Appendix 3

ULEV Hackney Carriage Business Model Assessment - Oxford

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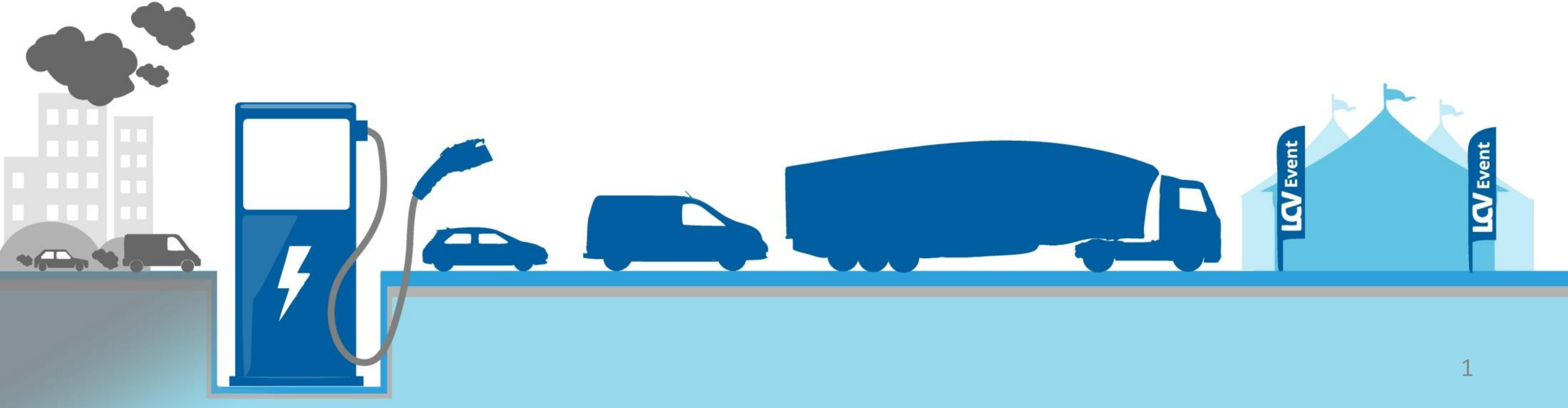


Disclaimer

This work was carried out by Cenex for Oxford City Council. The information presented is based on a combination of public domain sources, data supplied by companies and engagement with stakeholders. Details of this information and any assumptions made are noted in this report.

While the information is provided in good faith, the ideas presented in the report must be subject to further investigation, and take into account other factors not presented here, before being taken forward. Therefore the authors disclaim liability for any investment decisions made on the basis of the review.

Contents and Revision Record

Revision	Reason	Date Issued.
1	Report Issued	24/07/2018

Abbreviations Used in Report

Abbreviation	Meaning
BEV	Battery Electric Vehicle
CAZ	Clean Air Zone
CO_2	Carbon Dioxide
DEFRA	Department for Environment, Fool and Rural Affairs
GHG	Green House Gas
HP	Horse Power
ICE	Internal Combustion Engine
kW	Kilo-Watt
LEVC	London Electric Vehicle Company
mpg	Miles per gallon
NEDC	New European Drive Cycle (Legislative)
NO_2	Nitrogen Dioxide
NOx	Oxides of Nitrogen
OEM	Original Equipment Manufacturer
OTR	On the Road
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate Matter
REEV	Range Extended Electric Vehicle
RV	Residual Value
SMR	Service, Maintenance and Repairs
TCO	Total Cost of Ownership
TTW	Tank-to-Wheel
ULEV	Ultra Low Emission Vehicle
WTW	Well-to-Wheel
ZEC	Zero Emission Capable
ZEZ	Zero Emission Zone

Executive Summary

This report details an assessment of the operational and financial suitability of Ultra Low Emission Hackney Carriages as replacements for the 113 diesel vehicles currently licensed within the Oxford City Council boundary. Input information for the study was gathered from interviews with hackney carriage owners/drivers, ULEV hackney carriage suppliers, leasing companies and local authorities. To ensure that the results are representative of usage in Oxford a two month data logging trial was completed using 6 participant vehicles, additionally real world testing of equivalent electric vehicles was used where possible to provide a realistic assessment of the vehicle capabilities. Two ULEV hackney carriages had suitable maturity and adequate technical data to be included in the study, namely the range extended electric LEVC TX and battery electric Dynamo Nissan eNV200.

Driver opinions of ULEVs; Results from driver engagement showed that 78% of existing vehicles are acquired second hand with only 40% using finance to fund the purchase, the vehicles are then used until they are no longer fit for purpose with little concern for vehicle age. 100% of drivers questioned stated that the purchase price of £55,599 and £42,500 (including plug in taxi grants) for the LEVC TX and Dynamo respectively is too high. Battery reliability, vehicle reliability and real world electric only range were also raised as major concerns. 279 days worth of data were captured during the data logging trial during which the drivers completed 24,066 miles.

Driving habits and ULEV suitability; The average daily mileage was 88 miles (or 25,331 miles per annum) with a 61/30/9% split of urban, rural and motorway driving. Despite this relatively high mileage both ULEV options are operationally suitable covering between 49.5% (LEVC TX) and 85.2% (Dynamo) of the total mileage on one overnight charge only, it is worth noting that on 10 out of the 279 days (3.6%) the Dynamo would have required more than two charges.

Cost of ULEVs; The Dynamo is financially viable for drivers/owners with savings of £244 per month over 5 years of ownership at 25,000 miles per annum. The LEVC TX was found to be more challenging requiring up to 9 years of ownership, a one off contribution of £5,000 can reduce this to 5 years for low mileage users.

Executive Summary

Proposed lease options; Discussions with potential leasing partners were promising with multiple companies expressing interest in potentially taking on the management responsibilities. A number of concerns were raised primarily relating to future residual values and the risk of default if leasing to individuals. It is felt that the most suitable way to share this risk is for the council to purchase the vehicles and provide assurances (such as revoking vehicle or driver licenses) to the leasing company. In line with this model and to provide competitive lease rates the required payback period was calculated to be at least 4-6 years (excluding management costs). A coordinated approach, potentially partnering with other local authorities, would be required to seek investment to support the uptake of ULEV vehicles.

Emissions; Finally it was shown that the current fleet emits 1,284 tonnes TTW CO_2, 1,590 tonnes WTW CO_2, 4,678kg NOx and 225kg of PM per year. A high level of ULEV uptake (84%) can improve this significantly with reductions of 79% TTW CO_2, 56% WTW CO_2, 92% NOx and 99% PM possible.

Recommendations; The following recommendations are proposed to progress the use of ULEVs amongst the hackney carriage driver community.

- Present findings of vehicle suitability and total cost of ownership model to drivers with guidance of how the results impact their usage and ownership patterns. Educate owners/drivers on economic operating scenarios.
- Provide test drive/short term rental options with a focus on a high throughput of drivers, attention should also be paid to proving battery and vehicle reliability information.
- Fit CAN logger to Dynamo eNV200 and LEVC TX operating in Oxford to verify real world electric only range, usable battery capacity, energy and fuel consumption. This data could be used to provide a short tailored operation and TCO report following test lease.
- Monitor and review TCO changes including second hand vehicle market for both Euro 6 diesel and ULEV hackney carriages, particularly around key milestones – ULEV production volume increases, introduction of ZEZ, end of finance agreements etc.
- Oxford City Council should contact leasing companies to progress potential leasing models outlined in this report and to understand additional cost of implementation (which has not been considered in the council lease rate cost assessment).
- Finalise and present potential leasing business model to owners/drivers for feedback.

1. Project Introduction

68

As part of ongoing efforts to improve air quality (in line with the proposed Zero Emission Zone) and to ensure that the hackney carriage fleet is a modern integrated part of the transport system Oxford City Council has commissioned Cenex to assess the operational and financial viability of electric and range extended electric hackney carriages. The purpose of this study is to develop a total cost of ownership model (TCO) with a particular focus on the provision of a leasing business model. This section details the key project deliverables.

Work Packages and Deliverables

Due to the proposed Zero Emission Zone and potential vehicle licensing changes Oxford City Council commissioned Cenex to study the economic and operational proposition of ULEV hackney carriages. This work was delivered through the following work packages:

WP1; Engagement with the trade – including recruitment of participants to take part in data gathering trials and workshops covering social issues, perceptions of ultra low emission vehicles, barriers to adoption and reporting of findings

WP2; Trial management – installation and monitoring of CLEAR Capture telemetry devices fitted to participants existing vehicles for two months. Conducting surveys and interviews with licensed drivers.

WP3; Analysis of Oxford hackney carriage duty cycle – development of journey summaries, total cost of ownership model, uptake scenarios and emissions benefits.

WP4; Sensitivity analysis – sensitivity of TCO model to key factors such as purchase price, ownership period, annual mileage and electricity price.

WP5; Reporting of findings – recommendations on financial incentives and interventions that would be supported by the trade including council ownership of vehicles or a partnership with leasing companies/vehicle providers.

It is therefore intended that this work will deliver the following outputs:

1. Bespoke duty cycle for hackney carriages operating in Oxford
2. Total cost of ownership model for purchasing and leasing of ULEVs
3. Climate and air quality impact of transitioning to ULEVs
4. Advice and recommendations on how to establish or procure a leasing business

1.1 Clean Air Zone Compliant Vehicles

The following section details vehicles which will meet the minimum requirement of Clean Air Zones and have been included in the total cost of ownership model, this covers Euro 6 diesels and ULEVs (range extended electric and battery electric vehicles). A small number of additional vehicles are available but have not been included in the study due to similarity with included vehicles or a lack of detailed technical and/or cost information (most notably the Metrocab REEV).

cenex

Euro 6 Diesel; Ford Procab

- Supplier - Cab Direct (Allied Vehicles)
- Chassis - Ford Tourneo Custom
- Model – Titanium
- Powertrain – Internal Combustion Engine
- Price – from £34,295 OTR

Note: unless stated otherwise fuel consumption and emissions are manufacturers claims using the NEDC

Passenger Space and Wheelchair Access	
Number of seats	6 (rear) + up to 2 (front)
Luggage space	992 litre boot
Wheelchair access	Y
Technical Specification	
Engine	2.0l TDCi (with stop start)
Peak power and torque	130PS (128hp) and 385Nm
Fuel tank capacity	70l
Fuel consumption	44.8mpg (40.4mpg – auto)
CO_2 emissions	162g/km (181g/km – auto)
Warranty and Maintenance	
Warranty	3 year/100,000 mile Ford warranty
Breakdown	1 year road side assistance cover
Service interval	18,000 miles

Euro 6 Diesel; Mercedes Vito

- Supplier – Mercedes Benz
- Chassis – Mercedes Benz Vito Tourer
- Model – Compact or Long
- Powertrain – Internal Combustion Engine
- Price – from £45,247 OTR

93

Note: unless stated otherwise fuel consumption and emissions are manufacturers claims using the NEDC

Passenger Space and Wheelchair Access	
Number of seats	6 (passengers)
Luggage space	-
Wheelchair access	Y
Technical Specification	
Engine	2.2l turbo diesel (with stop start)
Peak power and torque	136hp and 330Nm
Fuel tank capacity	57l
Fuel consumption	43.5mpg (46.3mpg – A7)
CO_2 emissions	171g/km (161g/km – A7)
Warranty and Maintenance	
Warranty	3 year/unlimited mileage
Breakdown	3 year road side assistance cover
Service interval	Up to 24,000 miles

ULEV Hackney Carriage Business Model Assessment

ULEV; LEVC TX

- Supplier – LEVC
- Chassis – LEVC TX
- Model – VISTA
- Powertrain – Range Extended Electric Vehicle
- Price – from £55,599 OTR (£63,099 exc plug in taxi grant)

Note: unless stated otherwise fuel consumption and emissions are manufacturers claims using the NEDC

Passenger Space and Wheelchair Access	
Number of seats	6 (passengers)
Luggage space	440l (luggage compartment)
Wheelchair access	Y
Technical Specification	
Battery capacity (usable)	31kWh (23kWh)
EV only range	80.6 miles
Charging times	7kW – 4h, 50kW – 0.5h
Total range	377 miles
Range extender	1.5l turbo petrol
Fuel tank capacity	36l
Fuel consumption – range extender	36.7mpg
Peak power and torque	110kW (148hp) and 255Nm
CO_2 emissions	29g/km
Warranty and Maintenance	
Warranty (vehicle) Warranty (battery)	3 year/120,000 miles 5 year/unlimited mileage
Breakdown	3 year road side assistance cover
Service interval	25,000 miles

ULEV; Dynamo

- Supplier – Dynamo
- Chassis – Nissan eNV200
- Model – Evalia
- Powertrain – Battery Electric Vehicle
- Price – from £42,500 OTR (£49,995 exc plug in taxi grant)

95

Passenger Space and Wheelchair Access	
Number of seats	5 (passengers) – 3 forwards, 2 rear facing
Luggage space	Y
Wheelchair access	Y
Technical Specification	
Battery capacity (usable)	40kWh (36kWh - assumed)
EV only range	174 miles
Charging times	7kW – 4h, 50kW – 0.5h
Peak power and torque	80kW (107hp) and 254Nm
CO_2 emissions	0g/km
Warranty and Maintenance	
Warranty (vehicle) Warranty (battery)	3 year/60,000 miles 5 year/60,000 miles
Breakdown	3 year road side assistance cover
Service interval	18,000 miles

Note: unless stated otherwise fuel consumption and emissions are manufacturers claims using the NEDC

2. Driver Questionnaires

As part of ongoing engagement with the hackney carriage trade a workshop was held at the Kassam Stadium. The purpose of the workshop was to discuss the drivers concerns and gain their input into the total cost of ownership model. As such drivers were asked to complete a short questionnaire, the results of which are presented in this section.

