEVs can change with different utilisation of the vehicles. Then, the impact of market changes are presented in the second section. Finally, the last section is focused on the policies that the government can use to influence the competitiveness of BEVs.

4.1 Breakeven points at current market conditions

Sensitivity on the number of kilometres
The results of the sensitivity analysis on the number of kilometres are shown in Figure 3 for the quadricycles and in Figure 4 for LCVs. In both segments, the diesel vehicles receive a lower TCO than the BEVs when the number of kilometres driven per year is low. But when the kilometres increase, the BEVs benefit from their lower operational costs and become more competitive than their conventional counterparts.

The first electric vehicle to reach the breakeven point with a diesel vehicle in the quadricycles segment is around 16,000 kilometres per year. It becomes more competitive than all diesel vehicles when it drives a distance of about 18,000 kilometres per year. Since the other electric quadricycles are more costly, their breakeven points with the diesel quadricycles are located further: the most expensive electric quadricycle crosses the TCO of the most competitive diesel vehicle at around 25,000 kilometres per year.

In the second segment, Figure 4 depicts more breakeven points since petrol vehicles are also analysed. Petrol vehicles have the lowest TCO when kilometres are small but become quickly
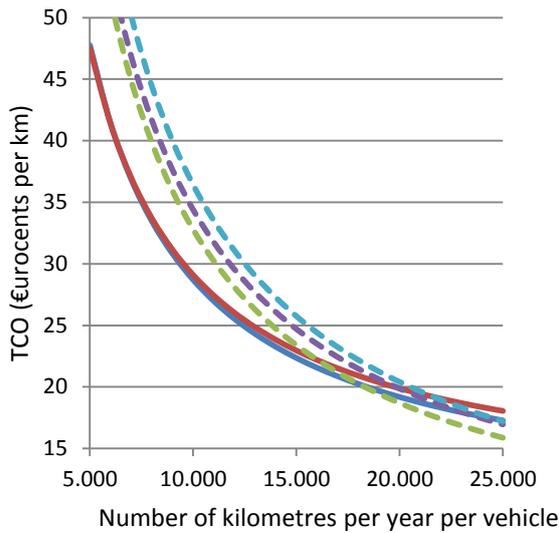
*Figure 3. TCO sensitivity on the kilometres driven per year by the quadricycles*
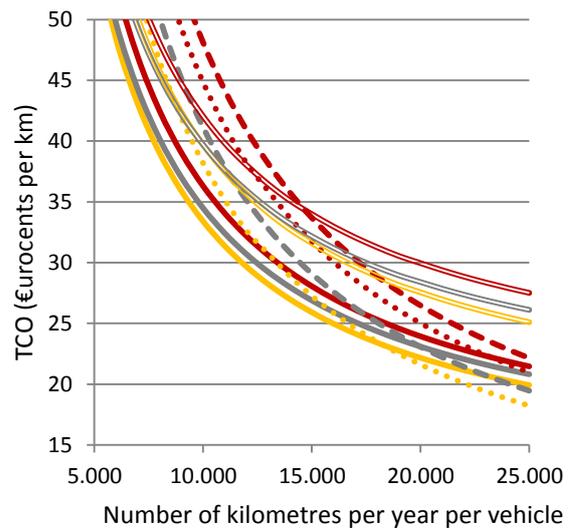
Figure 4. TCO sensitivity on the kilometres driven per year by the LCVs (N1)
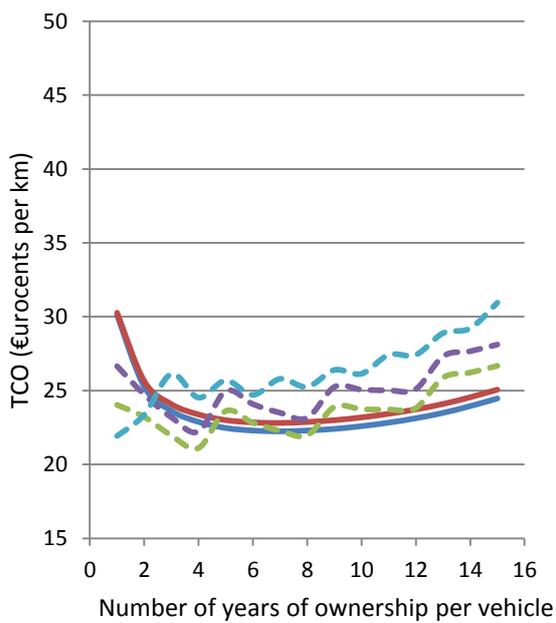
Figure 5. TCO sensitivity on the years of ownership of the quadricycles
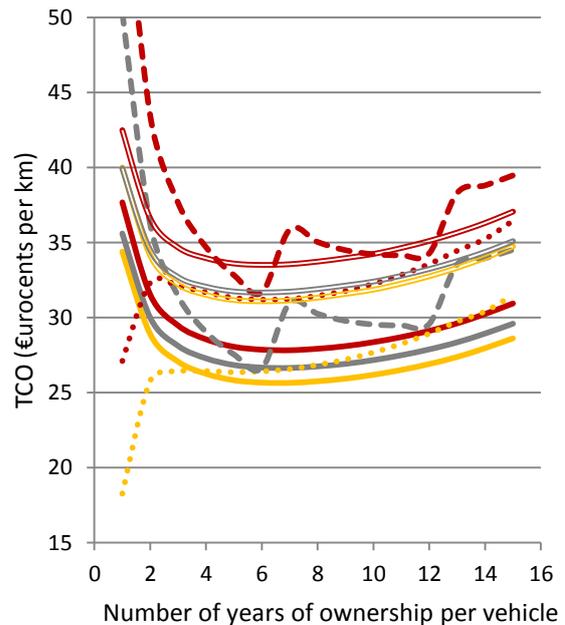
Figure 6. TCO sensitivity on the years of ownership of the LCVs (N1)

