This is a repository copy of *Hydrogen vehicles in urban logistics : a total cost of ownership analysis and some policy implications*.

White Rose Research Online URL for this paper:
http://eprints.whiterose.ac.uk/153513/

Version: Accepted Version

Article:

Jones, J., Genovese, A. and Tob-Ogu, A. orcid.org/0000-0002-4015-5643 (2019) Hydrogen vehicles in urban logistics : a total cost of ownership analysis and some policy implications. Renewable and Sustainable Energy Reviews. ISSN 1364-0321

https://doi.org/10.1016/j.rser.2019.109595

Hydrogen vehicles in urban logistics: A total cost of ownership analysis and policy implications

Jones, J.[1], Genovese, A.[1], Tob-Ogu, A.[1]*

Abstract: Freight transport accounts for 8-15% of total traffic flow in urban areas within the European Union. The majority of these deliveries are undertaken by diesel-powered vehicles with extremely disproportionate levels of CO_2, NO_x and particulate matter emissions. Accordingly, a variety of strategic option shave been advanced as key solutions for addressing fossil fuel demand and emissions in urban freight transport. This paper progresses the discourse on hydrogen vehicles as viable strategic options for addressing sustainability concerns in urban logistics by undertaking a comprehensive total cost of ownership analysis. Outcomes from this study not only support the economic competitiveness of hydrogen vehicles, but also analyse implications of several future policy and market scenarios.

Highlights:

- This paper advances a cost model for calculating the total cost of ownership, with results demonstrating highlighting the most competitive fuel vehicle options for commercial use in the UK, accounting for tax relief and grants for low emission vehicles. To the best of our knowledge, the proposed cost-model offers the most comprehensive model for evaluating economic competitiveness of alternative energy sources for transport vehicles.
- Our research also presents evidence to validate subsidies and other reliefs as critical to improving the competitiveness of battery-electric and hydrogen fuel cell vehicles for commercial use.
- Finally, the paper, informs on the importance of combined policy tools for promoting and achieving low carbon energy adoption in urban logistics and transport operations.

Keywords: Urban Logistics; Freight Transport; Alternative Vehicles; Total Cost of Ownership, Hydrogen, Policy

Word Count: 4595

List of Abbreviations:
BEV
Battery electric vehicle
CO_2
Carbon dioxide
EU
European Union
EUR
Euro (currency)
GBP
Great Britain pound
HFC
Hydrogen fuel cell

---

[1] Sheffield University Management School, The University of Sheffield, Conduit Rd, Sheffield S10 1FL, United Kingdom
*Corresponding author details: a.tob-ogu@sheffield.ac.uk

HFCV
Hydrogen fuel cell vehicle
ICE
Internal combustion energy
kWh
Kilowatt-hour
LCV
Light commercial vehicles
LEZ
Low emission zone
MPG
Miles per gallon
NO_x
Nitrogen oxide
OLEV
Office for low emission vehicle
PHEV
Plug-in hydrogen electric vehicle
TCO
Total cost of ownership
UK
United Kingdom
ULEV
Ultra-low emission vehicle
US/ USA
United States (America)
VAT
Value added tax

1.0 Introduction

Logistics and freight activities in cities are at heightened levels due to increased trade volumes and purchase behavioural shifts towards e-commerce options have intensified last-mile delivery activities [1]. Freight transport accounts for 8-15% of total traffic flow in urban areas within the European Union (EU) [2], and the majority of these deliveries are undertaken by diesel powered vehicles with extremely disproportionate levels of CO_2, NO_x and particulate matter emissions (25%, 33%, and 50%) [3]. Accordingly, a variety of strategic options (infrastructure; equipment; governance; modality and policy) have been advanced as key solutions for addressing fossil fuel demand and emissions in urban freight transport [4]–[6]. In spite of the understanding that policy is critical to the adoption of sustainable transport strategies, much of the discussion in this area has focused on general or passenger transport as opposed to freight related last mile logistics.

This paper progresses the discourse on alternative fuel vehicles as viable strategic options for addressing sustainability concerns in urban logistics. Buoyed by the understanding that a critical component of sustainable logistics solutions is the economic cost implications for concerned stakeholders, particularly for freight transport operators, this study offers a robust economic cost model that is applied to a contingent scenario to support policy decision making. The importance of this component is widely recognised as evidenced by ubiquitous policy based subsidies that support alternative vehicle and energy initiatives across the globe. Although studies have explored the cost competitiveness of battery electric vehicles (BEVs), there are gaps related to the cost competitiveness of hydrogen fuel cell vehicles (HFCVs) in logistics despite their weight, space and emissions advantages over BEVs [7], [8]. The outcomes from this study not only support the economic competitiveness of HFCVs but also provide sensitivity impact implications from changes in the value of market condition factors on cost competitiveness.

The remainder of this paper is organised as follows: the next section provides a review of the literature, followed by an overview of the methodology. Section 4 is devoted to an examination of the findings; Section 5 presents some scenario analysis, while conclusions are summarised in section 6.

2.0 Theory

2.1 The role of equipment and technology

Alternative fuel vehicles (AFVs) have been shown to reduce greenhouse gas emissions and lead to an improvement in air quality as well as offering a number of advantages. For example, electrification has been suggested as a way to reduce emissions [6], [9], although HFCVs have also been identified as offering some added benefits compared to BEVs in terms of their weight, space, refuelling time, lifecycle emissions savings [10], [11]. With AFVs in generally, the main advantages include high efficiencies, low emissions, and low levels of noise [12], (Table 2 for vehicle emissions output). Despite these reported advantages, the literature suggests that there are moderating factors that impact these advantages, with several studies advancing evidence to show that AFVs using fuel produced with non-renewable sources offer minimal advantages whether as hybrid electric vehicles or pure HFCVs for use in urban environments [13][14]. The implication here points to the importance of AFVs in terms of the sources of the energy as being renewable, emission-free and viable sources of energy for logistics and transport [7][14].

In terms of logistics application, the potency of AFVs have been investigated. For example, powering on-board appliances with hydrogen fuel cell power units in long-haul diesel trucks could lead to an 80% reduction in diesel consumption[15]. Additionally, the literature has identified reductions in air and noise pollutions as some outcomes of the AFVs [16]. Despite the position of the extant literature, we observe that there are still concerns regarding the adoption rates with seemingly slow uptake for AFVs amongst logistics firms[17]. One of the core barriers identified relates to cost where economic competitiveness is of increasing importance to decisions and practice [8], [18].

2.2 Cost studies

HFCV components are high-cost and less durable than ICE ones, meaning they must be replaced more often, driving up costs [19]; however, costs are falling for HFCVs and there is need to update the literature on their competitiveness [20]. To address this, da Silva Veras et al. investigate the production of hydrogen from endothermal and exothermal applications as well as renewable sources, highlighting differences in hydrogen (H_2) yields. Consequently, they link the uncertainties around HFCVs to the lacking technologies and limited insight on its economic competitiveness, recommending additional research on the economic competitiveness of HFCVs [8]. Furthermore, the establishment of total cost of ownership (TCO) information has been found to increase consumers' preferences for hybrids and BEVs in small-medium size vehicle classes [18].

In line with the cost focus, Al-Alawi and Bradley [21] reviewed cost models for PHEVs and found that typically fewer cost components were considered than for ICE vehicles. Their principal finding was that under the correct conditions BEVs could be cheaper than hybrids and conventional vehicles. Similarly, Offer et al. [22] advance a TCO model considering HFCVs and BEVs was constructed and a 2030 scenario discussed. In the 2030 modelled scenario both BEVs and HFCVs exhibited higher capital costs than ICE vehicles, although technological developments did reduce the difference. However, once fuel costs over the lifetime of the vehicle were considered they found that both BEV and hybrid HFCVs appeared cheaper than ICE and pure HFCVs. They noted however that both the HFCV and the ICE case were highly sensitive to fuel costs and that accurate predictions of future fuel costs are not possible. Additionally, Contestable et al. [23] compared BEVs, HFCVs, and biofuel passenger vehicles in a TCO model and found there was no significant difference in predicted cost by 2030. They conclude that smaller BEVs offer cost advantages when operating on a low-energy driving cycle. They made clear that such models should not be considered predictive due to the difficulty in predicting technological developments. Wu et al. [24] also produced a probabilistic model to simulate the TCO of both BEVs and ICE vehicles, concluding that BEVs have a good probability of becoming the most cost-efficient for smaller vehicles operating in urban contexts.

In terms of logistics, Davis and Figliozzi [25] focussed exclusively on ICE and BEV delivery trucks operating in urban environments (the last-mile scenario). They noted that electric trucks are more expensive for almost all cases but the possibility of rising energy costs and development of battery technology could lead to a situation where electric trucks would be competitive in most cases.

As part of previous literature on TCO analysis as per fiscal incentives that favour low emission activities, it is considered that they impact driving and business decisions in areas where implemented [17]. One example is congestion charging which discourages use of specific roads and thereby reduces both traffic and pollutant emission. As such, Börjesson et al. [26] assessed the impact of congestion charges in Stockholm and found that as a measure for incentivising a switch to alternative fuel vehicles congestion charges are effective. Also, Hidrue et al. [27]and Lévay et al. [28] analysed the demand for BEVs and buyers' attitudes in the USA and Norway and found that subsidies and tax relief were key to achieving BEV competitiveness, however the literature on the impact of subsidies on HFCV competitiveness is limited.

Despite the positive indicators, the link between subsidies, costs, hydrogen-powered light commercial vehicles (LCVs) and their role in last-mile or urban deliveries is yet to be explored in the literature, yet LCVs remain critical to the attainment of sustainable urban transport. As such, in this paper a TCO model is constructed that, unlike prior studies, includes HFC-LCVs operating in the UK and takes into consideration the indicators common to the models discussed previously as well as the impact of fiscal incentives. Our material and methods section below expands further on the components of our model.

3.0 Materials and Methods

A Total Cost of Ownership (TCO) approach models the costs of 'buying' a good or service from a particular supplier and includes the overall life costs associated with the ownership of a product. TCO models are traditionally implemented using aggregated forecast and historical data to establish costs [29], [30].

For this study, we selected 13 vehicles to reflect BEVs, PHEVs and ICEs, all with similar functionality, size, interiors and EU classifications (Table 2). To support comparison, annual mileage of 12921 miles was allocated per vehicle adopting industry assumptions[2] [31].

In line with our objective of modelling operating costs, the cost assumptions encompass critical operator costs for typical last mile fleet activities, deriving from the Office for National Statistics [32].

Ownership costs reflect those that are commonly accrued through usage over the lifetime of the vehicle and these costs are dependent on period of ownership, annual mileage, or both. Capital costs include typical upfront purchase costs associated with each vehicle; in the case of subsidies, these can be negative.

In this paper, the approach shown in Figure 1 was utilised in order to develop the employed calculation model, distinguishing between Capital Costs and Ownership Costs.

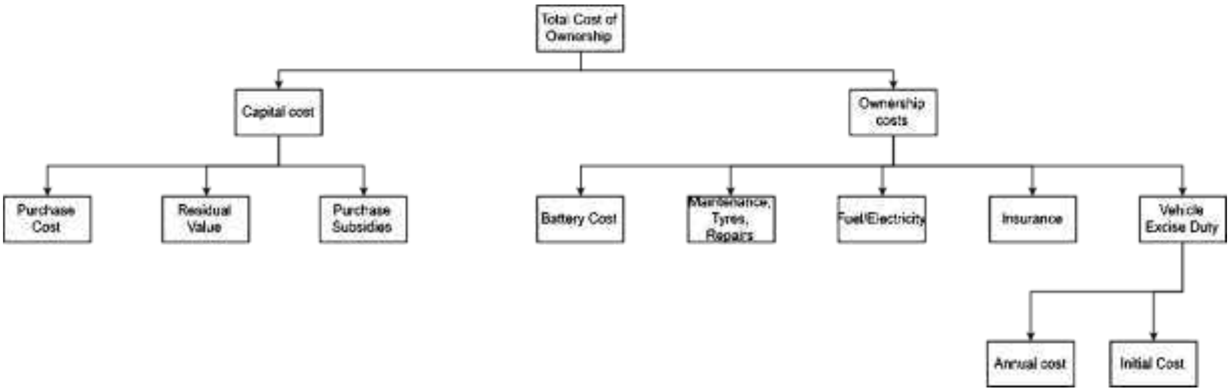


Figure 1 – Employed TCO approach

---

[2] 3.8 million licensed vans in the UK, driving a total of 49.1 billion miles. Per vehicle mileage average of 12,921.05 was chosen as our annual mileage variable

As a result, the following formula was used[3]:

$$TCO = (CE - RV - PS) + \sum_{x=1}^{5} \sum_{n=0}^{9} \left(C_{x_n} \times \frac{1}{(1+r)^n} \right)$$

The components of the formula are illustrated, in detail below.

CE represents capital expenditure; this included initial asset or purchase costs exclusive of VAT per HMRC regulations (businesses can reclaim VAT on business vehicles as long as they are not for private use). These reflect the initial purchases cost of the vehicles as advertised by the manufacturers. One-off payment costs were adopted, as financing options would be impossible to account for with the range of variable interests accessible. Where applicable, the costs were converted from EUR to £ (e.g. the Renault Kangoo Z.E and Symbio HYKangoo).