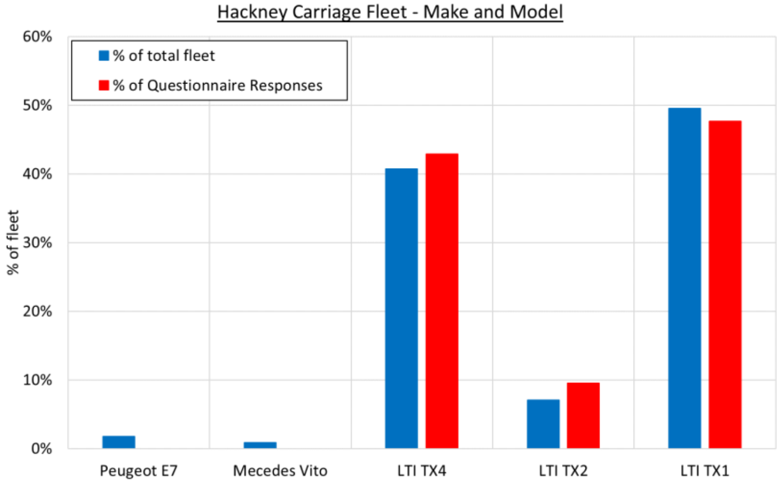
Introduction

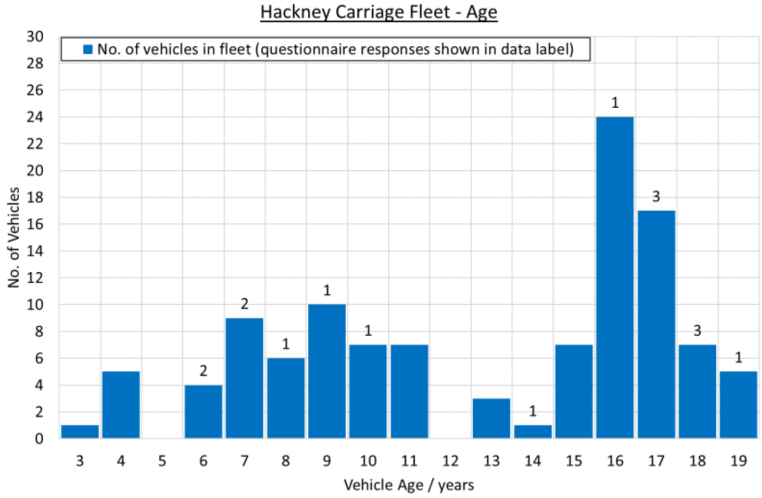
Oxford hackney carriage drivers were invited to attend a one day event at the Kassam Stadium on the 6th Feb 2018 to gain the necessary input into the low emission taxi business model. All attendees were invited to complete a 20 minute questionnaire regarding their present vehicle usage, ownership and running costs, purchasing priorities and their perceptions of low emission taxis.

22 drivers submitted completed questionnaires, this represents a reasonable proportional of the total vehicle licences (22/113 = 19.5%). Interestingly 55% of drivers reported sharing the use of a vehicle (to a maximum of 3 drivers/vehicle), this could have a significant impact on the usage patterns and the annual mileage.

To provide context for how representative the responses are of the entire fleet the vehicle type and age are compared:

97





It can be seen that the questionnaire responses are representative both in terms of the vehicle models (~50% TX1, ~40% TX4) and vehicle age (ranging from 6-19 years with a small peak at 16/17 years.

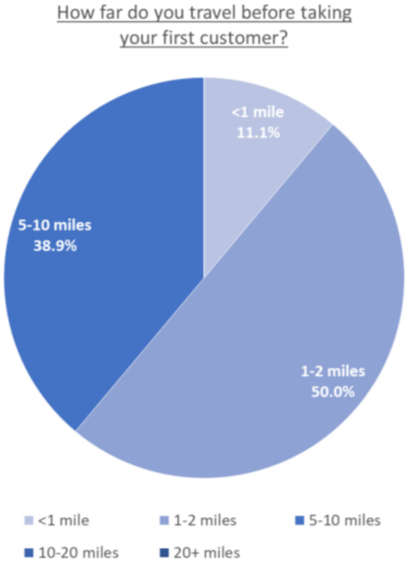
Present Vehicle Usage

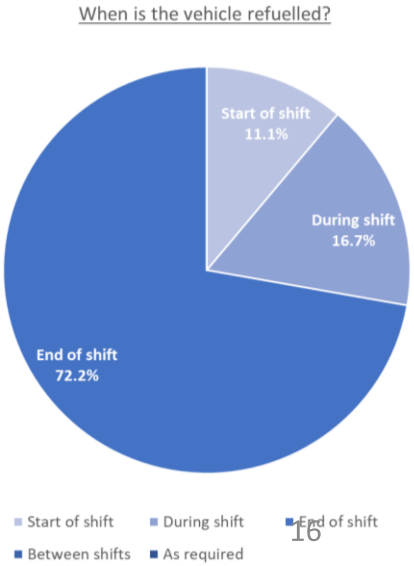
A number of questions were asked relating to the present usage pattern of Oxford hackney carriages. The intention being to understand the operational impact and suitability of zero emission capable taxis, in particular highlighting likely driving modes and charging requirements.

61% of drivers surveyed reported using the vehicle for **both personal and business use**, this should be an important consideration regarding vehicle suitability. Owing to an average vehicle age of 12.9 years the total vehicle mileage is also high across respondents with **50% reporting >250,000 miles**, potentially setting a high expectation for the reliability of new vehicles. In addition **64% of drivers are doing between 20,000-30,000 miles per year (with 3 drivers reporting >30,000 miles per year)**, at 6 days a week for 48 weeks a year this equates to 64-96 miles per day (an accurate value is expected from the ongoing vehicle trial). Finally the vast majority (**71%**) of vehicles are estimated to have a fuel consumption of **15-30 mpg**

Drivers were also asked questions regarding their typical working behaviour to see whether it would require significant change when using electric vehicles. The first pie chart on the right shows that **61% travelled less than 2 miles** before taking their first fare with **no respondents travelling further than 10 miles.** Assuming this is representative of the wider fleet and drivers charge their vehicles at home overnight this should allow them to start their shifts with a high state of charge.

At present drivers are used to refuelling in or around their shift with **~72% refuelling at the end of their shift,** no drivers reported refuelling in between shifts**.** Given the expected daily mileage and real world driving range of range extended electric vehicles it is anticipated that this behavior will have to change to charging during the shift.

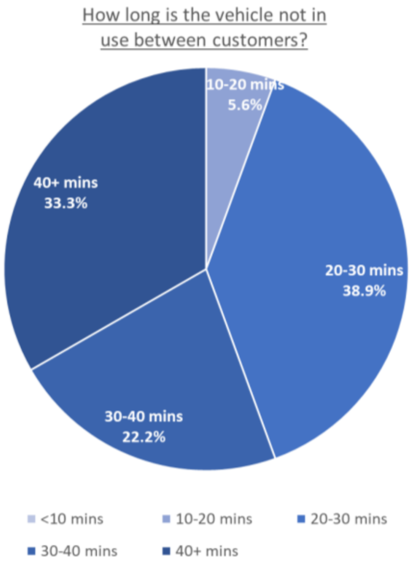


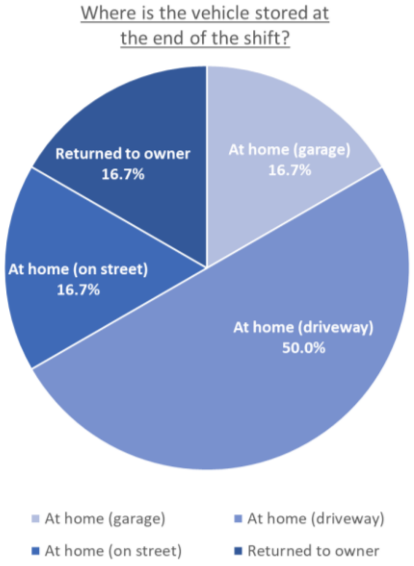


Present Vehicle Usage

If top up charging is required during shifts **56% of vehicles are not in use for >30 minutes between customers** (the time typically required to achieve 80% charge using a DC rapid charger), with the shortest wait time being **10 minutes**. In order to maximise earnings it is desirable for the drivers to reduce this down time, assuming additional council interventions in this area the opportunity for top up charging is likely to reduce in the future.

Even if this is not the case home charging is anticipated to be very important. In this regard responses relating to vehicle storage location are positive with **~80% of respondents** who store their own vehicle **having off street parking** (either via a driveway or garage), however at present only **41% of vehicles have access to an electric supply overnight**.



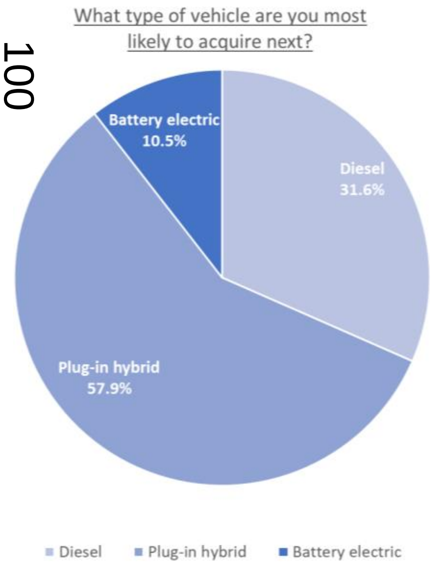


Purchasing Priorities

To provide a better understanding of the drivers purchasing behaviours they were asked about their existing vehicle ownership, replacement intentions and primary purchasing criteria.

At present **78% of vehicles are acquired second hand** with only **40% using finance** to fund the purchase. Given the lack of a used market and a significantly higher purchase cost of ULEV taxis it is apparent that this behaviour will need to shift to leasing/financing a brand new vehicle. Changing this purchasing behaviour represents a significant barrier to the adoption of low emission vehicles. This is reflected in the fact that only **16% of respondents would consider leasing** their next vehicle with **58% currently intending to own** their next vehicle. However **39%** of drivers **would consider acquiring a brand new vehicle**, with a further **50% responding maybe**.

