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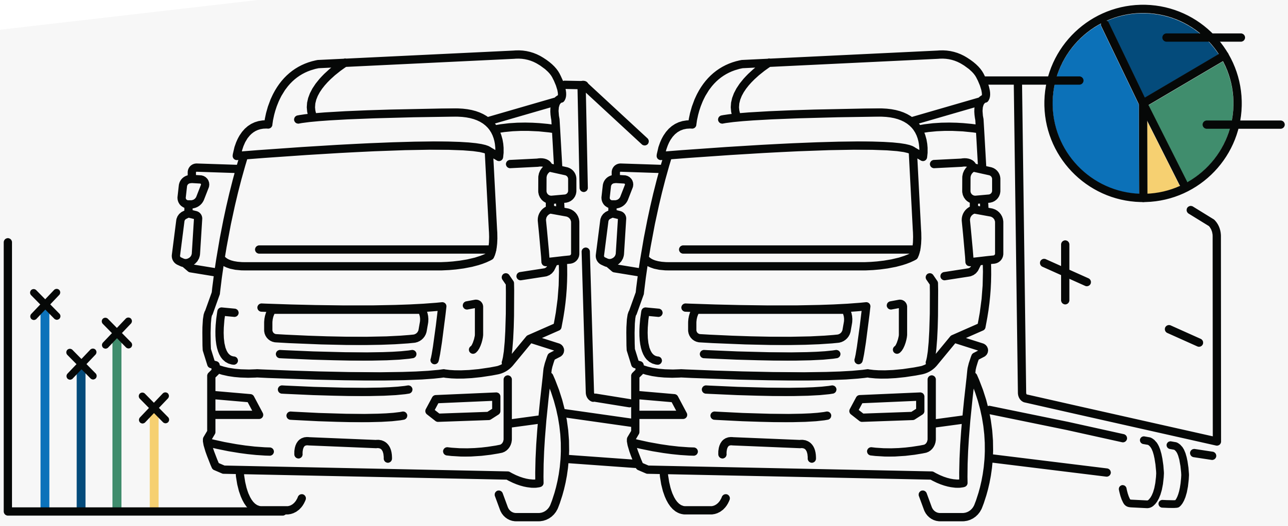
BETT – Battery Electric Truck Trial Final Report

JANUARY 2024



BETT
BATTERY ELECTRIC TRUCK TRIAL

- Trial of 20 19t DAF Electric Trucks
- 9 Public Sector Fleets
- 18-month Trial
- Dissemination of Study Learnings
- Battery Electric Truck Fleet Planning Tools

https://bett.cenex.co.uk

In Partnership with

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Executive Summary

Introduction to this Report

In June 2021 DAF Trucks were awarded funding from InnovateUK to commence with a deployment of 20 electric trucks in project BETT (Battery Electric Truck Trial). This BETT Final Report was published in early 2024 in conjunction with the conclusion of the 18-month trial.

Case for Electric Trucks

All vehicles in the UK must switch to zero tailpipe emission alternatives to reach 'net zero' carbon emissions by 2050. The UK has set targets to phase out non-zero-emission HGVs up to 26 tonnes in 2035, and all non-zero-emission HGVs by 2040. Decarbonising HGVs will be challenging due to the high mileages and weight of these vehicles.

One of the most promising options for decarbonising HGVs are battery electric vehicles (BEVs), which store energy in a battery and deliver power to the wheels through an electric motor. Electric HGV uptake is expected to increase in the coming decade. Product availability is improving and the economic case is strengthening.

The main drivers for fleets to switch to BEVs are to reduce emissions, comply with regulation, and save money.

Introduction to BETT

The trucks on trial were DAF Electric LF's, a 19-tonne battery electric truck. The truck has range of up to 175 miles on each battery charge and can be rapid charged at 150 kW for quick turn-around between shifts.

The objective of BETT was to generate evidence to show fleet operators that electric trucks can cover real-world operations. This was primarily achieved by collecting data from trial vehicles to understand their real-world performance and compare against diesel equivalents to assess operational, economic and environmental performance. The outputs can be used help fleets understand the best way to implement electric vehicles and charging, and inform on any barriers to adoption.

Executive Summary

The participating fleets were Blackpool Council, Eastern Shires Purchasing Organisation, Leeds Teaching Hospitals, NHS Supply Chain, NHS Northern Care Alliance, Rochdale Borough Council, Tameside Metropolitan Borough Council, University Hospitals Birmingham, and Yorkshire Purchasing Organisation.

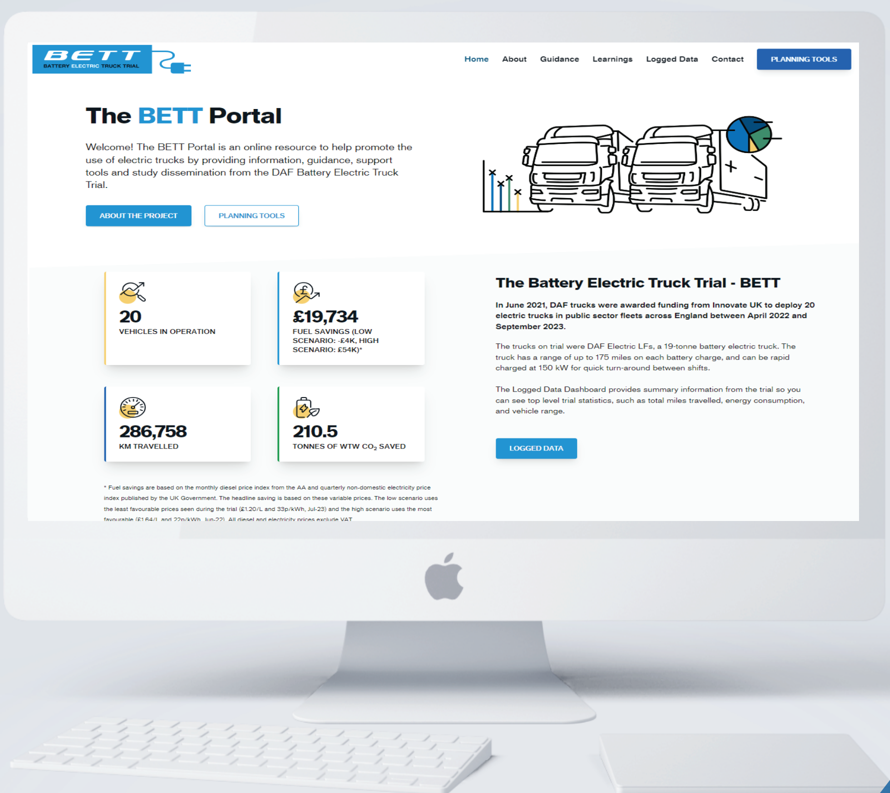
Throughout the trial, Cenex provided DAF Trucks with specialist support in the areas of independent trial analysis, study and dissemination.

Trial Statistics and The BETT Portal

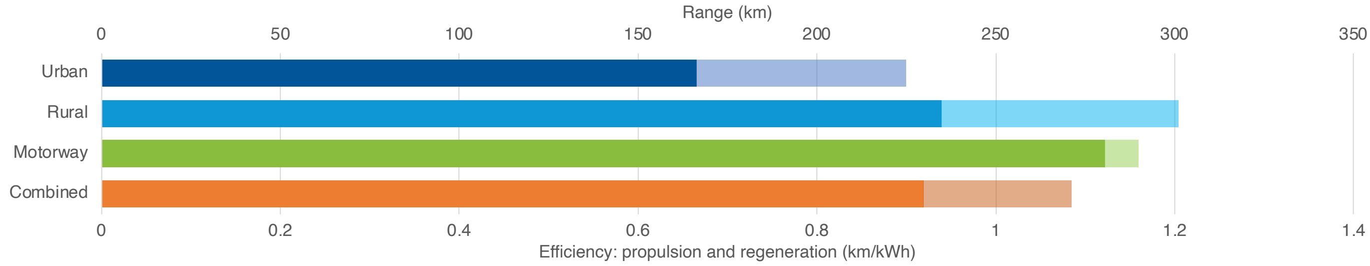
Telemetry loggers were installed to enable Cenex to collect data consisting of around 75 signals from each vehicle, including speed, position, energy consumption and charging status. This data was used to update a live feed of vehicle statistics on the BETT Portal, which sat alongside other outputs of the trial including in-depth analysis and reports on trial learnings, general guidance on electric HGVs, and two electric truck focussed fleet planning tools.

Trial statistics include:

- **Around 21,000 hours or nearly two and a half years of vehicle activity logged.**
- **Almost 21,000 journeys undertaken.**
- **287,000 km travelled by all vehicles.**
- **275,000 kWh consumed by all vehicles.**
- **Average daily distance was 95 km, the highest was 573 km.**
- **Typical range on a full battery was 270 km, varying between 225 km in urban driving and 300 km in rural conditions.**



Executive Summary

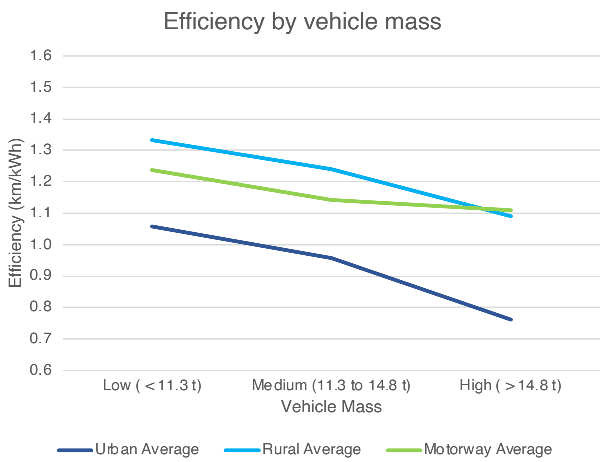


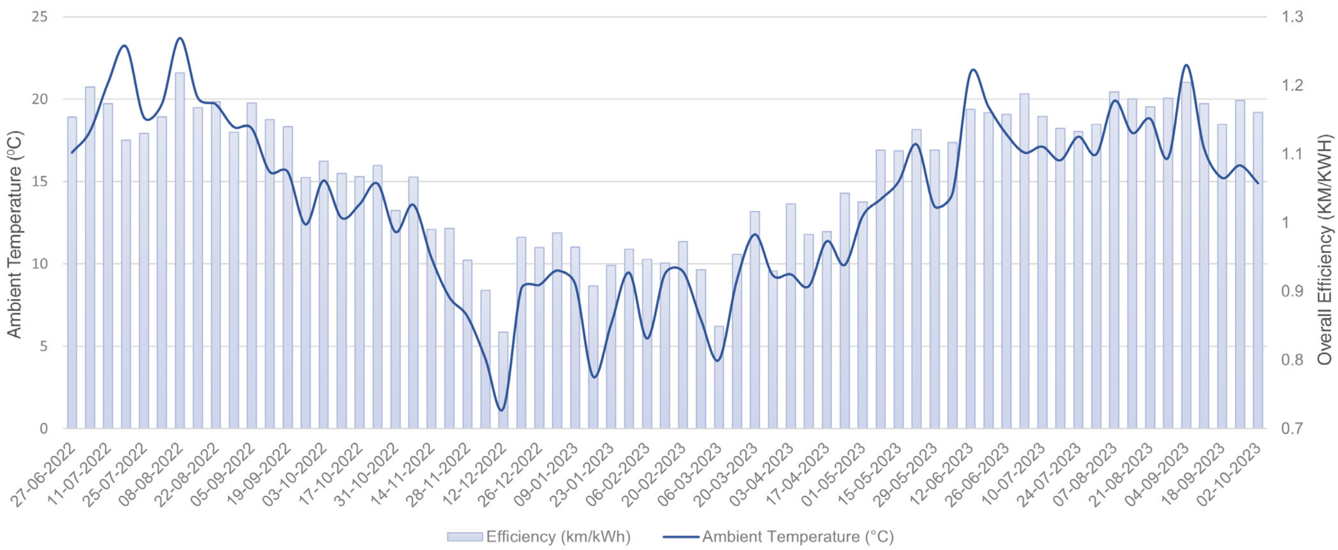
Factors Affecting Range

The overall energy efficiency, across all vehicles for the duration of the trial, varied between around 0.9 km per kWh for urban driving and 1.2 km per kWh for rural driving. The average across all vehicles and all drive cycles was 1.08 km/kWh or a range of 270 km on a full battery. The light parts of the bars in this graph show the contribution from regenerative braking.

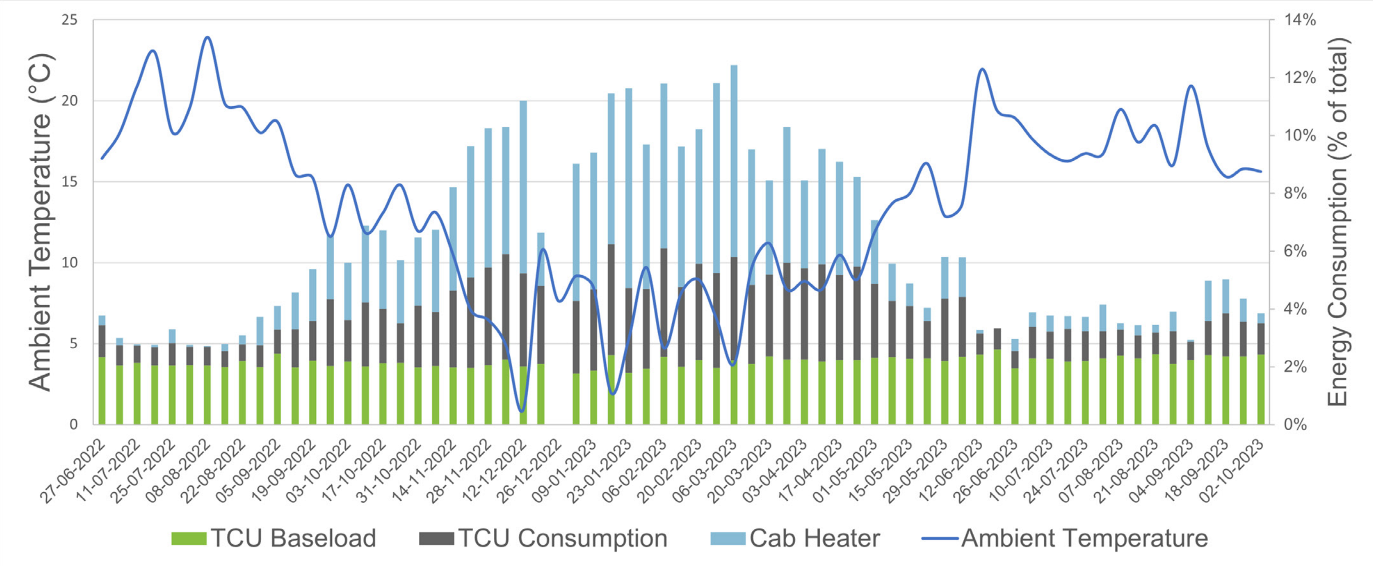
Temperature is a particularly important factor that affects the range of a vehicle, with a reduction of around 30% in winter compared to summer. Some of this reduction is due to increased consumption of energy for cab heating and for warming the temperature-controlled cargo bodies. A reduction in fuel efficiency would also be expected in diesel vehicles during colder temperatures.