RV represents residual value, computed using average depreciation factors [33]. Although the market for alternative vehicles remains largely underdeveloped, it was suggested that depreciation values for these vehicles converged overtime [33]. Residual values were computed as NPV of capital costs * residual % for period n, where n=10.[4]

Table 1 - Residual values with corresponding age

Age of car in years	0	1	2	3	4	5	6	7	8	9	10
Residual value	1.00	0.66	0.54	0.44	0.38	0.34	0.31	0.27	0.25	0.22	0.2

PS represents purchase subsidy. The UK government offers grants for vehicles with ultra-low emissions, the amount of which depends on the amount of emissions the vehicle produces. Eight different vans are listed on OLEV's release, including the three BEVs and the fuel cell conversion vehicle under consideration in this study[5]. The grant allows for a 20% reduction in the purchase price of the vehicle, up to a maximum of £8,000. The value of the grant is deducted from the upfront cost of the car at the point of sale and includes VAT, thus a factor of 0.20 will be applied to the after tax purchase cost of the vehicle to determine the magnitude of grant available. In the event of this value exceeding £8,000, it s corrected to £8,000.
r represents the discount rate; in line with LCV operation periods average 10 years, the applied discount rate followed a 10-year gilt, supported by a three-month average from historical data (adjusted to 1.2) to three significant figures [34], [35].

C_{x_n}represents operating costs x, for year n; in particular, the following costs are considered;

C_{1_n} represents the cost of road tax (*Vehicle Excise Duty,* a compulsory duty on operational vehicles within the UK) for year *n*. Road taxes are pro-rated according to CO_2. Where applicable, data from the Department for Transport or calculated the applicable road tax by

---

[3] It is assumed that all costs rise in-line with inflation such that their present value remains the same, not including the discount rate. The exception to this assumption is the residual value, for which the depreciation rate considered is set in terms of present value

[4] For the purpose of this study, we have excluded capital gains tax, as these are commercial vehicles used solely for business.

[5] It is assumed that the H350 will qualify for this grant as it meets all over criteria but is presumably not listed as it is not on general sale in the UK at the time of publication

using the given emissions range of the vehicles and allocated charges. Discounted lifetime costs were calculated by discounting the given rates.

Table 2 – Vehicle Exercise Duty values for different Category N vehicles.

Vehicle	**Fuel Type**	**CO_2 emissions, g/km (use)**	**First year tax rate/£**	**Annual rate (£)**
Renault Kangoo Z.E.	BEV	0	0	0
Peugeot ePartner	BEV	0	0	0
Nissan e-NV200	BEV	0	0	0
Renault Trafic	ICE	170	500	140
Peugeot Boxer	ICE	158	500	140
Citroen Berlingo	ICE	112	160	140
Peugeot Partner	ICE	110	140	140
Ford Transit Connect	ICE	129	160	140
Vauxhall Vivaro	ICE	170	500	140
Ford Transit Trend	ICE	185	800	140
Ford Transit Custom	ICE	163	500	140
HyKangoo	PHEV	0	0	0
Hyundai H350	HFCV	0	0	0

C_{2_n} represents fuel costs for year *n*. These were calculated for each vehicle in the form of pounds per mile (£/mi) using current diesel prices and MPG values from manufacturer specifications.

Similarly, electricity price averages for 6 small businesses [36] were adopted, accounting for the £ per kWh and premise standing charges. After averaging the costs for all 6 small businesses a £/mile figure was calculated which was then scaled up to an annual cost using the chosen annual mileage.

Table 3 – Consumption values for electric vehicles[6]

Vehicles	Estimates					
	£/Litre	Urban miles per litre	£/Mile	£/kWh	Urban Consumption per mile	£/Mile
Renault Trafic	1.38	9.6	0.144	n/a	n/a	n/a
Peugeot Boxer	1.38	11.5	0.121	n/a	n/a	n/a
Citroen Berlingo	1.38	14.6	0.095	n/a	n/a	n/a
Peugeot Partner	1.38	15.6	0.089	n/a	n/a	n/a
Ford Transit Connect	1.38	11.7	0.119	n/a	n/a	n/a
Vauxhall Vivaro	1.38	9.6	0.145	n/a	n/a	n/a
Ford Transit	1.38	9.6	0.145	n/a	n/a	n/a
Ford Transit Custom	1.38	10.2	0.136	n/a	n/a	n/a
Renault Kangoo	n/a	n/a	n/a	0.111	0.192	0.021
Peugeot ePartner	n/a	n/a	n/a	0.111	0.222	0.025
Nissan e-NV200	n/a	n/a	n/a	0.111	0.226	0.025

In order to find the cost for the HFCVs, we assumed (per Hyundai H350 Concept) that fuel consumption guides in the technical specification were applicable as averages. First we reflected mileage consumption in kilograms (kg) and employed the listed vehicle capacities to determine consumption. Next we factored the cost of hydrogen (£10 per kg), therefore the

---

[6] The £/mi costs include VAT at 20%, however the VAT rate on electricity used for charging battery electric /vehicles is set at 5%. Thus, the values were multiplied by 1.05/1.20 to obtain a new value inclusive of 5% VAT.

costs for the HFCVs were computed as a product of annual mileage, miles per kilometre, and GBP per kilometre[7].

C_{3_n} represents maintenance, repair, and tyre (MRT) costs for year n. This reflects the costs that a user would incur in operating the vehicle due to both maintenance, repairs and regular tyre replacements. MRT estimates for diesel vehicles were calculated by adding repair cost using pence per mile (5.2ppm) and tyre replacement costs (1.4ppm), i.e. 6.6ppm for diesel vehicles. Typical electric and hydrogen vehicles MRT costs have been pegged at 50% and 70% of ICEV types respectively, therefore we allocated this at 3.3ppm and 4.62ppm [33]. Annual MRT costs were set using the product of the relevant ppm value and annual mileage.

C_{4_n} represents insurance costs for year *n*; a variation of input data was used to inform insurance quotes for a typical UK based business van insurance in 2017. To support our data evaluation, we used a price comparison site (www.comparethemarket.com) to generate quotes. To account for difficulties of new models, we made some further adjustments to accommodate gaps in the returned quotes[8].

C_{5_n}represents battery costs for year n. As battery costs remain high, manufacturers offer a variety of purchase options to support customers; one such option is battery leasing whereby users pay a monthly fee that covers ownership and replacements. For example, the cost for the *Renault Kangoo Z.E. 33* is determined by contract length and mileage, and it was this cost model that was used to estimate battery cost gaps for similar vehicles. Annual battery costs could then be deduced and subject to the discount rate at each year.

Table 4: Notation Summary Table

Notation	
CE	Capital Expenditure: Purchase cost excluding VAT
RV	Residual Value: Depreciating asset value @ 20% of asset purchase value (straight line)
PS	Purchase Subsidy: Fixed at 20% up to £8000 max.
r	Discount rate: U.K bond average (10 year gilt based on data and 3MA values)
C_{x_n}	Operating costs total
C_{1_n}	Road tax – Given by DfT or calculated using CO_2 output
C_{2_n}	Fuel costs @ estimate unit cost per Kwh, with adjustments for VAT differences on engine types.
C_{3_n}	Maintenance, repair and tyre: Vehicle ppm * mileage
C_{4_n}	Insurance costs for year n.
C_{5_n}	Battery cost for year n @ r, based on contract * mileage assumptions.

3.1 Sensitivity Analysis

---

[7] Kangoo, operates using both battery electric means and hydrogen fuel cell, we assumed a ratio of energy draw was the same as the ratio of the ranges, i.e. hydrogen range at 180 miles and battery mode at 106 miles (180:106 or 62.9% hydrogen and 37.1% battery).

[8] This assumption is valid as an estimate as the same stock vehicle is used in both cases, with the HyKangoo having an aftermarket fuel cell conversion. For the H350 vehicle, the powertrain and vehicle allowed its estimation, and we used an average from the cost of the other BEVs to estimate the insurance cost for the H350. All prices were considered fixed for the 10-year period.

Additionally, the computation outcomes were subjected to 'what if' sensitivity analysis evaluating the impact of cost variable changes in determining outcomes for the different vehicles. The preliminary results presented in Figure 2 were used as baseline data. The sensitivity analysis focused on two main criteria: in the first instance, we adjusted for changes in operating conditions where all the market conditions remained the same (relationship between usage and cost). In the second instances, we adjusted for changes in market conditions where all operating elements remained unchanged. With respect to the operating variable, mileage was adjusted to explore cost competitiveness (mileage is considered a predictable control variable) and in the other market instances, we adjusted the prices for fuel duty and hydrogen fuel in order to explore the potential impact on the costs for operators.

Our analysis was performed using MS Excel Scenario Manager Tool and the results are reported below.

4.0 Results

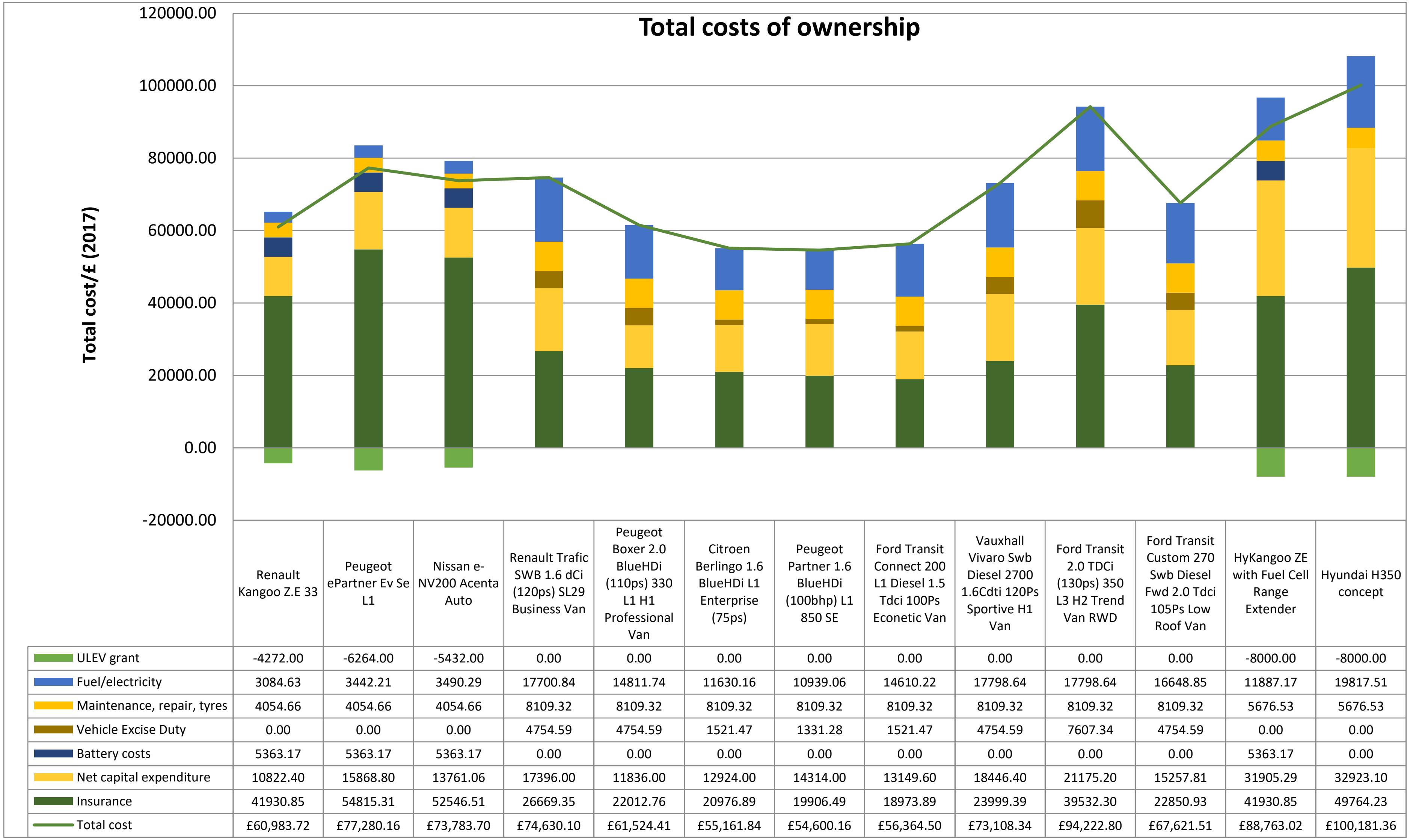
The computation model shows that typically, diesel vehicles offer lower TCO compared to the electric and fuel cell options. Our data shows insurance as the largest factor in this regard, constituting, on average, 64% of the total cost for BEVs and HFCVs. We project that this cost will reduce overtime as the market matures and insurers are better able to compute risks of coverage. Our data also suggests that the effect of 'duties' as a moderator is relatively limited in this regard.

As depicted in Figure 2, HFCVs remain the most expensive options without the OLEV grant, however our findings suggest that the grant effectively supports the competitiveness of HFCVs. Additionally, results highlight greater overall capital expenditure costs for the hydrogen options as opposed to the electric and diesel vehicles. It is possible that the cost implications will be steeper as our model assumes a relatively competitive residual value component for the HFCVs and this assumption may not always hold true since the market is still growing. Full results are shown in Figure 2.