100



The table below shows purchasing priorities ranked as either very important, important or not important. It can be seen that the three highest priority criteria (those with the highest proportion of very important) are **reliability (93.3%), total cost of ownership (86.7%) and fuel economy (85.7%)**. As no criteria had a majority response of not important the relatively lowest priority criteria are **vehicle age (35.7% not important)** and **emissions (7.1% not important).**

Finally the pie chart on the left shows that **68% intend to acquire an ULEV** taxi as their next vehicle with **32% most likely to acquire a diesel**. Interestingly plug-in hybrid vehicles appear to be favoured over pure electric vehicles with 57.9% and 23.5% respectively.

	Very Important	Important	Not Important	Responses
Total cost of ownership	86.7	6.7	6.7	68.2 (15/22)
Initial purchase cost	80.0	13.3	6.7	68.2 (15/22)
Maintenance costs	64.3	28.6	7.1	63.6 (14/22)
Fuel economy	85.7	14.3	0.0	63.6 (14/22)
Emissions	42.9	50.0	7.1	63.6 (14/22)
Reliability	93.3	6.7	0.0	68.2 (15/22)
Vehicle age	42.9	21.4	35.7	63.6 (14/22)

Perceptions of Ultra Low Emission Taxis

A number of questions were asked to gauge opinion about ULEV taxis and highlight any barriers to adoption, a range of potential incentives were also proposed to establish their suitability.

Experience of plug-in hybrid and electric vehicles is low with only **22% of those surveyed having driven such vehicles.** Knowledge of the national **Clean Air Zone framework was poor with only 15% demonstrating awareness**. There was however reasonable awareness of compliant vehicles. The LEVC TX is the most well known option followed by the Metrocab and finally the Dynamo (with **100%, 66.7% and 22.2%** awareness respectively).

The table below shows the concerns relating to low emission hackney carriages rated as a major concern, minor concern or not a concern.

101

	Major Concern	Minor Concern	Not a Concern	Responses
Purchase price too high	100.0	0.0	0.0	86.4 (19/22)
Maintenance costs	55.0	35.0	10.0	90.9 (20/22)
Fuel costs	55.6	22.2	22.2	81.8 (18/22)
Customers won't like them	17.7	29.4	52.9	77.3 (17/22)
Vehicle will be charging too long during shifts	83.3	16.7	0.0	81.8 (18/22)
Knowledge of how they work and drive	35.3	41.2	23.5	77.3 (17/22)
Range	83.3	16.7	0.0	81.8 (18/22)
Battery reliability	100.0	0.0	0.0	81.8 (18/22)
Vehicle reliability	94.4	5.6	0.0	81.8 (18/22)
Lack of charging points	84.2	15.8	0.0	86.4 (19/22)

The three greatest concerns (those with the highest proportion of major concern) are **purchase price too high (100%), battery reliability (100%) and vehicle reliability (94%)**. It is also worth noting that drivers reported a high percentage of major concerns (>80%) to all charging relating questions. **Customer perception** was the lowest concern **(52.9% not a concern)** followed by **knowledge of how they work and drive (23.5% not a concern)**. Given that total cost of ownership was highlighted as an important purchasing criteria it is interesting that initial purchase price is the largest concern and that this is not balanced by fuel and maintenance costs (which are also major concerns at 55%). This highlights the necessity to quantify these costs and enable an informed decision. Two additional concerns where also raised, namely maintenance facilities and ease of repair in the event of an accident.

Perceptions of Ultra Low Emission Taxis

The table below shows how likely the proposed incentives are to encourage drivers to acquire a hybrid or electric vehicle from very unlikely to very likely.

The incentives which prompted the most **'very likely'** responses were **reduced licence fees for ULEV (66.7%), priority at taxi ranks (57.9%) and try before you buy scheme (55.6%)**. These could be described as the incentives with the highest impact, however if the responses are simplified to likely or unlikely as shown in the table at the bottom it is clear that other options may appeal to a wider audience. When viewed in this manner the most popular incentives are a **factsheet of detailed costs compared to diesel (94.1%), test drive opportunities (93.3%) and try before you buy scheme (88.9%).**

	Very Likely	Likely	Unlikely	Very Unlikely	Responses
Reduced licence fees for ULEV	66.7	16.7	11.1	5.6	81.8 (18/22)
Factsheet of detailed costs compared to diesel	29.4	64.7	5.9	0.0	77.3 (17/22)
Test drive opportunities	40.0	53.3		6.7	68.2 (15/22)
Dedicated taxi charging infrastructure	40.0	46.7	6.7	6.7	68.2 (15/22)
Training on electric vehicle use and charging	31.3	31.3	18.8	18.8	72.7 (16/22)
Low cost leasing option	47.1	23.5	5.9	23.5	77.3 (17/22)
Try before you buy scheme	55.6	33.3	0.0	11.1	81.8 (18/22)
Priority at taxi ranks	57.9	21.1	0.0	21.1	86.4 (19/22)

	Very Likely + Likely	Unlikely + Very Unlikely
Reduced licence fees for ULEV	83.3	16.7
Factsheet of detailed costs compared to diesel	94.1	5.9
Test drive opportunities	93.3	6.7
Dedicated taxi charging infrastructure	86.7	13.3
Training on electric vehicle use and charging	62.5	37.5
Low cost leasing option	70.6	29.4
Try before you buy scheme	88.9	11.1
Priority at taxi ranks	78.9	21.1

The **incentives least likely** to encourage purchase of a ULEV taxi are **training on electric vehicle use and charging (37.5% unlikely or very unlikely) and low cost leasing option (29.4% unlikely or very unlikely)**.

It is suggested that the potential incentives are ranked against ease of implementation and impact on adoption. As an example test drives may offer a good incentive for drivers with relatively low effort (in comparison to dedicated charging infrastructure).

Summary

- **22 drivers submitted completed questionnaires**, this represents a reasonable proportional of the total licence holders (22/113 = 19.5%).
- There is a good spread of vehicle age (6-19 years) and vehicle type (with the top three types all represented) in the responses.
- Existing vehicles are on **average 12.9 years old** and have high mileage with **50% having >250,000 miles**, annual mileage is also reasonably high with **64% doing 20,000-30,000 miles** per year (equivalent to **64-96 miles a day**)
- <u>Daily usage patterns;</u>
  - Drivers were found to commute very short distances before taking their first fare (**61% travelling <2 miles**)
  - Drivers are used to refuelling at the end of their shift (**72% refuelling after**), it is worth noting however that **during the shift only accounts for 16.7%** of responses.
  - **56%** of drivers currently spend **>30 minutes waiting** between customers, with the minimum wait being 10 minutes.
  - **80%** of drivers have **off street parking** with **41%** of vehicles having **overnight access to an electric supply point**.

103

- <u>Purchasing priorities;</u>
  - At present **78% of vehicles are acquired second hand** with only **40% using finance** to fund the purchase
  - **39%** of drivers **would consider acquiring a brand new vehicle**, with a further **50% responding maybe. Only 15.8% of drivers would currently consider a leasing model.**
  - **Reliability (93.3%), total cost of ownership (86.7%) and fuel economy (85.7%)** are the most important purchasing criteria. **Vehicle age and emissions** are the least important. **68%** of drivers **intend to acquire an ULEV** taxi as their next vehicle.
- <u>Perceptions of ultra low emission taxis;</u>
  - Only **22%** of those surveyed have **driven plug-in hybrid or battery electric vehicles**
  - **Purchase price too high (100%), battery reliability (100%) and vehicle reliability (94%)** are the major concerns with ULEV taxis, **customer perception** was the lowest concern **(52.9% not a concern)** followed by **knowledge of how they work and drive (23.5% not a concern)**.
  - Most of the proposed incentives are likely to influence purchasing behaviour with **reduced licence fees for ULEV (66.7%) and priority at taxi ranks (57.9%)** receiving the most very likely responses. A **factsheet of detailed costs compared to diesel (94.1%)** and **test drive opportunities (93.3%)** received the most total positive responses (very likely <u>and</u> likely)
  - **Training on electric vehicle use and charging** and **low cost leasing option** are the least popular incentives and are unlikely to be effective

3. Duty Cycle – Oxford Hackney Carriage

104

To accurately assess vehicle operational and financial suitability it is important that any analysis is performed in the context of Oxford usage, as such this section discusses the use of telemetry fitted to existing vehicles to develop a Oxford specific hackney carriage duty cycle.

Data Collection Methodology

- As part of the initial engagement workshop hackney carriage drivers were asked to partake in a two month data collection trial using CLEAR Capture telematics devices (to be installed on their existing vehicles). The purpose of the trial was to build a typical drive cycle using journey patterns recorded during normal use of hackney carriages, this therefore includes both business and personal use of the vehicle (it is worth noting that no differentiation is made in the data analysis).
- The devices record key metrics including vehicle speed, mileage and vehicle position using GPS. Data is recorded every time a specified steering input or distanced travelled is exceeded, this typically leads to logging every 1-5s. A journey is determined to have ended when the vehicle is stationary for >5mins.
- The preferred device fits into the vehicles On Board Diagnostics port using the OBDII protocol (left image), this standard was introduced in 2005
105 for European diesel vehicles. However as much of the hackney carriage fleet pre dates this standard an alternative 12V power supplied device was required (right image):

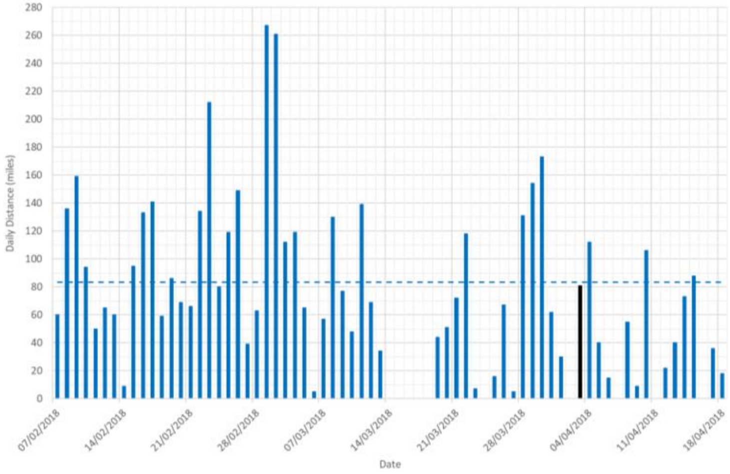
CLEAR Capture Devices (OBDII and 12V outlet)

- Participants were also asked to complete a mileage and refuelling log sheet to verify the results from the loggers and provide an accurate fuel consumption figure (in addition to the estimation from the questionnaire responses).
- To provide a representative data set it was suggested that 10% of the fleet should be logged. As participation in the trial was voluntary and there was some concern about having data loggers fitted a total of 6 drivers were recruited. Therefore the data collected from the loggers represents ~5.3% of the total fleet.

Indicative Logger Outputs

Daily Mileage Profile

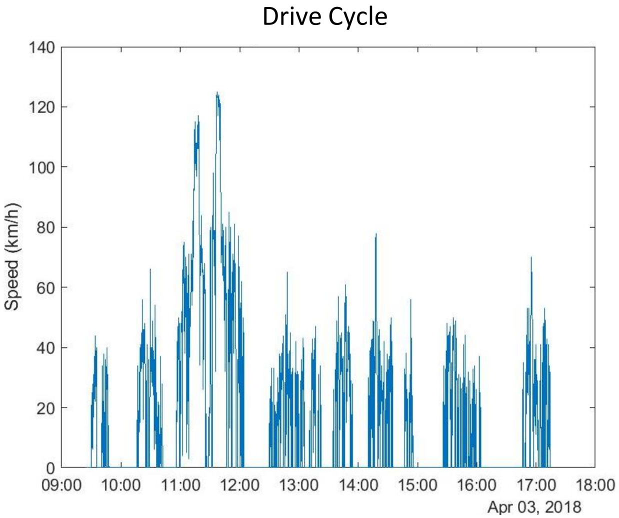
The chart below shows a typical daily mileage profile from an Oxford hackney carriage logged as part of the trial. The data is used to show the average daily mileage (dotted line), the maximum daily mileage and how many days a week the vehicle is used. This provides the basis for the assessment of the suitability of ULEV options. A representative day is highlighted in black which is the day where the distance travelled is closest to the average, this is used for illustrative purposes in the real world duty cycle description to the right.