Legend quadricycles

- Diesel Mega D-truck
- Diesel Ligier Flex
- Electric Mega e-Worker
- Electric Goupil G3
- Electric Alke ATX210E

Legend LCVs (N1)

- Diesel Renault Kangoo Express
- Diesel Peugeot Partner
- Diesel Nissan NV200
- Petrol Renault Kangoo Express
- Petrol Peugeot Partner
- Petrol Nissan NV200
- Electric Renault Kangoo ZE (battery leased)
- Electric Peugeot Partner
- Electric Nissan e-NV200 (battery leased)
- Electric Nissan e-NV200

less competitive compared to diesel vehicles. BEVs become competitive later. Their first breakeven points with a petrol vehicle can be located at a distance of about 7,500 kilometres per year. The last breakeven point between BEVs and petrol vehicles is located at around 18,000 kilometres per year. After that point, petrol is found to be the option with the highest TCO.

Regarding the competitiveness with diesel vehicles, BEVs reach their first breakeven points later in the LCV segment than in the quadricycle segment: the yearly distance should be around 13.000 kilometres for the first BEV to become more competitive than a diesel vehicle. When analysing the breakeven points between similar vehicle versions, the Electric Kangoo is the first one to reach the TCO of its diesel counterpart (at around 18,000km/y), then the electric Partner (at around 20,000km/y) and finally the e-NV200 with battery leased (at around 23,500km/y).

These breakeven points are significantly lower than what is reported in other journal papers. Feng and Figliozzi (2013) had indeed estimated a breakeven point at 45,000 kilometres per year for electric trucks. BEVs in the heavy goods vehicle segment might therefore compete less with their diesel counterparts than in the light commercial vehicles segment.

Sensitivity on the years of ownership
The results of the sensitivity analysis on the years of ownership are given in Figure 5 for the quadricycles and in Figure 6 for LCVs. We observe first important variations in the TCO of BEVs across time. They can be explained by the important costs that these vehicles face when the battery has to be replaced. These variations are less extreme but more frequent in the quadricycle segment than in the LCV segment. That difference is due to the type of batteries used. Lead acid batteries (used mostly for quadricycles) are less expensive but require more frequent replacements. Conversely, lithium ion batteries (used mostly in electric LCVs) require less frequent but more expensive battery replacements. Hence, BEVs with Lithium Ion battery show more extreme variations in the TCO according the years of ownership than BEVs with lead acid batteries. These variations are strengthened by the residual value of batteries that is considered to be null. The TCO of battery electric vehicles can therefore be optimised by operating them until the battery reaches its end life in transport applications (when the energy capacity of the battery is below 80% of its initial capacity). The sensitivity analysis shows indeed several minimum levels of the TCO across the years of ownership. Hence, we do not identify a minimum number of years of ownership as suggested by Davis and Figliozzi (2013). Instead, we recommend to sell the vehicle when the battery has to be replaced and the owner is not planning to use the BEV for another battery lifetime.