Payload is also a significant factor in energy consumption, but its impact depends on the drive cycle. The frequent accelerations and decelerations of urban driving mean a high payload has a larger impact than it does on motorway driving where speed is more consistent.





Executive Summary



The main ancillary loads are the cab heater and temperature control unit (TCU) for those vehicles with one fitted. Both are temperature dependent with most consumption in the winter. At their peak they can each consume around 6% of the total energy requirement of the vehicle.

Human Factors

Cenex collected the attitudes and experiences from drivers and fleet managers both before and at the end of the trial.

Our post-trial interviews with fleet managers found that:

- The overall experience with the BETT vehicle was positive, there were operational and cost benefits, and the reduced environmental impact helped meet fleets' climate goals and promote their decarbonisation agenda.
- Compared to the start of the trial, managers were more confident with the range of the vehicle and willing to push its limits.
- Fleet managers noted that their drivers gave especially positive feedback about driving the electric trucks and were eager to drive them.
- Many of the issues and concerns came from the charging of the vehicles. Vehicles were sometimes not available when needed due to unreliability of the chargers, and the present lack of public charging infrastructure for HGVs meant longer routes were not possible.
- Technical issues took some vehicles off the road for extended periods requiring fleets to fall back on diesel vehicles. However, downtime was exacerbated by the scarcity of BEV technicians, a problem likely to be resolved with greater BEV truck penetration.

Executive Summary

Our post-trial survey with drivers found that:

- Drivers were more positive about factors such as performance, ease of refuelling manoeuvrability and range compared to the pre-trial interviews.
- Reliability was a slightly greater concern than it was before the trial. Range and performance anxiety is mixed, while for some it is not an issue, for others it is very high.
- Drivers continue to be environmentally conscious and supportive of the introduction of BEVs.
- Drivers felt that more BEV specific training would be useful to enable them to drive the trucks more efficiently.

Business Case of Electric Trucks

Cenex has created and published a total cost of ownership (TCO) model to demonstrate the importance of 21 operational, policy and external factors on the finances of operating an electric HGV.

The model shows that:

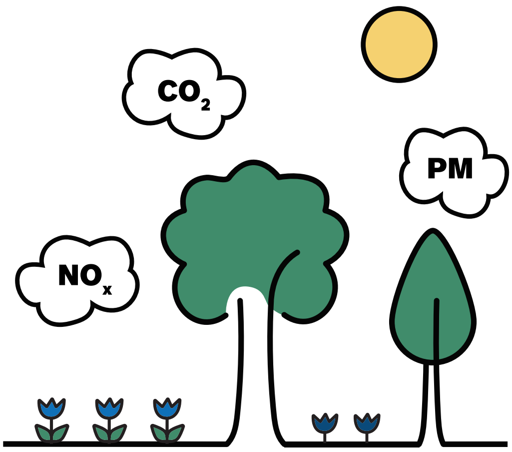
- Maintenance and taxes are lower for a BEV compared to diesel truck. However, the larger initial cost and high cost of public recharging means that if regularly using public chargers, the TCO of a BEV is higher than a diesel by around £10,000 per year.
- If fleets choose to charge only at the depot, then savings are increased but are still negative: minus £2,000 per year.
- The primary drivers for the TCO are mostly external and operational factors such as fuel prices and how the vehicles are used. Policy factors may have an impact in the short term, but their importance will diminish in the future.

Environmental Life Cycle Assessment

Cenex has performed a life cycle assessment (LCA) to understand the environmental impact over the entire life of a truck from production of raw materials through to construction, regular use and end-of-life. The assessment covered both an electric truck and its diesel equivalent to enable comparison of the difference.

The findings are:

- During the production phase the electric version contributes 1.6 times more emissions compared to the diesel truck, the vast majority of which is due to the battery.
- Emissions from the use phase is highly dependent on the source of the electricity. The baseline UK grid mix produces less than half the emissions of a diesel, while almost 90% reduction is possible with Danish electricity. However, a grid that is heavily dependent on coal could see a 13% increase over diesel emissions.
- Despite the higher production emissions, the high distance typically travelled by HGVs means savings from the use phase dominate, so with the baseline UK grid mix, environmental payback is possible in little more than a year.



Introducing The Case for Electric Trucks

Decarbonisation Challenge

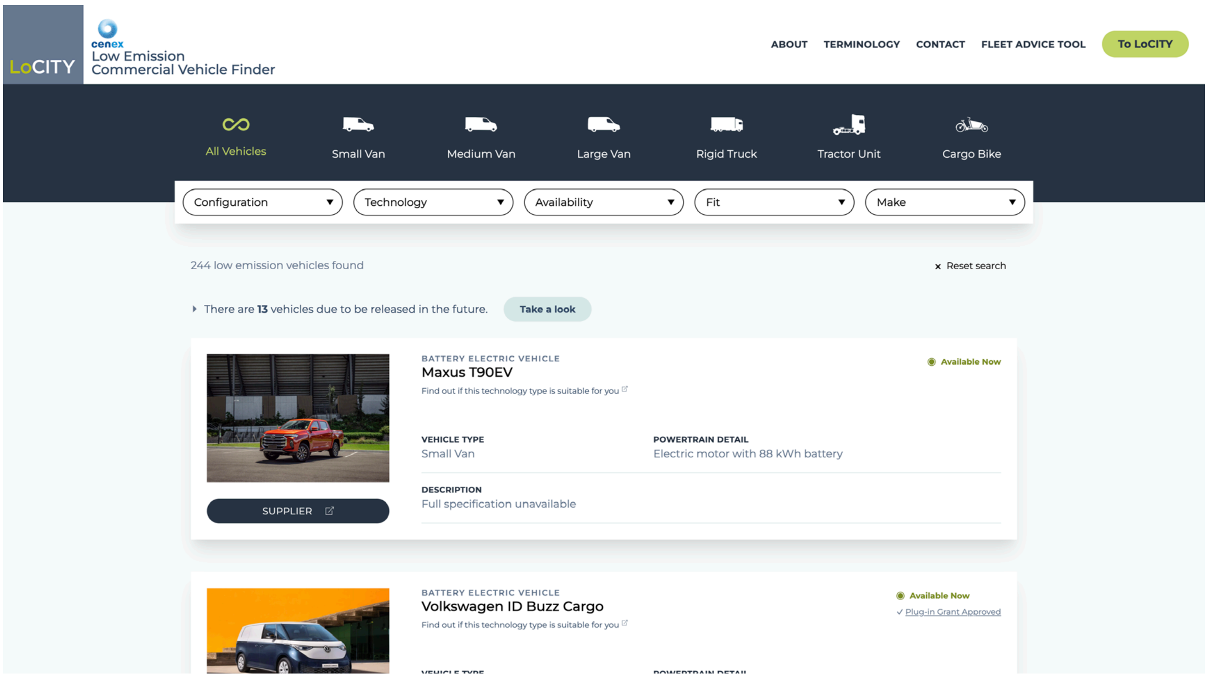
All vehicles in the UK must reduce their emissions to reach 'net zero' carbon emissions by 2050. Decarbonising heavy goods vehicles (HGVs) will be challenging for several reasons:

- The size and weight of HGVs mean they need large batteries to provide sufficient energy to move the vehicle.
- Large batteries are also necessary as HGVs often cover long distances. Public chargepoints are not currently designed for the physical size of HGVs, and the high energy requirements could put a strain on the National Grid.

Although HGVs are a small proportion of the UK vehicle parc (1.3% of all vehicles), it is important that they are decarbonised because they make a relatively high contribution to greenhouse gas emissions due to their high mileages and low fuel economy – they make up 5.4% of all miles travelled on UK roads, yet around 20% of emissions from road transport (Transport Statistics Great Britain: 2022). While HGVs are efficient in terms of tonnes of goods moved, the current diesel fleet must be replaced by low emission alternatives so the UK can meet its greenhouse gas emissions targets.

Battery Electric HGVs

Battery electric HGVs are classified by Cenex as a medium maturity technology, as manufacturers already offer products for sale in the UK, but they are deployed in small numbers or only on trials and demonstrations. However, ongoing improvements in battery technology and investment by manufacturers mean that the viability of Battery Electric Vehicles (BEVs) is increasing, even for the heaviest vehicles. Electric HGV uptake is expected to increase in the coming decade, with product availability improving and the economic case strengthening based on the total cost of ownership. **The Cenex Commercial Vehicle Finder**[1] has the latest information on the current vehicle market and expected release dates for new products.



[1] https://commercialvehiclefinder.cenex.co.uk

Introducing The Case for Electric Trucks

Why Consider Electric Trucks?

1. To reduce emissions.

Electric HGVs have zero pollutant tailpipe emissions at the point of use. As shown in the 'Life cycle assessment' section of this report, electric HGVs have lower greenhouse gas emissions than diesel vehicles on a life cycle basis when charged using standard UK grid electricity.

2. To comply with policy and regulation.

The EU has set emissions targets for HGV manufacturers, and these are likely to be adopted in the UK. The UK has set targets to phase out sales of new non-zero-emission HGVs up to 26 tonnes in 2035, and all non-zero-emission HGVs by 2040. Cities are also taking actions to reduce use of older diesel vehicles through emissions and congestion charging zones. Fleets should stay ahead of policy in this area by trialling zero emission capable vehicles.

3. To save money.

As per the 'Business case' section of this report, electric HGVs can save fleets money compared to diesel on a total cost of ownership (TCO) basis, under the right conditions and scenarios.

Introduction to BETT

Project Overview

In June 2021 DAF Trucks was awarded funding from Innovate UK to commence with a deployment of 20 electric trucks in the Battery Electric Truck Trial (BETT)

The deployment of the BEV trucks during BETT was in partnership with the end-users, government entities comprising the NHS, local authorities and purchasing framework providers, who trialled the vehicles and the respective chargers.

The vehicle on trial was the DAF Electric LF, a 19-tonne battery electric truck. It has a range of up to 175 miles or 280 km on each battery charge and can be rapid charged at 150 kW for quick turn-around between shifts. The trial vehicles included different types of ancillary systems that operate from the battery such as tail-lifts and temperature control units.

Participating Fleets

There were nine organisations operating a total of 20 vehicles. The organisations and the type of operation they did were:

FLEET	OPERATIONS
Blackpool Council	General movement of equipment around the town
Eastern Shires Purchasing Organisation	Distribution of goods to public sector organisations
Leeds Teaching Hospitals	Distribution and collection of hospital waste bins
NHS Supply Chain	Distribution of supplies to hospitals
NHS Northern Care Alliance	Distribution to and collection from hospitals
Rochdale Borough Council	Household distribution of wheelie bins
Tameside Metropolitan Borough Council	Household distribution of wheelie bins
University Hospitals Birmingham	Delivering supplies to hospitals
Yorkshire Purchasing Organisation	Delivering supplies to schools

Objectives and Approach

The UK Government is planning a shift to zero emission trucks to help meet their net-zero emission target, and zero emission zones are expected to appear in cities as we move to the middle of this decade. Fleets and cities are keen to shift to zero emission alternatives but there is little information available on the real-world performance of the vehicles. The purpose of the trial was to help understand the best way to implement the vehicles and charging into fleets, and inform on any barriers to adoption.

Introduction to BETT

The 18-month trial commenced in April 2022. Cenex provided specialist support on independent trial analysis, study and dissemination and reported study results in the Learnings section of the **BETT Portal**[2].

This involved:

- **Collecting data** from trial vehicles to understand their **real-world performance**.
- **Analysing and reporting** trial data.
- Surveying drivers and fleet managers to **gather feedback** on experience with driving, charging and operating EV vehicles compared to diesel trucks.

Data loggers were fitted to all trial vehicles to provide detailed telemetry about vehicle operations, energy consumption, driving behaviour and charging patterns. A bespoke dashboard was developed to enable all trial participants to view up-to-date information on how their vehicles were operating and performing.

Outputs and Reporting

Outputs were reported in the **BETT Portal** covering:

- **Truck performance:** environmental performance, cost, energy consumption, range and reliability.
- **User attitudes:** encompassing drivers, fleet managers, and customers.
- **Further research:** life-cycle analysis and battery degradation.