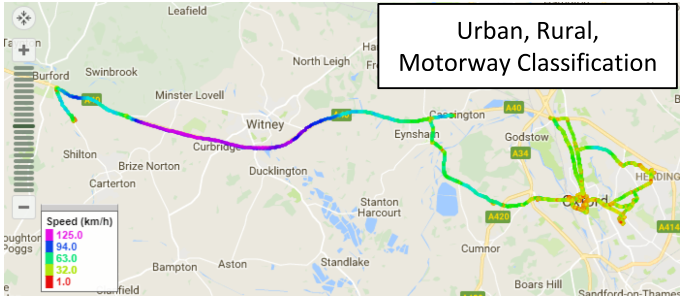


Real World Duty Cycle

The top chart on the right shows the vehicles speed vs the time of day. It is possible to use the vehicle acceleration and speed to categorise the duty cycle. The chart on the bottom right shows this well with low speeds in urban areas (red and green), moderate speed in rural areas (blue) and high speed on A roads/motorway (purple). Additionally it is possible to see and quantify specific journeys, this is used to calculate typical journey distances and driving times.

Although out of the scope of this study the drive cycle and GPS data could be used to show specific opportunities and locations for electric vehicle charging. For example on this day it may have been possible to charge between 4-5pm depending on location and availability.





Oxford Duty Cycle

The data recorded from the individual CLEAR capture devices was processed using in house routines then averaged to produce bespoke journey statistics for Oxford. A total of **279 days** worth of data were captured during which the drivers completed **24,066 miles**. A summary of the averaged journey statistics is shown in the table below:

Metric	Mean	Maximum
Average daily mileage / miles	88	132
Maximum daily mileage / miles	241	306
Days per week usage	5.4	6.2
Extrapolated annual mileage / miles	25,331	42,790
Average journey distance / miles	6.3	8.2
Average number of journeys per day	14	19
Average journey time / mins	24	28
Average daily driving time	5h 40min	8h 37min
Duty Cycle*	**%**	**miles**
Urban driving distance	61	14,722
Rural driving distance	30	7,200
Motorway driving distance	9	2,144

*included in total cost of ownership model

It can be seen that the **average daily mileage is 88 miles**, this combined with **5 days per week** correlates well with the calculated value of 64-96 miles from the questionnaire responses. Likewise this gives an **extrapolated annual mileage of 25,331 miles**, this is in agreement with 64% of questionnaire respondents reporting an annual mileage of 20-30,000 miles. It can therefore be assumed that the period of the data logging (Feb-Apr) provides an acceptable representation of overall operations.

An average driving time of **5.7h per day** should allow ample down time for opportunity vehicle charging if required, additionally as the average journey distance is only **6.3 miles** then the vehicle could operate down to a relatively low state of charge.

By comparing the vehicle speed and acceleration/deceleration to real world duty cycles it is possible to quantify the total number of miles spent on each type of duty.

This analysis yields a urban/rural/motorway split of:

61/30/9%

Oxford Duty Cycle – ULEV Suitability

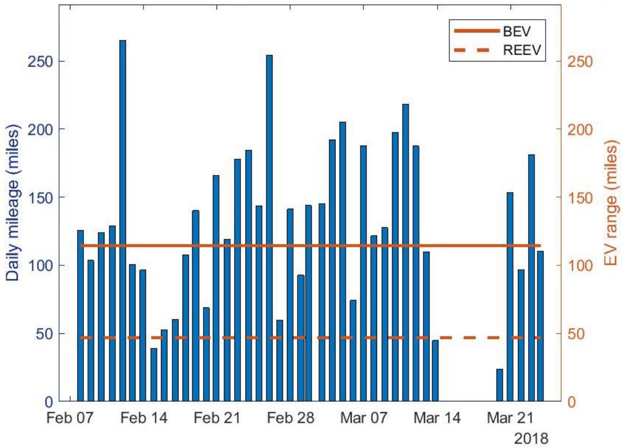
To demonstrate whether ULEV hackney carriages are operationally suitable the electric range is compared against the daily mileage. Each individual vehicles duty cycle is calculated to provide the % distribution of urban, rural and motorway driving. From previous projects Cenex has tested the real world reduction in range across these duty cycles in comparison to manufacturer quoted New European Drive Cycle (NEDC) results. These tests have been performed on a variety of battery electric, plug-in hybrid and range extended electric vehicles – if possible the factors from direct equivalent vehicles have been used. Real world fuel consumption factors have also been applied to internal combustion engine fuel consumption values from independent sources.

108

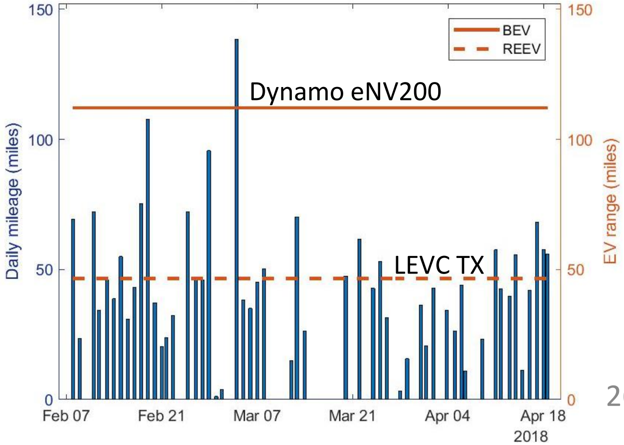
It is then possible to estimate and compare the 'real world' electric only range with the daily mileage profile as shown in the charts on the right. Any miles over the range of the Dynamo require the vehicle to be charged, any miles over the range of the LEVC can be fulfilled using the range extender or via recharging the battery.
It has been assumed that opportunity charging will be completed using a DC rapid charger (typically to 80% SOC), hence the range does not double.

The total number of miles covered in EV only mode has then been calculated for all participants for 1 and 2 charges per day. This provides a useful assessment of the vehicle capabilities but does not show how frequently the vehicle exceeds the electric only range (and therefore how often additional charges would be required). Therefore the number of days within the electric only range are counted and compared to the total number of days. It is worth noting that no safety factor has been included and it is assumed that the battery is fully depleted.

High mileage example



Low mileage example

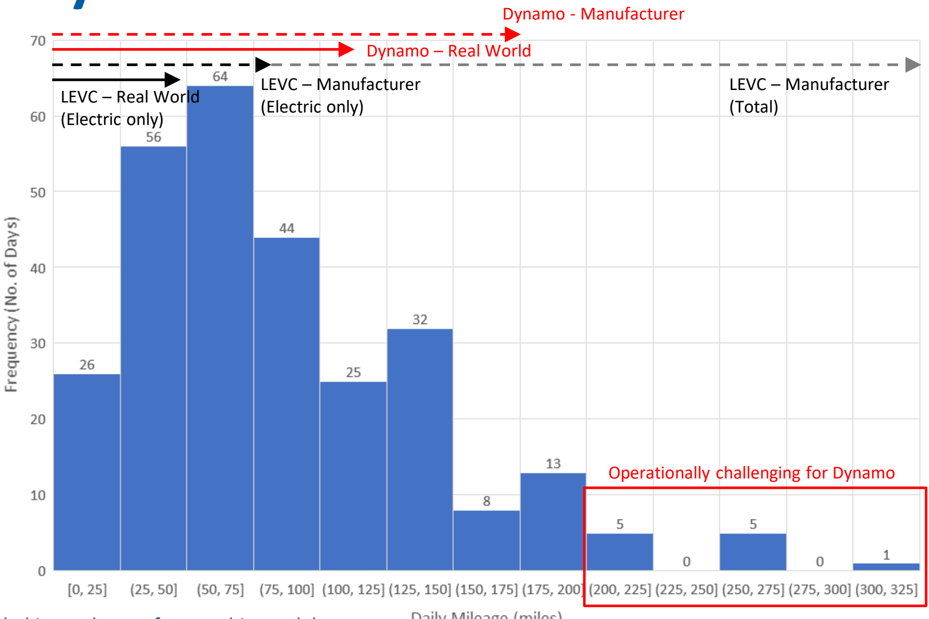


Oxford Duty Cycle – ULEV Suitability

A histogram of the daily mileage from every day logged during the trial yields the distribution shown in the chart on the right. The distribution is skewed right with the centre at **50-75 miles**. The maximum daily mileage is 306 miles.

Qualitatively it can be seen that the Dynamo real world range covers a significant proportion of the dataset. The LEVC real world range falls at the centre of the distribution, with a greater emphasis necessary on maximising range.

The table below shows the number of miles that both vehicles can achieve with the **LEVC TX able to cover 49.5% of miles on electric only with one charge and 74% of miles with two charges**. The **Dynamo eNV200** covers **85.2%** of the total mileage with one charge and **98.3%** with two. A total of **421 miles (over 10 days)** could **not** be covered on two charges. On these occasions (2% of mileage, 4% of days) the vehicle is considered operationally unsuitable (see red box on chart).



*included in total cost of ownership model

	Miles below EV only range	% of miles below EV only range*	No. of days below EV only range	% of days below EV only range
LEVC TX (REEV) – overnight charge	11,910	49.5%	70	25.1%
LEVC TX (REEV) – overnight + opportunity charge	17,820	74.0%	161	57.7%
Dynamo (BEV) – overnight charge	20,511	85.2%	204	73.1%
Dynamo (BEV) – overnight + opportunity charge	23,647	98.3%	269	96.4%
Total Mileage/Days	24,068	100%	279	100%

110

4. Total Cost of Ownership Analysis

In order to establish whether present ULEV hackney carriages are financially viable a total cost of ownership model has been developed with a view of understanding whether the high purchase price is a barrier to adoption. This model is based on the duty cycle reported in section 3 and is used as the basis for a proposed leasing model as discussed in section 4.1.

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Methodology and Assumptions

A total cost of ownership model was built to incorporate the major purchasing and running costs, costs that are assumed to be equivalent between all technologies (such as insurance, hackney carriage license) or are insignificant have been excluded. The model allows input of different ownership periods and annual mileage, providing a sensitivity analysis and break even points. The model assumptions are shown in the table below. The initial cost model assumes outright purchase of the vehicle, for context this cost is then compared with available finance products. All prices include VAT.

	Assumption	Source
Duty Cycle	61% urban, 30% rural, 9% motorway REEV covers 49.5% miles electric only (1 charge) REEV covers 74.0% miles electric only (2 charges)	Section 3
Fuel Costs (average of price over last 12 months)	Diesel - £1.21 per litre Petrol – £1.19 per litre Electricity (small/med non domestic user) – 10.65p per kWh	http://www.theaa.com/motoring_advice/fuel/ http://www.theaa.com/motoring_advice/fuel/ https://www.gov.uk/
Service, Maintenance and Repair Costs (SMR)	SMR curves (based on vehicle age and mileage) are available for equivalent models for the diesel and BEVs in the study. As there are few REEVs available the percentage difference between typical PHEV and modern diesel vehicles was established and used. This approach yielded an approx. 30-50% reduction in SMR for the BEV and a 10-25% reduction in SMR for REEV. Hackney carriage specific SMR costs have not been included and are assumed to be the same across vehicles.	https://www.fleetnews.co.uk/
Depreciation	Residual values (based on vehicle age and mileage) are available for equivalent models for the diesel and BEVs in the study. As there are few REEVs available the LEVC TX has been assumed to depreciate at the same rate as a diesel. Previous models have been shown to retain their value well, however it is proposed that this will be offset by the immaturity of the technology. The impact of the ZEZ on residual values has not been included. A vehicle is assumed to reach its final residual value after 7 years, beyond this it does not depreciation further.	https://www.fleetnews.co.uk/
Road Tax	Includes exemption for ULEV >£40,000	https://www.gov.uk/
Vehicle Cost	OTR cash price from the supplier (including plug-in taxi grant, no further discounts applied). All models have automatic gearboxes and are of a relevant trim level.	