These observations do not however apply on BEVs with a battery leasing model. Instead of supporting important sporadic battery costs, these are spread on a monthly basis. In that case, Figure 6 shows that it not possible to optimise the battery lifetime in order to reduce the TCO of these vehicles. As a result, they remain less competitive than diesel vehicles. Still, battery leasing model is shown to be the most interesting model for BEVs. That model remains indeed more competitive than the battery ownership model, even when the battery lifetime is optimised. In that regards, we should stress that a battery replacement every 6 years for Lithium Ion can be considered conservative. If the battery shows a longer lifetime, Figure 6 suggests that the TCO of the battery ownership model can indeed become more interesting than the battery leasing model.

An interesting observation of the sensitivity of the TCO in function of the ownership period is the particularly low TCO in the first year depicted in Figure 5 and Figure 6 for BEVs. This effect can be attributed to the subsidies granted by the Brussels-Capital Region. If the cost of the first battery purchased with the vehicle is small enough, the subsidy can cover the battery costs and a part of the depreciation of the vehicle. Authorities should therefore follow carefully subsidy demands in order to avoid abuses: transport operators could theoretically purchase a BEV, receive the subsidy, sell the vehicle after one year and purchase a new BEV with a new subsidy in order to operate vehicles with a low TCO.

4.2 Breakeven points at future market conditions

Sensitivity on the price of the battery

Among the different market changes expected, studies forecast that the cost of batteries for BEVs will decrease significantly in the upcoming decades (Nykvist and Nilsson, 2015). To understand such a change on the competitiveness of BEVs, we analysed the TCO of the vehicles in function of decreasing battery prices. The sensitivity was found to be linear and the results are therefore presented in Table 2. Since conventional vehicles do not have batteries, their TCO remain unchanged. Regarding BEVs, their sensitivity follow a similar trend: a decrease of 1% in battery costs, reduce their TCO by around 0.07 eurocents per kilometre. If battery prices are divided by two in 2020 as expected by DELIVER (2012) and Electrification Coalition (2010), the TCO of battery electric vehicles should therefore be reduced by 3.5 eurocents. By comparing that reduction with the results of the TCO in Figure 2, we can observe that such an evolution would change the competitive position of BEVs compared to the diesel vehicles. Only the e-NV200 would need a further decrease in battery prices: the breakeven point of the battery leasing version with the diesel version is located at a decrease of about 70% of battery costs. On the other hand, the first BEV to become more competitive with its diesel counterpart is the Kangoo ZE in the LCV segment and the e-worker in the quadricycle segment when battery costs drop by about 25%. The Partner Electric becomes more competitive than its diesel counterpart after a cost reduction of about 30%.

Sensitivity on the residual value from the battery

The sensitivity analysis has also investigated the possibility to recover a residual value from the used batteries. There is indeed a potential for a second hand market of BEV batteries since 80% of the battery capacity remains when it reaches its end life for transport applications. Table 2 shows how the TCO results are influenced by different battery residual values. The effects are similar to the sensitivity on battery prices but slightly less important because of the real discount rate: the money invested in the battery cannot be used for other investments before the residual value is recovered. Still, the major difference between these two sensitivity analyses can be observed on the BEVs with a battery leasing model. These vehicles do not benefit from an increased residual value. Since the battery is owned by the manufacturer, the residual value is not recovered by the customer. As a result, the TCO is not reduced, unless the manufacturer shares the reduced costs of batteries with the customers through a lower battery leasing price.