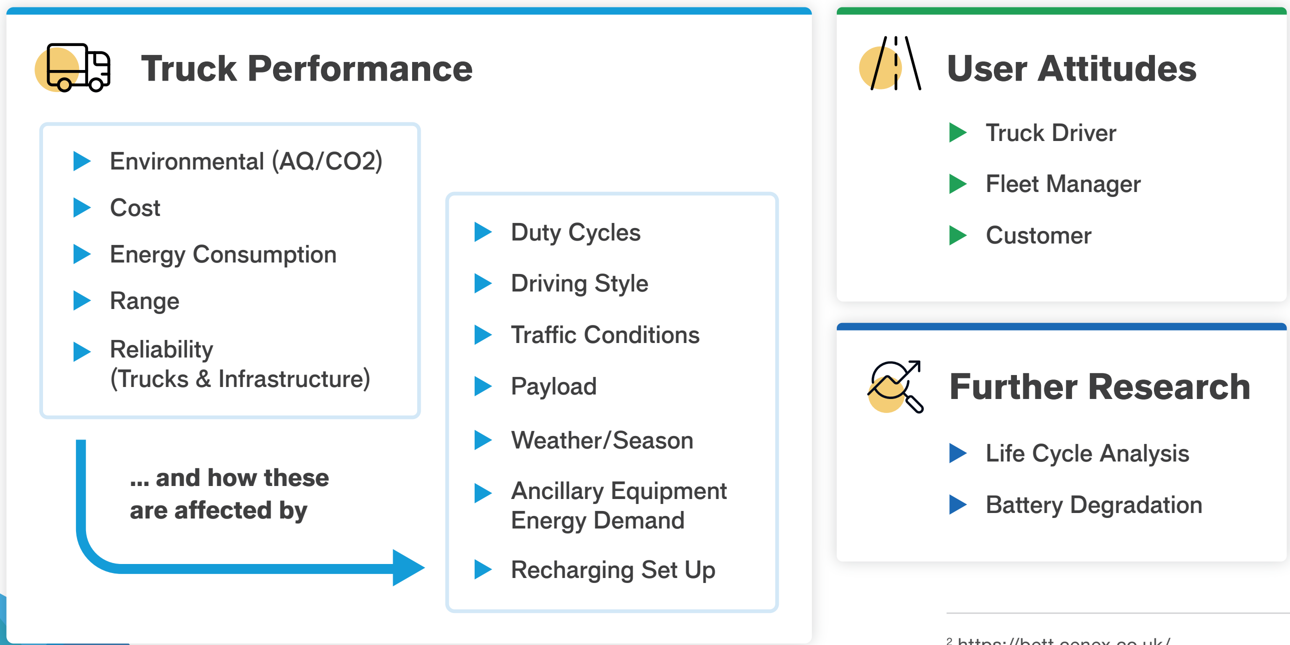
The project outputs are displayed in the graphic below.

Learnings from BETT were used as follows:

- DAF gained a detailed understanding of the real-world performance of individual vehicles and the overall fleet.
- Participating fleets understood how their drivers use and view the vehicles that they operate.

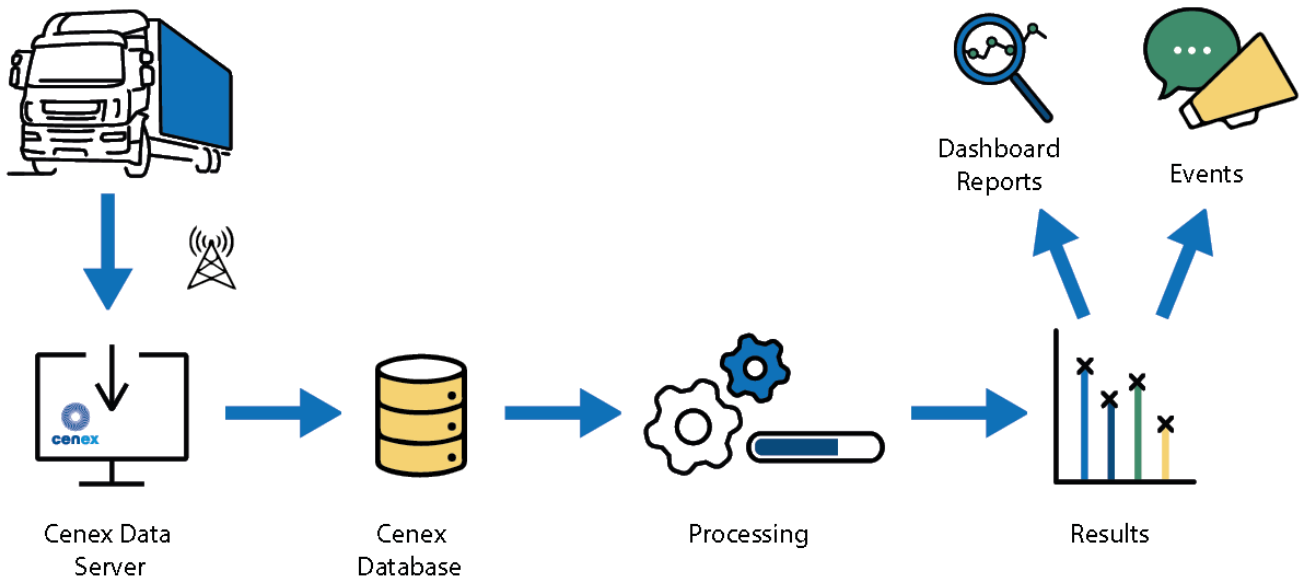
Beyond the trial the learnings can be used as follows:

- By non-participating fleets to learn from the trial and assess how electric trucks could fit with their operations, and dismantle EV myths via trial data.
- UK Government will be able to use the trial results and learnings to inform policy development in the area of zero emission trucks.



[2] https://bett.cenex.co.uk/

Trial Statistics



Data Collection

BETT collected data from three main sources: telemetry from each vehicle, usage information from chargers, and the attitudes and experiences of drivers and fleet managers via surveys and interviews. Results from the surveys can be read in the section on Human Factors, this section will focus on vehicle telemetry.

The telemetry data was fed into Cenex's "data processing pipeline", which is a collection of custom software scripts and databases designed to check, clean, store and analyse the data. The outputs of the pipeline are the results and insights which are presented on the public BETT Portal and the dashboard which was created for the end-users of the vehicles to see their own performance data.

Above is an overview diagram of the data processing pipeline.

Telemetry data was collected using CAN bus loggers which read data from 4 separate CAN buses on each vehicle. The loggers collected data from around 75 signals including speed, energy consumption, charging status, accelerator and brake pedal positions, temperatures, ancillary component operation and GPS data, at rates of up to 20 Hz.

Telemetry by Numbers

Data was collected from 20 vehicles operating for 18 months. In total, over the duration of the trial:

Around 58 gigabytes of raw (compressed) data was downloaded from the loggers.

This was contained in over 42,000 data files.

Once extracted and stored into our database, the raw data included over 16 billion individual data points, taking up 1.4 terabytes of storage space.

The data covered 21,000 hours (875 days or 2.4 years) of vehicle activity including 8,600 hours of active operation, 5,200 hours of fast charging and 1,800 hours of rapid charging.

Trial Statistics

Headline Results

During the trial, the BETT Portal has been constantly updated with the latest headline statistics, including:

Performance

THE NUMBER OF JOURNEYS RECORDED WAS NEARLY
21,000

THE DISTANCE TRAVELLED WAS ALMOST
287,000 km

THE ELECTRICITY CONSUMED WAS ALMOST
275,000 kWh

RANGE ON FULL CHARGE

270 km	303 km	226 km	292 km
AVERAGE	RURAL	URBAN	MOTORWAY

DAILY DISTANCE TRAVELLED

95 km
AVERAGE

573 km
MAX

AVERAGE UTILISATION

2 hours 48 minutes
DRIVING PER DAY

2 hours 10 minutes
CHARGING PER DAY

DAILY BATTERY USE

39% SoC
AVERAGE

The average range available on a full charge, 270 km, was almost exactly the figure originally quoted by DAF. The average daily distance actually travelled (only taking into account days when the vehicle was used) was less than 100 km meaning that typically less than half the battery was used.

However operating patterns varied considerably, and some vehicles regularly covered over 400 km in a day, making use of rapid top-up charging between shifts and during loading and unloading to achieve this. One of the vehicles took part in the Greenfleet EV Rally in July 2023 and covered a leg of 573 km in a single day using public rapid chargers, demonstrating the flexibility and capability of the vehicle.

Best of BETT

The highest daily figures from the entire trial:

573 km
TRAVELLED IN ONE DAY

441 kWh
USED IN ONE DAY

10:02
HOURS WORKED IN ONE DAY

527 kWh
CHARGED IN ONE DAY

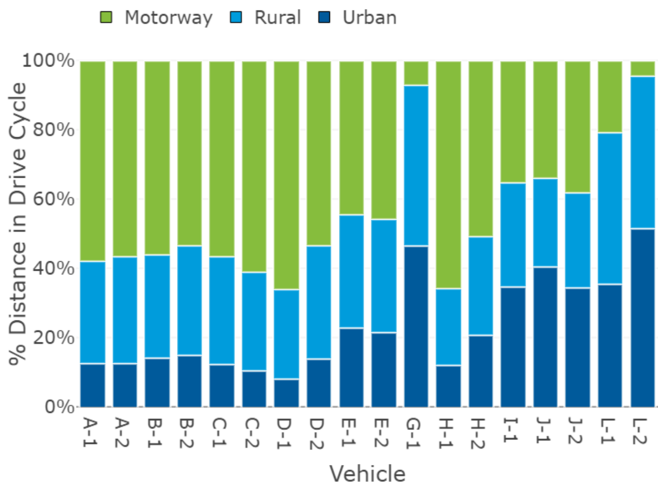
Factors Affecting Range

Drive Cycle

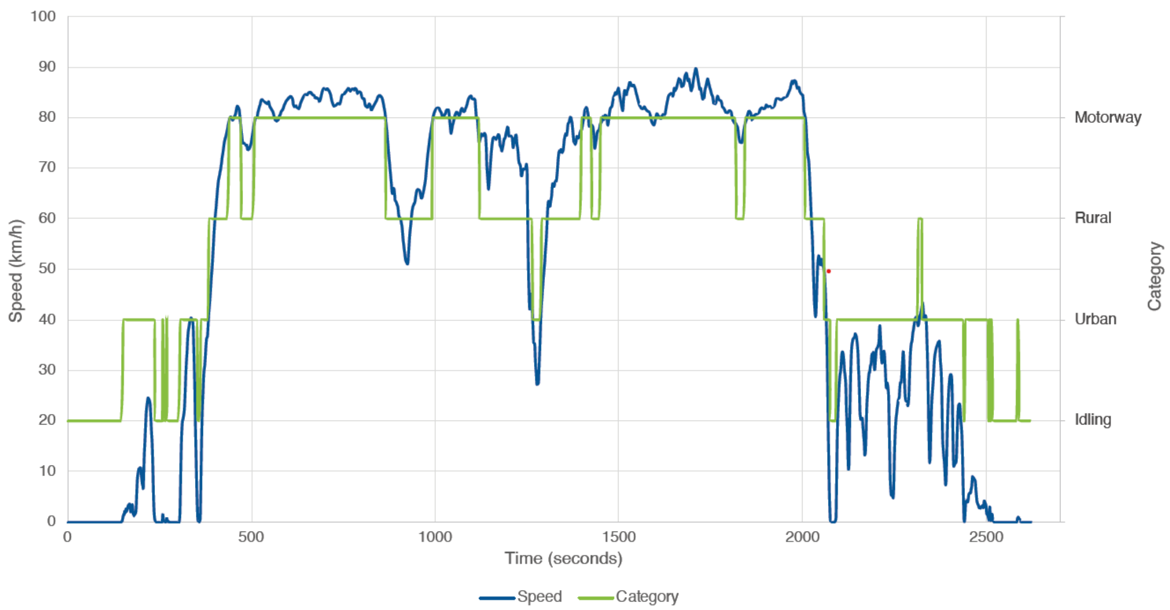
A drive cycle is how we categorise the broad type of driving. We use three categories: urban, rural and motorway, which represent typical driving patterns on these types of roads; the actual road type the vehicle is driving on is not used in the categorisation, it is based purely on the statistical properties of short periods of driving. Consistent high-speed driving will be classed as motorway while slower start-stop movements will be classed as urban; rural driving sits between them.

The graph below is an example of the categorisation applied to a journey. It demonstrates how the main high-speed section in the middle is categorised as motorway, while the slower sections with varying speed are classed as rural or urban. Stationary periods such as stopping at junctions are categorised as idling, and if a vehicle is stationary for more than about 5 minutes, this is classed as a new journey.

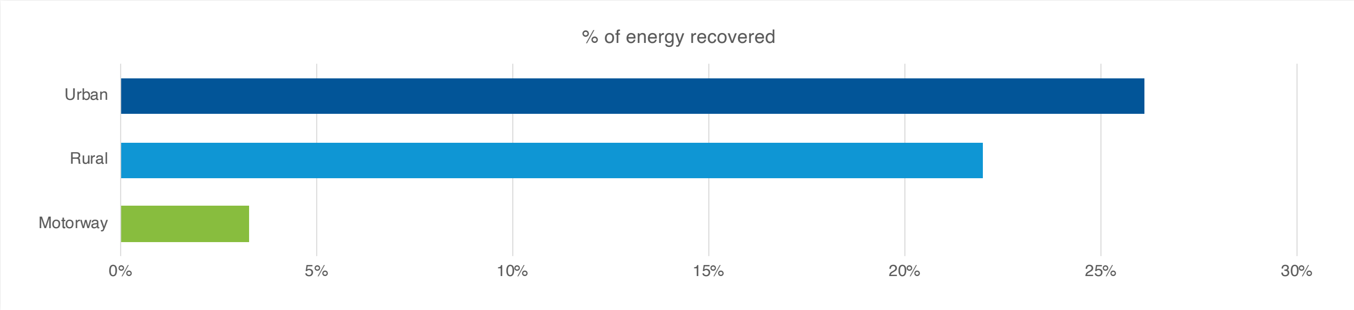
The BETT vehicles have been used for a variety of purposes, some do very local deliveries in city centres, while others make longer journeys along motorways. Therefore, the split between urban, rural and motorway driving varies by vehicle, although most vehicles operated on the motorway drive cycle for the majority of the time.



An important aspect in understanding the variation in efficiency between different drive cycles is the effect that regenerative braking has. Energy is recovered back into the battery during braking, but this effect is far more significant in the urban and rural drive cycles because there is a lot of acceleration and deceleration, so braking is common. This leads to more than 20% of the energy used for propulsion being recovered. On the motorway drive cycle which has high, consistent speeds and little braking, only 3% of the energy is recovered.