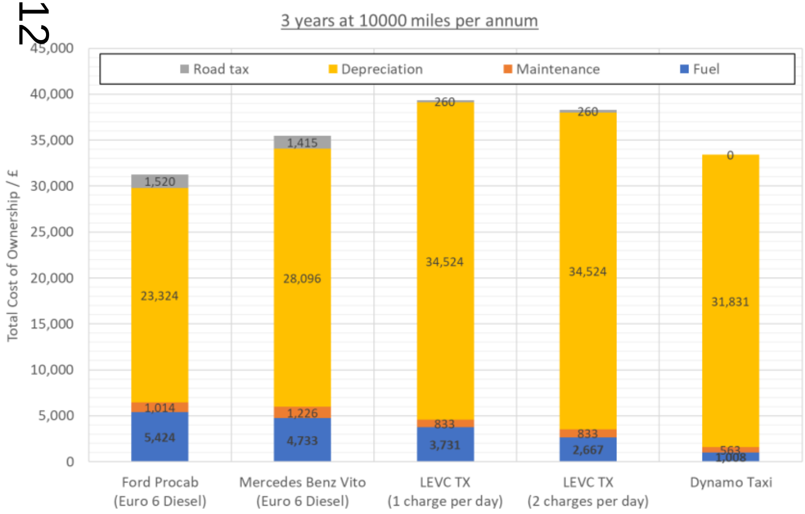
Total Cost of Ownership

<u>1. Low Ownership Period, Low Annual Mileage</u>

This case represents drivers doing than 10,000 miles per year, it also includes those with personal circumstances that do not want a long term commitment to the trade.

Even in this case both the **LEVC TX and Dynamo offer significant savings in fuel, SMR and road tax**. However the **higher initial purchase price and resulting depreciation** cost negate these gains. As a result the total cost of ownership over this period is **~£7k and ~£2k higher** for the LEVC TX and Dynamo respectively.

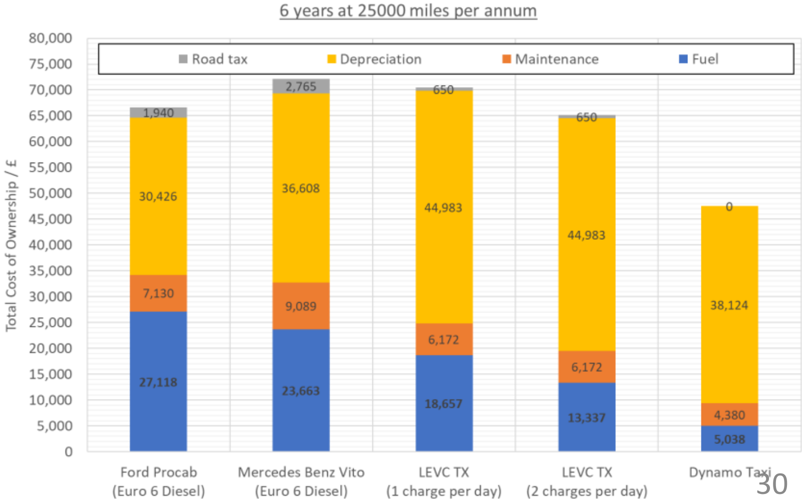
112



<u>2. Medium Ownership Period, Average Annual Mileage</u>

This case represents the average annual mileage of 25,000 miles and an reasonable ownership period of 6 years. The depreciation cost remains higher for the ULEVs, however due to the increased mileage there are **fuel savings of 51% and 81%** for the LEVC TX and Dynamo respectively.

This makes the Dynamo financially viable with a TCO **saving of ~£19k**. The LEVC TX is also **provides a saving of up to ~£1.5k**.



ULEV Hackney Carriage Business Model Assessment

Total Cost of Ownership

2. Medium Ownership Period, Average Annual Mileage

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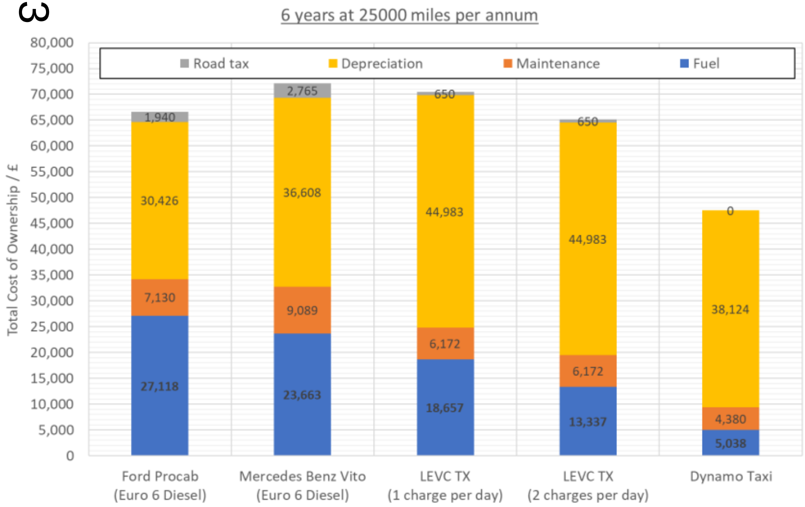
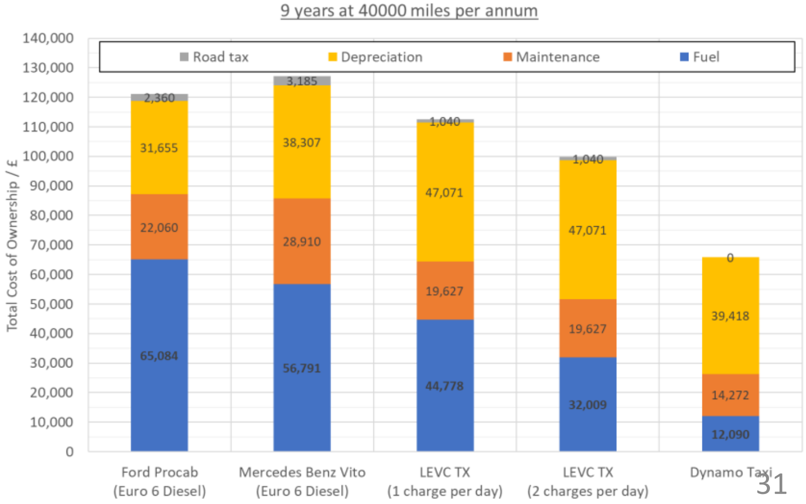
113



3. High Ownership Period, High Annual Mileage

Substantial TCO savings are available for both ULEV hackney carriages with increased ownership periods. Assuming the vehicle is used for 9 years at 40,000 miles per year provides considerable savings on both fuel and maintenance, additionally the rate of depreciation has decreased so has a smaller effect with each additional year of ownership. **Fuel costs** become dominant factor (accounting for **50% of the diesel TCO**). In this scenario the LEVC TX provides a **saving of up to ~£20k** and the Dynamo provides a **saving of ~£55k.**



Monthly Running Costs

Ford Procab (Euro 6 Diesel)

Ownership Period (years)	Annual Mileage (miles) 15,000	20,000	25,000	30,000
2	£320	£408	£495	£583
4	£309	£400	£491	£582
6	£312	£407	£503	£598
8	£320	£419	£518	£617
10	£329	£432	£535	£637

LEVC TX (REEV) 2 charges per day

Ownership Period (years)	Annual Mileage (miles) 15,000	20,000	25,000	30,000
2	-£174	-£215	-£256	-£297
4	-£149	-£190	-£231	-£272
6	-£141	-£182	-£223	-£264
8	-£137	-£178	-£219	-£260
10	-£135	-£176	-£217	-£258

Dynamo (BEV)

Ownership Period (years)	Annual Mileage (miles) 15,000	20,000	25,000	30,000
2	-£259	-£326	-£393	-£460
4	-£239	-£307	-£375	-£443
6	-£234	-£303	-£372	-£441
8	-£233	-£303	-£373	-£442
10	-£233	-£304	-£375	-£446

It is recognised that most drivers are **unlikely to purchase an ULEV outright**, as such the monthly running costs are presented separately to allow comparison with typical finance products. The first table shows the **total monthly running cost of a Euro 6 diesel** including fuel, maintenance and road tax. A typical user (25,000 miles per annum for 8 years) would spend **£518 per month running a Euro 6 diesel** with fuel costing £87 per week (~18p/mile).

The bottom two tables show the **difference in monthly running costs for the ULEVs** compared to the Euro 6 diesel with negative values representing a saving. At 25,000 miles per annum the **LEVC TX** offers a **monthly saving of £219** with fuel costs of £43 per week (~9p/mile). The **Dynamo** provides a **saving of £370 per month** with fuel costs of £16 per week (~3p/mile)

For context a four year personal contract purchase **(PCP) for a Euro 6** diesel typically costs **~£690 per month (£160 per week)**, an equivalent agreement for a **ULEV** can be up to **£855 per month (£197 per week)**. As such a **ULEV can cost up to £165 per month more** to purchase than an equivalent diesel, however **this cost is offset** by the savings in running costs.

<u>A note regarding used Euro 6 diesels:</u> The total cost of ownership analysis assumes purchasing (or PCP) of a brand new vehicle. An alternative to this would be to purchase a used vehicle either outright or on finance. A review of **approved used prices for Euro 6 LTI TX4** and **Ford Procab** gave prices of at least **£30,000 (or £145 per week)**. It also worth noting that the standard offering for these vehicles is a hire purchase agreement which carries a **higher interest rate and no guaranteed future value for the vehicle**. Additionally a search for **private sellers** yielded **very few examples of used Euro 6 hackney carriages**, this is likely due to the vehicles being recently purchased and offering compliance with Clean Air Zones.

Ownership and Usage Sensitivity

The total cost of ownership model was run through a range of ownership periods from 2-10 years and annual mileages from 10,000-40,000. The total cost of ownership per month (£) of the baseline diesel Ford Procab is shown in the table on the right.

The **difference per month** has then been calculated for each of the ULEVs to show the break even points, operation beyond this point represents a net saving.

Monthly cost of ownership (£)

Ford Procab (Euro 6 Diesel)		Annual Mileage / miles						
		10,000	15,000	20,000	25,000	30,000	35,000	40,000
Ownership Period / years	2	1,075	1,198	1,309	1,415	1,517	1,616	1,714
	3	869	983	1,088	1,190	1,289	1,386	1,482
	4	760	870	974	1,075	1,173	1,270	1,366
	5	690	794	895	994	1,091	1,188	1,284
	6	622	725	826	925	1,024	1,121	1,219
	7	575	679	780	880	980	1,079	1,178
	8	532	637	740	842	943	1,044	1,144
	9	500	607	711	814	917	1,020	1,122
	10	475	583	689	794	899	1,003	1,107

Difference in monthly cost of ownership relative to diesel (£)

115

LEVC TX (REEV) 2 charges per day		Annual Mileage / miles						
		10,000	15,000	20,000	25,000	30,000	35,000	40,000
Ownership Period / years	2	257	258	244	223	198	170	139
	3	195	169	138	105	70	34	-3
	4	152	122	89	54	17	-20	-58
	5	106	81	50	17	-19	-55	-92
	6	86	53	17	-20	-59	-97	-136
	7	67	32	-5	-43	-81	-120	-160
	8	48	13	-25	-63	-102	-142	-181
	9	34	-3	-41	-79	-119	-158	-198
	10	22	-15	-53	-92	-132	-172	-212

Dynamo (BEV)		Annual Mileage / miles						
		10,000	15,000	20,000	25,000	30,000	35,000	40,000
Ownership Period / years	2	196	136	73	9	-56	-122	-188
	3	59	-2	-67	-132	-198	-265	-331
	4	-5	-68	-134	-201	-268	-335	-403
	5	-49	-112	-178	-244	-312	-379	-447
	6	-69	-132	-198	-265	-333	-401	-469
	7	-83	-147	-214	-282	-350	-419	-488
	8	-92	-158	-225	-294	-363	-432	-501
	9	-100	-166	-234	-304	-373	-443	-513
	10	-106	-173	-242	-312	-382	-452	-523

The top chart on the left shows the results for the REEV, for the typical annual mileage of **25,000 miles** the **LEVC TX is financially viable** if owned for greater than **6 years.** However it is **financially challenging** below this mileage **with low mileage users** (10,000 miles per annum) **requiring ownership periods of over 10 years**.