4.1 Sensitivity to Operating Conditions (Mileage)

Electric vehicles typically exhibit lower running costs with higher capital expenditure and it is expected that they become increasingly more competitive as the number of miles driven increases as indicated in Figures 2 and 3[28]. We also observe that all of the non-diesel vehicles exhibit higher pence per mile ownership costs than their diesel counterparts that are at lower end of the mileage scale. The exception to this is the Ford Transit Trend which remains disproportionately high, which can be explained by its high insurance cost; at £4157 per year it is far higher than any other diesel vehicle to insure (usually range within £1995 to £2804). Furthermore, we observe that the pence per mile cost for the Renault Kangoo drops below all diesel vehicles at approximately 21,000 miles (Figure 3).

HFCVs do not fare as well as BEVs with adjusted mileage. Disregarding the Transit Trend as an outlier, the pence per mile cost of the Hyundai H350 never falls into the range of the diesel vehicle costs and never becomes competitive, although the HyKangoo falls into the range, this occurs at approximately 37,000 miles where the cost is comparable with the Renault Trafic and the Vauxhall Vivaro (Figure 3). As mileage increases up to 100,000 miles, only the Peugeot Partner and the Citroen Berlingo offer lower pence per mile ownership costs than the HyKangoo. BEVs on the other hand become competitive with diesel alternatives at approximately 17,000 miles. Whilst it may be plausible for HFCVs to become competitive beyond the 100,000-mile range, our study did not account for periods beyond 100,000 p.a limits, which we think is a boundary possibility for logistics vans. It is noteworthy that BEVs will tend to be the preferred option for operators looking to switch to low or ultra-low emission vehicles as they become competitive significantly sooner than the PHEVs. These results are shown in further detail in Annex A.



	Renault Kangoo Z.E 33	Peugeot ePartner Ev Se L1	Nissan e-NV200 Acenta Auto	Renault Trafic SWB 1.6 dCi (120ps) SL29 Business Van	Peugeot Boxer 2.0 BlueHDi (110ps) 330 L1 H1 Professional Van	Citroen Berlingo 1.6 BlueHDi L1 Enterprise (75ps)	Peugeot Partner 1.6 BlueHDi (100bhp) L1 850 SE	Ford Transit Connect 200 L1 Diesel 1.5 Tdci 100Ps Econetic Van	Vauxhall Vivaro Swb Diesel 2700 1.6Cdti 120Ps Sportive H1 Van	Ford Transit 2.0 TDCi (130ps) 350 L3 H2 Trend Van RWD	Ford Transit Custom 270 Swb Diesel Fwd 2.0 Tdci 105Ps Low Roof Van	HyKangoo ZE with Fuel Cell Range Extender	Hyundai H350 concept
🟩 ULEV grant	-4272.00	-6264.00	-5432.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-8000.00	-8000.00
🟦 Fuel/electricity	3084.63	3442.21	3490.29	17700.84	14811.74	11630.16	10939.06	14610.22	17798.64	17798.64	16648.85	11887.17	19817.51
🟧 Maintenance, repair, tyres	4054.66	4054.66	4054.66	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	5676.53	5676.53
🟫 Vehicle Excise Duty	0.00	0.00	0.00	4754.59	4754.59	1521.47	1331.28	1521.47	4754.59	7607.34	4754.59	0.00	0.00
🟦 Battery costs	5363.17	5363.17	5363.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5363.17	0.00
🟨 Net capital expenditure	10822.40	15868.80	13761.06	17396.00	11836.00	12924.00	14314.00	13149.60	18446.40	21175.20	15257.81	31905.29	32923.10
🟩 Insurance	41930.85	54815.31	52546.51	26669.35	22012.76	20976.89	19906.49	18973.89	23999.39	39532.30	22850.93	41930.85	49764.23
— Total cost	£60,983.72	£77,280.16	£73,783.70	£74,630.10	£61,524.41	£55,161.84	£54,600.16	£56,364.50	£73,108.34	£94,222.80	£67,621.51	£88,763.02	£100,181.36

Figure 2 – Total cost of ownership results

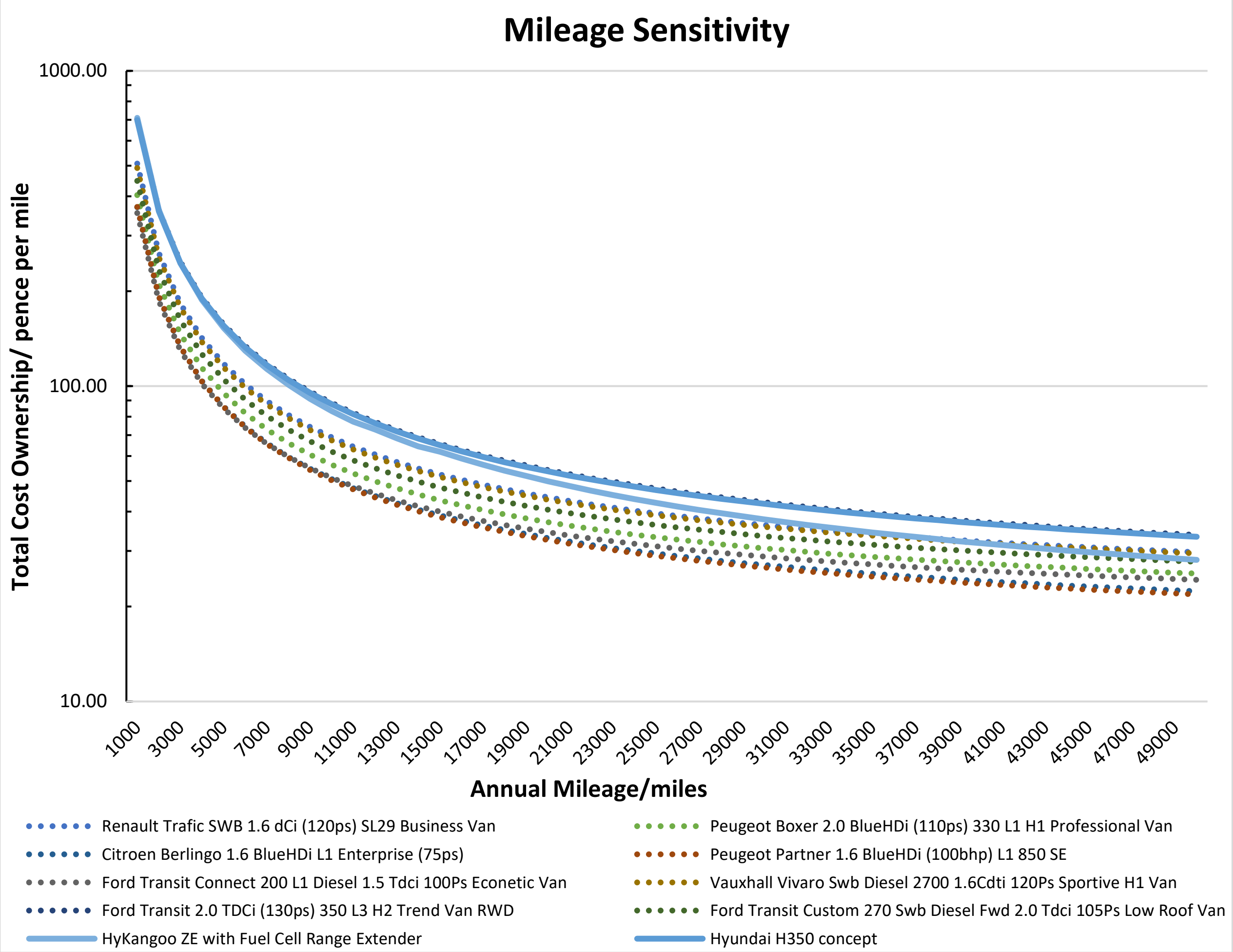


Figure 3 – Sensitivity to Annual Mileage

4.2 Sensitivity to Market conditions (Prices)

In terms of market conditions, we determined fuel costs as a viable variable for controlling competitive market conditions. Fuel costs were broken down into three components; VAT, fuel duty, and the fuel cost. For example, in the UK, fuel duty is currently charged at 57.95 pence per litre [37] which equates to 263.45 pence per gallon, and VAT is charged at 20% of the fuel cost plus the fuel duty, working out at 16.7% of the final price [32]. In this study the price per litre of diesel was set at £1.154/L or £5.246/gal, therefore the applicable cost for control within the market condition scenario planning (duty = £2.634, VAT = £0.876, Fuel cost = £1.735).

Figure 4 shows the results of changes in fuel duty up to a maximum of £7 per gallon (up to £25 per gallon at which point all total costs for all diesel vehicles are greater than all other vehicles is presented in the Appendix). We observe that at £7, ICEs are still most competitive compared to PHEVs, whilst at £25, (a price that is perhaps unattainable but there are some valid findings from the adjustment), ICE becomes least competitive. For example, the table highlights the intersecting boundaries, dictating the price at which diesel vehicles are no longer competitive with BEVs and PHEVs. An increase of about £2 per gallon can make BEVs significantly more compelling compared to their diesel counterparts.