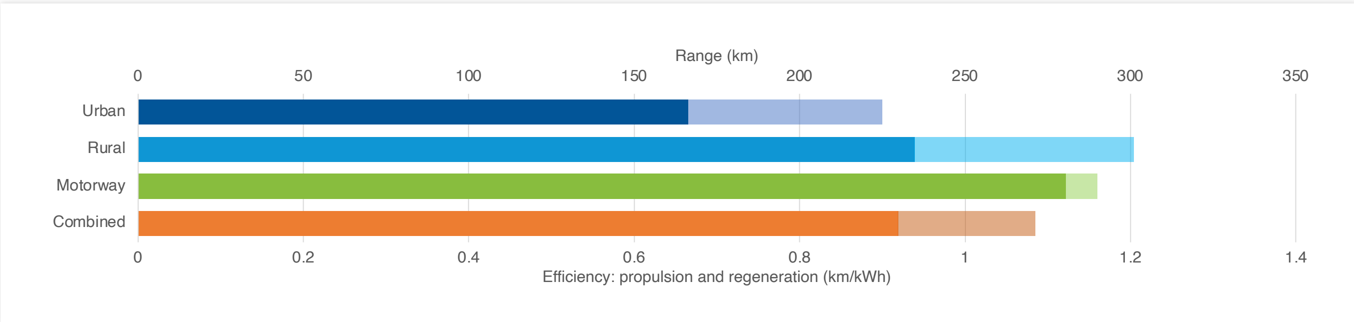


Factors Affecting Range

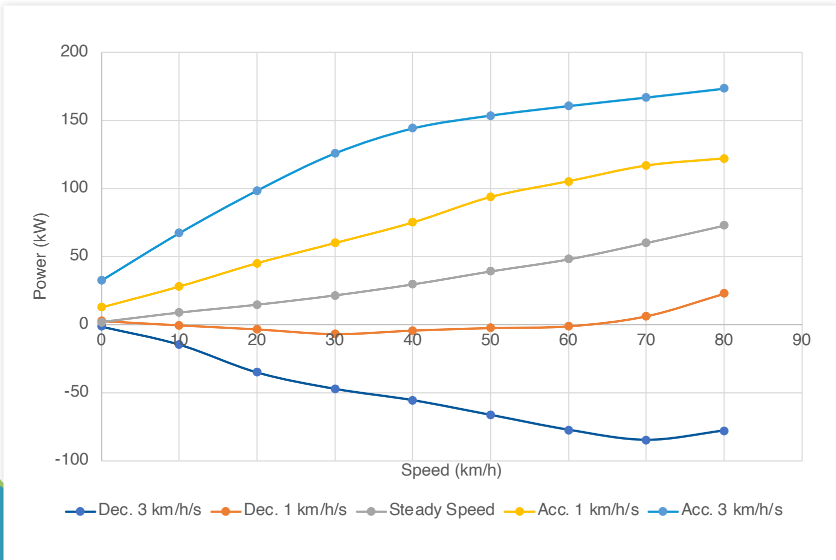


The overall energy efficiency, across all vehicles for the duration of the trial, varies between around 0.9 km per kWh for urban driving and 1.2 km per kWh for rural driving. On a full battery, this leads to a single-charge range of between 225 km and 300 km depending on the drive cycle, and a significant proportion of this achieved due to the energy recovered under braking, shown as the lighter part of the bar in the graph below. The average across all vehicles and all drive cycles is 1.08 km/kWh or a range of 270 km on a full battery.

Note that all efficiency and range figures are based on usable energy stored in the battery and do not account for charging efficiency.



While regeneration is important to achieve the full capabilities of the vehicle, regenerative braking can never recover all of the energy used to accelerate the vehicle due to efficiency losses. The power curve graph below demonstrates this and shows that the power required to accelerate the vehicle is significantly higher than the power recovered when decelerating the vehicle at the same rate during braking.

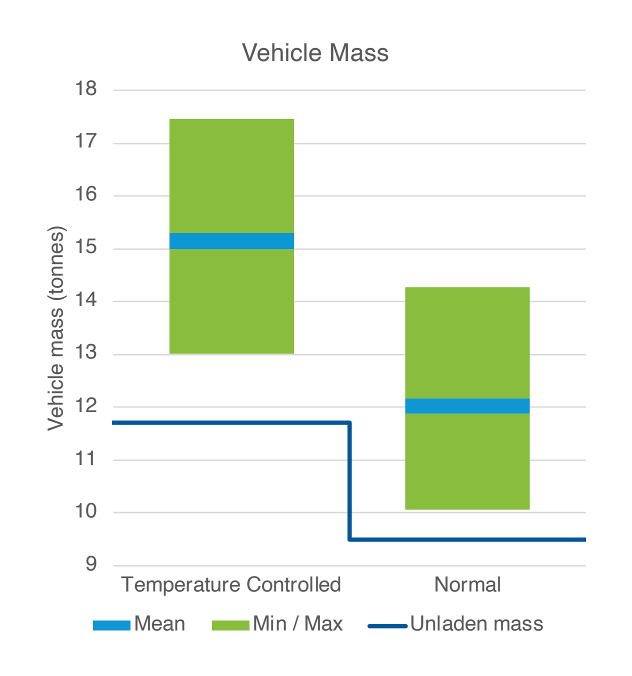


This explains why the efficiency of the urban drive cycle is relatively low. Although the speed of urban driving is slow, which means air resistance and friction losses are low, energy is consumed by repeatedly accelerating and decelerating the vehicle.

Factors Affecting Range

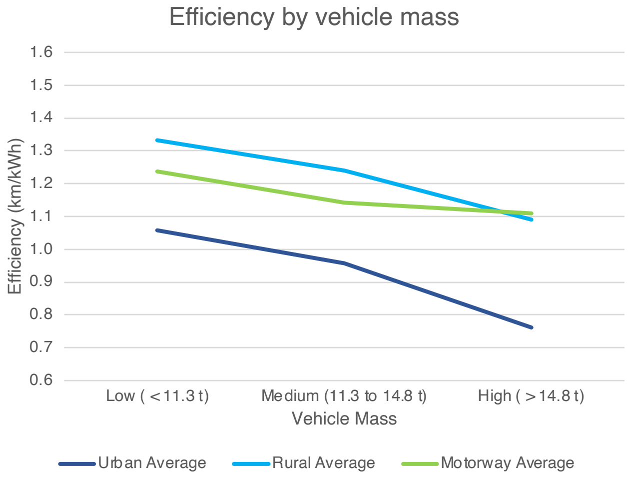
Payload

Repeated acceleration and deceleration is an especially important factor for the efficiency of heavy goods vehicles as heavier vehicles require more energy to both accelerate and climb up hills. The BETT vehicles have a Gross Vehicle Weight (GVW) of 19 tonnes; its unladen weight is about 9.5 tonnes for standard body versions, and 11.7 tonnes for those with a temperature-controlled body.



The temperature-controlled vehicles happen to carry around 1 tonne more payload on average, so overall their average weight is 3 tonnes more than the non-temperature-controlled vehicles.

An analysis of the overall efficiency of vehicles of different weights across the three drive cycles does indeed show that the efficiency drops as the payload increases. However the shape of the reduction varies by drive cycle: the drop is relatively high for the urban drive cycle due to the high number of accelerations and decelerations, while in the motorway drive cycle the more consistent speed means a higher payload has only a small effect on the efficiency.



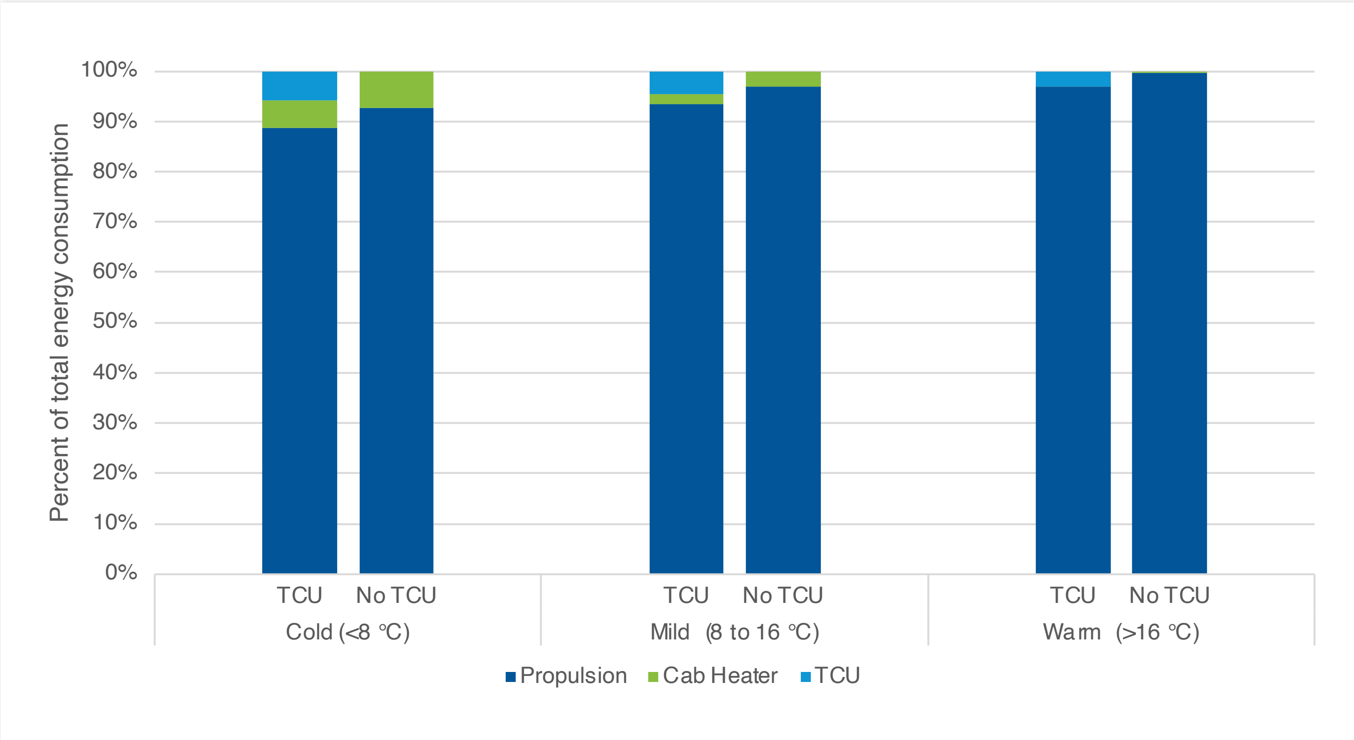
Ancillaries

The BETT vehicles are fitted with a number of ancillary devices which consume power over and above that required for propulsion. All vehicles are fitted with a tail lift, but these consume negligible energy. The propulsion batteries may require heating or cooling to keep them within their optimum temperature, but while this can consume significant instantaneous power, it happens rarely enough that the overall energy consumption is minor.

The most significant ancillary power draws are from the temperature control unit (TCU) (for temperature-controlled vehicles) and the cab heater. Unfortunately there was no data about consumption of cab aircon in the telemetry feed.

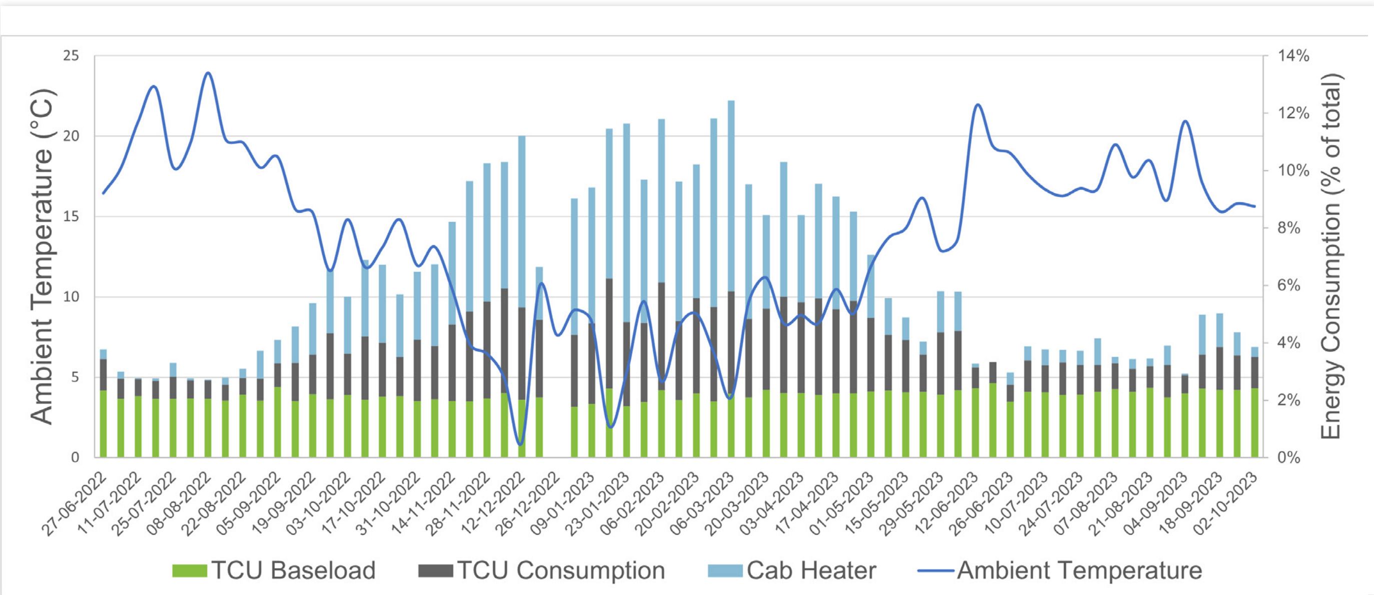
The usage of the TCU and cab heater are both dependent on the ambient temperature and therefore time of year. All of the BETT vehicles with a TCU transport goods that require maintaining a temperature of around 20°C, so like the cab heater, the majority of energy consumption is in cold weather.

