Hydrogen Vehicles in Urban Logistics: A Total Cost of Ownership Analysis
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Abstract - Freight transport accounts for 8-15% of total traffic flow in urban areas within the European Union. Majority of these deliveries are undertaken by diesel powered vehicles with extremely disproportionate levels of CO₂, NOₓ and particulate matter emissions. Accordingly, a variety of strategic options have 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.

Keywords – Urban Logistics; Freight Transport; Alternative Vehicles; Total Cost of Ownership
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1. Introduction

Logistics and freight activities in cities are at heightened levels due to increased trade volumes and purchase behavioural shifts towards e-commerce options intensifying last-mile delivery activities. Freight transport accounts for 8-15% of total traffic flow in urban areas within the European Union (EU) (MDS Transmodal Limited, 2012). 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%) (Dablanc, 2007). Accordingly, a variety of strategic options (infrastructure; equipment; governance; modality) have been advanced as key solutions for addressing fossil fuel demand and emissions in urban freight transport (Asif and Muneer, 2007; Russo and Comi, 2011; Li et al., 2015).

This paper progresses the discourse on alternative (hydrogen) vehicles as viable strategic options for addressing sustainability concerns in urban logistics. A critical component of sustainable logistics solutions is economic cost for concerned stakeholders, particularly for freight transport operators. The importance of this component is widely recognised as evidenced by ubiquitous 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 (Ni et al., 2007; Silva Veras et al. 2017). The outcomes from this study not only support the economic competitiveness of HFCVs but also provide sensitivity impact 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. Literature Review

2.1 The role of equipment and technology

Electrification has been suggested as a way to reduce emissions (Sharma et al., 2012). Partial electrification, or hybrid vehicles, could reduce emissions by 38-41% compared to conventional vehicles (Samaras and Meisterling, 2008). Fully electric vehicles are emission free during use and so can reduce emissions by 100% if renewable sources are utilised for electricity generation (Schiffer and Walther 2017). Smith (2010) showed that electric vehicle
technology allows for a reduction of 25-40% in CO₂ emissions in urban areas in Ireland. Longer term, Nicolaides et al. (2017) estimated that 88-93% reductions were possible by 2040. The US Department of Energy found that by powering on-board appliances in long-haul diesel trucks, diesel consumption could be reduced by up to 80% (Garbak, 2003).

HFCVs are also a suggested alternative to internal combustion engine (ICE) vehicles. HFCVs have been shown to reduce greenhouse gas emissions and lead to an improvement in air quality (Jacobson, 2005; Thomas, 2009). However, BEVs exhibit lower fuel costs per kilometre and so it follows that lower hydrogen costs and greater accessibility would increase the attractiveness of HFCVs.

Demirdoven (2004) found that HFCVs using fuel produced with non-renewable sourced electricity offered little to no advantage over hybrid electric vehicles for use in urban environments. However, it is possible to use renewable, or emission-free, sources of electricity to produce hydrogen fuel (Ni et al., 2007).

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 (Chalk and Miller, 2006); however, costs are falling and HFCVs are expected to be competitive with BEVs by 2020 (Pollet et al. 2012). To address this, da Silva Veras et al. (2017) recommended additional research on economic competitiveness. The provision of total cost of ownership (TCO) information has been found to increase consumers’ preferences for hybrid and BEVs in small-medium size vehicle classes (Dumortier et al., 2015).

Al-Alawi and Bradley (2013) 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.

In Offer et al. (2010) 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.

Contestabile et al. (2011) 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. Davis and Figliozzi (2013) 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. Wu et al. (2015) produced a probabilistic model to simulate the TCO of both BEVs and ICE vehicles. They concluded that BEVs have a “good probability” of becoming the most cost-efficient for smaller vehicles operating in urban contexts.

As part of TCO analysis fiscal incentives that favour low emission activities must be considered. One example is congestion charging which discourages use of specific roads and thereby reduces both traffic and pollutant emissions. Börjesson et al. (2012) 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. Hidrue et al. (2011) and Lévay et al. (2017) 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.

None of the discussed models have dealt with hydrogen-powered light commercial vehicles (LCVs) and their role in last-mile or urban deliveries. 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.

3. Methodology and Results

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 (Heilala et al., 2006; Kimmel et al., 2013; Harrison and Theil, 2017).