Subsidising licence (£400 per driver, £123 per vehicle per year) **and test fees** (£66 or £132 per year depending on age) would **reduce the payback period by 1-3 years** depending on mileage.

Owing to its competitive pricing and all electric operation the **Dynamo** has a **strong financial case**, providing **savings of £244** and **£312 per month** over 5 and 10 years of ownership respectively at 25,000 miles per annum. It is suggested that **additional financial incentives are not required** as the **maximum payback period is only 4 years**.

Total Cost of Ownership – Financial Incentives

As the LEVC TX is more financially challenging (particularly for low mileages or short ownership periods) it **may require additional financial incentives,** such as scrappage scheme payments for the oldest diesel vehicles**, to encourage uptake**. The table below shows the difference in total cost of ownership relative to the diesel baseline (with negative values representing a saving over the ownership period).

Financial incentives of **£2,000**, **£3,500 and £5,000** can **reduce the payback period on the LEVC TX by 1-4 years** – significantly improving the proposition for drivers doing 15,000-25,000 miles per annum, this also enables drivers completing 10,000 miles per annum to achieve payback relative to a new diesel vehicle in less than 10 years.

116

LEVC TX (REEV) 2 charges		Annual Mileage / miles						
		10,000	15,000	20,000	25,000	30,000	35,000	40,000
Ownership Period / years	2	6,169	6,182	5,854	5,352	4,745	4,070	3,345
	3	7,004	6,077	4,970	3,770	2,512	1,217	-105
	4	7,310	5,844	4,275	2,573	815	-980	-2,801
	5	6,343	4,866	3,026	1,006	-1,118	-3,309	-5,547
	6	6,201	3,804	1,215	-1,472	-4,218	-7,002	-9,813
	7	5,643	2,725	-379	-3,576	-6,828	-10,117	-13,432
	8	4,639	1,224	-2,377	-6,070	-9,820	-13,606	-17,417
	9	3,633	-281	-4,379	-8,571	-12,819	-17,103	-21,412
	10	2,624	-1,789	-6,387	-11,078	-15,825	-20,608	-25,417

Required Financial Incentive
£0
£2,000
£3,500
£5,000

Total cost of ownership – difference to diesel(£)

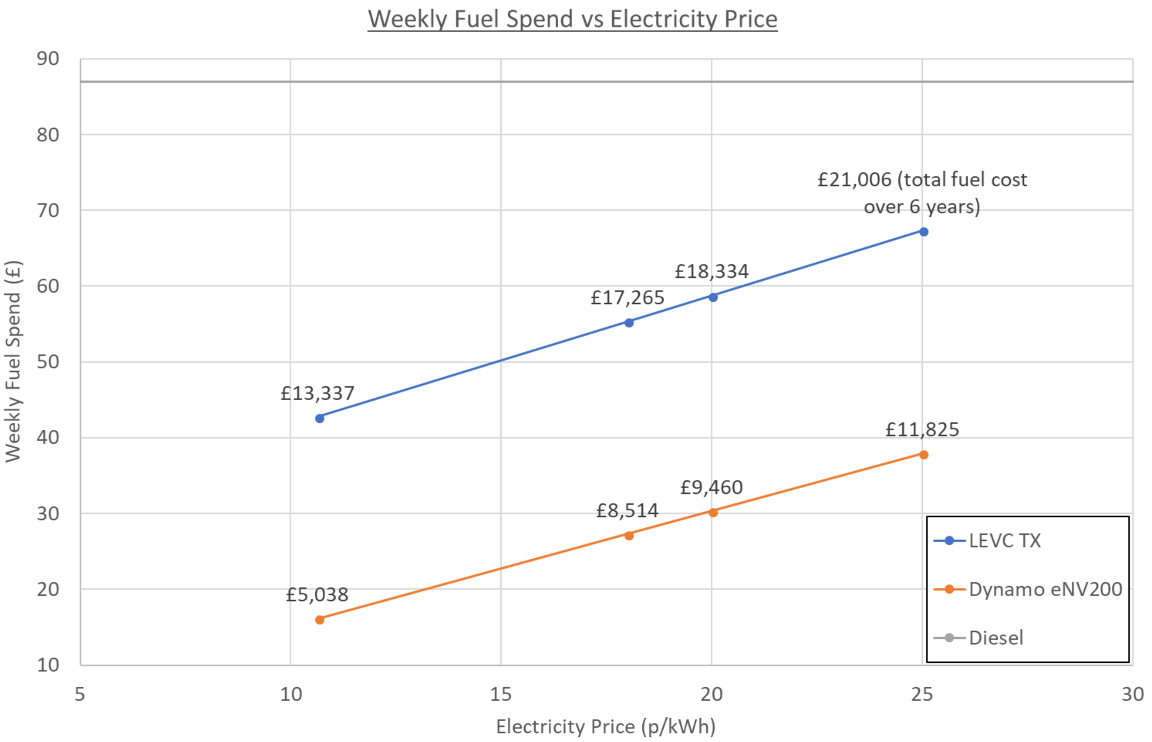
Electricity Price Sensitivity: Cost per Week

To assist with its infrastructure procurement Oxford City Council requested a sensitivity analysis based on the electricity price of public/taxi charging infrastructure. As such the impact of electricity prices ranging from 10.65p/kWh (as assumed in the model) to 25p/kWh was investigated. The main metrics used to quantify this effect are the weekly fuel spend and payback period relative to the diesel baseline.

At 25,000 miles per annum increasing the cost of electricity from **~11p/kWh to 25p/kWh increases** the weekly fuel spend from **£43 to £67 for the LEVC TX** and **£16 to £38 for the Dynamo.**

Over a 6 year ownership this equates to an **increase** in total cost of ownership of **£6,750 to £7,750.**

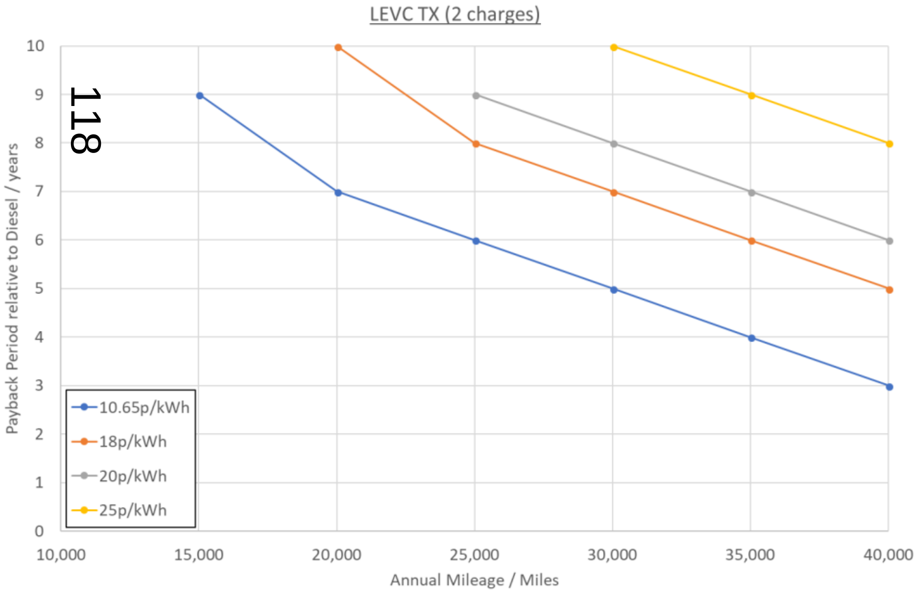
If all charging was completed at 25p/kWh the **LEVC TX** would only be **£20 per week cheaper than a diesel**, although this is a worst case scenario it could be possible for drivers who do not have access to home charging.

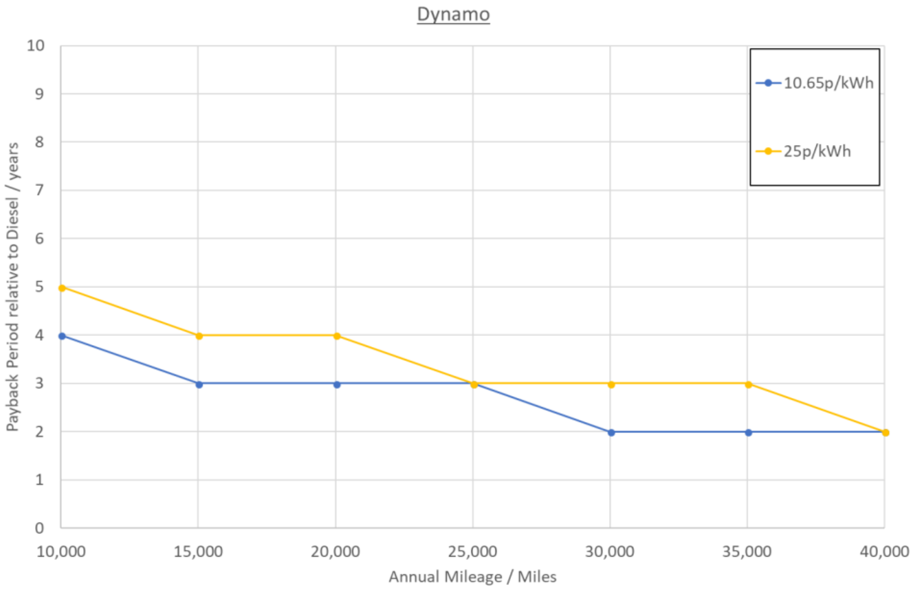


Electricity Price Sensitivity: Impact on Payback Period

Increasing the price of electricity significantly impacts the already challenging **payback period** for the **LEVC TX, increasing the payback period by 2-5 years** if electricity cost is between **18-25p/kWh**. If all charging was completed at 25p/kWh the vehicle would only be financially viable for drivers completing >30,000 miles per annum who intend to own the vehicle for >8 years.

The **Dynamo is much less sensitive** in terms of payback period (**increasing by 1 year in the worst case**) as the monthly savings are already large compared to a diesel, even at 25p/kWh fuel costs are still >50% lower than the diesel baseline.





4.1 Leasing Business Model Guidance

119

Given the weak second hand market and rate of technology development leasing of electric vehicles has proven to be an increasingly popular alternative to ownership. A similar model is therefore of interest for hackney carriages. Cenex interviewed a range of organisations to gain input regarding the feasibility of a leasing business model with a view of highlighting the key information and support that leasing companies would require.

Leasing Business Model Interviews

Interviews were conducted with Green Investment Group (GIG), Westward Leasing (WL), rentEcars (REC) and DriveElectric (DE). With the exception of rentEcars (who work with Uber), all companies reported having little or no experience of successfully leasing taxis (one company entered discussions with a private hire firm in Manchester regarding Nissan eNV200). Additionally contact with local authorities on this topic was limited with discussions tending to relate to infrastructure or standard cars/vans. Key answers from the interviews are summarised in the table below:

What are the main barriers to leasing hackney carriages (both personal and business agreements)?

- **Uncertainty around future residual values [DE] [GIG]**
- **Personal contract leasing to drivers (risk of default – difficult to underwrite) [DE] [WL] [GIG]**
- Vehicle and supplier maturity, quality of conversions [DE], Operational suitability of vehicle [WL]
- Future of hackney carriage trade (due to changing services/business models) [REC]
- Investment scale typically needs to be £30-50m for Green Investment Group [GIG]
- Additional management costs associated with hackney carriage regulation and plating requirements [DE]

If a local authority wanted to establish a partnership with a leasing company what information/assurances would they need to provide?

- Guarantees or underwrites if leasing directly to individuals [GIG]
- Guaranteed future residual value – buy back agreement with vehicle supplier? [DE] [WL]
- Access to charging infrastructure [REC], infrastructure could be included in any investment [GIG]
- Promotion of customer base, suitable timescale for replacement [GIG]

How are leasing costs determined? What are the key factors?

- **Depreciation [DE] [WL]**
- Overheads [DE]
- Borrowing rates and credit score [DE] [GIG]
- Driver income based, all inclusive package [REC]

For reference all companies interviewed were keen to discuss the matter further with local authorities.