Factors Affecting Range

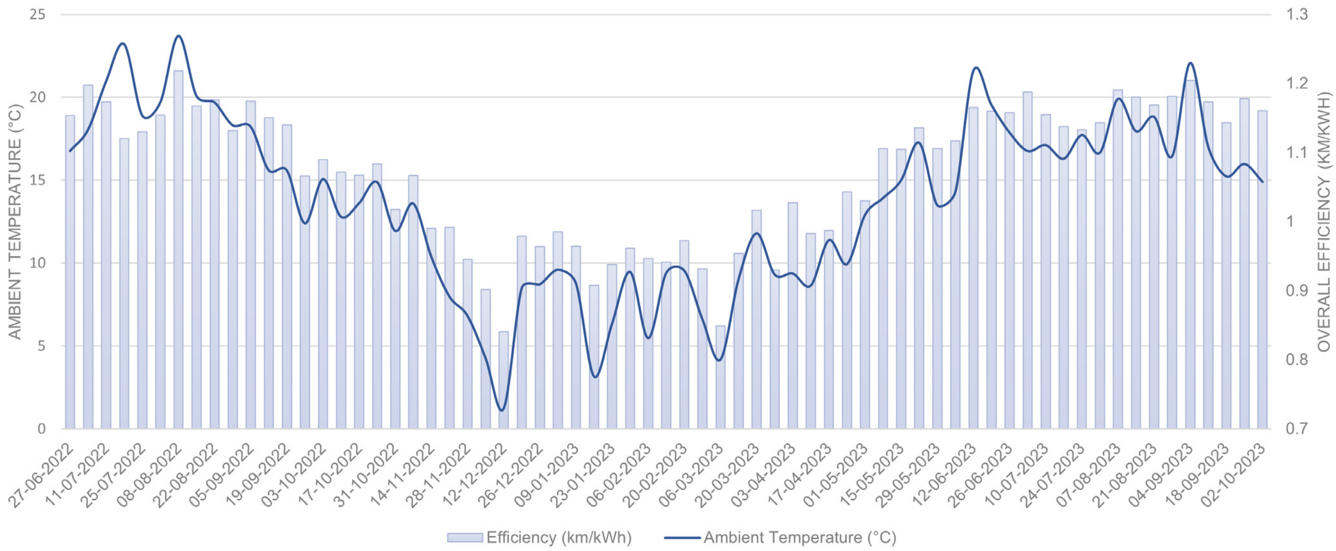


The graph above shows the energy consumption of these major ancillary loads compared to the energy required for propulsion. In warm conditions, the TCU consumes 3% of the total energy in the vehicles with one fitted. In cold conditions, the TCU consumption increases to around 6%, with total ancillaries consuming 11% for vehicles with a TCU, and 7% for those without.

The following graph shows the energy consumption of the TCU and cab heater as a proportion of all energy usage, for the duration of the trial, alongside the ambient temperature. The consumption of the TCU is split into baseload, which is consistently around 1 kW regardless of the actual cooling or heating requirement, and the actual usage. As would be expected, peak ancillary consumption is during the winter.



Factors Affecting Range



Seasonality

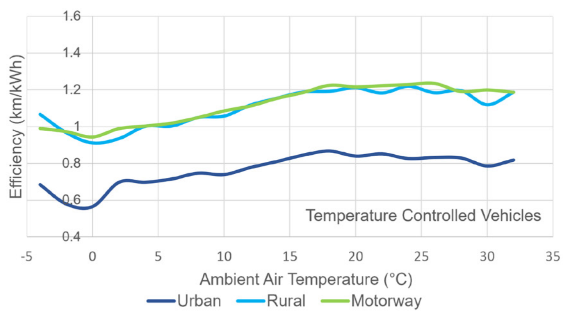
It's not just the ancillary consumption that varies by temperature, the efficiency of the propulsion also varies considerably by the time of year. The following graph shows the weekly average efficiency of all vehicles with the ambient temperature overlaid, and it is clear there is an extremely strong correlation.

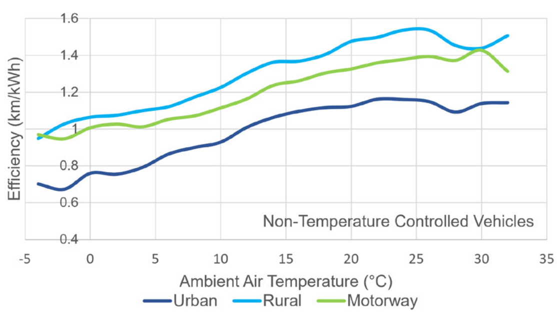
The efficiency varies from around 0.8 to 1.2 km for every kWh used. This is a drop of around 30% between summer and winter. There are many reasons for this: batteries tend to be less efficient in colder conditions which may account for some of the loss, however wind, rain and colder, more dense air, all increase rolling resistance and drag which increases energy consumption. These effects are also seen in internal combustion powered vehicles.

When looking at how the efficiency changes across the range of temperatures, the pattern varies by both the drive cycle and whether the vehicle has a TCU.

In all cases the efficiency is higher in warmer weather, but vehicles with a TCU not only have a lower efficiency overall, but the temperature dependence is also less pronounced. Additionally, the efficiency of the urban drive cycle is particularly low for vehicles with a TCU, while the rural and motorway efficiencies are almost identical.

While some of this is explained by the additional energy required by the TCU, this does not explain all the differences as the TCU only consumes up to 6% of the total energy, far below the observed difference in efficiency. The variations by drive cycle are in fact explained by the higher weight of vehicles with a TCU. This especially impacts the urban drive cycle where there is a lot of start-stop operation, and explains why the efficiency of the motorway drive cycle, with fewer acceleration and decelerations, is closer to that of urban driving.





Human Factors: Real-World Deployment

This section presents qualitative and quantitative insights from pre- and post-trial interviews with fleet managers and surveys with drivers. This includes their pre-trial expectations and concerns, and compares them with their end of trial experiences and challenges.

Fleet Manager Perceptions

Cenex interviewed managers from all 9 participating fleets before the trial commenced, and followed up with 7 of those fleets shortly before the trial ended. These end-of-trial interviews covered fleet operations, BETT truck performance, driver training, attitudes and perceptions, environmental impact and behaviour. The following analysis presents the findings from comparing interview discussions at the start and end of the trial.

As the trial progressed, fleet managers observed a decrease in range anxiety and an increase in confidence among drivers who drove the BETT vehicles. Most fleet managers prefer to continue using the BETT vehicle, citing its reduction in environmental impact, ease of use and cost-saving potential. They also aim to add more BEVs like the BETT truck in the future. Different fleet managers have varying needs: some prefer smaller vehicles, while others require solutions for charging, range, and technical/maintenance issues to effectively use and integrate the vehicles.

Strengths

The majority of fleet managers said they had a positive experience with the BETT truck. The strengths of the BETT vehicles include environmental benefits over diesel equivalent vehicles, operational benefits, cost reduction, positive driver feedback, marketing impact, and energy efficiency. Details of these are presented below.

Environmental Impact and Behaviour

At the beginning of the trial, fleet managers expected that BETT trucks would considerably improve air quality and reduce noise compared to their existing diesel vehicles. End-of-trial interviews have shown that fleet managers recognise the potential of the BETT truck to lower emissions and align with wider organisational sustainability goals targeting carbon emissions reductions.

Operational Benefits

Fleets in noise restricted areas have experienced benefits from the reduction in noise, allowing them to make deliveries at night when loud diesel vehicles are forbidden. For most fleets, the BETT trucks were used alongside conventional diesel vehicles. Using both diesel vehicles and BEVs offered fleet managers a chance to assess the performance and feasibility of replacing diesel trucks in the future and evaluate their suitability for different activities.

Energy Efficiency

Fleet managers noted that, in congested urban environments, brake regeneration improves energy efficiency, making the BETT truck well-suited for city driving. This correlates well with telemetry data as per previous sections, with 26% energy recovery via regenerative braking in urban drive cycles.

Human Factors: Real-World Deployment

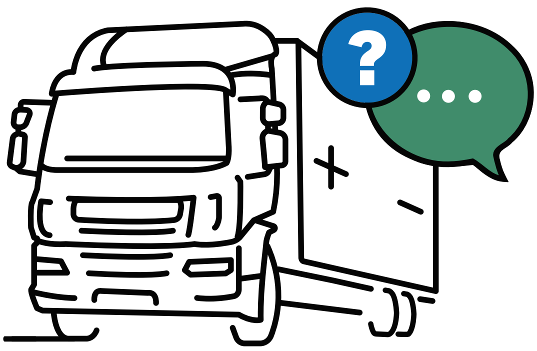
Cost Reduction

Exclusively employing the BEV for day-to-day operations has resulted in lower fuel and operational costs for many fleet managers. Fleet managers who have routes that enter Clean Air Zones (CAZ) noted their truck's usefulness in reducing costs in these urban areas.

Despite the BETT truck lowering costs for most fleets, some fleet managers have mentioned that the surge in electricity prices reduced savings at some points during the trial. A business case analysis for fleet operators is shown in The Business Case for Electric Trucks section.

Marketing

During the pre-trial interviews, some managers saw the truck on the fleet as a chance to promote their decarbonisation agenda, while others were more cautious. Post-trial interviews revealed that the BETT trucks caught the attention of diesel HGV drivers on the road. For most fleets, BEVs are seen as advantageous for brand marketing, showcasing their dedication to carbon reduction, with one noting that "people have been posting pictures of the BETT tuck on social media while it is out on the road, praising us for going electric."



Challenges

Fleet managers have highlighted some issues related to temperature, charging infrastructure, range anxiety, and vehicle maintenance. The following is a summary of the main challenges expressed by fleet managers.

Impact of Temperature

The cab's temperature was hard to control during winter, with some managers noting that the heating systems were not powerful enough to heat the cab. Other fleet managers saw a spike in energy usage from the heater which affected range. One fleet saw a spike in technical issues with the BETT truck during winter, ultimately affecting the use of some of the vehicles during colder months.

Technical Issues

In some fleets, technical difficulties have taken the BETT trucks off the road for a considerable time. In the worst scenario, a BETT truck was intermittently out of commission for three months due to battery warning faults, while other BEVs were only off the road for a week or less for power steering replacement or maintenance.

Maintenance

Electric truck maintenance proved to be a learning curve for many fleets. The need for better maintenance support was identified to avoid having long periods of time where the vehicles are not in use. On some occasions, the BETT truck had to be temporarily replaced with a diesel one due to challenges with maintenance. Part of the issue was due to the scarcity of engineers trained to work on electric vehicles, a problem that should be alleviated as electric HGVs become more common.

Human Factors: Real-World Deployment

Charging Infrastructure

Managers have identified the need for faster charging facilities to help drivers top-up between shifts and reduce charging time. Fleets have also recognised the advantage of implementing smart charging at their facilities in the future to optimise energy costs by making better use of cheaper overnight charging.

Ongoing charging issues have been experienced by some fleets, with problems originating from the charger, cable, or software. Some common experiences included:

- The charging speed in some depots was slower than expected and prevented drivers from sufficiently charging the BEV during their lunch hour.

- Technical issues with the chargers, including software and communication faults between vehicle and chargepoint, which left some trucks unable to be used until the issues were fixed.

The concerns around charging were a common theme across the BETT fleets, for example:

- Lack of grid capacity or space for installing more chargpoints at depot to cater for additional BEVs in the fleet.

- Cost of installing high-power chargers to ensure that BEVs can be charged during the day and maximise their daily mileage.

Some fleet managers noted that there needs to be either an improvement in the range of the vehicle, or access to public infrastructure suited to HGVs to ensure the vehicle can match the range and reliability of diesel vehicles.

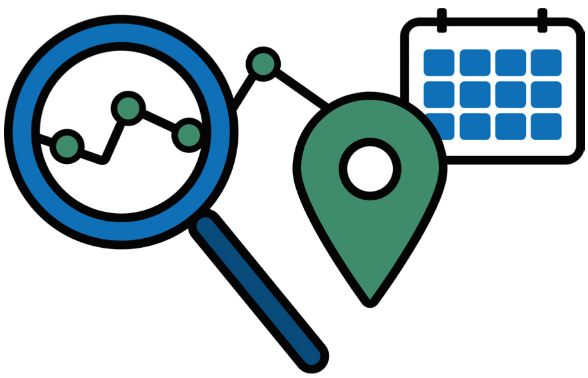
Range Anxiety

Fleet managers have unanimously recognised that the absence of a range gauge to indicate how much distance is left in the battery has contributed to range anxiety. Building confidence in the range of the BETT trucks during deliveries is essential for all fleet managers, and while many fleets said they gained confidence during the trial, some fleets reported drivers being worried about the available range due to the battery state of charge (SOC) gauge being hard to accurately read. It is worth mentioning that the SOC gauge in the trial vehicle was temporary, and the production version will have a significant dashboard upgrade.

Some fleets prioritised diesel vehicles for longer distance operations even if they were technically within the range of the BETT vehicle due to range anxiety and lack of backup public chargers, and used the BETT truck only for shorter routes.

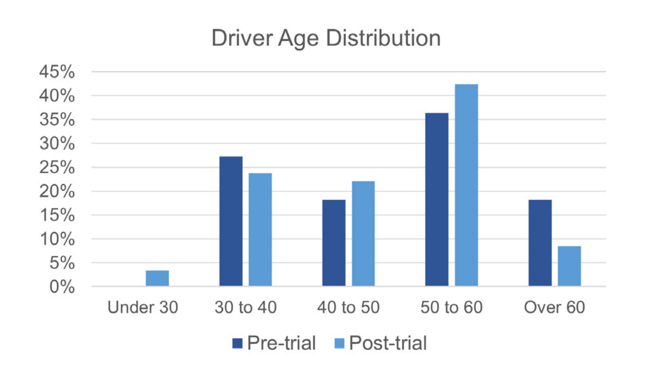
Training

Fleet managers have expressed the need for more EV specific training to help drivers understand how to better manage their driving style and the quiet nature of the BETT truck in congested and pedestrian-heavy locations.



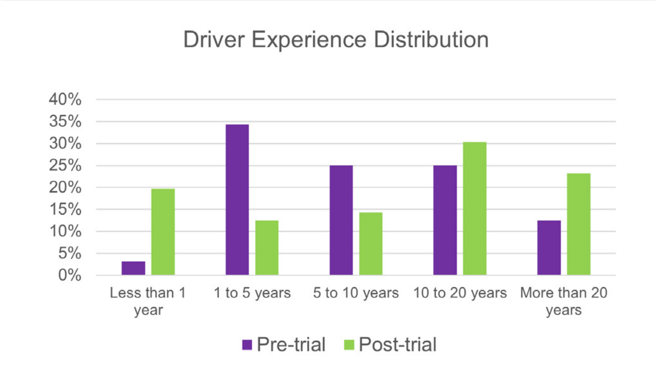
Driver Survey Findings

The following presents a comparison of pre-trial and end-of-trial surveys to show the progression of driver opinions on experience with driving, charging and operating the BETT truck compared to diesel trucks. The initial pre-trial survey was filled out by 59 drivers who were identified as potential BETT truck drivers by fleets. The end-of-trial survey gathered feedback from 33 drivers who actually drove the BETT truck.



