ULEV Hackney Carriage Business Model Assessment - Nottingham

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Revision	Reason	Date Issued.
1	Draft report issued	26/04/2018
2	Revised following feedback and presentation to Nottingham City Council – section 4.1 completed	08/05/2018
3	Revised following feedback from Steve Carroll	06/06/2018

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

Executive Summary

This report details an assessment of the operational and financial suitability of Ultra Low Emission Hackney Carriages as replacements for the 411 diesel vehicles currently licensed within the Nottingham 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 Nottingham a two month data logging trial was completed using 18 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 79% of existing vehicles are acquired second hand with only 27% 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 and real world electric only range were also raised as major concerns. 368 days worth of data were captured during the data logging trial during which the drivers completed 19,954 miles.

Driving habits and ULEV suitability; The average daily mileage was 53 miles (or 16,574 miles per annum) with a 74/24/2% split of urban, rural and motorway driving. This relatively low mileage ensures that both ULEV options are operationally suitable covering between 67 (LEVC TX) and 96.5% (Dynamo) of the total mileage on one overnight charge only, it is worth noting that without a second charge the additional total range of the LEVC TX (over the Dynamo) would only have been required for 20 of the 368 days (5.4%).

Cost of ULEVs; The Dynamo is financially viable for drivers/owners with savings of £112 per month over 5 years of ownership at 15,000 miles per annum. The LEVC TX was found to be more challenging requiring between 6-8 years of ownership, an additional financial intervention of ~£100 per month would be required to encourage uptake.

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 2,803 tonnes TTW CO_2, 3,471 tonnes WTW CO_2, 10,113kg NOx and 496kg of PM per year. A high level of ULEV uptake (70%) can improve this significantly with reductions of 72% TTW CO_2, 51% WTW CO_2, 85% 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 Nottingham 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 CAZ in 2020, end of finance agreements etc.
- Nottingham 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

As part of ongoing efforts to improve air quality (in line with Clean Air Zone proposals) and to ensure that the Hackney Carriage fleet is a modern integrated part of the transport system Nottingham 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 project background and key deliverables.



Background - Clean Air Zone (CAZ)

The primary driver for the project is the introduction of Clean Air Zones in 2020 to combat poor local air quality caused by transportation in cities. The Royal College of Paediatrics and Child Health (RCPCH) and the Royal College of Physicians (RCP) estimate that exposure to air pollution is linked to 40,000 premature deaths in the UK each year and costs the NHS £20 billion. A Clean Air Zone is a defined area where targeted action is taken to improve air quality, in particular reducing NOx (which the UK is currently failing to meet its legal obligation). The government has mandated that **Nottingham**, Derby, Leeds, Birmingham and Southampton are required to create a CAZ by 2020. Clean air zones are to be set up and run by local authorities in line with the CAZ framework. This allows the authority choice in the class, type and size of the zone:

Class A	Class B	Class C	Class D
Buses, coaches, **taxis** and private hire vehicles (PHV's)	Class A + Heavy goods vehicles (HGV's)	Class B + Large/small vans (light goods vehicles, LGV's) and minibuses	Class C + Cars and motorcycles/mopeds (optional)

Type	
Charging	Non-charging

Charge level
TBC (set by framework)

Hours of operation
24/7 (can be amended by L.A.)

Exemptions (enforced)	Exemptions (optional)
Military	Residents
Historic	Non-road going (e.g. cranes, tractors)
Disabled	Blue badge
Emergency (non-fleet)	Emergency (fleet)
ULEV (<75 g/km CO_2)	Community transport

Vehicle type	Emission standard
Bus, coach, HGV	Euro VI
Large/small van, minibus, car, **taxi**, PHV	Euro 6 (diesel) Euro 4 (petrol)
Motorcycles, mopeds	Euro 3

A key message of the CAZ framework is actively supporting and facilitating the use of ULEVs through: 'Promotion and demonstration schemes both to the public and to particular sectors or business groups likely to be affected by Clean Air Zones, such as taxi drivers, can showcase technologies and allow people to become more familiar with ULEVs. This might include demonstration and test drives; together with advice on use, the business case, and the financial incentives available'

Background – Hackney Carriage Licensing Policies

Hackney carriage vehicle licensing is a hard measure that Nottingham City Council intend to use to assist the transition to ultra low emission vehicles, it also provides a representative timescale for the key decision points for the acquisition of new vehicles and business models. As such the age and specification policies for Nottingham hackney carriages are detailed below (correct at the time of writing):

- Vehicle owners are encouraged to contact the Licensing Office for advice at least two years before the vehicle is due to reach the upper age limit or purchasing a new vehicle
- From 01/01/2018
    - All hackney carriages over the age of three years will be subject to six monthly MOT inspections
    - Hackney carriages over the age of ten years will ordinarily be refused a license unless the vehicle is in exceptionally good road worthy condition
- From 01/01/2020
    - All hackney carriages must be a minimum of Euro 6 diesel or Zero Emission Capable (ZEC) ULEV
    - Euro 6 diesel age limit of ten years
    - ULEV age limit of fourteen years
- From 01/01/2025
    - ULEV age limit of twelve years
- From 01/01/2030
    - All hackney carriages must be a ULEV

Work Packages and Deliverables

Due to the CAZ legislation and aggressive licencing policies being introduced Nottingham 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 a maximum of 40 CLEAR Capture telemetry devices fitted to participants existing vehicles for two months. Conducting surveys and interviews with licensed drivers.

WP3; Analysis of Nottingham 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 and annual mileage.

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 Nottingham
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 the 2020 Clean Air Zone 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).



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



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; LEVC TX

- Supplier – LEVC
- Chassis – LEVC TX
- Model – VISTA
- Powertrain – Range Extended Electric Vehicle
- Price – from £55,599 OTR



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



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 Nottingham Racecourse. 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.

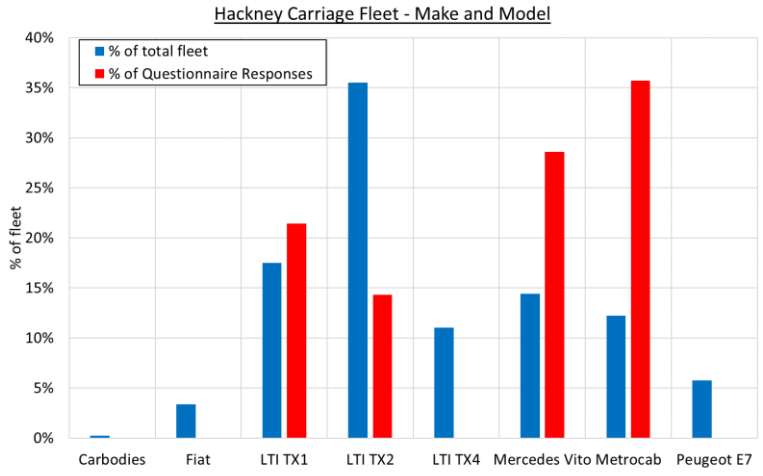


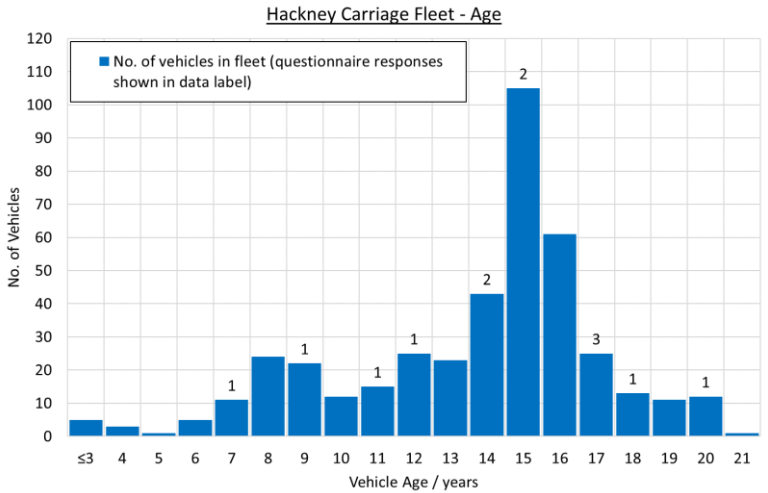
Introduction; Questionnaire Demographics