Leasing Business Model – Options

The table below summarises the pros and cons of different lease models as discussed during the interviews with lease providers detailed on page 36 .

Role					
Vehicle Owner	**Lease Management**	**Lessee**	**Pros**	**Cons**	**Enablers**
Vehicle Supplier		Driver	• No risk or cost to local authority	• Not yet available • Driver credit score • May not encourage uptake	• Market
Leasing Company		Driver	• No risk to local authority • Leasing company may be able to negotiate discount with supplier • Leasing company may have access to finance products	• Leasing company must raise capital • Leasing company carries depreciation risk vs. reward • Leasing company carries risk of default	• Local authority could act as a guarantor (or revoke plates/licenses) • Vehicle supplier could offer buy backs at pre agreed residual value
Local Authority		Driver	• No external management fees – may be able to offer best deal to drivers	• Local authority must raise capital • Local authority carries depreciation risk vs. reward • Local authority carries risk of default • Leasing business set up and management	• Vehicle supplier could offer buy backs at pre agreed residual value
Local Authority	Leasing Company	Driver	• No leasing business set up and management • Lowest risk for leasing company	• Local authority must raise capital • Local authority carries depreciation risk vs. reward • Local authority or leasing company carries risk of default	• Vehicle supplier could offer buy backs at pre agreed residual value
Vehicle Supplier Suggested for further investigation		Leasing or rental company (rental to multiple drivers)	• Vehicle supplier carries depreciation risk vs. reward • Vehicle asset maximised • Driver only pays for vehicle when working • All inclusive package for driver	• Not yet available, unproven business model for hackney carriages • Suitable partner required	• Access to infrastructure • Leasing agreement with vehicle supplier for this usage • Guarantee of future trade

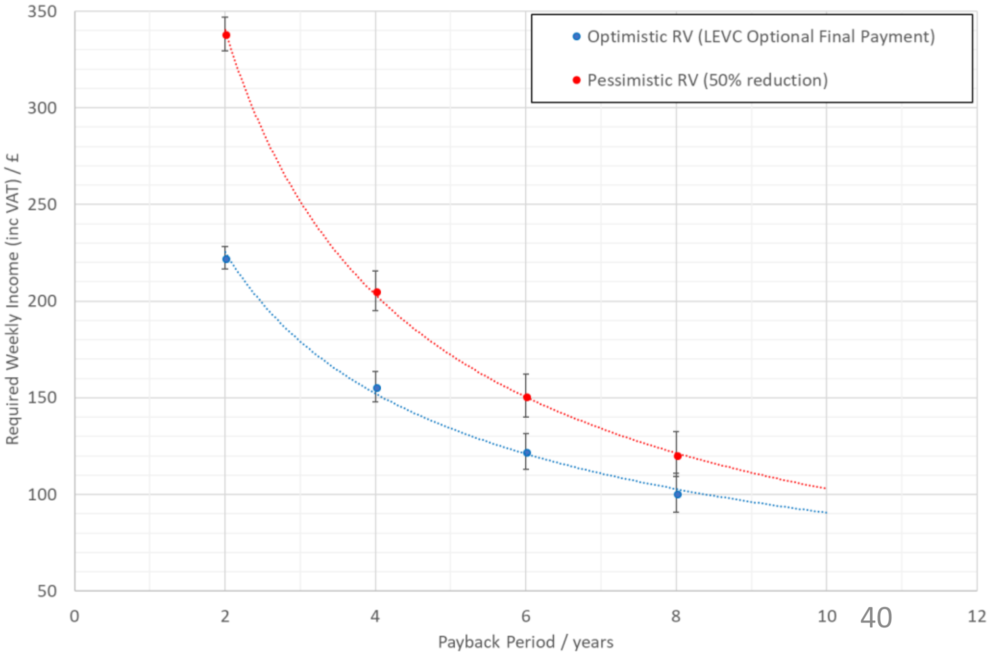
Due to high risk of new technology, unknown residual values, a fragmented market and the credit rating of drivers a conventional lease model was not an attractive option to providers; it is recommended that a shared/reduced risk model could be investigated with providers instead.

Payback Period

To justify the council purchasing a number of ULEV hackney carriages (as part of the establishment of a leasing business) it is important to evaluate the payback period and the implications on leasing fees. As the depreciation costs are a determining cost in lease fees and the effective cost of owning the vehicle for the council they have been used to estimate payback time. The following assumptions have been made:

- Vehicle purchase cost excludes VAT, drivers monthly payments include VAT
- Optimistic residual value is based on LEVCs PCP optional final payment, pessimistic residual value is 50% less
- Required income per month is equal to purchase cost – depreciation with 2.5% interest (error bars +/- 2.5%) over the payback period
- No management fees included (either internal or external)
- 6 months deposit
    - Optimistic; £456 – 8 years, 0% interest
    - Pessimistic; £1,735 - 2 years, 5% interest

As it is possible to effectively lease a vehicle (via a PCP) for ~£160 per week then any alternative leasing arrangements must be lower than this to be competitive.
On this basis a **lease charged at £150 per week** will take between **4 and 6 years to payback** just the vehicle depreciation.
Alternatively a more **aggressive pricing of £120 per week** would take **6-8 years** to cover the depreciation.
This would be lower than an equivalent diesel weekly lease allowing drivers to benefit fully from the fuel savings.
The analysis was repeated for the Dynamo eNV200 based on the residual values from the total cost of ownership model, the results were similar to the optimistic LEVC TX so are not shown.
Although the purchase cost is cheaper a higher rate of depreciation has been assumed.



5. Influence of Uptake Scenarios on Emissions Benefits

123

This section reports three possible uptake scenarios based on present driver opinions, expected charging behaviours and the proportion of drivers for which ULEVs are currently economically and operationally viable. The impact on greenhouse gas and air quality emissions is then assessed to suggest the most suitable solution to meet environmental and zero emission zone requirements.

Emissions Factors (Exhaust Only)

Fleet CO_2 emissions can be calculated by applying DEFRAs 2017 GHG Reporting CO_2e Emission Factors to petrol, diesel and electricity consumption. Tank-to-wheel (TTW) or Scope 1 emissions represent the amount of CO_2 (derived from fossil fuels) which is released from a vehicle's tailpipe. Under UK Greenhouse Gas (GHG) reporting protocol, these Scope 1 emissions are the direct responsibility of the transport operator. Well-to-wheel (WTW) or All Scope emissions represent the amount of CO_2 emitted during the fuel's life cycle. This includes the carbon intensity of fuel extraction, processing, transportation and final combustion. This allows a wholistic approach to the carbon intensity of using different fuel types. Although the upstream emissions from fuel manufacture are not the reporting responsibility of the transport operator (under UK emission reporting guidance), they are considered important by environmentally conscious fleets when making decisions on fuel and transport options.

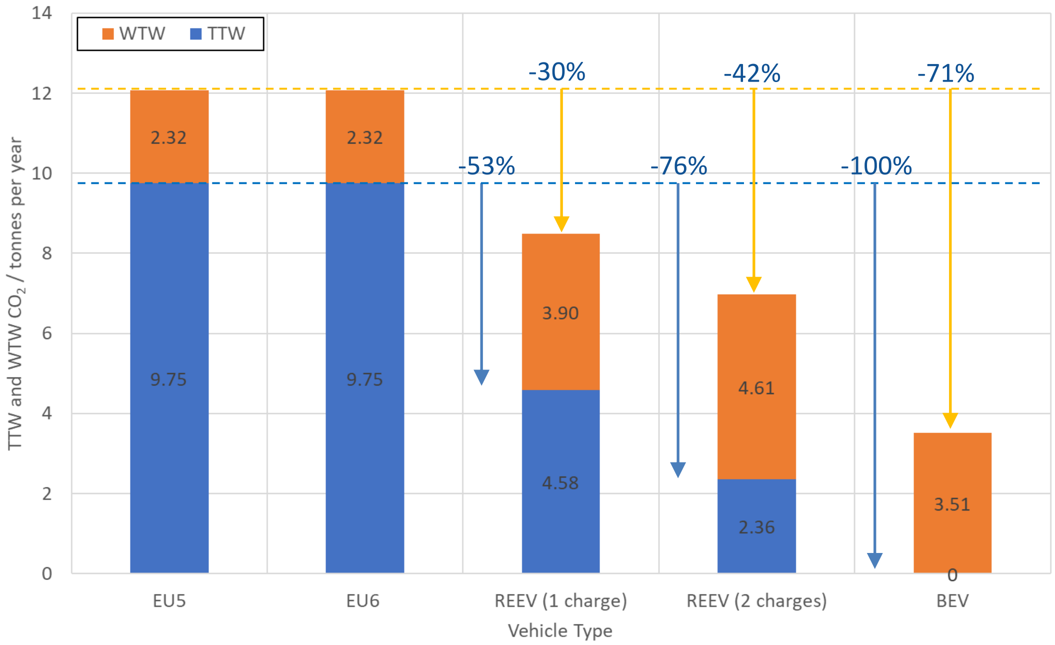
In addition the UK National Atmospheric Emissions Inventory (NAEI) provides estimated real-world air quality emission look-up tables by vehicle
124 weight, euro standard, and average vehicle speed. These tables were used to estimate the air quality emissions. Average vehicle speed was derived from the Oxford specific and real world duty cycles at 37km/h.
The existing diesel fleet Euro standards were applied with an average fuel consumption of 26mpg (calculated from the participant drivers mileage and refuelling logs). All calculations assumed an annual mileage of 25,000 miles and a fleet of 113 hackney carriages. The emissions are presented on a per vehicle basis on pages 43 and 44 with the current fleet total emissions and future uptake scenarios on pages 45 and 46.

Emissions per Vehicle Type: CO_2

The **LEVC TX (REEV)** gives a **76% reduction in TTW CO_2** and **42% reduction in WTW CO_2** compared to diesel (if charged twice per day).
The **Dynamo (BEV)** produces **no tailpipe CO_2** and gives a **71% reduction in WTW CO_2** compared to diesel based on the current UK electricity generation mix. Future increases in renewable electricity generation will reduce this value further.
Euro 5 and 6 have been assumed to have the same fuel consumption for the purpose of this analysis.

125

Annual CO_2 Emissions per Vehicle

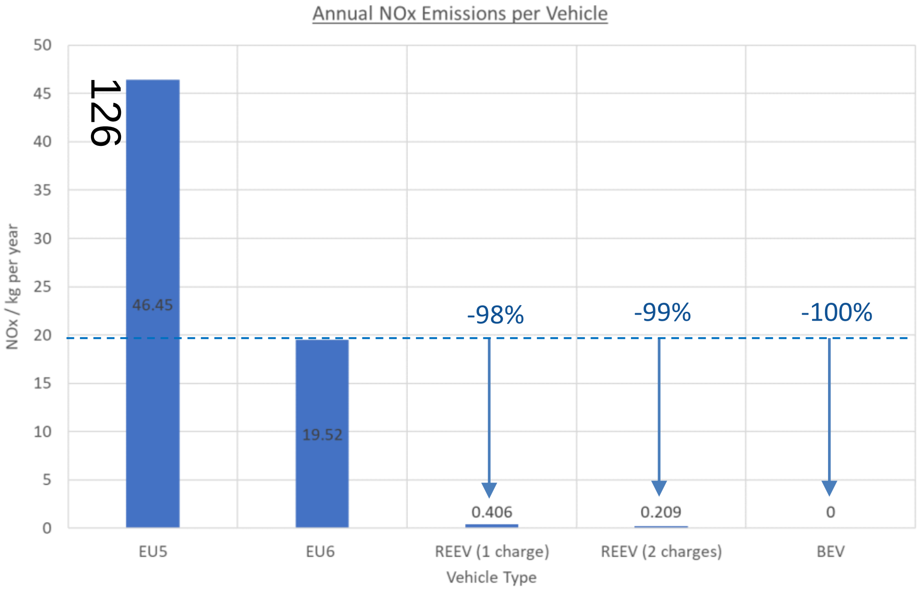


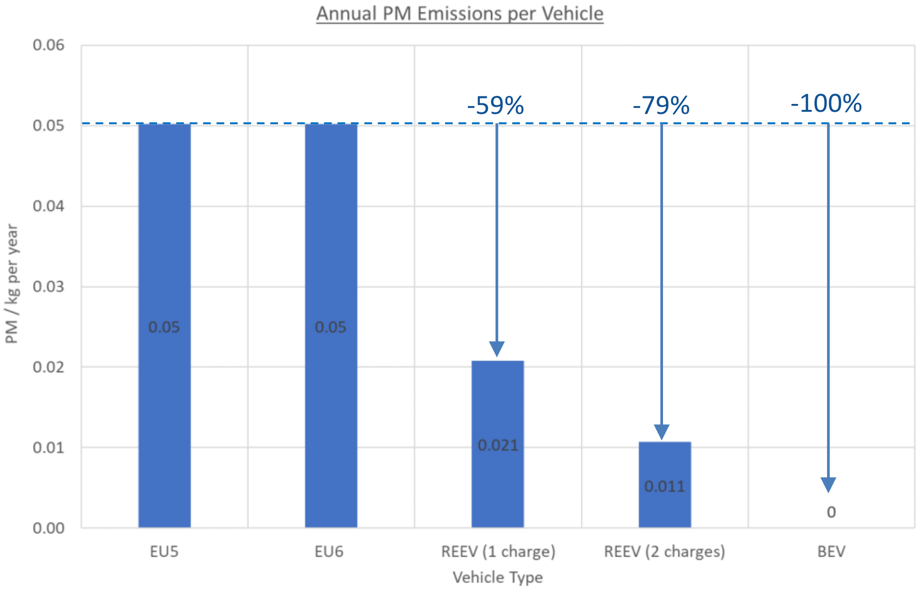
ULEV Hackney Carriage Business Model Assessment