About the Drivers

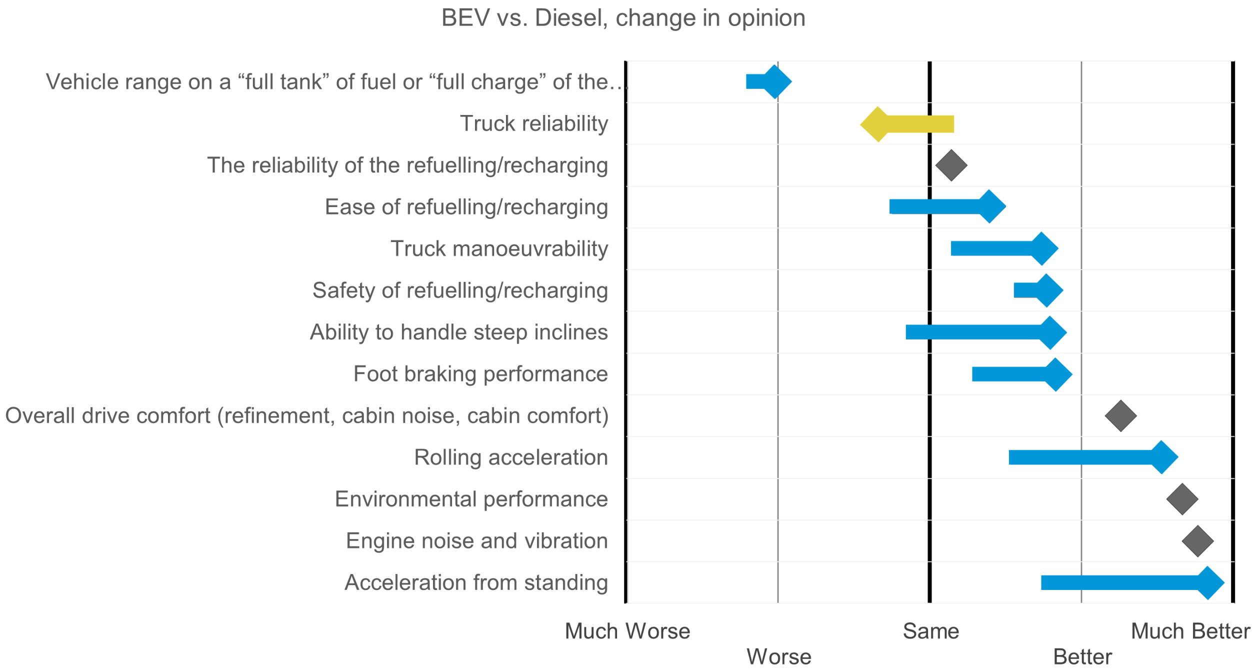
Only 22% of drivers in the end-of-trial surveys had driven an electric vehicle prior to the BETT truck. The following graphs show the age and experience of the drivers.



Performance and Driving Features

Drivers were surveyed about their pre-trial expectations and post-trial experience of the performance and driving features of the BETT truck compared to a conventional diesel vehicle. The following chart shows how experiences compared to expectations.

Blue markers show where the experience was better than the expectation, and yellow where it was worse; the length of the bar shows how much the opinion changed. A grey marker indicates there was no significant change.



Driver Survey Findings

Pre vs Post-Trial Comparison

The categories which have significantly exceeded pre-trial expectations (shown with a long blue bar) are acceleration, both rolling and from a standing position, and the ability to handle steep inclines. Other categories that have also exceeded expectations are foot braking performance (due to regeneration), truck manoeuvrability, and ease of recharging.

On the other hand, truck reliability was the only category in which the experience was worse than the expectation. It must be noted that the trial vehicles were an initial prototype-like model and that newer vehicle generations will be including improvements in several features, such as dashboard and in-cab heater.

Best and Worst Categories vs. Diesel

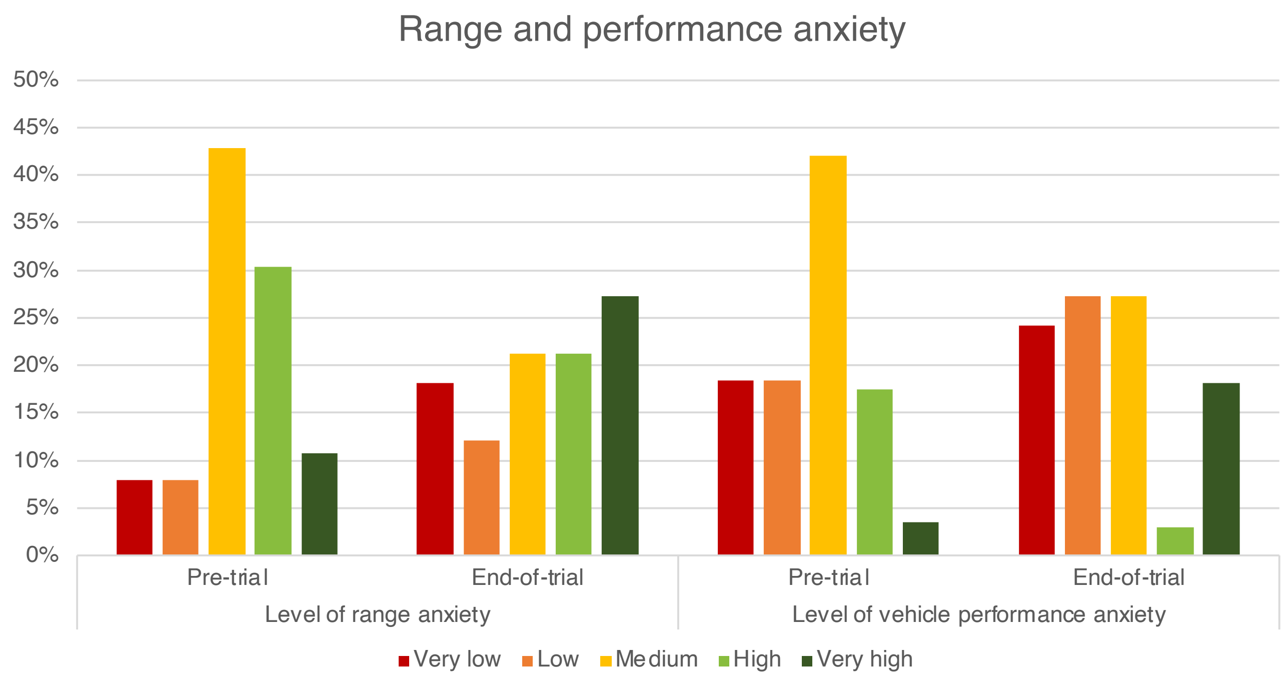
The categories that have performed the best against diesel at the end of the trial are acceleration, engine noise and vibration, overall driving comfort (refinement, cabin noise and cabin comfort), and environmental performance. All of these achieved average scores between 'better' and 'much better' than diesel.

The categories that scored approximately the same as diesel at the end of the trial are truck reliability, ease of recharging, and reliability of recharging. Interestingly, even though some fleet managers were vocal about unreliable charging infrastructure, drivers scored this latter category as being similar to diesel.

Finally, the only category that underperformed significantly compared to diesel at the end of the trial is range on full charge, marked as 'worse' than diesel on average both pre- and post-trial. However, this is not surprising considering the truck is only expected to have a 270 km range. The BETT data demonstrated that most trucks were mostly being used well within their range limit, indicating that range was not an issue for the majority of operations.

Vehicle Performance Anxiety and Range Anxiety

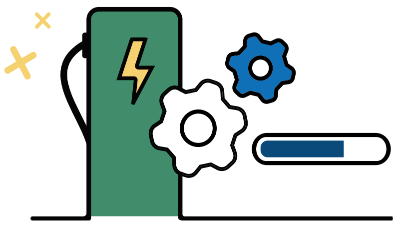
The following graph shows the level of range anxiety in drivers, defined as the fear of not making the destination due to restricted vehicle range, and performance anxiety, defined as the fear of the vehicle not being able to perform the job.



Driver Survey Findings

The most common response to both questions in the pre-trial survey was "medium" while responses after the trial were more polarised with higher numbers of both "high" and "low" responses. This could be due to pre-trial respondents choosing the middle option when they were actually uncertain, while after the trial respondents could draw on their experience to provide a definitive response.

Nonetheless, after the trial the proportion of drivers indicating that their level of range anxiety was high or very high increased compared to before the trial, indicating that despite fleet managers being more comfortable with the range of the vehicle, this is still an area of concern for drivers. It is worth repeating that a strong reason for this is likely the lack of a remaining range indicator and the fact that the SOC gauge was hard to read, both of which are issues that will be resolved in newer generations of the vehicle.

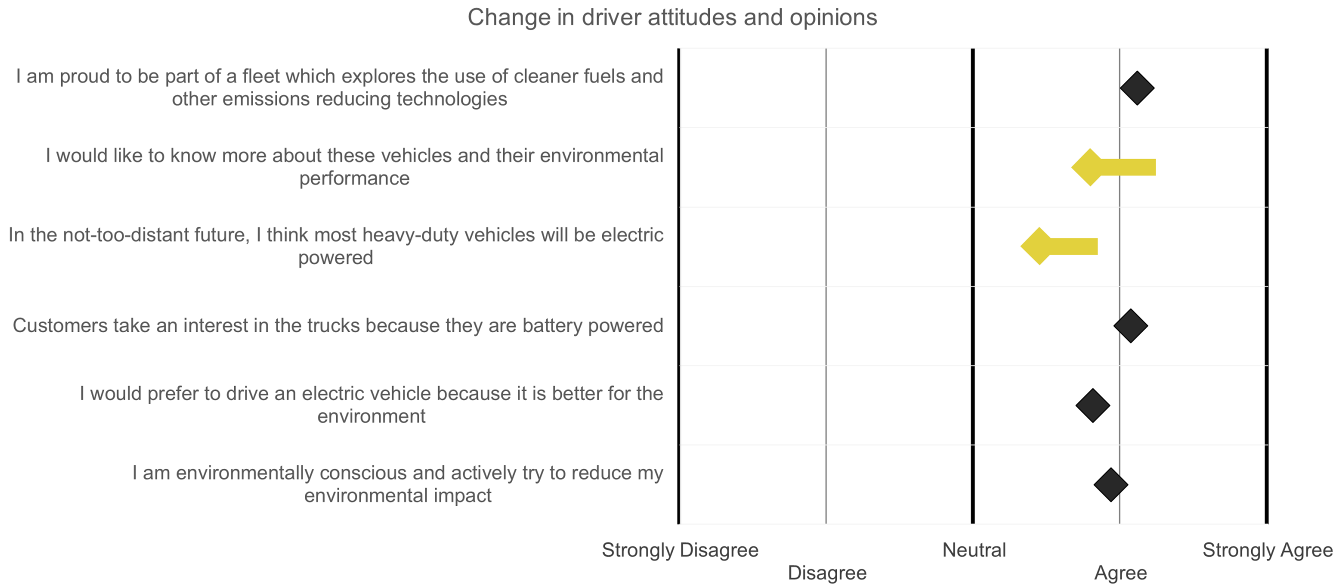


Attitudes and Opinions

The following graph represents the changes in attitudes and opinions of drivers towards the use of battery electric HGVs and battery electric vehicles in general. Blue markers show where the opinion was more positive at the end of the trial compared to the start, and yellow where it was worse; the length of the bar shows how much the opinion changed. A grey marker indicates there was no significant change.

The challenges identified below have meant that drivers' attitudes are either the same or slightly less positive towards electric HGVs compared to the beginning of the trial. However, the overall scores are positive and drivers have continued to be environmentally conscious and supportive of the introduction of the BETT truck, with most "agreeing" or "strongly agreeing" with most statements.

Over 50% of drivers in pre-trial and end-of-trial surveys felt a sense of pride to be part of a fleet exploring cleaner fuels and emission reducing technologies, and 45% of drivers in end-of-trial surveys indicated that they would like to know more about BEVs and their environmental performance. On average, most drivers feel positive about the new BETT truck.

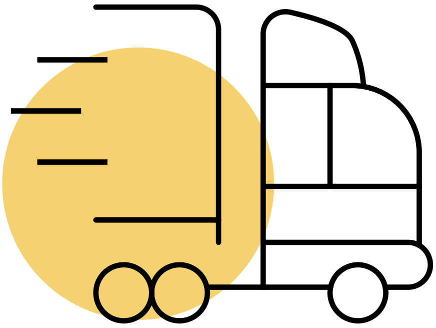


Driver Survey Findings

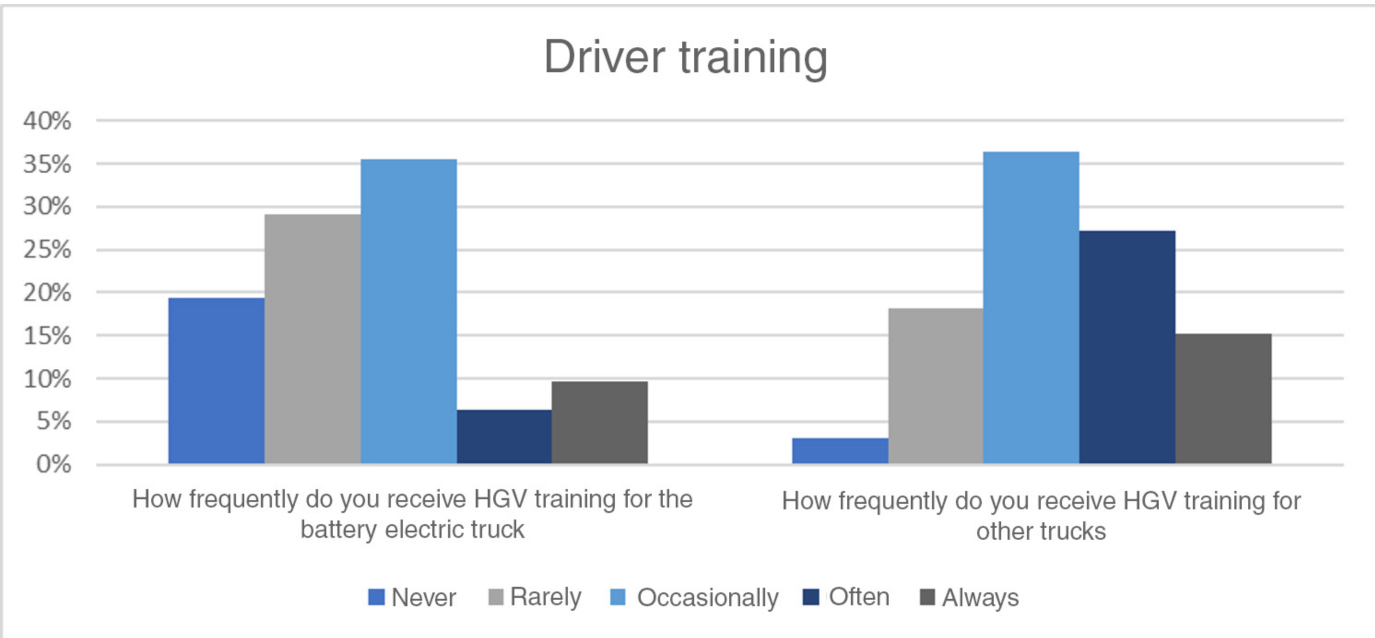
Driver Training and Driver Behaviour

The following graph explores driver training insights, both for BEVs and diesel vehicles.