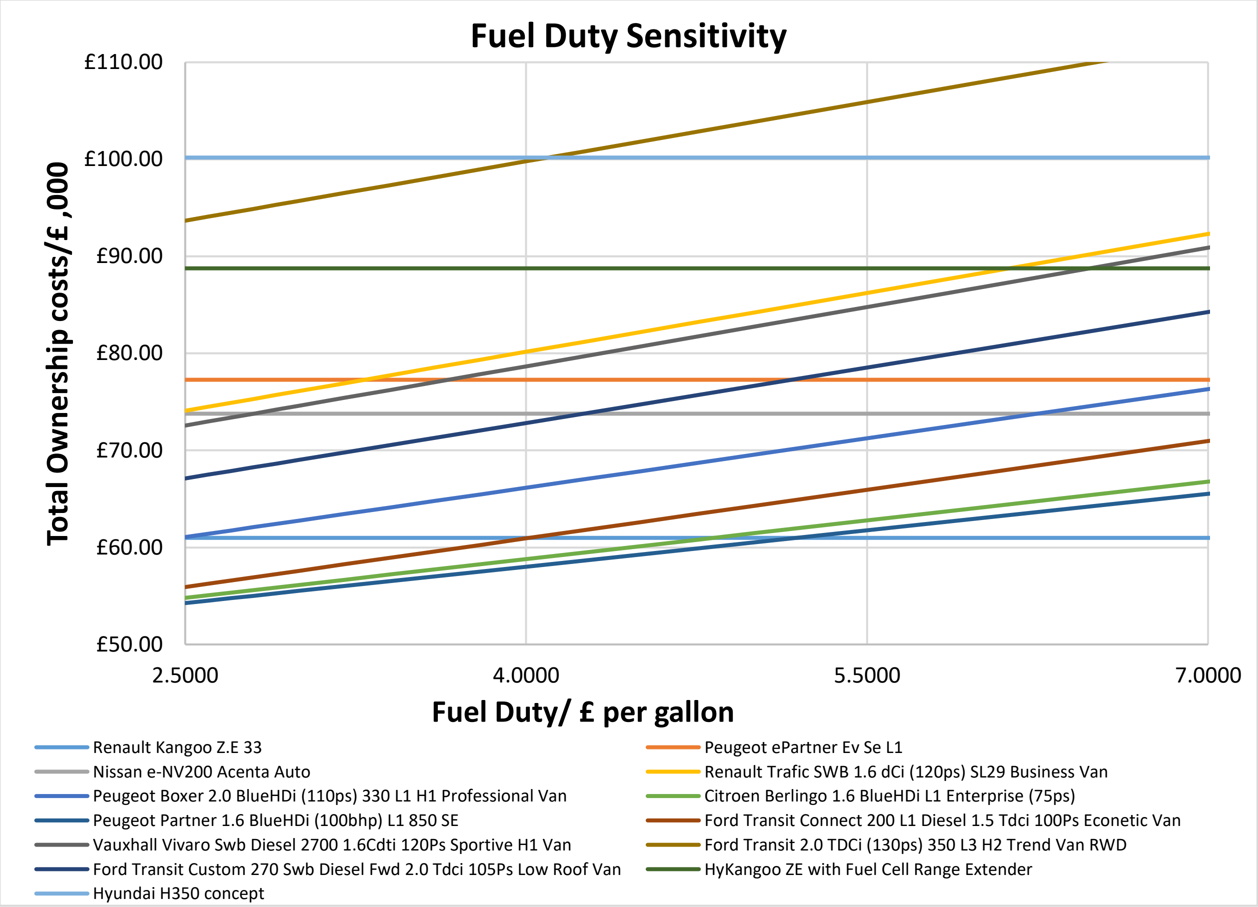


Figure 4 - Sensitivity to fuel duty

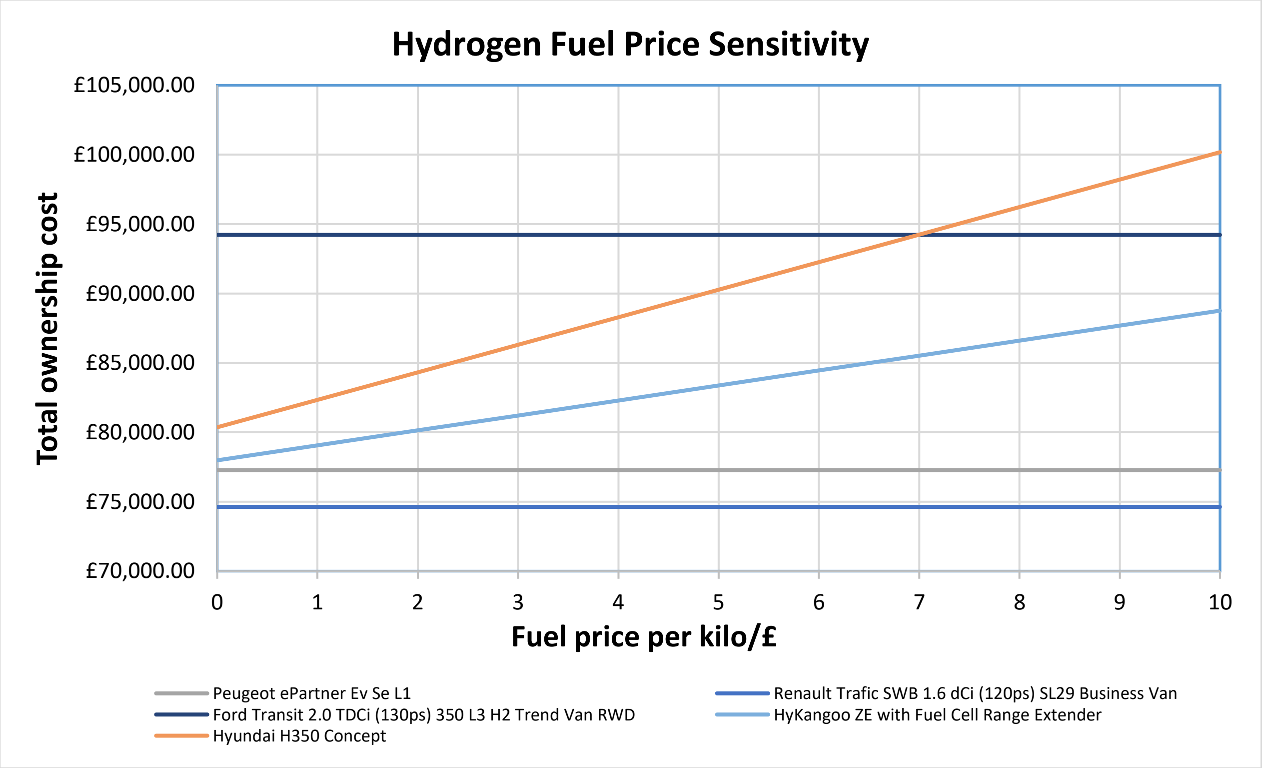


Figure 5 - Sensitivity to hydrogen fuel price

4.3 Sensitivity to Hydrogen Prices

Figure 5 above reveals our findings on HFCVs competitiveness dues to changes in price. A comparison with one BEV is shown. Of all three models, the H350 concept exhibits a steeper gradient as it is powered solely by hydrogen fuel, whereas the HyKangoo has a supplementing battery pack and therefore we observe that the total cost drops less as hydrogen fuel cost drops. From the computations presented in Figure 5, it is noted that at £7/kg both vehicles fall beneath the total cost of the Ford Transit Trend, but neither will reach the next most expensive diesel vehicle, or the BEV, even with a complete removal of hydrogen cost. This raises some significant concerns about the technology's feasibility as an alternative without cost penalties for operators. Observably, each £1 per kilo cost decrease results in a 1.29% and a 2.18% decrease in total ownership costs of the HyKangoo and H350 respectively. Since generating hydrogen fuel requires electricity, perhaps an avenue to reducing the cost is to promote a reduction in electricity prices, although that would further increase the appeal of BEVs as opposed to increasing the attractiveness for HFCVs.

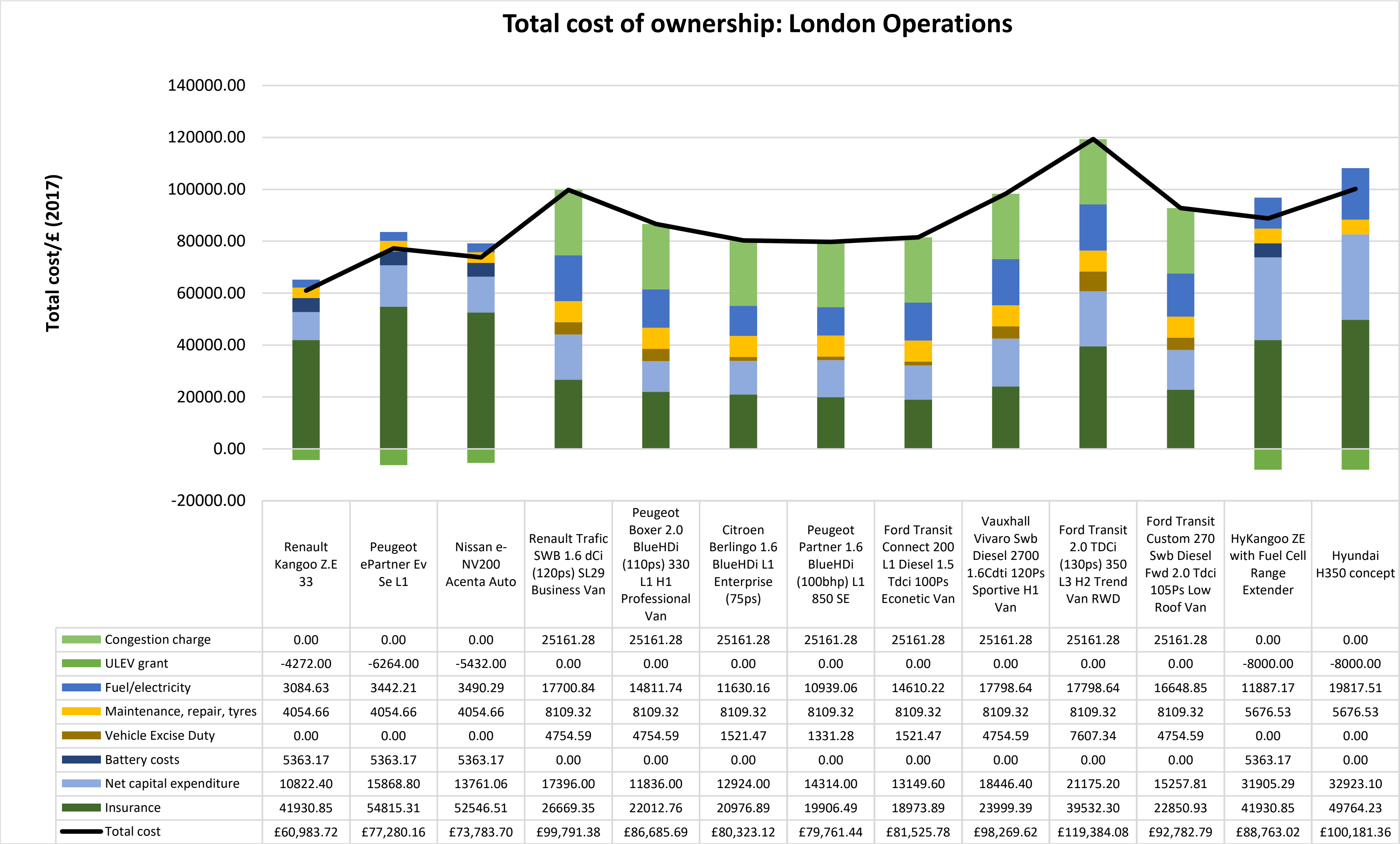
5.0 Scenario Analysis

5.1 London Congestion Charge

The congestion charge is charged daily, excluding weekends and public holidays, and applies to most vehicles that are driven in a designated zone (Annex B) within London. BEVs are exempt, as are vehicles that emit less than 75g CO_2/km and meet the Euro 5 emissions standards. For this study, all diesel vehicles are liable for the congestion charge, whilst all BEVs and HFCVs are exempt. The fee is nominally £11.50 a day but can be reduced to £10.50 a day for business users or for individuals subscribing to the "autopay" system. It is assumed that there are 252 working days a year, as is the case in 2017. Inflation and discount rates are applied to future costs.

A further charge that was considered for vehicles operating within London is the Low Emission Zone (LEZ). The LEZ boundaries are shown alongside the congestion charge zone in Annex B. LEZ restrictions apply for a greater period of time with charges valid every day of the year, including public holidays and weekends. The charge (£100 a day) applies to any diesel lorry, van, bus, or other larger vehicle that does not meet the Euro 3 emissions standards. While all diesel vehicles considered in this study are registered after this date, the charge will be considered here as it is possible that over time the threshold will drop until such a point that the considered vehicles are liable.

Finally, annual mileage figures are altered to reflect urban use only. Using the same report that was used to set the original mileage variable, Department for Transport, [31], annual urban mileage was found to be 4342.11. The results for the London scenario are shown in Figure 6. The associated outcome of the congestion charge is highlighted as all diesel vehicles now exhibit a higher TCO than all BEVs. Furthermore, both HFCVs are within diesel cost ranges, making them competitive for use within London. Their competitiveness with BEVs remains unchanged however as both are exempt.



	Renault Kangoo Z.E 33	Peugeot ePartner Ev Se L1	Nissan e-NV200 Acenta Auto	Renault Trafic SWB 1.6 dCi (120ps) SL29 Business Van	Peugeot Boxer 2.0 BlueHDi (110ps) 330 L1 H1 Professional Van	Citroen Berlingo 1.6 BlueHDi L1 Enterprise (75ps)	Peugeot Partner 1.6 BlueHDi (100bhp) L1 850 SE	Ford Transit Connect 200 L1 Diesel 1.5 Tdci 100Ps Econetic Van	Vauxhall Vivaro Swb Diesel 2700 1.6Cdti 120Ps Sportive H1 Van	Ford Transit 2.0 TDCi (130ps) 350 L3 H2 Trend Van RWD	Ford Transit Custom 270 Swb Diesel Fwd 2.0 Tdci 105Ps Low Roof Van	HyKangoo ZE with Fuel Cell Range Extender	Hyundai H350 concept
🟩 Congestion charge	0.00	0.00	0.00	25161.28	25161.28	25161.28	25161.28	25161.28	25161.28	25161.28	25161.28	0.00	0.00
🟩 ULEV grant	-4272.00	-6264.00	-5432.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-8000.00	-8000.00
🟦 Fuel/electricity	3084.63	3442.21	3490.29	17700.84	14811.74	11630.16	10939.06	14610.22	17798.64	17798.64	16648.85	11887.17	19817.51
🟨 Maintenance, repair, tyres	4054.66	4054.66	4054.66	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	5676.53	5676.53
🟫 Vehicle Excise Duty	0.00	0.00	0.00	4754.59	4754.59	1521.47	1331.28	1521.47	4754.59	7607.34	4754.59	0.00	0.00
🟦 Battery costs	5363.17	5363.17	5363.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5363.17	0.00
🟦 Net capital expenditure	10822.40	15868.80	13761.06	17396.00	11836.00	12924.00	14314.00	13149.60	18446.40	21175.20	15257.81	31905.29	32923.10
🟩 Insurance	41930.85	54815.31	52546.51	26669.35	22012.76	20976.89	19906.49	18973.89	23999.39	39532.30	22850.93	41930.85	49764.23
— Total cost	£60,983.72	£77,280.16	£73,783.70	£99,791.38	£86,685.69	£80,323.12	£79,761.44	£81,525.78	£98,269.62	£119,384.08	£92,782.79	£88,763.02	£100,181.36

Figure 6 - TCO in London

Applying the LEZ to all diesel vehicles renders them obsolete with all vehicles exhibiting TCOs of different magnitudes to the BEV and HFCVs, the plotted results can be found in Annex C.

These results have policy implications for other cities within the UK as the magnitude of a congestion charge necessary to raise low emission vehicles' competitiveness can be deduced. Utilising the Solver add-in for Excel the congestion charge value can be changed until such a point that all BEVs and HFCVs exhibit lower TCO than all diesel vehicles. Using this procedure, it was found that a congestion charge of £17.52 would be necessary to ensure competitiveness for all non-diesel vehicles. This represents an increase of 66.86% on the current congestion charge of £10.50. At its inception in 2003, the congestion charge was set at £5 and by 2005 it had raised to £8; a percentage increase of 60% [38]. As such a 66.86% change in order to obtain total competitiveness for non-diesel vehicles is not beyond the realms of possibility, although it should be noted that although the percentage increase is comparable the absolute increase in terms of GBP is larger and therefore may have different effects on elasticity (please see Annex C).

5.2 Green Energy

As was discussed in the previous sections, a vehicle with 0gCO2/km emissions can still have a carbon cost associated with it. If the electricity used to charge a BEV is sourced from a coal-fired power station for example, there may be a hidden carbon footprint that an operator is not aware of. Electricity from a provider generating their electricity from 100% renewable energy sources can be more expensive and a decision to opt for this provider can have impacts on the TCO.

Electricity prices were sourced using an electricity price aggregator, uswitch.com. Only providers utilising 100% renewable energy sources were selected for averaging. These values were then set as the respective variable values and the total cost results are shown in Annex D.

As expected, the BEVs exhibit greater total costs than previously, there is also a slight increase in the HyKangoo total cost due to the supplementary battery pack. The Kangoo Z.E, ePartner, and e-NV200 exhibit percentage increases in total cost of 1.16%, 1.03%, and 1.09% respectively. The HyKangoo sees a 0.32% increase. These increases have a minimal effect on their overall competitiveness and as such, switching to an all renewable energy provider is a viable decision for most operators wishing to reduce lifetime emissions of their vehicles.