Nottingham hackney carriage drivers were invited to attend a one day event at Nottingham Racecourse on the 29th Jan 2018 to gain the necessary input into the low emission taxi business model. Attendance on the day was estimated to be ~70 licensed drivers. 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.

14 drivers submitted completed questionnaires, this represents a reasonably low proportional of the total licence holders (14/417 = 3.4%). Therefore care should be taken when reviewing the following analysis in consideration of the total population. It is also worth noting that all of the vehicles included in the responses are driven by an individual driver so shared use of vehicles is not represented.

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





It can be seen that TX2 owners are underrepresented in the questionnaire relative to their share of the fleet (15% rather than 35%), the opposite is true for Mercedes Vito and Metrocab. There is however a good spread of vehicle age ranging from 7-20 years with a small peak between 14-17 years.

Current Vehicle Usage; Mileage and Refuelling Patterns

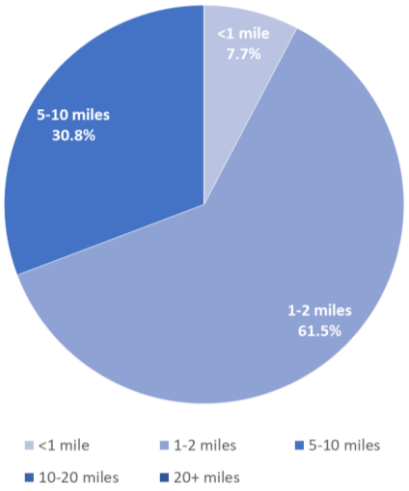
A number of questions were asked relating to the present usage pattern of Nottingham hackney carriages. The intention being to understand the operational impact and suitability of zero emission capable taxis, in particular highlighting likely driving modes and charging requirements.

57% of drivers surveyed reported using the vehicle for **both personal and business use**, this will be an important factor when considering vehicle suitability. Owing to an average vehicle age of 13.6 years the total vehicle mileage is also high across respondents with **57% reporting >250,000 miles**, potentially setting a high expectation for the reliability of new vehicles. In addition **50% of drivers are doing 15,000-20,000 miles per year (with 71% doing >15,000 miles)**, at 6 days a week for 48 weeks a year this equates to ~52 miles per day. Finally the vast majority (**69%**) of vehicles are estimated to have a fuel consumption of **15-30 mpg**

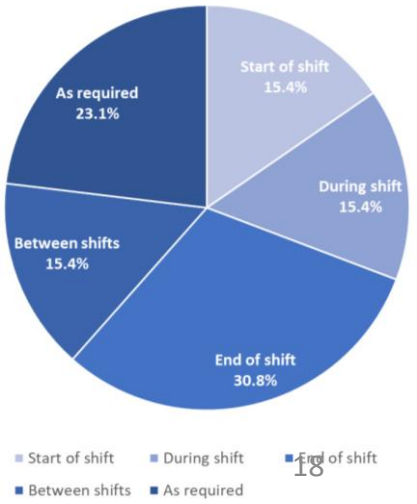
Drivers were also asked questions regarding their typical working behaviour to see whether it would require significant change when using electric vehicles. The first pie chart on the right shows that **69% travelled less than 2 miles** before taking their first fare with **no respondents travelling 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 **~62% refuelling at the start (15%), during (15%) or at the end (31% of their shift.** Depending on duty cycle an increased number of drivers may be required to recharge their vehicle during the shift itself. This would represent a change in behavior for 85% of the drivers questioned.

How far do you travel before taking your first customer?

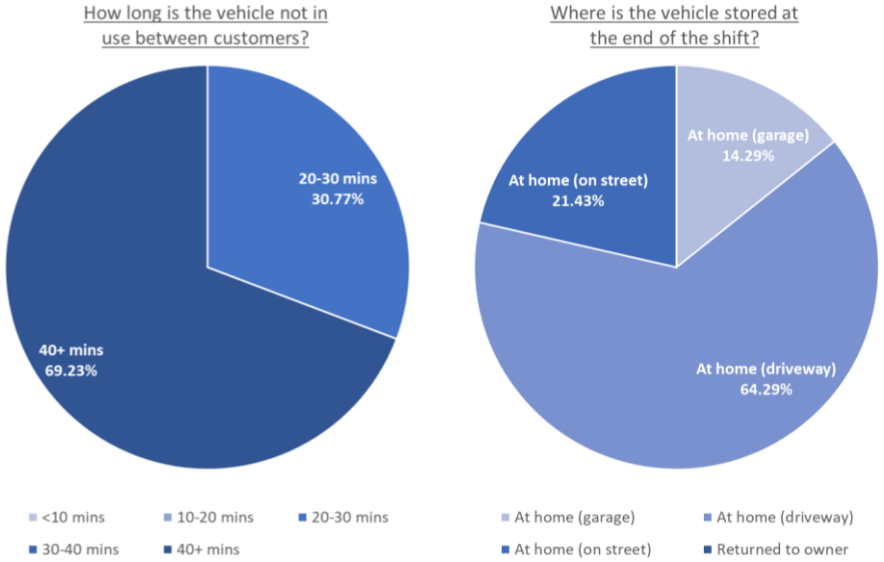


When is the vehicle refuelled?



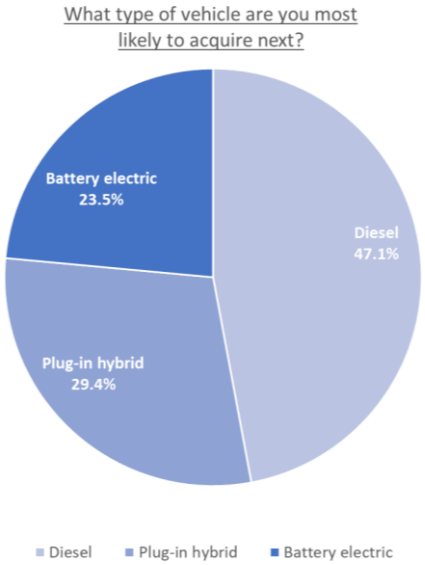
Present Vehicle Usage; Suitability for ULEV Charging

Data showed that top up charging could be integrated during a shift with relative ease with **69% of vehicles not in use for >40 minutes between customers**, with the shortest wait time being **20 minutes**. In order to maximise earnings it is desirable for the drivers to reduce this down time, given the additional council interventions (such as mytaxi) 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 **~79% of respondents having off street parking** (either via a driveway or garage), furthermore **64% of vehicles currently 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 **79% of vehicles are acquired second hand** with only **27% 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 **0% of respondents would consider leasing** their next vehicle with a **50/50 split between either buying or not knowing** their next purchasing method. However **62%** of drivers **would consider acquiring a brand new vehicle**, with a further **30% responding maybe**.