Sensitivity on energy prices

An important factor influencing the TCO results is the fuel prices of petrol and diesel. The results in Table 2 show that petrol LCVs would be the most affected vehicles by rising fuel prices. Indeed, petrol vehicles have a higher consumption than diesel vehicles and the fuel price is also more expensive than diesel. On the other hand, BEVs are not influenced since they are operated with electricity. Hence, BEVs become more competitive with rising fuel prices. The first breakeven point of BEVs with their diesel counterpart is reached by the Kangoo ZE in the LCV segment and by the e-worker in the quadricycle segment when fuel prices increase by about 20%. The electric Partner becomes competitive later with its diesel counterpart, when diesel prices increase by 35%. Finally, the e-NV200 (battery leasing) receives a lower TCO than its diesel versions after an increase of minimum 55% of diesel prices.

But electricity prices might also change in the future. Hence, the sensitivity analysis explored also their impact on the TCO. Table 2 shows that the TCO of electric vehicles are entailed by an added cost of between 0.15 and 0.19 eurocents per kilometres when electricity price rise by 1 eurocent per kWh. This sensitivity on electricity prices shows the importance of charging BEVs at the best time of the day in order to optimise their TCO with the lowest electricity rates.

Table 2. Sensitivity analysis of TCO results on battery prices, fuel prices and residual value of the battery

	On battery prices (variation of TCO for every increase of 1%)	**On residual value of the battery** (variation of TCO for every increase of 1%)	**On fuel prices** (variation of TCO for every increase of 1%)	**On electricity prices** (variation of TCO for every increase of 1eurocents/kWh)
Diesel Mega D-truck	0	0	0.05	0
Diesel Ligier Flex	0	0	0.06	0
Electric Mega e-Worker	0.06	-0.06	0	0.15
Electric Goupil G3	0.07	-0.07	0	0.19
Electric Alke ATX210E	0.07	-0.07	0	0.14
Diesel Renault Kangoo Express	0	0	0.07	0
Diesel Peugeot Partner	0	0	0.07	0
Diesel Nissan NV200	0	0	0.07	0
Electric Renault Kangoo ZE (b. leased)	0.06	0	0	0.15
Electric Peugeot Partner	0.08	-0.08	0	0.18
Electric Nissan e-NV200 (b. leased)	0.06	0	0	0.16
Electric Nissan e-NV200	0.08	-0.08	0	0.16
Petrol Renault Kangoo Express	0	0	0.11	0
Petrol Peugeot Partner	0	0	0.13	0
Petrol Nissan NV200	0	0	0.14	0

4.3 Breakeven points with market intervention

Sensitivity on the subsidy level for BEVs

In order to support the competitiveness of BEVs, a traditional instrument used by authorities is subsidies. The sensitivity analysis investigated the impact of different subsidy levels for BEVs on the TCO results. Table 3 shows that it influences every BEV to the same extent: an increase of 1,000 euros subsidy to BEVs decreases their TCO by 0.68 eurocents per kilometre. As a result, the regional subsidy level should be set at around 10,000 euros to have a similar effect than a decrease of the battery costs by 50% (a decrease of the TCO of 3.4 eurocents per kilometre). In that case, almost every BEVs were competitive with their diesel counterpart.

The sensitivity analysis shows also that the current regional subsidy supports the competitiveness of the BEVs: without the subsidy of 5,000 euros, the TCO of electric vehicles would increase by 3.4 eurocents per kilometre. In such a case, petrol vehicles would become more competitive than BEVs. Under the current market conditions, subsidies are therefore required in order to support the competitiveness of BEVs with their conventional vehicles.

Sensitivity on the deductibility rate for BEVs

In Belgium, the corporate taxable base can be reduced by deducting 120% of costs related to the BEVs. However, that fiscal regime does not apply on vehicles designed for goods transport. In this sensitivity analysis, we investigated the impact of that incentive, extended to freight vehicles. We considered for that analysis a company making a profit between 1 and 25,000 euros, implying a corporate tax rate of 24.25% (Fisconetplus, 2012b). The sensitivity analysis evaluated the impact of different deductibility rate for BEVs on the TCO results.

Table 3 summarises the results. Conversely to the subsidy scheme, the fiscal system is more flexible: more expensive BEVs are better supported. If the fiscal system applied on passenger cars

was extended to freight vehicles, the TCO could be reduced by about 1.6 eurocents per kilometre. In that case, the Kangoo ZE and e-worker would become more competitive than their diesel counterparts. But higher deductibility rates are required to support the competitiveness of the other BEVs. The breakeven points of the Electric Partner and the e-NV200 (battery leased) with their diesel counterparts are located respectively at a deductibility rate of about 130% and 150%.