6.0 Conclusion

This study found that diesel vehicles remain the *most* competitive option for commercial use in the UK, even after consideration of tax relief and grants for low emission vehicles. However, both BEVs and HFCVs, with these considerations, do fall within the total lifetime cost range of a number of diesel vehicles and can therefore be considered competitive under current conditions. Competitiveness can be accelerated with an increase in ULEV grant that was found to be crucial, especially for HFCVs. BEVs would remain competitive with a reduced grant, however it would obviously slow uptake.

Analysis found that, due to lower running costs, the competitiveness of both BEVs and HFCVs was sensitive to mileage. On average, BEVs become more competitive than their diesel counterparts, once annual mileage surpasses 17,000 miles. For HFCVs, competitiveness did increase although for the H350 an increase in mileage was not enough to result in overall competitiveness. It was found that congestion charges are incredibly effective in incentivising the use of low emission vehicles; also, the impact of low emission charges (which currently only applies to diesel vehicles failing to meet Euro 3 emission standards) was considered. Furthermore, it was shown that opting for electricity sourced only from renewable sources does little to dampen the competitiveness of BEVs. It follows that current market conditions dictate that electricity sourced from renewable methods of generation is not drastically more expensive, and as such hydrogen fuel production from renewable electricity should be encouraged.

In terms of policy, this study should make the importance of the ULEV grant abundantly clear as it hugely increases the competitiveness of both BEVs and HFCVs. This tallies with the position in the literature where fiscal policy has been identified as impacting competitiveness of HFCVs [8], [14]. Furthermore, the analysis suggests a greater probability that the vehicle excise duty plays a relatively small role during the period of ownership and this poses a fresh perspective to policy approaches as the LEZ scenario input seemed to have greater impact on levelling ownership costs compared to duty. More specifically, our findings suggest that an average reduction of prices to £7.00 per kg in the fuel price of hydrogen would make both hybrid fuel cell and pure hydrogen vehicles competitive with diesel vehicles. Additionally, an emerging implication of the analysis is the importance of capital expenditure necessary for fuel cell vehicles with viable capital subsidies increasing the competitiveness of these AFVs.

Our TCO model offers significant advantages in terms of supporting analytical flexibility, such as the scenario analysis, however a weakness of such models is the large number of assumptions, particularly later end cost assumptions that are impossible to predict perfectly. Additionally, since all the cases considered in the analysis section are univariate, future studies will do well to establish an optimum change in all constituent costs as this could yield much more applicable results with limited effect from the cost assumptions that may affect outcomes.

Acknowledgments

This research was partially supported by the project "*Promoting Sustainable Freight Transport in Urban Contexts: Policy and Decision-Making Approaches* (ProSFeT)", funded by the H2020-MSCA-RISE-2016 programme (Grant Number: 734909).

List of References

[1] C. Lin, K. L. Choy, G. T. S. Ho, H. Y. Lam, G. K. H. Pang, and K. S. Chin, “A decision support system for optimizing dynamic courier routing operations,” *Expert Systems with Applications*, vol. 41, no. 15, pp. 6917–6933, 2014.

[2] MDS Transmodal Limited and La Logistica Trasporto Centro di ricerca per il CTL), “DG MOVE European Commission: Study on Urban Freight Transport,” 2014.

[3] L. Dablanc, “Goods transport in large European cities: Difficult to organize, difficult to modernize,” *Transportation Research Part A: Policy and Practice*, vol. 41, no. 3, pp. 280–285, 2007.

[4] M. Asif and T. Muneer, “Energy supply, its demand and security issues for developed and emerging economies,” *Renewable and Sustainable Energy Reviews*, vol. 11, no. 7, pp. 1388–1413, 2007.

[5] F. Russo and A. Comi, “Measures for Sustainable Freight Transportation at Urban Scale: Expected Goals and Tested Results in Europe,” *Journal of Urban Planning and Development*, vol. 137, no. 2, pp. 142–152, 2011.

[6] Z. Rezvani, J. Jansson, and J. Bodin, “Advances in consumer electric vehicle adoption research: A review and research agenda,” *Transportation Research Part D: Transport and Environment*, vol. 34, pp. 122–136, 2015.

[7] M. Ni, M. K. H. Leung, D. Y. C. Leung, and K. Sumathy, “A review and recent developments in photocatalytic water-splitting using TiO2 for hydrogen production,” *Renewable and Sustainable Energy Reviews*, vol. 11, no. 3, pp. 401–425, 2007.

[8] T. da Silva Veras, T. S. Mozer, D. da Costa Rubim Messeder dos Santos, and A. da Silva César, “Hydrogen: Trends, production and characterization of the main process worldwide,” *International Journal of Hydrogen Energy*, vol. 42, no. 4, pp. 2018–2033, 2017.

[9] R. Sharma, C. Manzie, M. Bessede, M. J. Brear, and R. H. Crawford, “Conventional, hybrid and electric vehicles for Australian driving conditions – Part 1: Technical and financial analysis,” *Transportation Research Part C: Emerging Technologies*, vol. 25, pp. 238–249, 2012.

[10] M. Z. Jacobson, “Cleaning the Air and Improving Health with Hydrogen Fuel-Cell Vehicles,” *Science (New York, N.Y.)*, vol. 1901, no. 2005, pp. 1901–5, 2014.

[11] C. E. Thomas, “Fuel cell and battery electric vehicles compared,” *International Journal of Hydrogen Energy*, vol. 34, no. 15, pp. 6005–6020, 2009.

[12] S. F. Tie and C. W. Tan, “A review of energy sources and energy management system in electric vehicles,” *Renewable and Sustainable Energy Reviews*, vol. 20, pp. 82–102, 2013.

[13] N. Demirdoven, J. Deutch, and D. M. Golden, “Hybrid Cars Now, Fuel Cell Cars Later,” *Science*, vol. 305, no. 5686, pp. 974–976, 2004.

[14] J. Shin, W. S. Hwang, and H. Choi, “Can hydrogen fuel vehicles be a sustainable alternative on vehicle market?; Comparison of electric and hydrogen fuel cell vehicles,” *Technological Forecasting and Social Change*, no. May 2018, pp. 1–10, 2019.

[15] J. Garbak, “Fuel cell auxiliary power units for trucks,” Seattle, WA.

[16] J. M. Andújar and F. Segura, “Fuel cells: History and updating. A walk along two centuries,” *Renewable and Sustainable Energy Reviews*, vol. 13, no. 9, pp. 2309–2322, 2009.

[17] L. Dablanc, G. Giuliano, K. Holliday, and T. O’Brien, “Best Practices in Urban Freight Management: Lessons from an International Survey,” in *Transportation Research Record: Journal of the Transportation Research Board*, 2013, vol. 2379, no. 2379, p. pp 29–38.

[18] J. Dumortier *et al.*, “Effects of providing total cost of ownership information on consumers’ intent to purchase a hybrid or plug-in electric vehicle,” *Transportation Research Part A: Policy and Practice*, vol. 72, pp. 71–86, 2015.

[19] S. G. Chalk and J. F. Miller, “Key challenges and recent progress in batteries, fuel cells, and hydrogen storage for clean energy systems,” *Journal of Power Sources*, vol. 159, no. 1 SPEC. ISS., pp. 73–80, 2006.

[20] B. G. Pollet, I. Staffell, and J. L. Shang, “Current status of hybrid, battery and fuel cell electric vehicles: From electrochemistry to market prospects,” *Electrochimica Acta*, vol.

84, pp. 235–249, 2012.

[21] B. M. Al-Alawi and T. H. Bradley, “Review of hybrid, plug-in hybrid, and electric vehicle market modelling Studies,” *Renewable and Sustainable Energy Reviews*, vol. 21, pp. 190–203, 2013.

[22] G. J. Offer, D. Howey, M. Contestabile, R. Clague, and N. P. Brandon, “Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system,” *Energy Policy*, vol. 38, no. 1, pp. 24–29, 2010.

[23] M. Contestabile, G. J. Offer, R. Slade, F. Jaeger, and M. Thoennes, “Battery electric vehicles, hydrogen fuel cells and biofuels. Which will be the winner?” *Energy and Environmental Science*, vol. 4, no. 10, pp. 3754–3772, 2011.

[24] G. Wu, A. Inderbitzin, and C. Bening, “Total cost of ownership of electric vehicles compared to conventional vehicles: A probabilistic analysis and projection across market segments,” *Energy Policy*, vol. 80, pp. 196–214, 2015.

[25] B. A. Davis and M. A. Figliozzi, “A methodology to evaluate the competitiveness of electric delivery trucks,” *Transportation Research Part E: Logistics and Transportation Review*, vol. 49, no. 1, pp. 8–23, 2013.

[26] M. Börjesson, J. Eliasson, M. B. Hugosson, and K. Brundell-Freij, “The Stockholm congestion charges-5 years on. Effects, acceptability and lessons learnt,” *Transport Policy*, vol. 20, pp. 1–12, 2012.

[27] M. K. Hidrue, G. R. Parsons, W. Kempton, and M. P. Gardner, “Willingness to pay for electric vehicles and their attributes,” *Resource and Energy Economics*, vol. 33, no. 3, pp. 686–705, 2011.

[28] P. Z. Lévay, Y. Drossinos, and C. Thiel, “The effect of fiscal incentives on market penetration of electric vehicles: A pairwise comparison of total cost of ownership,” *Energy Policy*, vol. 105, no. February, pp. 524–533, 2017.

[29] J. Heilala, K. Helin, and J. Montonen, “Total cost of ownership analysis for modular final assembly systems,” *International Journal of Production Research*, vol. 44, no. 18–19, pp. 3967–3988, 2006.

[30] G. Harrison and C. Thiel, “An exploratory policy analysis of electric vehicle sales competition and sensitivity to infrastructure in Europe,” *Technological Forecasting and Social Change*, vol. 114, pp. 165–178, 2017.

[31] Department for Transport, “Road Traffic Estimates: Great Britain 2016,” London, 2017.

[32] Office for National Statistics., “Fuel prices explained: A breakdown of the cost of petrol and diesel.” 2016. .

[33] Element Energy, “Low carbon cars in the 2020s: Consumer impacts and EU policy implications,” Cambridge, 2016.

[34] HM Treasury, *HMT (2018), The Green Book: appraisal and evaluation in central government, Chapter 6, p39-47, HM Treasury, London.* 2018.

[35] M. Clarke, G., Johnson, A., Nankivell, J., Turpin, “Van travel trends in Great Britain.,” *RAC London*, 2014. [Online]. Available: http://www.racfoundation.org/assets/rac_foundation/content/downloadables/van_report_aecom_100414.pdf. [Accessed: 01-Aug-2017].

[36] Businesselectricityprices.org.uk., “Business Commercial Electricity Prices and Cost per kWh,” 2017. [Online]. Available: https://www.businesselectricityprices.org.uk/cost-per-

kwh/#typical-kwh-prices. [Accessed: 05-Sep-2017].

[37] Her Majesty's Customs and Revenue, "Fuel Duty," London, 2016.

[38] Transport for London Policy Analysis Division, "Demand Elasticities for Car Trips to Central London as revealed by the Central London Congestion Charge." TfL, London, pp. 1–28, 2008.

[39] Open Street Maps, "London congestion charge zone," *Wikimedia Commons*, 2016. [Online]. Available: https://commons.wikimedia.org/wiki/File:London_congestion_charge_zone.png. [Accessed: 12-Dec-2018].

[40] Ars Technica, "Ars Technica. Low emission zone map. [Image]." [Online]. Available: https://cdn.arstechnica.net/wp-content/uploads/sites/3/2017/04/london-congestion-charge-and-low-emission-zone.jpg. [Accessed: 18-Sep-2017].