Emissions per Vehicle Type: NOx and PM

Euro 5 diesel is estimated to emit **27kg more NOx** per year than a Euro 6, representing a **138% increase.** The NAEI emissions factors have recently been updated to reflect new real world evidence of Euro 5 and Euro 6 emissions, this is therefore considered to be a robust comparison. However similar evidence does not exist for pre Euro 5 standards and has therefore not been included in this analysis. The **LEVC TX (REEV)** gives a **99% reduction in NOx** and **59% reduction in PM** compared to a Euro 6 diesel (if charged twice per day), if operation in electric only mode is enforced within the zero emission zone it will produce no tailpipe emissions.

The **Dynamo (BEV)** produces **no tailpipe NOx or PM** and guarantees compliance with the zero emission zone.





ULEV Uptake Scenarios

Uptake Scenarios

Three uptake scenarios are proposed representing a low, medium and high uptake of ULEV hackney carriages in the fleet. A specific timescale has not been associated with these uptake scenarios. However with the implementation of a Zero Emission Zone and potential changes to hackney carriage licensing it is suggested that the scenarios are targeted for completion by 2025 (it is assumed that vehicle availability is not an issue). The assumptions for the three uptake scenarios are detailed below:

Low; Diesel uptake is double questionnaire responses, REEV uptake is reduced accordingly. LEVC TX users only charge once per day and therefore cover 49.5% of their miles on electricity.

Medium; Fleet composition is in line with questionnaire responses, this is an optimistic scenario in which only 32% of drivers purchase a diesel vehicle (if possible). LEVC TX users only charge once per day and therefore cover 49.5% of their miles on electricity.

High; Only 16% of fleet is diesel, of the remainder there is an approx. 30/70 REEV/BEV split for low mileage users and a 60/40 REEV/BEV split for high mileage users (>25,000 miles per annum). Driver training and economic benefit ensures that LEVC TX drivers charge twice a day and therefore cover 74% of their miles on electricity.

The relative percentage of each vehicle type is shown in the table below for the three scenarios:

Uptake Scenario	EU6 Diesel	REEV	BEV	Charges per day
Low	64%	26%	10%	1
Medium	32%	58%	10%	1
High	16%	37.5%	46.5%	2

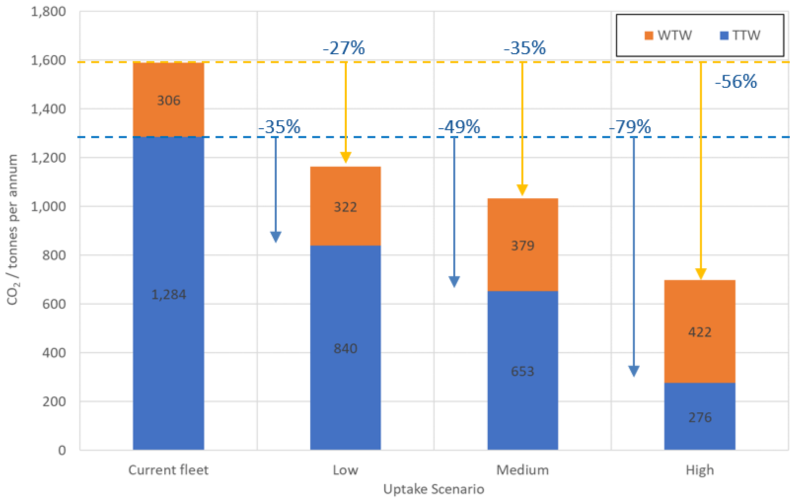
Impact on Fleet Emissions

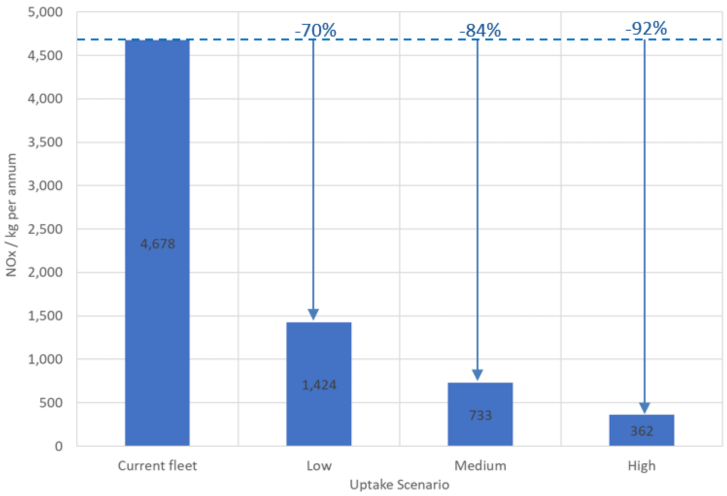
The charts below shows that the fleet of 113 hackney carriages currently emits **1,284 tonnes TTW** and **1,590 tonnes WTW of CO_2** each year. The current fleet also emits **4,678kg NOx** and **225kg PM per year**.

The reduction in emissions can then be seen for each uptake scenario, reducing the diesel fleet from 64% (low ULEV uptake) to 16% (high ULEV uptake) **reduces the TTW and WTW CO_2 emissions by 464 tonnes per year**. In the high uptake scenario this equates to a **reduction of 79% TTW and 56% WTW** compared to the current fleet.

The chart on the right shows the impact on NOx. As expected this demonstrates the main benefit of adopting ULEVs with even the low scenario **saving 3,254kg (70% reduction) NOx**. Likewise the **low scenario reduces PM from 225kg to 4kg per year (98% reduction). T**he strongest environmental case lies with **maximising the amount of BEV vehicles in fleet** - benefitting from no TTW CO_2, NOx or PM. If this is not viable then the emphasis needs to be maximising the miles travelled in electric only mode with REEVs.

128





6. Conclusions and Recommendations

Conclusions and Recommendations

- **Engagement with the hackney carriage driver trade** highlighted that drivers have typically purchased used diesel vehicles then operated them until they are no longer fit for purpose, the requirement to change this approach to that of financing a new vehicle purchase or not owning a vehicle at all is a concern. Additionally drivers are concerned about the upfront purchase price, battery reliability and real world range of ULEV hackney carriages. Feedback from workshops where vehicle suppliers showcased their vehicles was generally positive and as a minimum enabled discussion. Test drive opportunities are seen as a low impact incentive that could alleviate the above concerns.
  - **Recommendation; dissemination of the results from this study, ongoing driver engagement activities should be as 'hands on' as possible**
- The **average duty cycle** of a Oxford hackney carriage was found to be dominated by urban driving (61%) with some rural driving (30%), additionally vehicles were shown to average 88 miles per day.
- The **predicted real world electric only range** of the LEVC TX would allow it to cover 11,910 (49.5%) of the 24,068 miles covered during the data logging trial on one overnight charge only, however the Dynamo eNV200 is seen as a better operational fit covering 20,511 (85.2%) of the total miles. The predicted real world range of the Dynamo was exceeded on 75 out of the 279 days of use, although these are the days where it may be beneficial to use a range extended electric vehicle it is worth noting that to maximise the financial benefits it is suggested that both vehicles would require an additional opportunity charge. Doing so leaves 10 days where the Dynamo is unable to complete the total daily mileage.
  - **Recommendation; trial LEVC TX (REEV) and Dynamo eNV200 (BEV) with CAN bus and GPS data logger for real world verification of results, determine barriers to adoption of Dynamo**
- A **total cost of ownership model** was developed to highlight the required ownership and usage patterns required to make ULEVs financially viable. Owing to a purchase price that is competitive to diesel alternatives the fuel and SMR savings ensure that the longest payback period for the Dynamo is 4 years, savings for a driver doing 25,000 miles per annum of £244 and £312 per month are possible for 5 and 10 years of ownership respectively.
- The relatively high purchase price and uncertain residual value makes the LEVC TX financially challenging for low mileage users, payback is possible in 7 years or less if drivers do >20,000 miles per annum.
  - **Recommendation; determine approach to incentivising ULEVs – Dynamo is already financially viable but seemingly unpopular with the driver community, subsiding license fees or a scrappage scheme are suggested to encourage LEVC TX uptake if desired (depending on target composition of fleet and consideration of air quality, customer perception, vehicle availability etc).**

Conclusions and Recommendations

- Research into the **used Euro 6 diesel market** showed that there are very few vehicles for sale through private sellers and approved used vehicles cost >£30,000, additionally most are only available on a hire purchase agreement (placing all of the depreciation risk on the owner)
    - **Recommendation; periodic review of the second hand market for Euro 6 diesel and ULEV hackney carriages. Factors such as licensing, Zero Emission Zone introduction and vehicle availability could have a significant impact on future purchase options for drivers.**
- At present ULEV hackney carriage vehicle suppliers do not offer **leasing** as a standard product, it is possible to effectively lease a vehicle through a Personal Contract Purchase (PCP) where the vehicle is returned at the end of the agreement. An example of this type of ownership shows that both ULEV options are competitive with an equivalent diesel, this is due to the high optional final payment on the LEVC TX (£21,570) and a reduction of £219 and £373 per month in running costs for the LEVC TX and Dynamo respectively.
    - **Recommendation; presentation of total cost of ownership based on PCP plus running costs to drivers**
- **Discussions with potential leasing partners** were very positive with many expressing interest in managing leases on behalf of the council. Their primary concerns were around the depreciation risk and maturity of the new vehicles, as such their preferred route would be that the vehicles are owned by the local authority. Additionally entering into personal leasing agreements with individuals was seen as challenging, use of vehicle plates and/or drivers licenses as security against payment default has been suggested as a potential route to reducing the risk.
- **Payback period calculations** showed that in order to provide a competitive monthly leasing cost (<£150) the council would have to own the vehicle for 4-6 years. However it is worth noting this does not include set up and management costs, as such the lease price or payback time is likely to be longer. It is suggested that alternative models, such as rental to multiple drivers, are further investigated. Multiple solutions are likely necessary given the demographic of the drivers/owners.
    - **Recommendation; Oxford City Council to review payback periods then enter into discussions with potential partners and vehicle suppliers, collect feedback from all drivers regarding suggested options.**
- A high level of ULEV uptake can improve the hackney carriage **fleet emissions** significantly with reductions of 79% TTW CO_2, 56% WTW CO_2, 92% NOx and 99% PM.
    - **Recommendation; Consider approach to maximising electric only driving – driver education, BEV uptake incentives, infrastructure availability and pricing.**

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cenex

132