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 **total cost of ownership (100%), reliability (90.9%) and maintenance costs (81.8%)**. As no criteria had a majority response of not important the relatively lowest priority criteria are **vehicle age (36.4% not important) and emissions (10% not important).**

Finally the pie chart on the left shows that **53% intend to acquire an ULEV** taxi as their next vehicle with **47% most likely to acquire a diesel**. Interesting plug-in hybrid vehicles appear to be slightly favoured over pure electric vehicles with 29.4% and 23.5% of likely purchases respectively.

	Very Important	Important	Not Important	Responses
Total cost of ownership	100.0	0.0	0.0	78.6 (11/14)
Initial purchase cost	72.7	27.3	0.0	78.6 (11/14)
Maintenance costs	81.8	18.2	0.0	78.6 (11/14)
Fuel economy	72.7	27.3	0.0	78.6 (11/14)
Emissions	50.0	40.0	10.0	71.4 (10/14)
Reliability	90.9	9.1	0.0	78.6 (11/14)
Vehicle age	36.4	27.3	36.4	78.6 (11/14)

Perceptions of Ultra Low Emission Taxis; Adoption Barriers

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 **29% of those surveyed having driven such vehicles.** Knowledge of **Clean Air Zone introduction was good with 77% demonstrating awareness**. Similarly there was reasonable awareness of compliant vehicles. The LEVC TX is the most well known option followed by the Dynamo and finally the Metrocab (with **92%, 58% and 50%** 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.

	Major Concern	Minor Concern	Not a Concern	Responses
Purchase price too high	100.0	0.0	0.0	92.9 (13/14)
Maintenance costs	46.2	46.2	7.7	92.9 (13/14)
Fuel costs	18.2	36.4	45.5	78.6 (11/14)
Customers won't like them	0.0	20.0	80.0	71.4 (10/14)
Vehicle will be charging too long during shifts	83.3	16.7	0.0	85.7 (12/14)
Knowledge of how they work and drive	50.0	25.0	25.0	85.7 (12/14)
Range	90.0	0.0	10.0	71.4 (10/14)
Battery reliability	92.3	0.0	7.7	92.9 (13/14)
Vehicle reliability	75.0	16.7	8.3	85.7 (12/14)
Lack of charging points	53.9	30.8	15.4	92.9 (13/14)

The three greatest concerns (those with the highest proportion of major concern) are **purchase price too high (100%), battery reliability (92.3%) and driving range (90%)**. It is also worth noting that all drivers reported either a major (83.3%) or minor concern (16.7%) with 'vehicle will be charging too long during shifts', this is an interesting response given that at present the majority of vehicles are not in use for >40 minutes between customers. **Customer perception** was the lowest concern **(80% not a concern)** followed by **fuel costs (45.5% not a concern)**. Likewise **maintenance costs** ranked relatively low with **54% reporting it as either a minor concern or not a concern.** Given that total cost of ownership was highlighted as the most important purchasing criteria it is interesting that initial purchase price is the largest concern, this is only partially balanced by fuel and maintenance costs being comparatively low concerns. This highlights the necessity to quantify these costs to enable an informed decision.

Perceptions of Ultra Low Emission Taxis; Incentives

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 **dedicated taxi charging infrastructure (70%), reduced licence fees for ULEV (63.6%) and try before you buy scheme (63.6%)**. 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 **test drive opportunities (90%), low cost leasing option (88.9%), try before you buy scheme (81.8%) and a factsheet of detailed costs compared to diesel (81.8%).**

	Very Likely	Likely	Unlikely	Very Unlikely	Responses
Reduced licence fees for ULEV	63.6	9.1	18.2	9.1	78.6 (11/14)
Factsheet of detailed costs compared to diesel	36.4	45.5	18.2	0.0	78.6 (11/14)
Test drive opportunities	40.0	50.0	10.0	0.0	71.4 (10/14)
Dedicated taxi charging infrastructure	70.0	10.0	20.0	0.0	71.4 (10/14)
Training on electric vehicle use and charging	20.0	40.0	40.0	0.0	71.4 (10/14)
Low cost leasing option	55.6	33.3	0.0	11.1	64.3 (9/14)
Try before you buy scheme	63.6	18.2	9.1	9.1	78.6 (11/14)
Priority at taxi ranks	27.3	18.2	18.2	36.4	78.6 (11/14)

	Very Likely + Likely	Unlikely + Very Unlikely
Reduced licence fees for ULEV	72.7	27.3
Factsheet of detailed costs compared to diesel	81.8	18.2
Test drive opportunities	90.0	10.0
Dedicated taxi charging infrastructure	80.0	20.0
Training on electric vehicle use and charging	60.0	40.0
Low cost leasing option	88.9	11.1
Try before you buy scheme	81.8	18.2
Priority at taxi ranks	45.5	54.5

The **incentives least likely** to encourage purchase of a ULEV taxi are **priority at taxi ranks (54.5% unlikely or very unlikely) and training on electric vehicle use and charging (40% unlikely or very unlikely)**.

It is suggested that the potential incentives are ranked against ease of implementation. As an example test drives may offer a good incentive for drivers with relatively low effort.

Summary

- **14 drivers submitted completed questionnaires**, this represents a reasonably low proportional of the total licence holders (14/417 = 3.4%).
- There is a good spread of vehicle age (7-20 years) and vehicle type (with the top three types all represented) in the responses.
- Existing vehicles are on **average 13.6 years old** and have high mileage with **57% having >250,000 miles**, annual mileage is also reasonably high with **50% doing 15,000-20,000 miles** per year (equivalent to **~52 miles a day**)
- Daily usage patterns;
  - Drivers were found to commute very short distances before taking their first fare (**69% travelling <2 miles**)
  - Drivers are used to refuelling around their shift (**62% refuelling before, during or after**), it is worth noting however that **during the shift only accounts for 15%** of responses.
  - **69%** of drivers currently spend **>40 minutes waiting** between customers, with the minimum wait being 20 minutes.
  - **79%** of drivers have **off street parking** with **64%** of vehicles having **overnight access to an electric supply point**.
- Purchasing priorities;
  - At present **79% of vehicles are acquired second hand** with only **27% using finance** to fund the purchase
  - **62%** of drivers **would consider acquiring a brand new vehicle**, with a further **30% responding maybe. No drivers would currently consider a leasing model.**
  - **Total cost of ownership (100%), reliability (90.9%) and maintenance costs (81.8%)** are the most important purchasing criteria. **Vehicle age and emissions** are the least important. **53%** of drivers **intend to acquire an ULEV** taxi as their next vehicle.
- Perceptions of ultra low emission taxis;
  - Only **29%** of those surveyed have **driven plug-in hybrid or battery electric vehicles**
  - **Purchase price too high (100%), battery reliability (92.3%) and driving range (90%)** are the major concerns with ULEV taxis, **customer perception** was the lowest concern **(80% not a concern)** followed by **fuel costs (45.5% not a concern)**.
  - Most of the proposed incentives are likely to influence purchasing behaviour with **dedicated taxi charging infrastructure (70%)** and **reduced licence fees for ULEV (63.6%)** receiving the most very likely responses. **Test drive opportunities (90%)** and **low cost leasing option (88.9%)** received the most total positive responses (very likely and likely)
  - **Priority at taxi ranks** and **training on electric vehicle use/charging** are the least popular incentives and are unlikely to be effective