Annex A

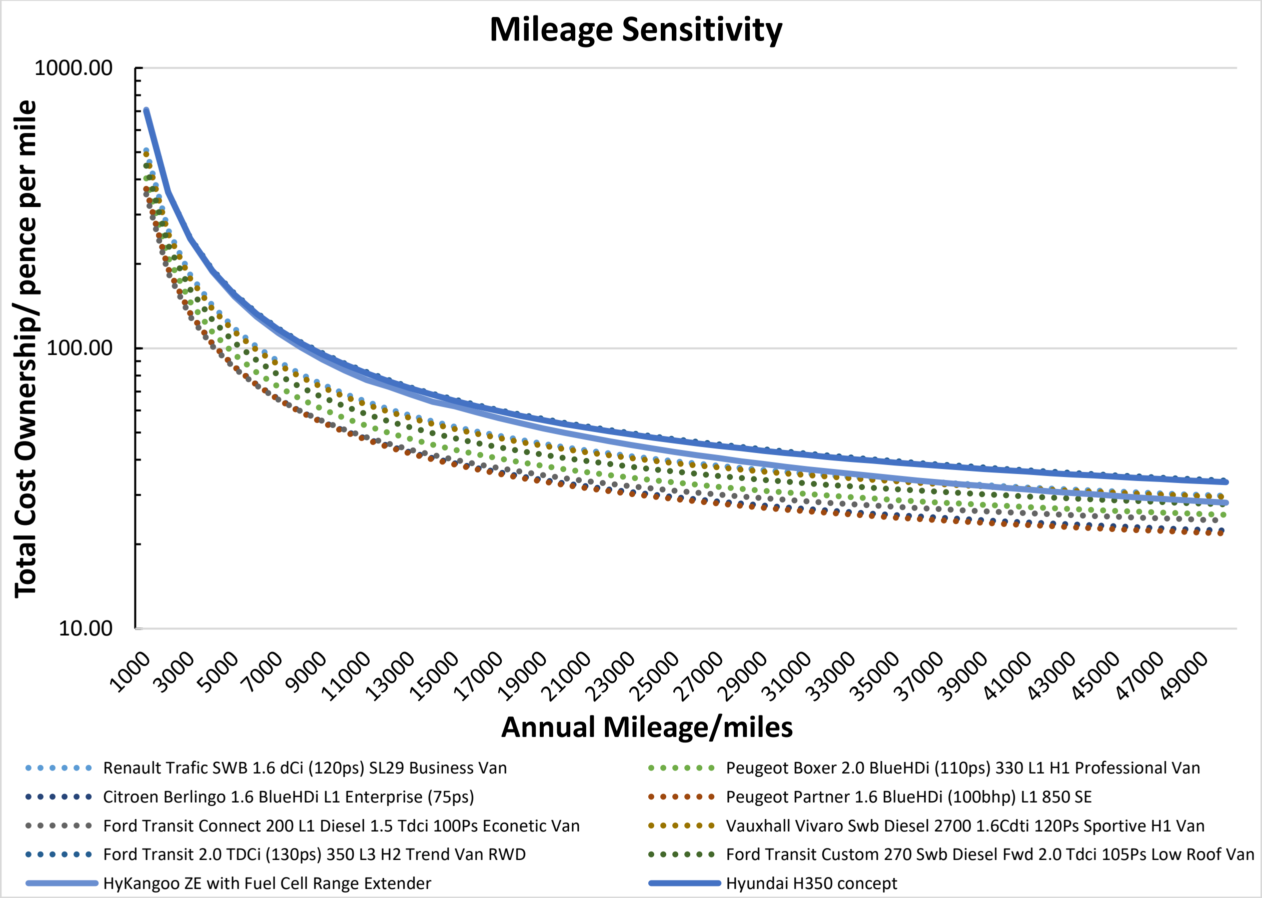


Figure 7 - Sensitivity to Mileage - Hydrogen vehicles and diesel vehicles

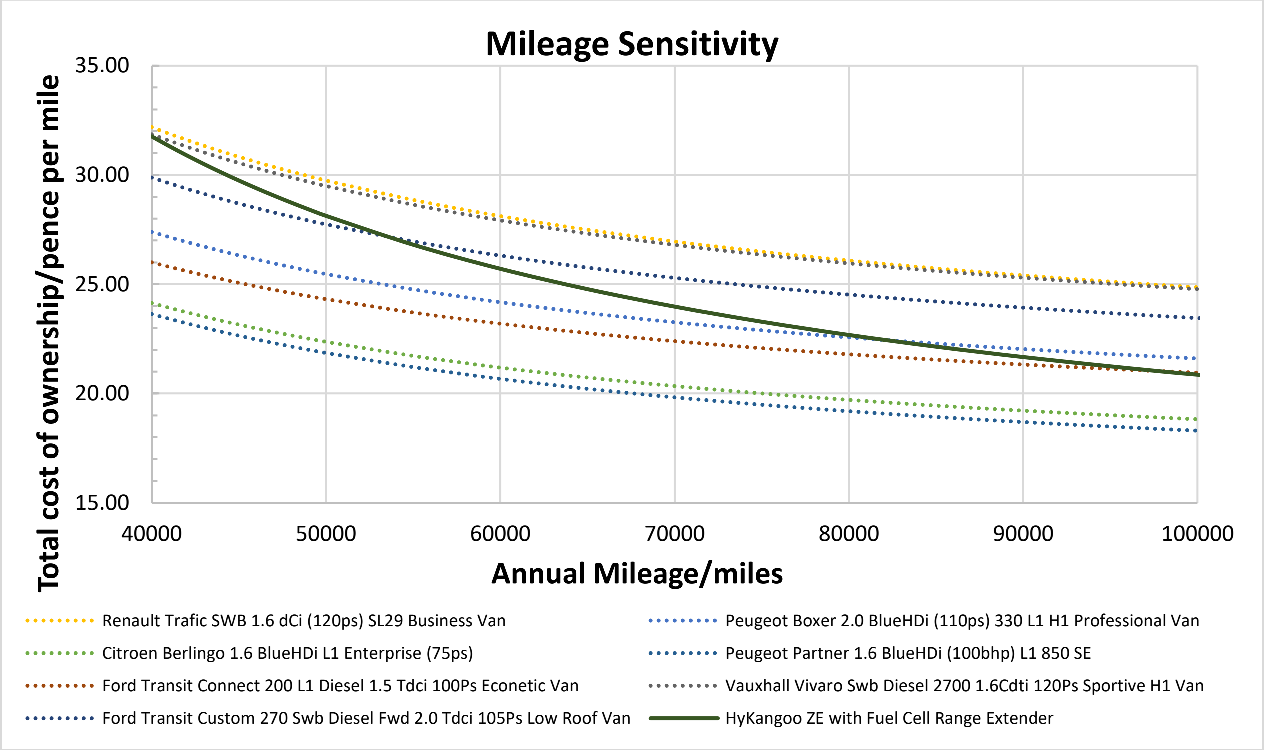


Figure 8 - Sensitivity to mileage - HyKangoo and diesel vehicles

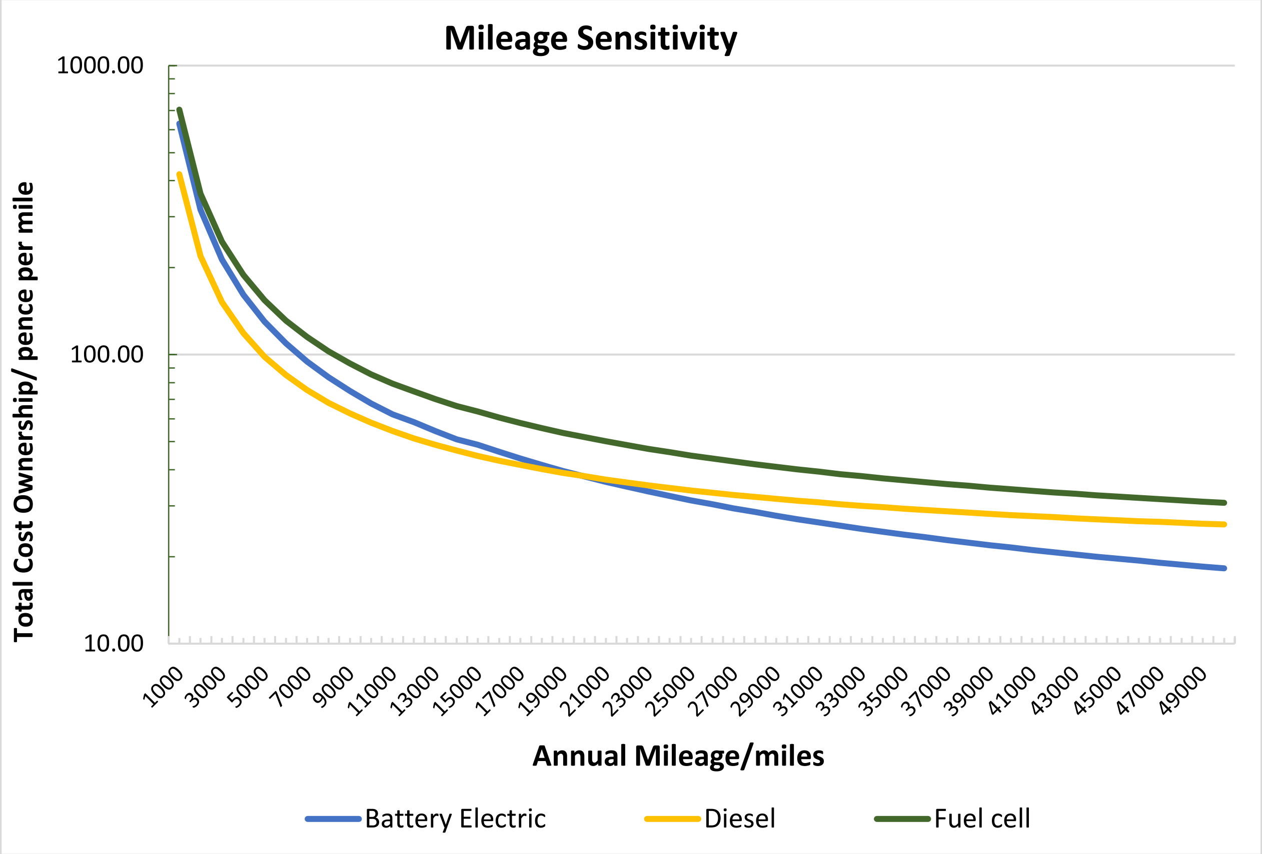


Figure 9a - Average sensitivity to mileage by vehicle class

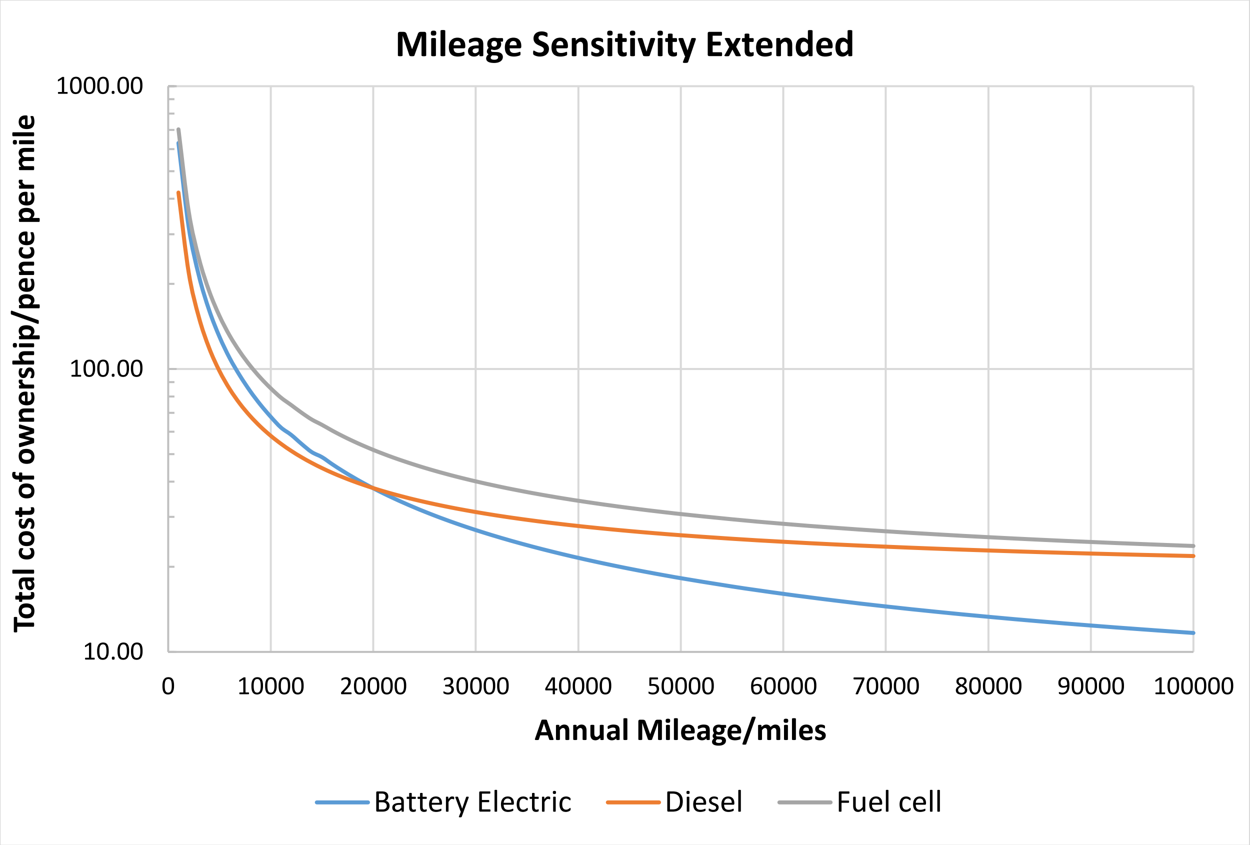