For this study, we selected 13 vehicles to reflect BEVs, PHEVs and ICEs, all with similar functionality, size, interiors and EU classifications. To support comparison, annual mileage of 12921 miles was allocated per vehicle adopting industry assumptions\(^1\) (DfT, 2017).

\(^{1}\)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
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 literature and the office of national statistics (ONS, 2015; Kohler et al., 2017).

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.

As a result, the following formula was used:\(^2\):

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

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

\(CE\) 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

\(^2\) 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
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 (Element Energy, 2016). Although the market for alternative vehicles remains largely underdeveloped, it was suggested that depreciation values for these vehicles converged overtime (Element Energy 2016). Residual values were computed as NPV of capital costs * residual % for period n, where n=10.3

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 study4. 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 is 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 (HM Treasury, 2013; Clarke et al., 2014).

C_{x_n} represents running cost 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 CO₂. Where applicable, data from the Department for Transport or calculated the applicable road tax by using the given emissions range of the vehicles and allocated charges. Discounted life time costs were calculated by discounting the given rates.

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3 For the purpose of this study, we have excluded capital gains tax as these are commercial vehicles used solely for business.
4 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
$C_{2n}$ 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 (Business Electricity, 2017) 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. 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 costs for the HFCVs were computed as a product of annual mileage, miles per kilometre, and GBP per kilometre$^5$.

$C_{3n}$ 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 and repairs and also 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 (Element Energy 2017). Annual MRT costs were set using the product of the relevant ppm value and annual mileage.

$C_{4n}$ 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$^6$.

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$^5$ 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).

$^6$ 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 as a BEV 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.
$c_{5n}$ 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 which 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 which 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.

3.1 Sensitivity Analysis
Results were then subjected to ‘what if’ sensitivity analysis evaluating the impact of changing the determining characteristics on the cost outcomes for the different vehicles, using the preliminary results as baseline data. Ultimately there are two situations that were analysed; a change in operating conditions at current market conditions, and a change in market conditions under current operating conditions. All analysis was performed using MS Excel Scenario Manager; results are reported below.

4. Results
The 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. It is also clear that the effect of duties as a moderator is relatively limited. 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 may 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 Mileage
Electric vehicles typically exhibit lower running costs with higher capital expenditure; it follows that they become increasingly more competitive as the number of miles driven increases. All of the non-diesel vehicles exhibit higher pence per mile ownership costs than
their diesel counterparts 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 and 4).

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 Vauxhaul 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.

4.2 Sensitivity to Diesel Prices
Fuel cost can be broken down into three constituent components; VAT, fuel duty, and the fuel cost. Fuel duty is currently charged at 57.95 pence per litre (HM Revenue & Customs, 2016) 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 (Office for National Statistics, 2016). In this study the price per litre of diesel was set at £1.154/L or £5.246/gal (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 £25 per gallon at which point all total costs for all diesel vehicles are greater than all other vehicles. This results in a diesel price that is perhaps unattainable but there are some valid findings from the adjustment. 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 2 – Total cost of Ownership results

<table>
<thead>
<tr>
<th>Model</th>
<th>Total cost (£) 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renault Kangoo Z.E. 33</td>
<td>£80,983.72</td>
</tr>
<tr>
<td>Peugeot ePartner Ev Se L1</td>
<td>£77,280.16</td>
</tr>
<tr>
<td>Nissan e-NV200 Acenta Auto</td>
<td>£73,783.70</td>
</tr>
<tr>
<td>Renault Traffic SWB 1.6 dCi (120ps) S29 Business Van</td>
<td>£71,566.80</td>
</tr>
<tr>
<td>Peugeot Boxer 2.0 BlueHDI 110ps SWB L1 H1</td>
<td>£58,481.11</td>
</tr>
<tr>
<td>Citroen Berlingo 1.6 BlueHDI L1 Enterprise (75ps)</td>
<td>£54,991.65</td>
</tr>
<tr>
<td>Peugeot Partner 1.6 BlueHDI 100ps Econetic Van</td>
<td>£54,600.16</td>
</tr>
<tr>
<td>Ford Transit Connect 200 L1 Diesel L1 100ps Trend Van</td>
<td>£56,194.32</td>
</tr>
<tr>
<td>Vauxhall Vivaro SWB Diesel 2.0 1.6CDTi 120ps Sportive H1 Van</td>
<td>£70,045.04</td>
</tr>
<tr>
<td>Ford Transit Custom 270 L2H2 Trend Van P/V</td>
<td>£88,606.74</td>
</tr>
<tr>
<td>Ford Transit Custom 270 L3H2 Trend Van P/R</td>
<td>£64,558.21</td>
</tr>
<tr>
<td>Hyundai H350 concept with Fuel Cell Range Extender</td>
<td>£88,763.02</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>£100,181.36</strong></td>
</tr>
</tbody>
</table>