3. Duty Cycle – Nottingham Hackney Carriage

To accurately assess vehicle operational and financial suitability it is important that any analysis is performed in the context of Nottingham usage, as such this section discusses the use of telemetry fitted to existing vehicles to develop a Nottingham 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 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)

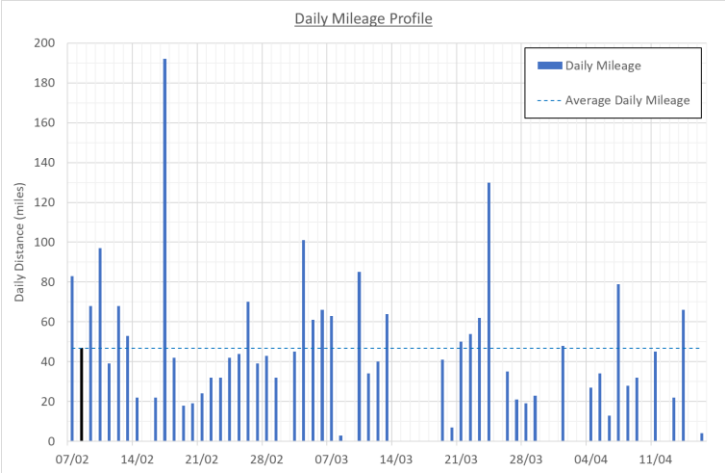
- Participants were also asked to complete a mileage and refuelling log sheet to verify the results from the loggers and provide an accurate fuel consumption figure (in addition to the estimation from the questionnaire responses).
- To provide a representative data set it was suggested that 10% of the fleet (~40 vehicles) should be logged. As participation in the trial was voluntary and there was some concern about having data loggers fitted a total of 18 drivers were recruited.
- Additionally out of the 18 loggers provided 8 recorded insufficient data and were therefore removed from the analysis (likely due to removal or issues with the vehicle power supply). Therefore the data collected from the remaining 10 loggers represents ~2.5% of the total fleet.

Indicative Logger Outputs

Daily Mileage Profile

The chart below shows a typical daily mileage profile from a Nottingham 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.

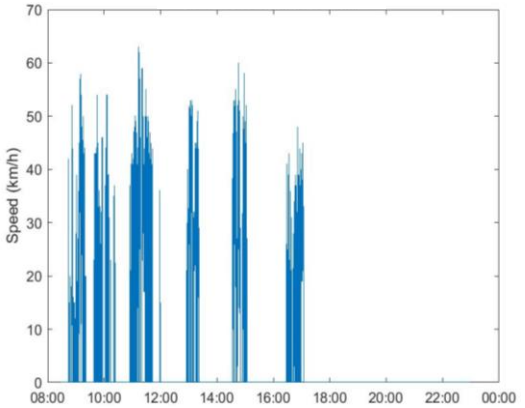


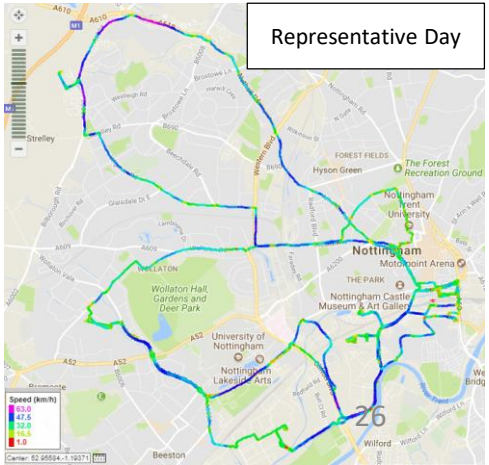
Real World Duty Cycle

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 12-1pm depending on location and availability.





Nottingham 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 Nottingham. A total of **368 days** worth of data were captured during which the drivers completed **19,954 miles**. A summary of the averaged journey statistics is shown in the table below:

Metric	Mean	Maximum
Average daily mileage / miles	53	73
Maximum daily mileage / miles	142.1	246
Days per week usage	6	7
Extrapolated annual mileage / miles	16,574	23,631
Average journey distance / miles	5.4	7.4
Average number of journeys per day	10	13
Average journey time / mins	21	29
Average daily driving time	3h 36min	5h 14min
Duty Cycle	**%**	**miles**
Urban driving distance	74.4	14,833
Rural driving distance	23.5	4,690
Motorway driving distance	2.1	412

It can be seen that the **average daily mileage is 53 miles**, this combined with **6 days per week** correlates well with the calculated value of 52 miles from the questionnaire responses. Likewise this gives an **extrapolated annual mileage of 16,574 miles**, this is in agreement with 50% of questionnaire respondents reporting an annual mileage of 15-20,000 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 **3.6h per day** should allow ample down time for opportunity vehicle charging if required, additionally as the average journey distance is only **5.4 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:

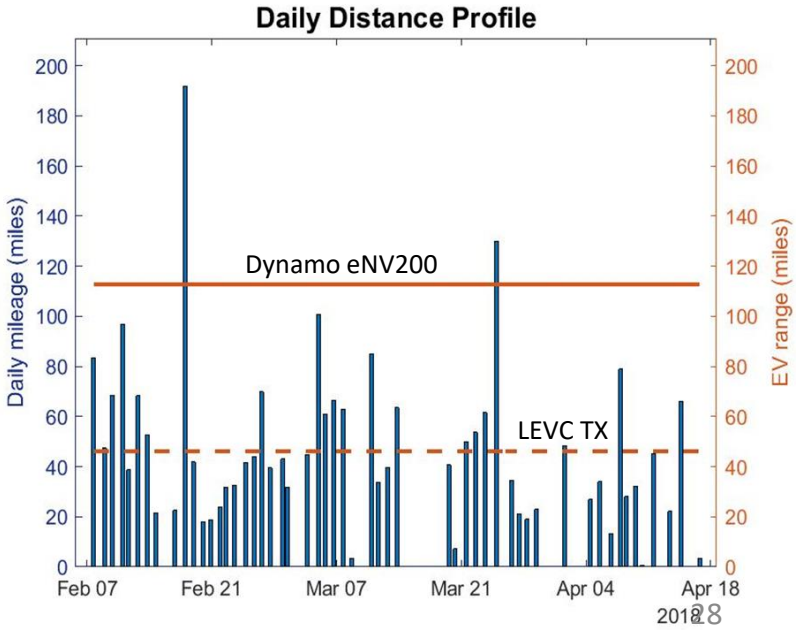
74.4/23.5/2.1%

Nottingham 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.