There is a clear need for further driver training related to BEVs compared to diesel vehicles, as most drivers only received occasional BEV truck training. Drivers noted that they would benefit from in-cab training for a week to understand how to navigate all routes, and 64% of drivers indicated that training sessions influence their driving style.

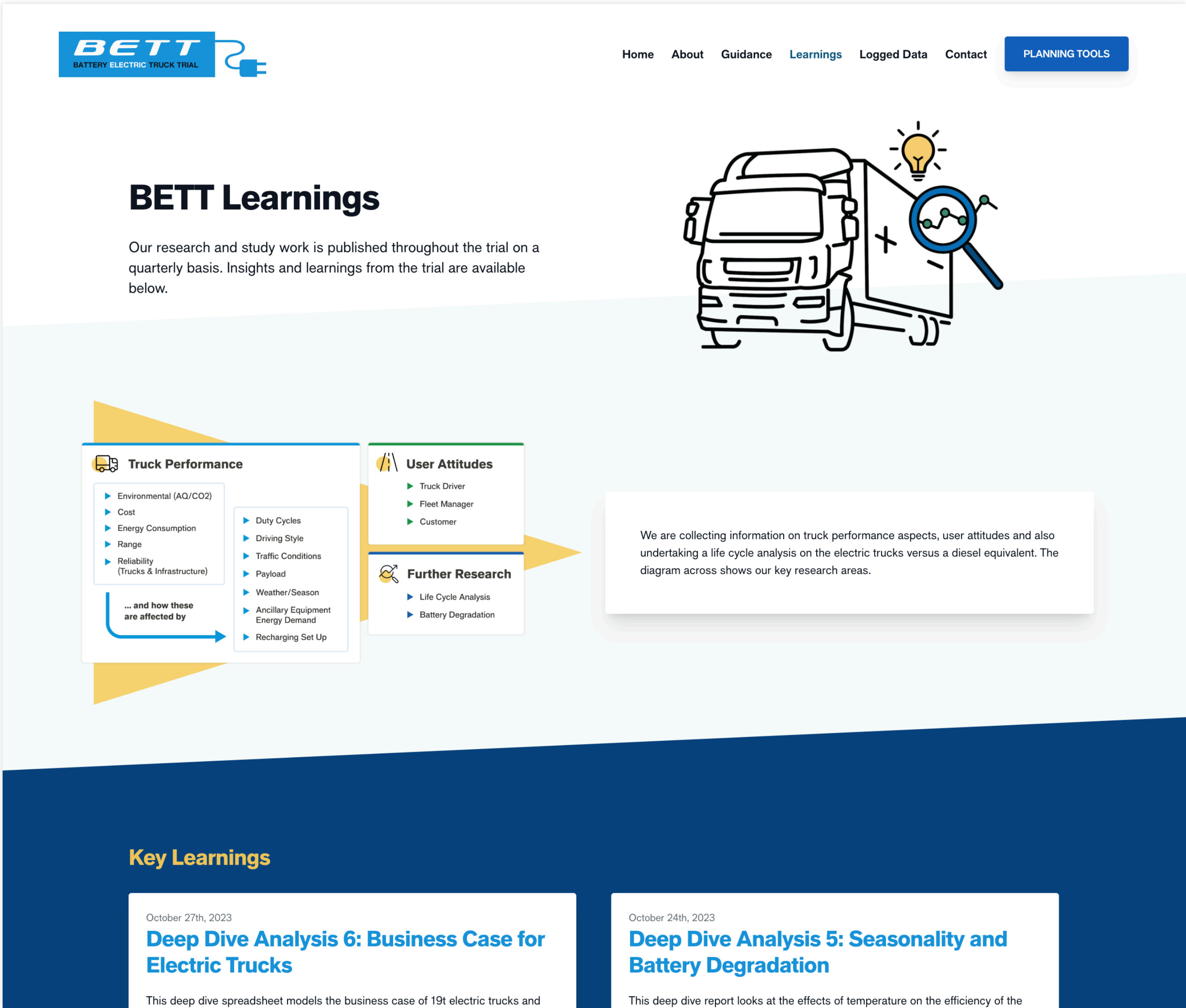


Drivers have identified training as important for forward planning to recharge, learning how to coast, building confidence, awareness, better control, eco driving techniques, increasing the range of the vehicle, and even vehicle maintenance in the event of loss or power or breakdown. Out of the specific BEV training that the drivers received, charging was the most common topic, but it also included eco-driving, regenerative breaking, and range management.



Business Case of Electric Trucks

This section showcases the modelled business case of a fleet of 19t electric trucks and their charging infrastructure compared to diesel, from the point of view of a fleet operator. Many different scenarios were simulated to test how sensitive electric vs diesel total cost of ownership (TCO) savings are to 21 operational, policy and external factors. The objective of this section is not to provide exact TCO values for fleets, but to provide commercial vehicle stakeholders with a framework to assess how large or small an impact several variables can have on the business case of BEVs. The spreadsheet model on which this section is based can be found on the **BETT Portal (https://bett.cenex.co.uk/bett-learnings)**.



Methodology

The sensitivity factors are grouped into 'Policy', 'Operational' and 'External'. 'Policy' refers to actions that public authorities take to either promote or discourage the uptake of BEVs and diesel vehicles, respectively. 'Operational' refers to how fleets use vehicles and chargepoints. 'External' refers to factors that are at least partially out of the control of fleets or public authorities. Each factor has been given three values: low, medium and high. An explanation on why these factors were selected and their likely impact is shown in the table below (OPEX=operational expenditure, CAPEX=capital expenditure).

POLICY	
CAZ (£/day)	Clean Air Zone charges are being applied to diesel vehicles in multiple UK cities to preserve air quality in urban areas.
Diesel VED & levy (£/year) BEV VED & levy (£/year)	Current tax structures could be replaced by a 'road user charge' in the future, with drivers paying per km driven.
Vehicle grant (£)	Grants provided by governments to purchase electric vehicles to incentivise market uptake.
Chargepoint grant (£/plug)	Grants provided by governments to purchase and install electric vehicle chargepoints to incentivise market uptake.

OPERATIONAL	
Average daily distance (km)	Higher distances mean more potential OPEX savings for BEVs, but charging and range could be challenging.
Daily time outside depot (hours)	More time outside depots mean less opportunity to charge cheaply at the depot.
Days per week usage	Higher usage means more potential OPEX savings for BEVs.
Days per week into CAZ	More days per week into CAZ means higher OPEX cost for diesel, hence higher BEV savings.
Stops per day at public chargers	Public charging in places such as motorway service stations can be twice as expensive as depot charging (per kWh), so avoiding public charging means lower BEV OPEX.
Vehicle to plug ratio	If depot chargepoints can be managed efficiently then they can be shared between multiple vehicles, but higher charging power per plug may be required, which increases the BEV CAPEX via increased charger cost and the potential need for grid upgrades.
% energy savings BEV vs diesel	This is the difference in primary energy used per unit of distance. Higher energy savings mean higher OPEX BEV savings.
BEV fleet size	Higher BEV fleet sizes mean potential CAPEX discounts on large orders.
Available headroom (kW)	The power available for chargepoints once the normal power usage of a depot (lighting, tooling, etc.) is discounted. A higher headroom avoids the need for grid upgrades, lowering CAPEX and hence increasing BEV savings.

Methodology

EXTERNAL	
Manufacturing maturity	A more mature product means more automated manufacturing processes, improving economies of scale and hence reducing vehicle CAPEX.
Battery pack cost (£/kWh)	As battery technology improves, a decrease in HGV battery pack cost is expected in the next decade, which reduces vehicle CAPEX.
Electricity price depot (£/kWh) / price public (£/kWh)	As more renewable energy sources are embedded into the grid in the coming years, a decrease in electricity price is expected.
Diesel price (£/L)	This is a highly fluctuating factor and hence it has been included within the sensitivity factors.
BEV residual value	Residual value of electric HGVs remains an uncertainty, but the use of second life batteries in other applications could improve this.
Grid upgrade cost (£/kW)	If several BEVs need to be charged simultaneously, the contracted power at depot might not be sufficient and a grid upgrade could be required to cope with the increased power demand.

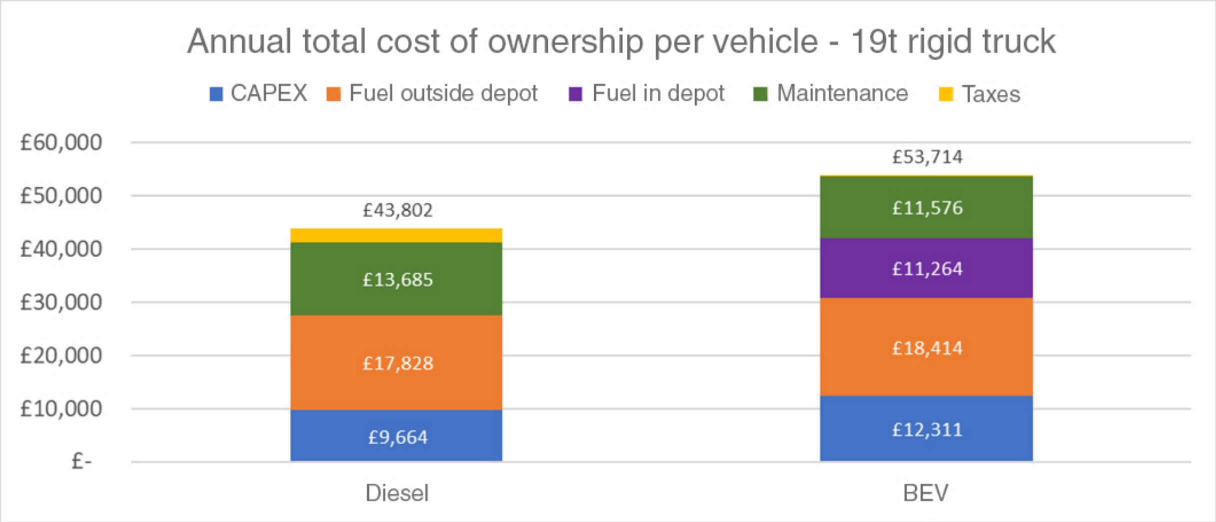
An explanation on the range of values selected for these sensitivity factors is available in the spreadsheet model, and the low/medium/high values can be seen in the tornado charts in the following pages. The model also contains all constants, with the most relevant ones being: 7 year ownership period, 250 kWh battery capacity, and the fuel consumption in various driving conditions shown in the table below. The diesel efficiency in mile per gallon (MPG) at 50% payload comes from vehicle test data in past R&D projects following the procedure by Zemo Partnership (2022). The BEV electricity consumption is then obtained by applying a percentage of energy savings, which is one of the sensitivity factors. The medium value was obtained from real-world drive cycle data at 50% payload from the entire BETT trial.

DRIVE CYCLE	DIESEL MPG
Urban	10.1
Rural	12.1
Motorway	13.1

TCO is split into capital and operational expenditures, CAPEX and OPEX respectively. Under CAPEX we have included the depreciation of vehicles and chargepoints, and a potential grid upgrade at the depot if required to cater for the additional power demand from chargepoints. OPEX includes fuel, both at depot and elsewhere: while BEVs can be charged both at depot or public chargepoints (based on upcoming public infrastructure deployments), we have assumed that diesel is only refuelled out of depot with a 5p/L discount usually obtained by fleet operators to account for bulk orders. OPEX also includes vehicle and chargepoint maintenance, a battery refurbishment once it drops under 80% state of health after 350,000 km (Trucknews, 2022), vehicle excise duty (VED), and clean air zone (CAZ) charges if applicable.

The sensitivity analysis via 'tornado' graphs in this report are produced in the following way. The baseline scenario, i.e. the central axis of the tornado, are the BEV savings per vehicle compared to diesel, when all variables have medium values. We then vary one variable at a time from low to high, while keeping the rest of the variables as medium, with the extremes of the tornado in the graphs also reflecting BEV savings. This way we can isolate the impact of each of the variables on BEV savings and observe which have the largest or smallest impact. The variable values are indicated within the graph for further guidance.