Figure 9b – Extended average sensitivity to mileage by vehicle class

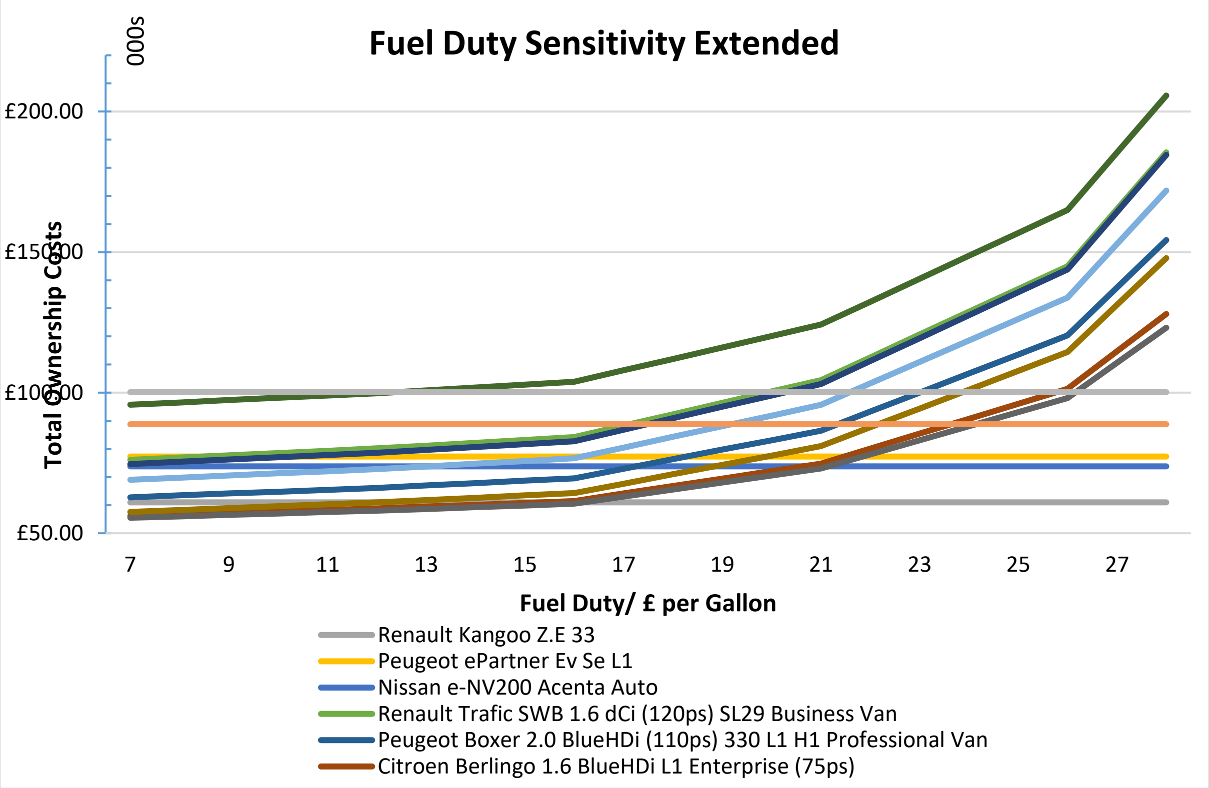


Figure 10 – Extended sensitivity to fuel duty by vehicle class

Annex B

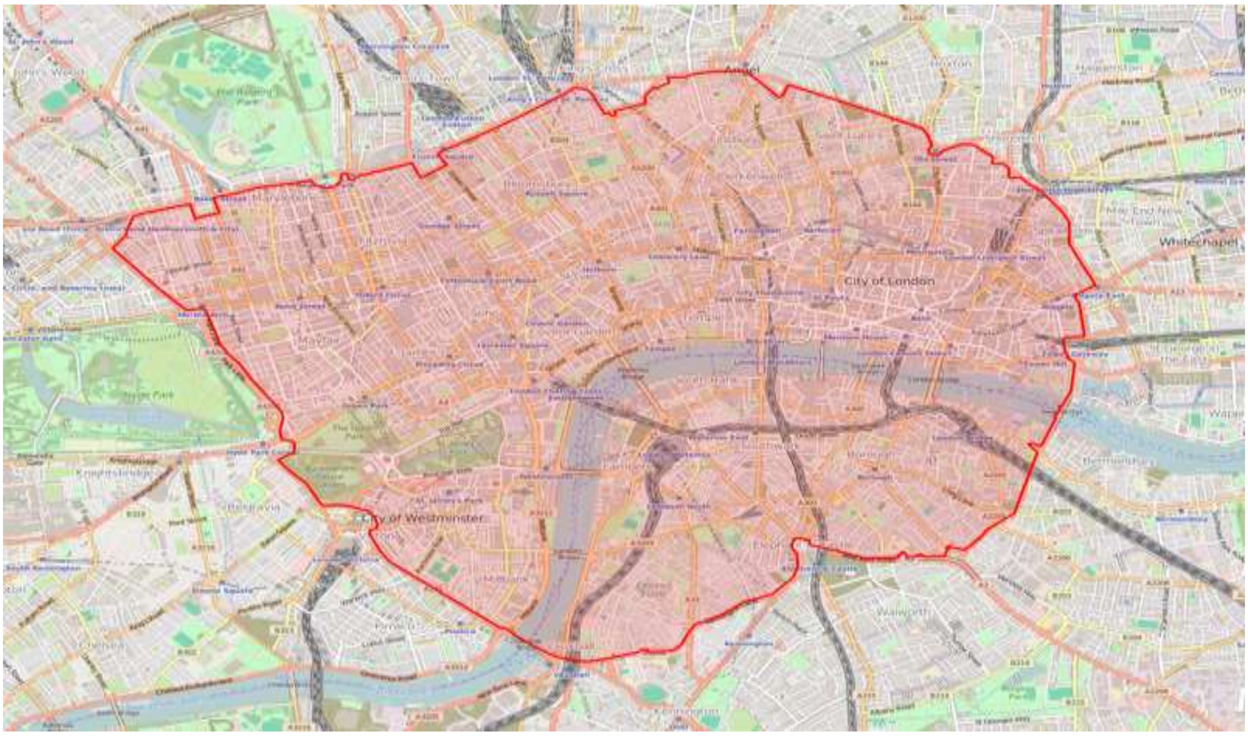


Figure 11 - Congestion charge zone map [39]

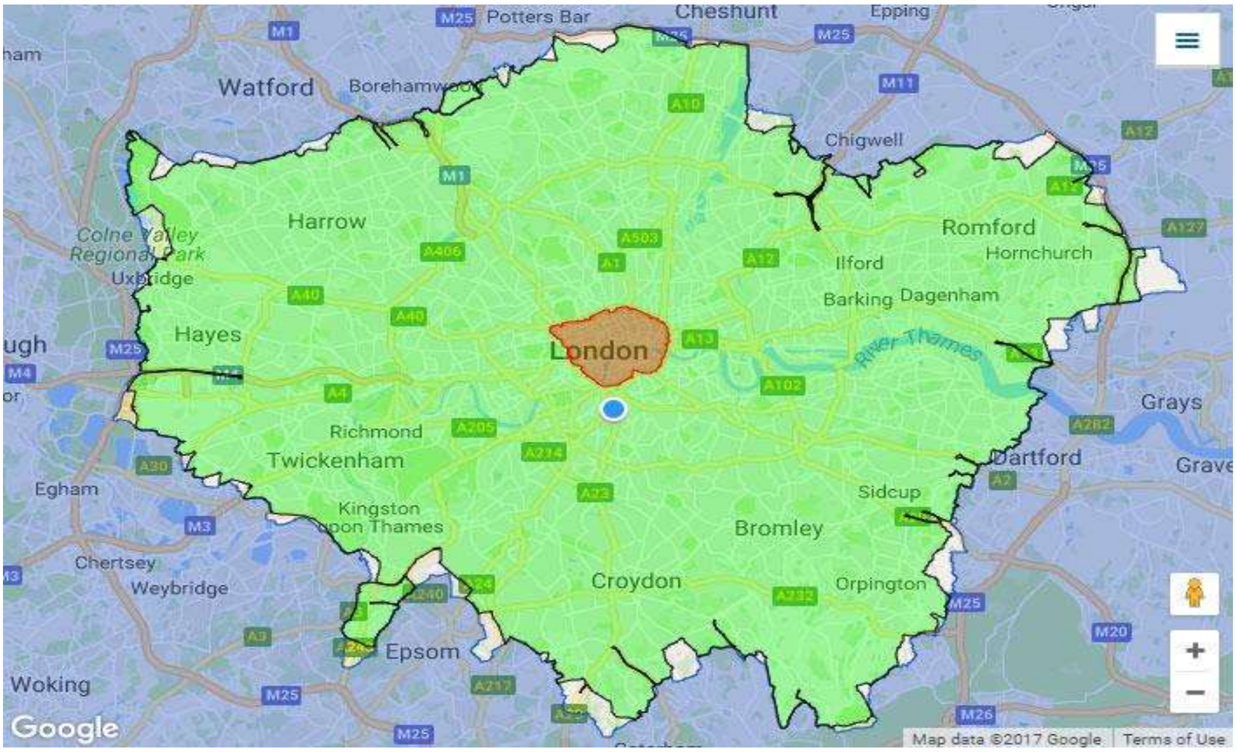
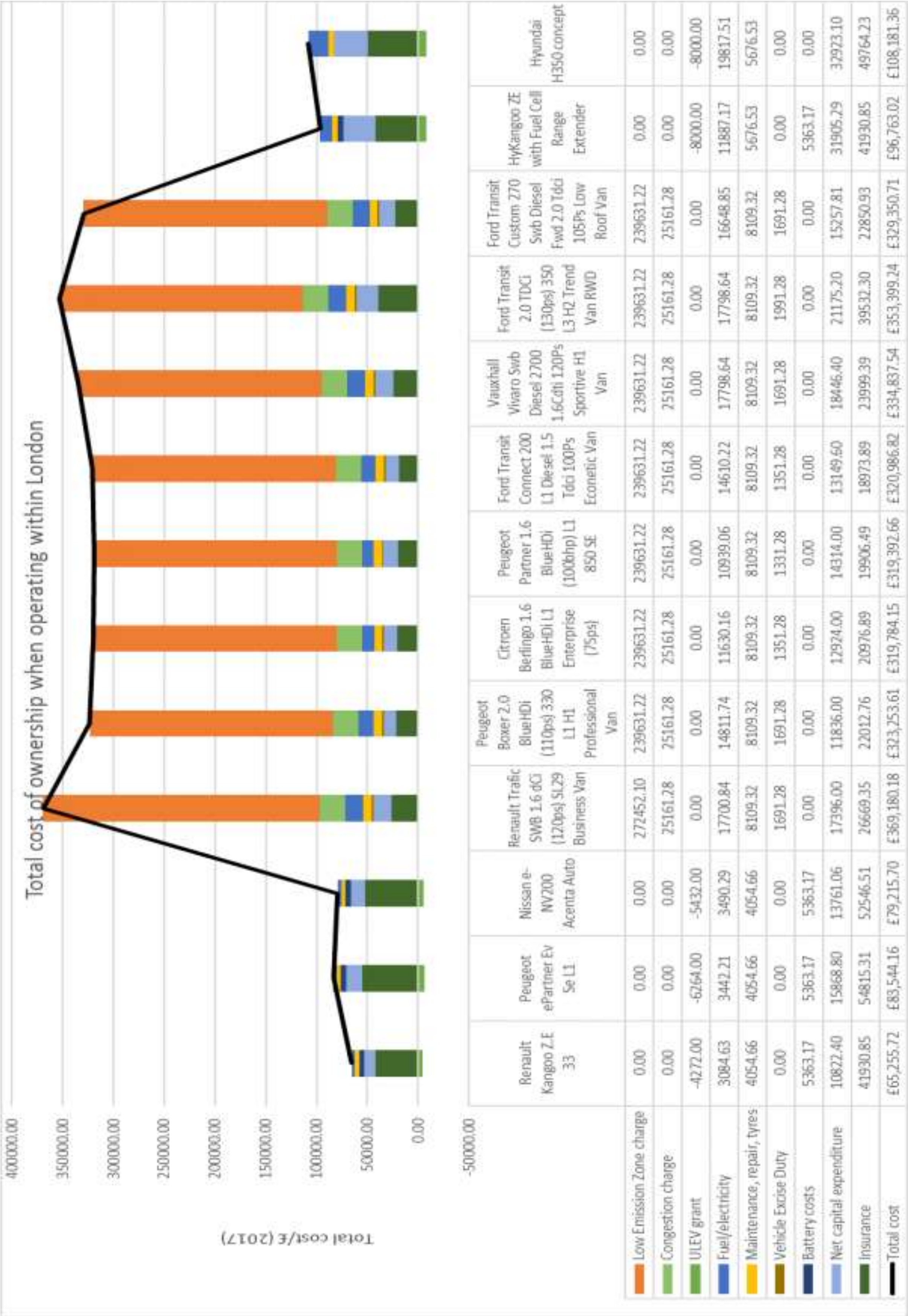