It is then possible to estimate and compare the 'real world' electric only range with the daily mileage profile as shown in the chart 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.

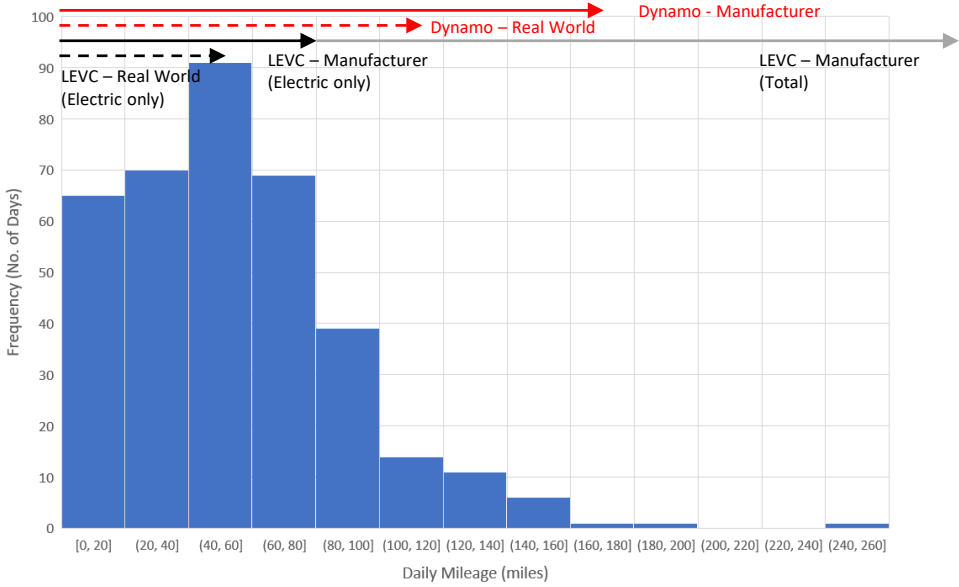


Nottingham Duty Cycle – ULEV Suitability

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 **40-60 miles**. The maximum daily mileage of 246 miles appears to be an outlier, occurring only on one day at a significantly increased distance. 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 67.4% of miles on electric only with one charge and 88.7% of miles with two charges**. The **Dynamo covers 96.5% of the total mileage**, in many cases this would result in less than one charge per day.

As the LEVC TX real world range is close to the average daily mileage it will fully deplete the battery on **25-51% of days**.



Electric Only Operation	Miles	% of miles on electric	Days	% of days on electric
LEVC TX (REEV) – overnight charge	13,452	67.4	180	48.9
LEVC TX (REEV) – overnight + opportunity charge	17,705	88.7	275	74.7
Dynamo (BEV) – overnight charge	19,258	96.5	348	94.6
Total Mileage/Days	19,954	100	368	100

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.



Methodology and Assumptions

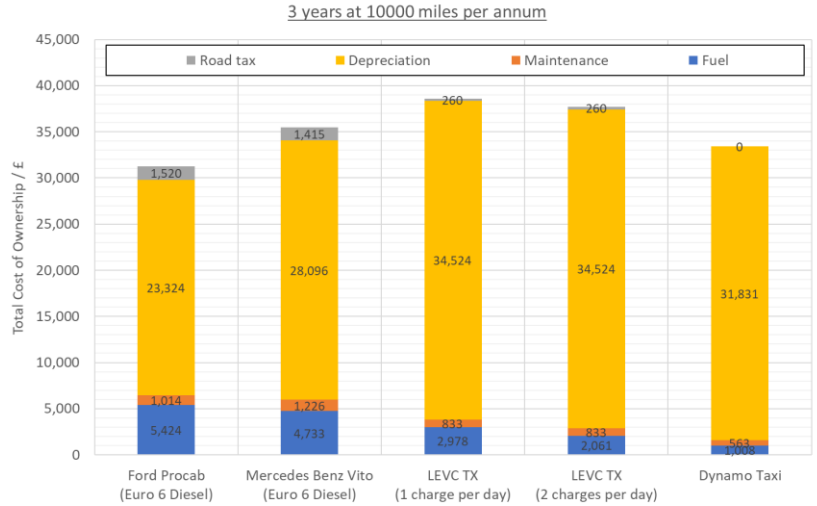
A total cost of ownership model was built to incorporate the major purchasing and running costs, costs that are assumed to be equivalent between all technologies (such as insurance, hackney carriage license) or are insignificant have been excluded. The model allows input of different ownership periods 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	74.4% urban, 23.5% rural, 2.1% motorway REEV covers 67.4% miles electric only (1 charge) REEV covers 88.7% 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 Clean Air Zones 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

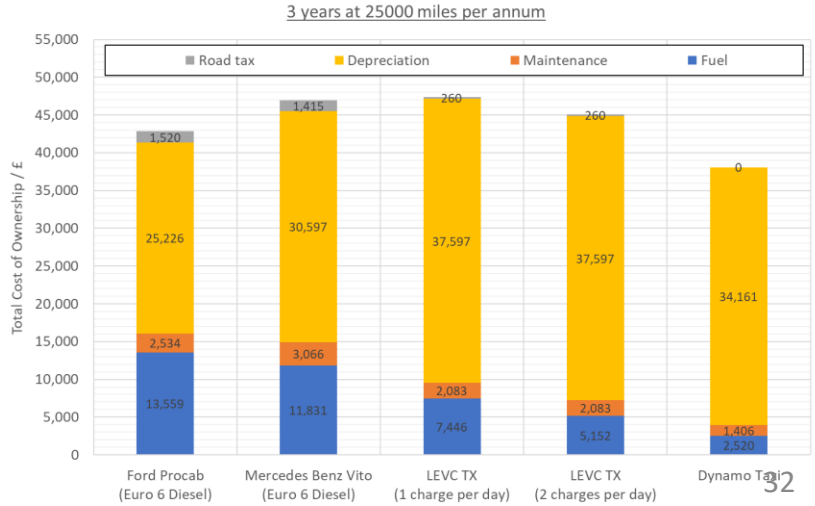
1. Low Ownership Period, Low Annual Mileage

This case represents the ~30% of drivers who reported doing less than 15,000 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 **~£6k and ~£2k higher** for the LEVC TX and Dynamo respectively.



2. Low Ownership Period, High Annual Mileage

~20% of drivers reported doing greater than 20,000 miles per year, in this case the mileage is 25,000 miles and the ownership period remains at 3 years. The depreciation cost remains higher for the ULEVs, however due to the increased mileage there are **fuel savings of between ~£6-8.5k and ~£11k** for the LEVC TX and Dynamo respectively. This makes the Dynamo financially viable with a TCO **saving of £4,752**. The LEVC TX is **cost neutral with a Mercedes Vito** but still at least £2k more expensive than the Ford Procab.