Legend:
- **ULEV grant**
- **Fuel/electricity**
- **Maintenance, repair, tyres**
- **Vehicle Excise Duty**
- **Battery costs**
- **Net capital expenditure**
- **Insurance**
- **Total cost**
Figure 3 – Sensitivity to Annual Mileage

Figure 4 - Sensitivity to fuel duty

4.3 Sensitivity to Hydrogen Prices

Figure 5 reveals our findings on HFCVs competitiveness due 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. By £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. 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 attractiveness of BEVs.

**Figure 5 - Sensitivity to hydrogen fuel price**

### 5. 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 which emit less than 75g CO2/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 must be 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.
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, (2017), annual urban mileage was found to be 4342.11. The results for the London scenario are shown in Figure 6. The effect of the congestion charge is immediately apparent; 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.

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 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% (Transport for London, 2008). 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. This scenario is plotted in Annex C.
Figure 6 - TCO in London

|                     | Renault Kangoo Z.E | Peugeot ePartner EV | Nissan e-NV200 | Acerenta Auto | Renault Traffic SWB 1.6 dCi (120ps) | S129 Business Van | Peugeot Boxer 2.0 BlueHDi (110ps) | Citroen Berlingo 1.6 BlueHDi L1 | Peugeot Partner 1.6 BlueHDi (99bhp) | Ford Transit Connect 200 L1 | L3 H2 Trend Van RWD | Ford Transit Custom 270 | SWB 2.0 TDCi (130ps) | Ford Transit Custom 270 | SWB 2.0 TDCi (130ps) | Low Roof Van | HyKangoo ZE | with Fuel Cell Range Extender | with 350 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                   | 25161.28                 | 25161.28                 | 25161.28                 | 25161.28              | 0.00               | 0.00               |
| ULEV grant          | -672.00             | -626.00             | -543.00        | 0.00          | 0.00                                | 0.00              | 0.00                             | 0.00                        | 0.00                      | 0.00                     | 0.00                      | 0.00                     | 0.00                     | 0.00                     | 0.00                 | 0.00              | -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                | 5676.53                  | 5676.53              | 0.00               | 0.00               |
| Maintenance, repair, | 4054.66             | 4054.66             | 4054.66        | 8103.32       | 8109.32                            | 8109.32           | 8109.32                          | 8109.32                     | 8109.32                  | 8109.32                 | 8109.32                   | 8109.32                  | 8109.32                  | 8109.32                  | 8109.32              | 0.00               | 0.00               |
| Tyres               | 0.00                | 0.00                | 0.00           | 1691.28       | 1691.28                            | 1351.28           | 1331.28                          | 1691.28                     | 1991.28                  | 1691.28                 | 1691.28                   | 1691.28                  | 1691.28                  | 1691.28                  | 1691.28              | 0.00               | 0.00               |
| Vehicle Excise Duty | 0.00                | 0.00                | 0.00           | 0.00          | 0.00                                | 0.00              | 0.00                             | 0.00                        | 0.00                      | 0.00                     | 0.00                      | 0.00                     | 0.00                     | 0.00                     | 0.00                 | 0.00               | 5363.17            |
| Battery costs       | 5363.17             | 5363.17             | 5363.17        | 0.00          | 0.00                                | 0.00              | 0.00                             | 0.00                        | 0.00                      | 0.00                     | 0.00                      | 0.00                     | 0.00                     | 0.00                     | 0.00                 | 5363.17            | 0.00               |
| Net capital expenditure | 10827.40         | 15868.80             | 13761.06       | 17396.00      | 11836.00                           | 12924.00          | 14314.00                         | 13149.60                    | 18446.40                 | 21175.20                | 15257.81                  | 31905.79                 | 32923.10                 | 49764.23                | 0.00                 | 0.00               |
| Insurance           | 41930.85            | 54815.31            | 52546.51       | 26669.35      | 22012.76                            | 20976.89          | 19066.49                         | 18973.89                    | 23999.39                 | 39532.30                | 22850.93                  | 41930.85                 | 49764.23                 | 0.00                     | 0.00                 | 0.00               | 0.00               |
| Total cost          | £61,688.08          | £78,075.76          | £74,591.58     | £90,728.08   | £83,622.39                          | £80,152.93        | £79,761.44                       | £83,355.60                   | £35,206.31              | £113,768.02             | £89,719.48               | £89,045.23               | £100,181.36              | 0.00                     | 0.00                 | 0.00               | 0.00               |
5.2 Green Energy