Table 3. Sensitivity analysis of TCO results on the level of subsidies, BEV deductibility, city access toll, urban kilometre toll and road taxes.

	On subsidies (variation of TCO for every additional subsidy of 1000€)	On BEV deductibility (variation of TCO for every increase of 1%)	On city access toll (variation of TCO for every increase of 1€ per day)	On urban kilometre toll (variation of TCO for every increase of 1€cents per km)	On BEV road taxes (variation of TCO for every decrease of 1%)
Diesel Mega D-truck	0	0	1.76	1.00	0
Diesel Ligier Flex	0	0	1.76	1.00	0
Electric Mega e-Worker	-0.68	-0.07	0	0	0
Electric Goupil G3	-0.68	-0.07	0	0	0
Electric Alke ATX210E	-0.68	-0.07	0	0	0
Diesel Renault Kangoo Express	0	0	1.76	1.00	0
Diesel Peugeot Partner	0	0	1.76	1.00	0
Diesel Nissan NV200	0	0	1.76	1.00	0
Electric Renault Kangoo (b. leased)	-0.68	-0.08	0	0	-0.01
Electric Peugeot Partner	-0.68	-0.08	0	0	-0.01
Electric Nissan e-NV200 (b. leased)	-0.68	-0.09	0	0	-0.01
Electric Nissan e-NV200	-0.68	-0.09	0	0	-0.01
Petrol Renault Kangoo Express	0	0	1.76	1.00	0
Petrol Peugeot Partner	0	0	1.76	1.00	0
Petrol Nissan NV200	0	0	1.76	1.00	0

Sensitivity on an urban toll fee
Another way to support the competitiveness of BEVs in cities is to introduce a toll for accessing the urban area, except for zero emission vehicles. The sensitivity analysis investigated this option by introducing a daily fee in the TCO model. The variation in the TCO results are summarised in Table 3. We observe that the influence is the same for every conventional vehicle: their TCO increases by 1.76 eurocents per kilometre when the access fee increases by 1 euro per day. As a result, with a fee of 1 euro per day, the electric Kangoo ZE and the e-worker become more competitive than their diesel counterparts. The breakeven point of the Partner Electric with its diesel version is located at a fee of 1.5 euros per day and the electric e-NV200 (battery leased) at a fee of 2.5 euros per day.

Sensitivity on a kilometre toll fee
The toll can also be based on a kilometre basis rather than on a daily basis. Table 3 shows the results of the sensitivity analysis where a fee per kilometre has been added for conventional vehicles only. Since the fee is expressed in the same units than the TCO, the sensitivity analysis is straightforward: an increase of 1 eurocent per kilometre on conventional vehicles increases their TCO by 1 eurocent per kilometre. The first BEV to reach the breakeven point with their diesel

counterpart is the Kangoo ZE in the LCV segment and the e-worker in the quadricycle segment when the kilometre toll is set at about 1.5 eurocents per kilometre. The breakeven points for the Partner electric and the e-NV200 (battery leased) are located at a respective fee of about 2.5 and 4 eurocents per kilometre.

Sensitivity on road taxes

Finally, the sensitivity analysis investigated the effects of a reduction of road taxes for BEVs. That advantage is not granted in the Brussels Capital Region but other cities like in London give an exemption to BEVs. The results of the analysis in Table 3 show that the segment of quadricycles is not impacted by this type of measure since they are already exempted from this tax scheme. A reduction of taxes reduces the TCO of battery electric vehicles only in the LCV segment. This effect is however shown to be limited: a full exemption of the road taxes for BEVs would reduce by 0.72 eurocents their TCO. That impact is similar to an additional subsidy of 1,000 euros for the purchase of BEVs.