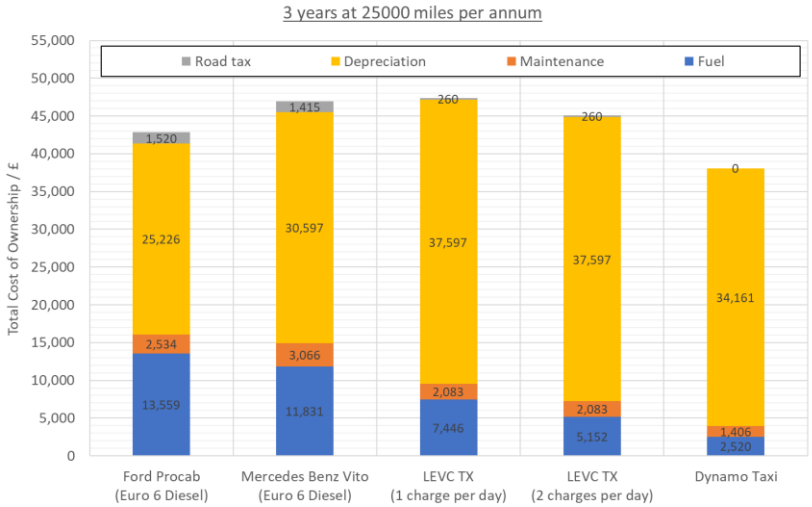


Total Cost of Ownership

2. Low Ownership Period, High Annual Mileage

As per the previous slide, provided as reference for high ownership period and annual mileage scenario (3)

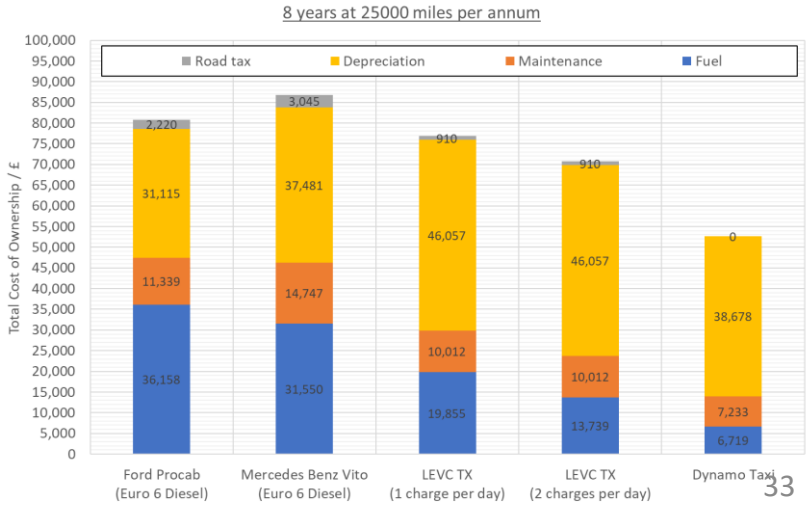
The Dynamo is financially viable with a TCO **saving of £4,752**. The LEVC TX is **cost neutral with a Mercedes Vito** but still at least £2k more expensive than the Ford Procab.



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 8 years at 25,000 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.

In this scenario the LEVC TX provides a **saving of up to ~£15k** and the Dynamo provides a **saving of ~28k.**



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 5,000-35,000. 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.

Ford Procab (Diesel)

Ownership Period / years	Annual Mileage / miles						
	5,000	10,000	15,000	20,000	25,000	30,000	35,000
2	922	1,075	1,198	1,309	1,415	1,517	1,616
3	734	869	983	1,088	1,190	1,289	1,386
4	631	760	870	974	1,075	1,173	1,270
5	575	690	794	895	994	1,091	1,188
6	510	622	725	826	925	1,024	1,121
7	465	575	679	780	880	980	1,079
8	422	532	637	740	842	943	1,044
9	389	500	607	711	814	917	1,020
10	363	475	583	689	794	899	1,003

Dynamo (BEV)

Ownership Period / years	Annual Mileage / miles						
	5,000	10,000	15,000	20,000	25,000	30,000	35,000
2	246	196	136	73	9	-56	-122
3	112	59	-2	-67	-132	-198	-265
4	50	-5	-68	-134	-201	-268	-335
5	5	-49	-112	-178	-244	-312	-379
6	-14	-69	-132	-198	-265	-333	-401
7	-26	-83	-147	-214	-282	-350	-419
8	-33	-92	-158	-225	-294	-363	-432
9	-39	-100	-166	-234	-304	-373	-443
10	-44	-106	-173	-242	-312	-382	-452

LEVC TX (REEV)

Ownership Period / years	Annual Mileage / miles						
	5,000	10,000	15,000	20,000	25,000	30,000	35,000
2	210	240	232	210	181	147	111
3	199	178	144	104	63	19	-25
4	163	135	97	55	12	-34	-79
5	104	89	56	17	-25	-69	-114
6	104	69	28	-17	-63	-109	-156
7	87	50	7	-38	-85	-132	-179
8	70	31	-13	-58	-105	-153	-201
9	57	17	-28	-74	-121	-169	-217
10	46	5	-40	-87	-134	-182	-231

Values represent the monthly cost difference from diesel

The top chart on the left shows the results for the BEV, the solid black lines represent the typical annual mileage range of Nottingham hackney carriages and the red shows the maximum. It can be seen that there is a strong financial case for most drivers, assuming an annual mileage of 15,000 miles yields **savings of £112 and £173 per month over 5 and 10 years of ownership respectively**.

In order to make the REEV financially viable against the most affordable diesel it is necessary to do **greater than 15,000 miles per annum and own the vehicle for 8 years** (this halves to 4 years if the annual mileage increases to 30,000 miles per annum). If encouragement of REEV uptake is desired **an additional financial incentive of £100 per month** would increase access of the vehicle to those with usage shown in amber.

As a new hackney carriage driver license costs ~£510 for 3 years and the vehicle license costs £273 per year it is unlikely that this entire incentive could be achieved through differential licensing fees.

Alternative Purchasing Methods

1; https://www.carwow.co.uk/pcp-calculator
2; http://www.sbcommercials.co.uk/pages/mercedes-benz-vito-london-taxi-offer.php
3; http://www.levc.com/finance/tx-pcp-offers/

It is recognised that the total cost of ownership model likely represents the cheapest but highest risk method of owning the vehicle outright (as it includes no interest due to borrowing of money and the owner carrying all of the depreciation risk).
However it is unlikely that customers would be willing or able to meet the expense of purchasing the vehicle outright. Therefore many will choose to finance their purchase, as such the table below shows example finance offers and running costs calculated from the TCO model. For comparative purposes the deposit and term have been fixed, the interest rate and optional final payment have been taken directly from the manufacturer and an online finance calculator[1] has been used where details of an existing finance product is not available.

Example Personal Contract Purchase (PCP) / £	Mercedes Vito[1,2]	LEVC TX[3]	Dynamo[1]
Length of Finance	48 months		
APR %	5.3	6.9	5
OTR Cash Price	45,247	55,599	42,495
Deposit	3,250		
Monthly Vehicle Payment	688	**855**	**734**
Equivalent Weekly Payment	159	197	169
Optional Final Payment	15,191	21,570	9,000
Total Vehicle Cost	33,024	41,040	35,232
Monthly Running Costs	**295**	134	70
Total Running Costs	14,177	6,445	3,350
Total Cost of Ownership (Vehicle returned)	47,201	47,485	38,582

Without additional ownership or purchasing methods this is the most likely scenario for the owner driver. It is therefore promising that despite the **monthly payments being £46 to £167 more expensive for the ULEVs** the total cost of ownership over the four years **is equivalent for the LEVC TX** and **~£8500 less for the Dynamo**. This is due to a **reduction of monthly running costs** of between **£161** and **£225 per month.**

A note regarding used Euro 6 diesels: 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.