As was discussed in the previous sections, a vehicle with 0 kgCO2/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. 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 which 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 battery electric and HFCVs; furthermore, it is clear that over the period of ownership the vehicle excise duty plays a relatively small role. It was shown that a reduction in the fuel price of hydrogen to £7 per kilo would make both hybrid fuel cell and pure hydrogen vehicles competitive with diesel vehicles; also, of key concern is reducing capital expenditure necessary for fuel cell vehicles.

All the cases considered in the analysis section are univariate, which is to say the impact on competitiveness is found for each considered factor in turn. Finding an optimum change in all constituent costs could yield much more applicable results as diminishing returns may make it difficult to take any one cost to its most efficient. This could also consider simultaneously falling electricity/hydrogen costs and rising diesel prices.

Acknowledgments

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Annex A

Sensitivity to annual mileage - Kangoo Z.E. and diesel vehicles

Sensitivity to mileage - Hydrogen vehicles and diesel vehicles

Sensitivity to mileage - HyKangoo and diesel vehicles
Average sensitivity to mileage by vehicle class
Annex B

Congestion charge zone map (Transport for London, 2011)

Low emission zone boundaries (green), congestion charge zone (red) (Ars Technica, 2017)
## Annex C

TCO in London with low emission zone charge applied

<table>
<thead>
<tr>
<th>Model</th>
<th>Low Emission Zone charge</th>
<th>Congestion charge</th>
<th>ULEV grant</th>
<th>Fuel/electricity</th>
<th>Maintenance, repair, tyres</th>
<th>Vehicle Excise Duty</th>
<th>Battery costs</th>
<th>Net capital expenditure</th>
<th>Insurance</th>
<th>Total cost (£/2017)</th>
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**Total cost when operating within London: £65,255.72**
|                      | Renault Kangoo Z.E | Peugeot ePartner 8 | Nissan e-NV200 Acenta Auto | Renault Traffic SWB 1.6 dCi (120ps) SL29 Business Van | Peugeot Boxer 2.0 BlueHDI (150ps) L1 H1 Professional Van | Citroen Berlingo 1.6 BlueHDI L1 Enterprise (75ps) | Peugeot Partner 1.6 BlueHDI L1 (100bhp) L1 850 SE | Ford Transit Connect 200 L1 Diesel 1.5 Tdci 100Ps Econetic Van | Vauxhall Vivaro Swb Diesel (170ps) 1.6CDi 120Ps Sportive Ht. Van | Ford Transit 2.0 TDCi (130ps) J200 L2 H2 Trend Van RWD | Ford Transit Custom 2.0 TDCi (130ps) J370 L3 H2 Trend Van RWD | Hyundai H350 ECO | Hyundai H350 ZE with Fuel Cell Range Extender |
|----------------------|---------------------|-------------------|---------------------------|-----------------------------------------------|------------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|------------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Congestion charge   |                     |                   |                           |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |
| LLEV grant          |                    |                   |                           |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |
| Fuel/electricity    |                     |                   |                           |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |
| Maintenance, repair, |                     |                   |                           |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |
| Vehicle Excise Duty |                     |                   |                           |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |
| Battery costs       |                     |                   |                           |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |
| Net capital expenditure |                 |                   |                           |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |
| Insurance           |                     |                   |                           |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |                                               |
| **Total cost**      | **£61,688.08**      | **£78,075.76**     | **£74,591.58**            | **£113,550.19**                              | **£100,444.50**                                | **£96,595.04**                                 | **£96,583.55**                                | **£98,177.71**                                | **£112,028.43**                                | **£130,590.13**                                | **£106,541.60**                                | **£89,045.23**                                | **£100,181.36**                                |
Annex D

TCO using renewable electricity

Total cost of ownership using renewable sources
References