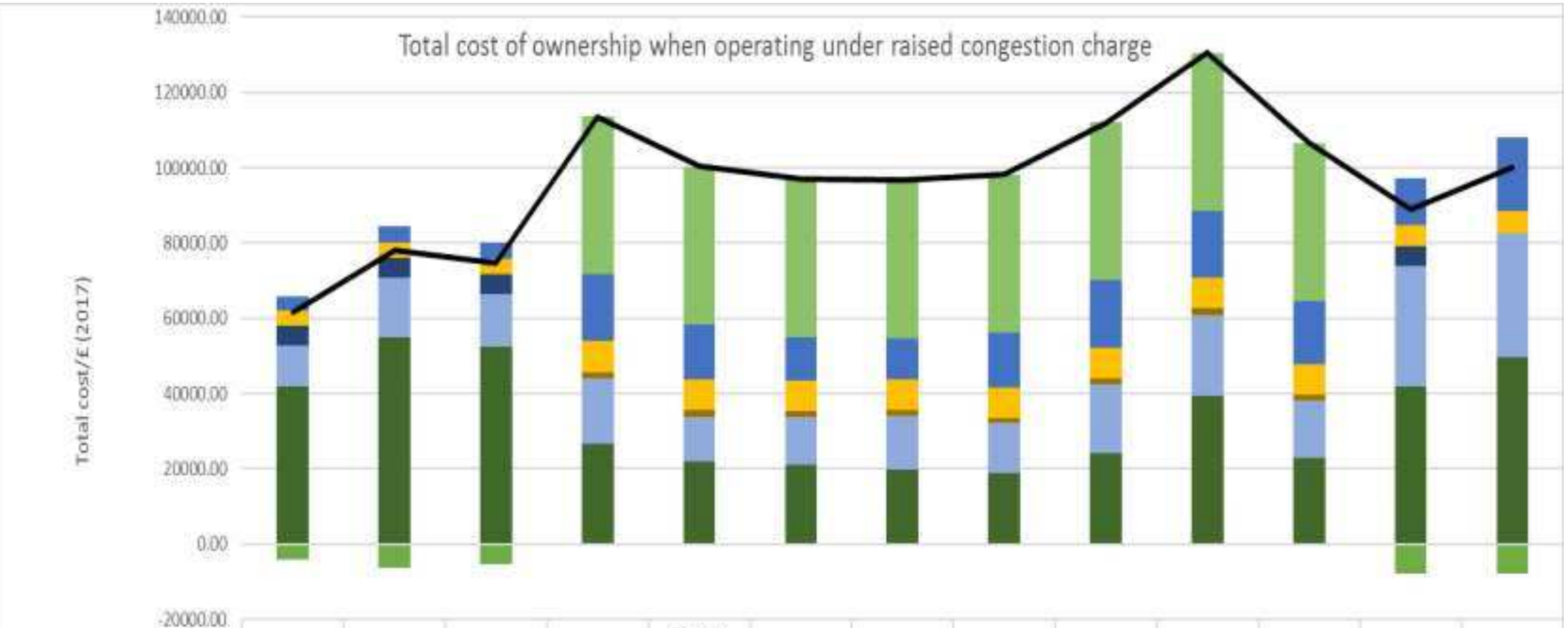
Figure 12 - Low emission zone boundaries (green), congestion charge zone (red)[40]

Annex C



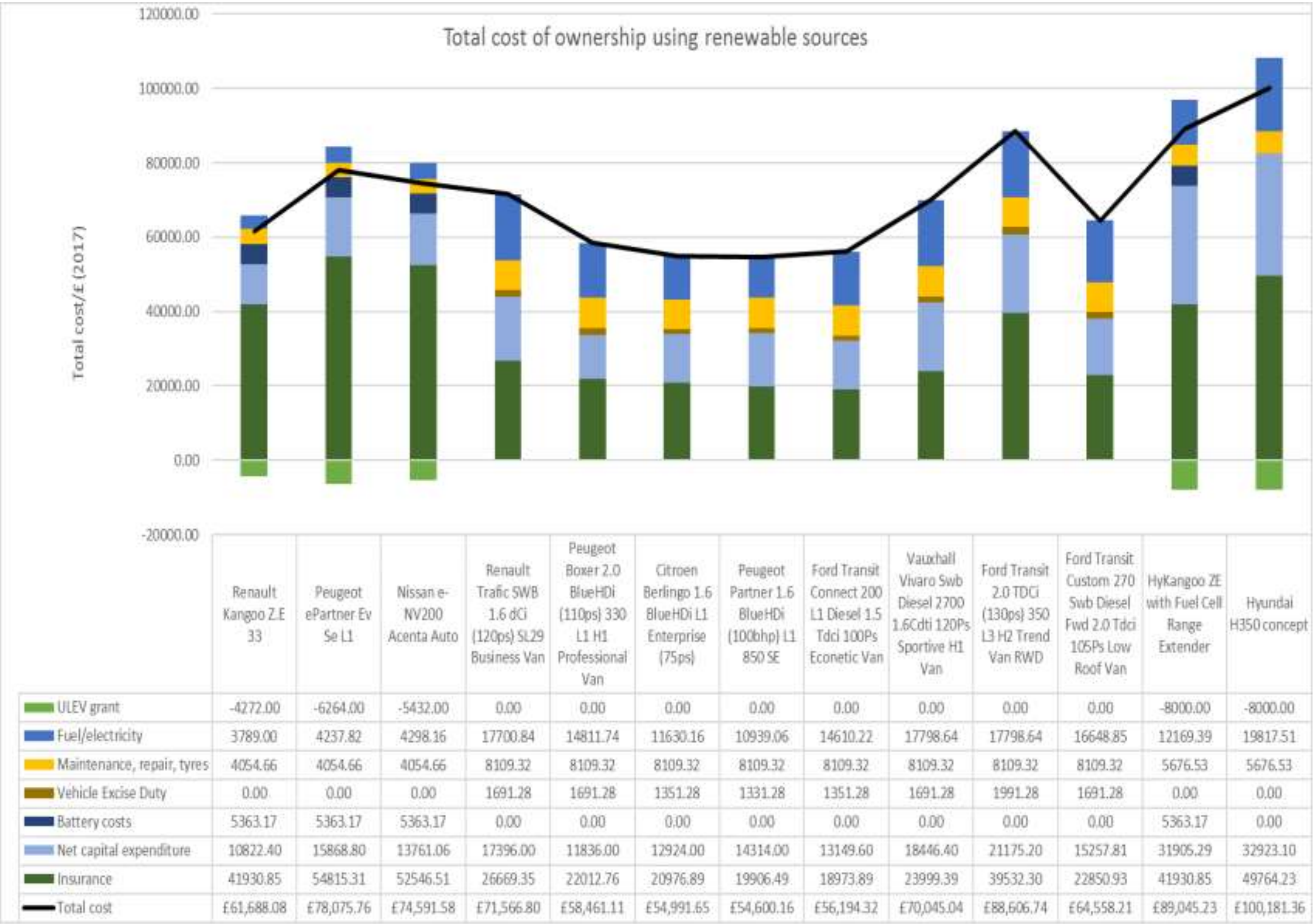
	Renault Kangoo Z.E 33	Peugeot ePartner Ev Se L1	Nissan e-NV200 Acenta Auto	Renault Trafic SWB 1.6 dCi (120ps) SL29 Business Van	Peugeot Boxer 2.0 BlueHDi (110ps) 330 L1 H1 Professional Van	Citroen Berlingo 1.6 BlueHDi L1 Enterprise (75ps)	Peugeot Partner 1.6 BlueHDi (100bhp) L1 850 SE	Ford Transit Connect 200 L1 Diesel 1.5 Tdci 100Ps Econetic Van	Vauxhall Vivaro Swb Diesel 2700 1.6Cdti 120Ps Sportive H1 Van	Ford Transit 2.0 TDCi (130ps) 350 L3 H2 Trend Van RWD	Ford Transit Custom 270 Swb Diesel Fwd 2.0 Tdci 105Ps Low Roof Van	HyKangoo ZE with Fuel Cell Range Extender	Hyundai H350 concept
🟧 Low Emission Zone charge	0.00	0.00	0.00	272452.10	239631.22	239631.22	239631.22	239631.22	239631.22	239631.22	239631.22	0.00	0.00
🟩 Congestion charge	0.00	0.00	0.00	25161.28	25161.28	25161.28	25161.28	25161.28	25161.28	25161.28	25161.28	0.00	0.00
🟩 ULEV grant	-4272.00	-6264.00	-5432.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-8000.00	-8000.00
🟦 Fuel/electricity	3084.63	3442.21	3490.29	17700.84	14811.74	11630.16	10939.06	14610.22	17798.64	17798.64	16648.85	11887.17	19817.51
🟨 Maintenance, repair, tyres	4054.66	4054.66	4054.66	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	5676.53	5676.53
🟫 Vehicle Excise Duty	0.00	0.00	0.00	1691.28	1691.28	1351.28	1331.28	1351.28	1691.28	1991.28	1691.28	0.00	0.00
🟦 Battery costs	5363.17	5363.17	5363.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5363.17	0.00
🟦 Net capital expenditure	10822.40	15868.80	13761.06	17396.00	11836.00	12924.00	14314.00	13149.60	18446.40	21175.20	15257.81	31905.29	32923.10
🟩 Insurance	41930.85	54815.31	52546.51	26669.35	22012.76	20976.89	19906.49	18973.89	23999.39	39532.30	22850.93	41930.85	49764.23
— Total cost	£65,255.72	£83,544.16	£79,215.70	£369,180.18	£323,253.61	£319,784.15	£319,392.66	£320,986.82	£334,837.54	£353,399.24	£329,350.71	£96,763.02	£108,181.36

Figure 13 - TCO in London with low emission zone charge applied



	Renault Kangoo Z.E 33	Peugeot ePartner Ev Se L1	Nissan e-NV200 Acenta Auto	Renault Trafic SWB 1.6 dCi (120ps) SL29 Business Van	Peugeot Boxer 2.0 BlueHDi (110ps) 330 L1 H1 Professional Van	Citroen Berlingo 1.6 BlueHDi L1 Enterprise (75ps)	Peugeot Partner 1.6 BlueHDi (100bhp) L1 850 SE	Ford Transit Connect 200 L1 Diesel 1.5 Tdci 100Ps Econetic Van	Vauxhall Vivaro Swb Diesel 2700 1.6Cdti 120Ps Sportive H1 Van	Ford Transit 2.0 TDCi (130ps) 350 L3 H2 Trend Van RWD	Ford Transit Custom 270 Swb Diesel Fwd 2.0 Tdci 105Ps Low Roof Van	HyKangoo ZE with Fuel Cell Range Extender	Hyundai H350 concept
🟩 Congestion charge	0.00	0.00	0.00	41983.39	41983.39	41983.39	41983.39	41983.39	41983.39	41983.39	41983.39	0.00	0.00
🟩 ULEV grant	-4272.00	-6264.00	-5432.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-8000.00	-8000.00
🟦 Fuel/electricity	3789.00	4237.82	4298.16	17700.84	14811.74	11630.16	10939.06	14610.22	17798.64	17798.64	16648.85	12169.39	19817.51
🟨 Maintenance, repair, tyres	4054.66	4054.66	4054.66	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	5676.53	5676.53
🟫 Vehicle Excise Duty	0.00	0.00	0.00	1691.28	1691.28	1351.28	1331.28	1351.28	1691.28	1991.28	1691.28	0.00	0.00
🟦 Battery costs	5363.17	5363.17	5363.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5363.17	0.00
🟦 Net capital expenditure	10822.40	15868.80	13761.06	17396.00	11836.00	12924.00	14314.00	13149.60	18446.40	21175.20	15257.81	31905.29	32923.10
🟩 Insurance	41930.85	54815.31	52546.51	26669.35	22012.76	20976.89	19906.49	18973.89	23999.39	39532.30	22850.93	41930.85	49764.23
— Total cost	£61,688.08	£78,075.76	£74,591.58	£113,550.19	£100,444.50	£96,975.04	£96,583.55	£98,177.71	£112,028.43	£130,590.13	£106,541.60	£89,045.23	£100,181.36

Figure 14 - TCO with raised congestion charge



	Renault Kangoo Z.E 33	Peugeot ePartner Ev Se L1	Nissan e-NV200 Acenta Auto	Renault Trafic SWB 1.6 dCi (120ps) SL29 Business Van	Peugeot Boxer 2.0 BlueHDi (110ps) 330 L1 H1 Professional Van	Citroen Berlingo 1.6 BlueHDi L1 Enterprise (75ps)	Peugeot Partner 1.6 BlueHDi (100bhp) L1 850 SE	Ford Transit Connect 200 L1 Diesel 1.5 Tdci 100Ps Econetic Van	Vauxhall Vivaro Swb Diesel 2700 1.6Cdti 120Ps Sportive H1 Van	Ford Transit 2.0 TDCi (130ps) 350 L3 H2 Trend Van RWD	Ford Transit Custom 270 Swb Diesel Fwd 2.0 Tdci 105Ps Low Roof Van	HyKangoo ZE with Fuel Cell Range Extender	Hyundai H350 concept
🟩 ULEV grant	-4272.00	-6264.00	-5432.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-8000.00	-8000.00
🟦 Fuel/electricity	3789.00	4237.82	4298.16	17700.84	14811.74	11630.16	10939.06	14610.22	17798.64	17798.64	16648.85	12169.39	19817.51
🟨 Maintenance, repair, tyres	4054.66	4054.66	4054.66	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	8109.32	5676.53	5676.53
🟫 Vehicle Excise Duty	0.00	0.00	0.00	1691.28	1691.28	1351.28	1331.28	1351.28	1691.28	1991.28	1691.28	0.00	0.00
■ Battery costs	5363.17	5363.17	5363.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5363.17	0.00
■ Net capital expenditure	10822.40	15868.80	13761.06	17396.00	11836.00	12924.00	14314.00	13149.60	18446.40	21175.20	15257.81	31905.29	32923.10
🟩 Insurance	41930.85	54815.31	52546.51	26669.35	22012.76	20976.89	19906.49	18973.89	23999.39	39532.30	22850.93	41930.85	49764.23
— Total cost	£61,688.08	£78,075.76	£74,591.58	£71,566.80	£58,461.11	£54,991.65	£54,600.16	£56,194.32	£70,045.04	£88,606.74	£64,558.21	£89,045.23	£100,181.36

Figure 15 - TCO using renewable electricity