4.1 Leasing Business Model Guidance

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. Contact details can be provided by Cenex if desired.

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 the page 37.

Role			Pros	Cons	Enablers
Vehicle Owner	Lease Management	Lessee			
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

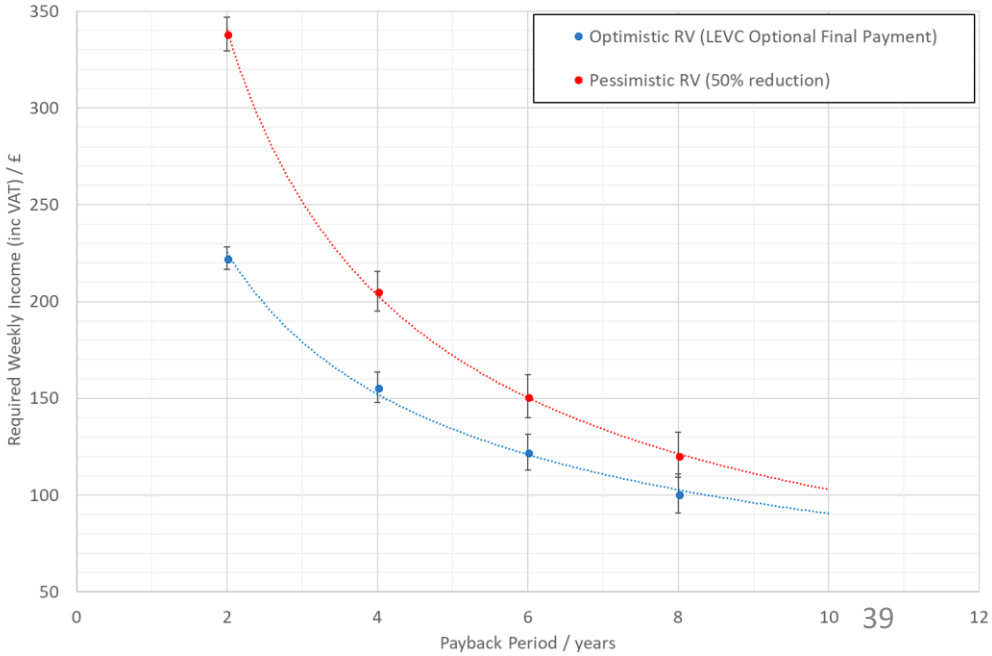
Due to high risk of new technology, unknown residual values, a fragmented market and the credit rating of drivers a conventional lease model was not an attractive option to providers; it is recommended that a shared/reduced risk model could be investigated with providers instead.

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

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 clean air 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. Weel-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 weight, euro standard, and average vehicle speed. These tables were used to estimate the air quality emissions. Average vehicle speed was derived from the Nottingham specific and real world duty cycles at 30km/h.
The existing diesel fleet was baselined assuming that 70% of the vehicles comply to Euro 3 standards and the remainder comply to Euro 4, an average fuel consumption of 26mpg was used (calculated from the participant drivers mileage and refuelling logs). All calculations assumed an annual mileage of 15,000 miles and a fleet of 411 hackney carriages.

The entire fleet emissions under different vehicle types is shown in the table below:

	CO_2 (tonnes per year)		Air Quality (kg per year)	
Vehicle	TTW (% reduction from baseline)	WTW (% reduction from baseline)	NOx (% reduction from baseline)	PM (% reduction from baseline)
Baseline (Current Nottingham Hackney Carriage)	6.82	8.44	24.607	1.207
Euro 6 Diesel	5.85 (-18%)	7.25 (-14%)	12.14 (-51%)	0.03 (-98%)
REEV (1 charge per day)	1.78 (-74%)	4.48 (-47%)	0.329 (-99%)	0.015 (-99%)
REEV (2 charges per day)	0.62 (-91%)	3.70 (-56%)	0.114 (-99.5%)	0.005 (-99.5%)
BEV	0 (-100%)	2.11 (-75%)	0 (-100%)	0 (-100%)

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 Clean Air Zone and changes to hackney carriage licensing both occurring from 2020 it is suggested that the scenarios are targeted for completion by 2025 (it is assumed that vehicle availability is not an issue). As Nottingham is designated as a Go Ultra Low City and has a well defined taxi strategy the uptake scenarios are optimistic, a very low uptake scenario is therefore not considered as it would likely not meet the target improvements. The assumptions for the three uptake scenarios are detailed below:

Low; 20% less drivers adopt ULEV vehicles compared to questionnaire responses – 70% purchase diesel vehicles with a 50/50 spilt between REEV and BEV. LEVC TX users only charge once per day and therefore cover 67.4% of their miles on electricity.

Medium; 50% of drivers purchase a diesel (in line with questionnaire responses) with a 50/50 spilt between REEV and BEV. LEVC TX users only charge once per day and therefore cover 67.4% of their miles on electricity.

High; 70% of drivers have economic and operational case to purchase an ULEV (as per the cost model drivers are more likely to purchase a battery electric vehicle). Council interventions ensure that these drivers can access the vehicles and are additionally incentivised (e.g. short term rentals, reduced license fees, ULEV only ranks and dedicated charging infrastructure). Driver training ensures that LEVC TX drivers charge twice a day and therefore cover 88.7% of their miles on electricity.

The relevant 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	70%	15%	15%	1
Medium	50%	25%	25%	1
High	30%	30%	40%	2

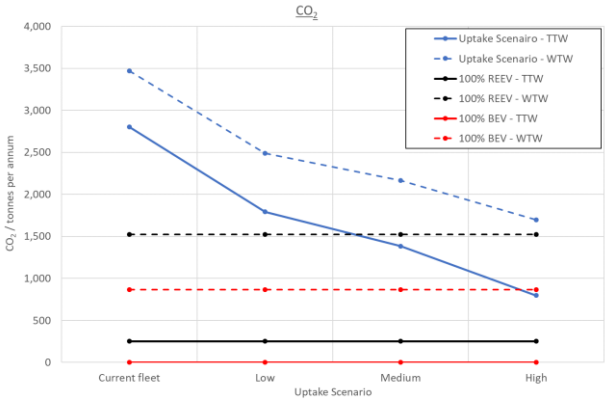
Impact on Fleet Emissions

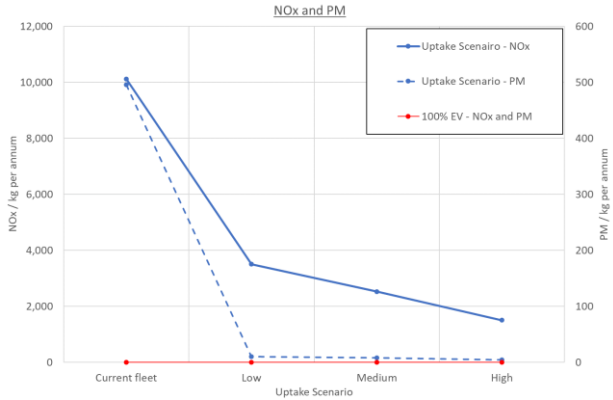
The charts below shows that the fleet of 411 hackney carriages currently emits **2,803 tonnes TTW** and **3,471 tonnes WTW of CO2** each year. As Euro 3 standards were six times higher for NOx and ten times higher for PM than Euro 6 the impact on local air quality is significant. The current fleet therefore emits **10,113kg NOx** and **496kg PM per year**.