5. Conclusion

The results of the total cost of ownership analysis show that electric quadricycles and LCVs can be more financially attractive than their petrol counterparts for freight transport companies in the Brussels-Capital Region but are still more costly than diesel vehicles. They were found to benefit from low operating costs due to their efficient energy consumption, low energy prices and low maintenance costs. But these advantages are offset by the high purchase of the vehicle, the faster depreciation of BEVs and the additional battery costs. The subsidies provided to freight vehicles in the Brussels Capital Region limit however their TCO at a competitive level with conventional vehicles. As a result, electric quadricycles were found to be an affordable solution for transporters to switch from diesel LCVs to battery electric vehicles.

These conclusions are however limited to the context of the Brussels-Capital Region. In order to generalize the findings, the authors conducted a sensitivity analysis so more insights are given on the evolution of the competitiveness position of BEVs. First, the influences of different vehicle utilisations on the TCO were explored. The analysis shows that BEVs are more competitive with conventional vehicles when larger distances are driven per year. The breakeven points of BEVs with diesel vehicles are located between a distance of 16,000 and 25,000 kilometres per year. In a second sensitivity analysis, the evolution of the TCO in function of the years of ownership was investigated. The replacements of the batteries are found to play a critical influence on the costs which results in important variations in the TCO across the years of ownership. The analysis showed that the TCO of battery electric vehicles can be minimized when the ownership period of the vehicle corresponds to the full lifetime of the battery (in transport applications, end life of batteries is reached when its energy capacity is below 80% of its initial capacity). Hence, BEVs should ideally be sold when the battery has to be replaced and the owner is not planning to use the BEV for another battery lifetime. That observation does not however apply on BEVs with a battery leasing model since the battery costs are spread on a monthly basis and risks of battery replacement are supported by the manufacturer.

The paper explored also how the competitive position of BEVs will change with future market conditions. An important expected evolution is the reduction of battery prices. The sensitivity analysis estimated that a reduction of between 25% and 75% in battery prices is required in order for BEVs to be competitive with their diesel counterparts. Residual values might also be captured from used batteries thanks to the development of second hand applications of BEVs batteries. These residual values should be able to recover between 25% and 75% of the initial price in order to reduce the TCO of battery electric vehicles below the TCO of their diesel versions. Finally energy prices were investigated. Diesel prices need to increase between 20% and 55% in order for BEVs to reach the breakeven points with their diesel counterparts. On the other hand, the TCO of

battery electric vehicles was found to be sensitive to electricity prices which showed the importance of charging at the best rates.

However, given the current market conditions, BEVs require still government support. The current subsidies of the Brussels Capital Region is shown to support effectively their competitiveness with petrol vehicles but should be increased to 10,000 euros in order to support their competitiveness with diesel vehicles. The fiscal system applied on passenger cars could also reduce the TCO of BEVs in city logistics if it was extended to freight vehicles. A deductibility rate of 120% support the competitive position of some BEVs with their diesel counterparts but a rate of 150% is recommended to support every BEVs analysed in this paper. Access fee to the city was also investigated. An urban toll between 1 euro and 2.5 euros or an urban kilometre tax between 2.5 and 4 eurocents per kilometre on conventional vehicles could support the competitive position of BEVs with their diesel counterparts. Finally, an exemption of road taxes for BEVs was found to have a limited impact on the TCO.

A combination of these effects can easily lead to a situation where the BEVs have a lower TCO than diesel vehicles in a near future. Still, these conclusions cannot be extended to the whole segment of LCVs, the heaviest vehicles could not be analysed. Indeed, the comparison of the results with other studies suggested that BEVs compete less with their diesel counterparts in the heavier segments. But new models are coming on the market. New electric LCVs from Smith vehicles and Iveco for example are expected to be marketed soon in the heaviest segment of light commercial vehicles (3.5 tonnes). Future research should therefore analyse the costs of these larger LCVs. Future research should also integrate these results in a more global approach. The competitive position of a vehicle is indeed not limited to the costs aspects. At a meta level, these results could be used in a fleet management model so operational constraints of range can be integrated for better decision making. At a macro level also, the private interests and public interests of the policies described in the paper could be evaluated like in Melo, Baptista & Costa (2014). The relevance of such policies could then be discussed by comparing the investments needed for policy support of BEVs and their benefits on the urban environment. Finally, the environmental impact of the vehicles could be integrated in the TCO analysis in order to evaluate their eco-efficiency like in Messagie et al. (2013).

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