The reduction in emissions can then be seen for each uptake scenario, reducing the diesel fleet from 70% (low ULEV uptake) to 30% (high ULEV uptake) **reduces the TTW and WTW CO_2 emissions by 1,000-2,000 tonnes per year**. In the high uptake scenario this equates to a **reduction of 72% TTW and 51% WTW**.

The chart on the right shows the impact on air quality. As expected this demonstrates the main benefit of adopting ULEVs with even the low scenario **saving 6,600kg (65% reduction) NOx and 486kg (98% reduction) PM**.

Finally the table at the bottom shows that the 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.





	% reduction from existing fleet (absolute values shown in appendix)			
Uptake Scenario	**TTW**	**WTW**	**NOx**	**PM**
Current Nottingham Fleet	0%	0%	0%	0%
Low	36%	28%	65%	98%
Medium	51%	38%	75%	98%
High	72%	51%	85%	99%
100% REEV	91%	56%	99.5%	99.6%
100% BEV	100%	75%	100%	100%

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 Nottingham hackney carriage was found to be dominated by urban driving (74%) with some rural driving (24%), additionally vehicles were shown to average only 53 miles per day.
- The **predicted real world electric only range** of the LEVC TX would allow it to cover 13,452 (67.4%) of the 19,954 miles covered during the data logging trial on one overnight charge only, however the Dynamo eNV200 is seen as a better operational fit covering 19,258 (96.5%) of the total miles. The predicted real world range of the Dynamo was only exceeded on 20 out of the 368 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 only leaves one day 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 5 years, savings for a driver doing 15,000 miles per annum of £112 and £173 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 6 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, a financial intervention of ~£100 per month is suggested to encourage LEVC TX uptake if desired (depending on target composition of fleet and consideration of air quality, customer perception, vehicle availability etc).**

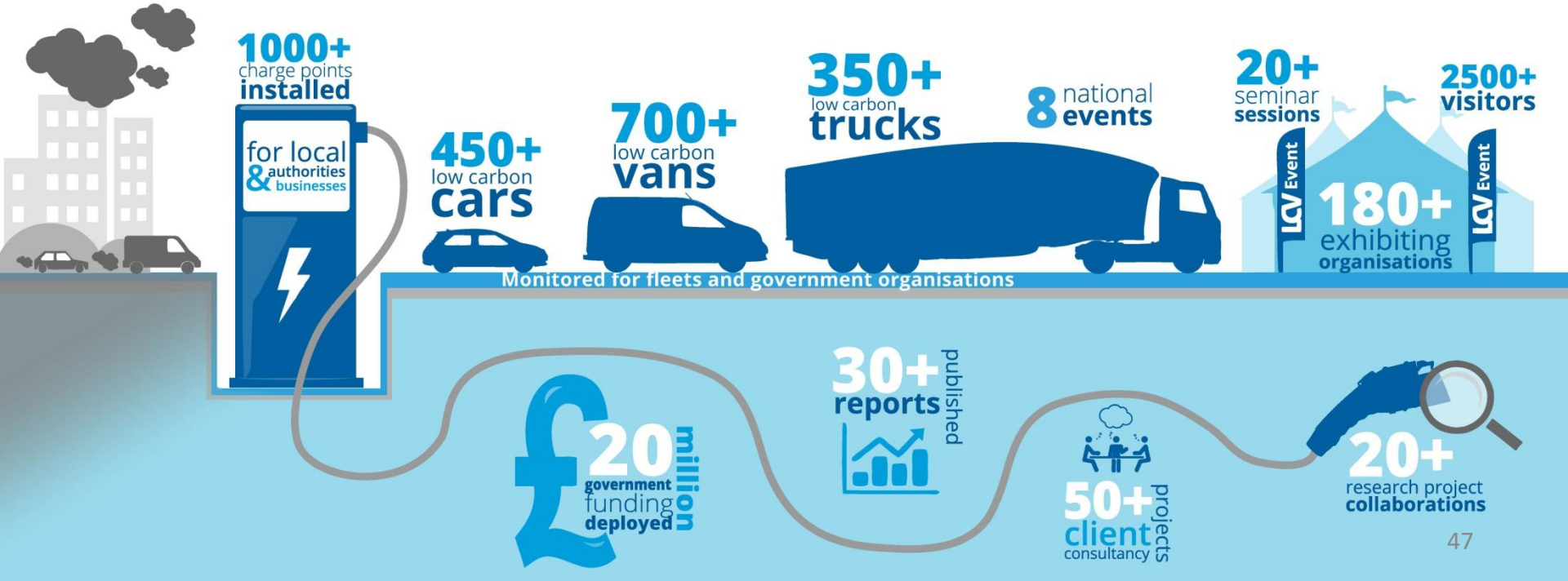
Conclusions and Recommendations

- 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, Clean Air 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 £161 and £225 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; Nottingham 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 72% TTW CO_2, 51% WTW CO_2, 85% 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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Appendix – Additional Tables (Emissions)

	CO_2 (tonnes per year)		Air Quality (kg per year)	
Uptake Scenario	TTW	WTW	NOx	PM
Current Nottingham Fleet	2,803	3,471	10,113	496
Low	1,793	2,491	3,512	11
Medium	1,385	2,166	2,528	8
High	797	1,697	1,510	5
100% REEV	253	1,523	47	2
100% BEV	0	867	0	0

Appendix – Additional Tables (TCO)

Dynamo (BEV)

Ownership Period / years	Annual Mileage / miles						
	5,000	10,000	15,000	20,000	25,000	30,000	35,000
2	27%	18%	11%	6%	1%	-4%	-8%
3	15%	7%	0%	-6%	-11%	-15%	-19%
4	8%	-1%	-8%	-14%	-19%	-23%	-26%
5	1%	-7%	-14%	-20%	-25%	-29%	-32%
6	-3%	-11%	-18%	-24%	-29%	-32%	-36%
7	-6%	-14%	-22%	-27%	-32%	-36%	-39%
8	-8%	-17%	-25%	-30%	-35%	-38%	-41%
9	-10%	-20%	-27%	-33%	-37%	-41%	-43%
10	-12%	-22%	-30%	-35%	-39%	-42%	-45%

LEVC TX (REEV)

Ownership Period / years	Annual Mileage / miles						
	5,000	10,000	15,000	20,000	25,000	30,000	35,000
2	23%	22%	19%	16%	13%	10%	7%
3	27%	20%	15%	10%	5%	1%	-2%
4	26%	18%	11%	6%	1%	-3%	-6%
5	18%	13%	7%	2%	-3%	-6%	-10%
6	20%	11%	4%	-2%	-7%	-11%	-14%
7	19%	9%	1%	-5%	-10%	-13%	-17%
8	17%	6%	-2%	-8%	-13%	-16%	-19%
9	15%	3%	-5%	-10%	-15%	-18%	-21%
10	13%	1%	-7%	-13%	-17%	-20%	-23%