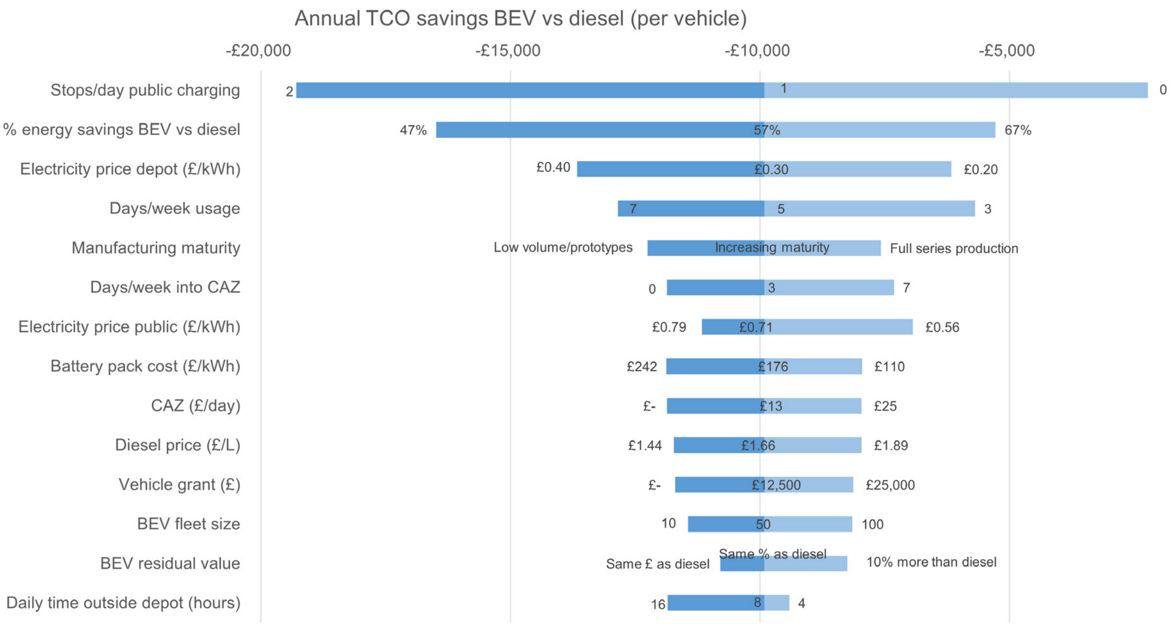
Results With Public Charging



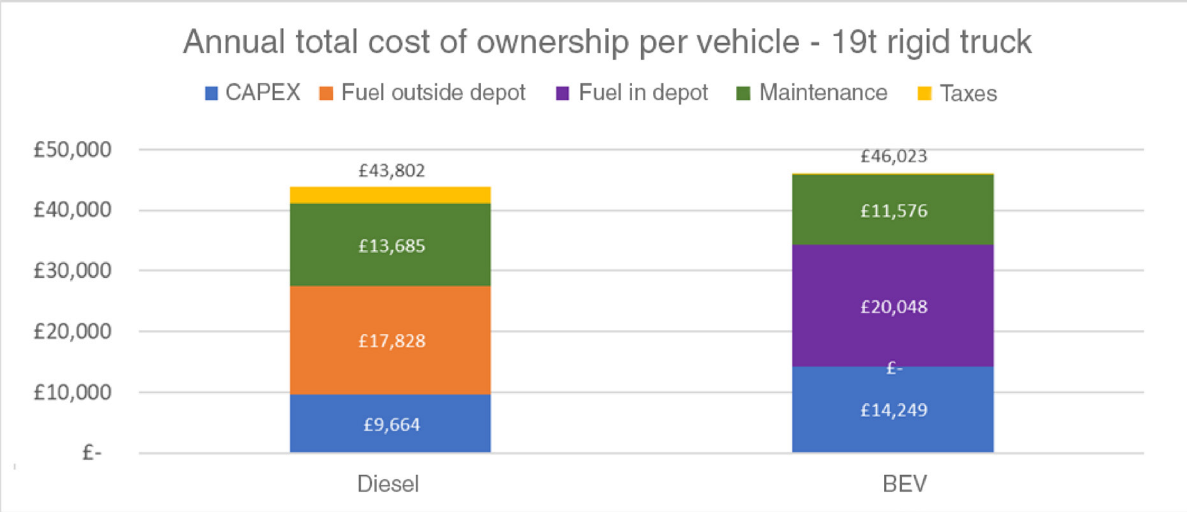
The graph above shows the TCO breakdown in the baseline scenario, i.e. when all variables have medium values. Some categories have been merged for clarity, e.g. all CAPEX elements.

The baseline scenario provides negative BEV savings of £10,000 per year. Even though maintenance and taxes are smaller for the BEV, the larger CAPEX and especially the larger fuel costs are the reasons for the negative savings. The baseline scenario includes one stop per day at public chargepoints, which currently have tariffs that can be twice as expensive as depot charging, which increases the BEV OPEX significantly. To achieve TCO parity in the 'medium' scenario where depot charging costs 30p/kWh and diesel costs £1.28/L (all excluding VAT), then public charging would need to cost 29p/kWh excl. VAT, i.e. almost the same price as depot charging. The tornado graph below shows the sensitivity analysis for the most significant variables (all variables available in the spreadsheet model).

Out of the top 10 variables with the largest impact on BEV savings, 5 are 'External', 4 are 'Operational', and only 1 is 'Policy' related. This means that fleets still have some control over their economics if they operate their vehicles efficiently. However, there are still many external factors that have a large impact, mostly related to diesel and electricity prices and vehicle maturity (and hence purchase cost). Policy related variables (bonus/malus incentives) can help in the short term, but are likely to have diminished impact in the future.



Results Without Public Charging



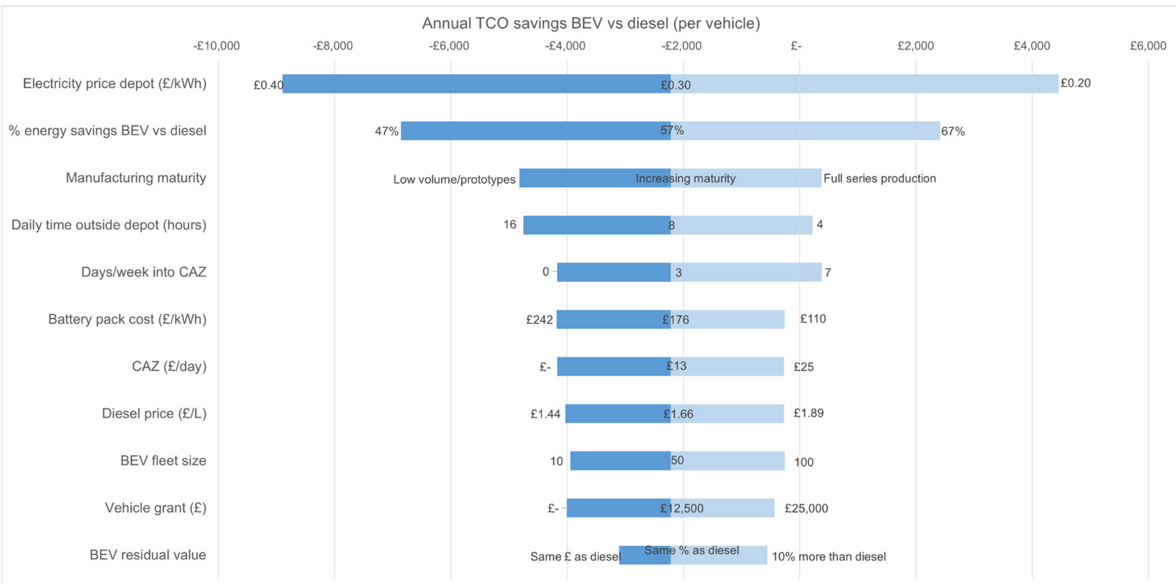
Because using public chargepoints has such a large impact, we have dedicated a separate analysis for the situation when a fleet could always charge at their depot. The TCO breakdown is shown above.

In this new baseline scenario, BEV savings are still negative, but have been increased to minus £2,000 per year. The additional BEV CAPEX from increased depreciation of both vehicle and depot chargepoints, plus a small grid upgrade, cannot be recovered by the reduced maintenance and tax costs because fuel costs are still more expensive for the BEV. The tornado chart below is a repetition of the previous sensitivity analysis, but fixing the 'Stops/day public charging' in their low value (zero).

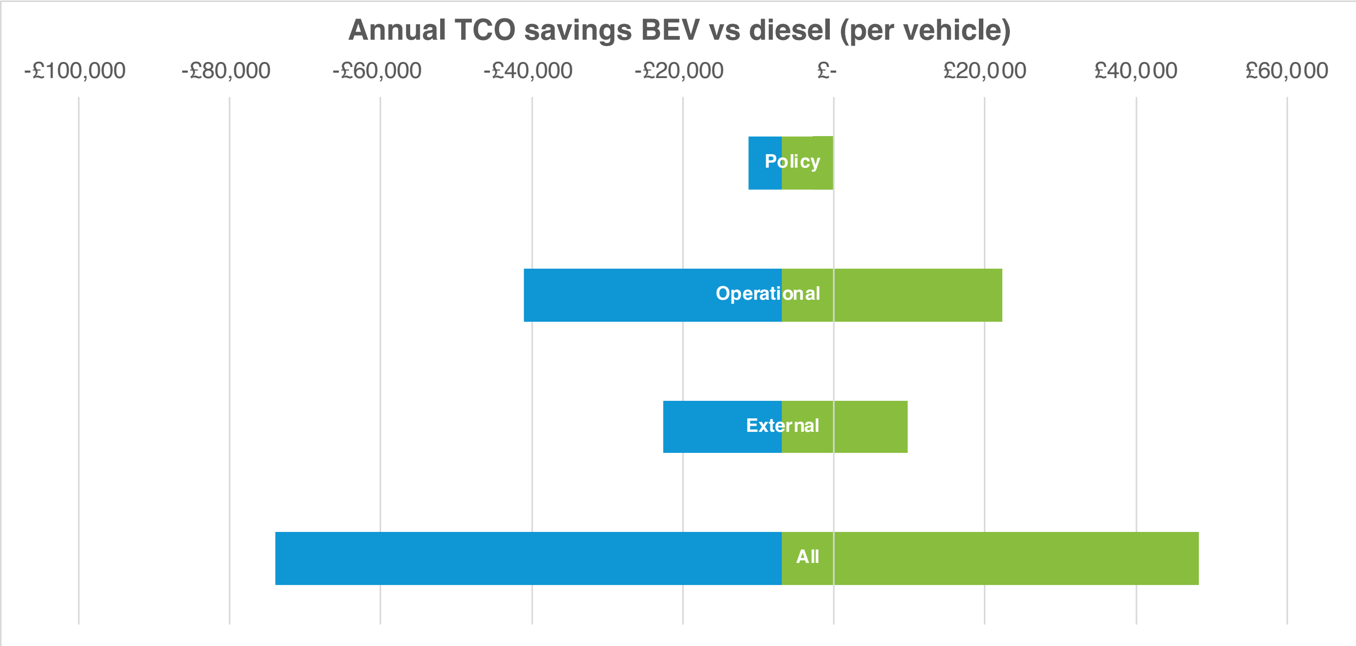
The baseline savings are still negative in this case, but some of the sensitivity results (the extremes of the tornado) provide positive savings. The trend of mostly 'Operational' and 'External' variables showing high impact is maintained in this case.

Diesel and electricity prices have a key effect on business case, so we have conducted the following analysis (all prices exclude VAT):

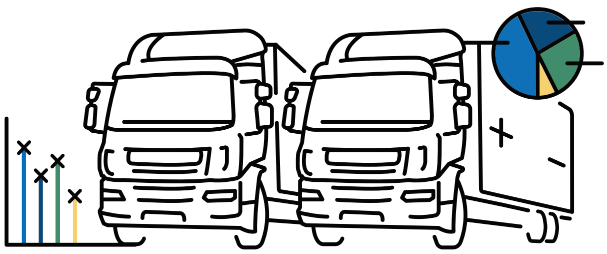
- TCO parity can be achieved at 30p/kWh and a high diesel price (£1.42/L)
- TCO parity can be achieved at 27p/kWh and a medium diesel price (£1.28/L)
- TCO parity can be achieved at 24p/kWh and a low diesel price (£1.15/L)



Results – Extreme Scenarios



In the previous sensitivity analyses we were changing a single variable at a time to isolate the impact of each of them. However, in the real world usually several factors can vary simultaneously. We have varied all 'Policy' variables to provide the worst and best possible BEV savings, while keeping all 'Operational' and 'External' variables as medium. We have repeated the same exercise for 'Operational' and 'External' in order to show the whole range of possible results. Finally, in the 'All' results, we have modified all variables at the same time to present the extremes of the possible BEV savings if everything is ideal, or everything is the worst case.



As hinted at in the other sensitivity analyses, 'Operational' and 'External' factors have the largest impact compared to 'Policy'. Favourable operational and external conditions can have a positive effect on BEV savings. In particular operational conditions, so fleets with enough flexibility to adapt their operations and manage their vehicles efficiently can obtain annual savings of up to £13,700 per vehicle.

As per previous sections, reasonable electricity tariffs for both depot and public charging are required for electric trucks to at least achieve TCO parity compared to diesel, or to achieve savings depending on diesel prices. A mechanism to avoid large fluctuations in charging tariffs may be required in the future to provide confidence and security to fleet operators and organisations to invest in BEVs. This could either be a policy-related instrument implemented by the government, or charging providers would need to absorb costs while providing a stable price to fleet operators, or a combination of both. A range of electricity prices were nevertheless simulated as one of the 'External' factors to account for their fluctuation.

Environmental Impact: Life Cycle Assessment (LCA)

Introduction

Life Cycle Assessment (LCA) is a crucial tool for evaluating the environmental impacts associated with the entire life cycle of a product or process. This assessment offers insights into environmental hotspots and opportunities for improvement, helping organisations make informed and sustainable decisions. In this section we outline the scope, methodology, and key findings of the LCA.

Methodology

Goal and Scope Definition

This analysis was performed using the specialised software OpenLCA to compare the environmental footprint of a 19t rigid DAF electric truck with an equivalent DAF diesel truck. Detailed modelling was done of the components that are different between the electric and the diesel version to determine the difference in environmental impact between the two vehicle types. This means that only components that are present in the EV but not in the diesel one, and vice versa, are analysed in detail. Examples of "core" components which are the same in the diesel and electric vehicles include tyres, the cab and the chassis, together known as a glider, and we used data from Hill et al. (2020) to estimate their lifecycle emissions.

Assumptions and Data Sources

To conduct our comprehensive LCA, we made use of several data sources and assumptions.

Energy Requirements During Production:

To calculate the energy requirements during the production phase of vehicle components, we referred to the study by Sato et al. (2020).

Recycling Benefits:

In a life cycle assessment, emissions savings can be achieved through the recycling and reuse of materials and components. This acknowledges the reduction in environmental impact that occurs when materials are diverted from disposal and incorporated back into the production cycle, resulting in lower resource consumption and emissions compared to the use of new, virgin materials. The recycling benefits were derived from data provided by GaBi and ecoinvent, both well-established sources for life cycle assessment and environmental impact data.

Battery Recycling Benefits:

The benefits associated with the recycling and reuse of batteries were calculated based on research by Dong et al. (2023).

Charge Efficiency:

A charge efficiency of 90% was assumed, indicating that 90% of the energy supplied to the chargepoints is input into the battery. This was based on AC charging data from the BETT trial.

Vehicle Lifetime:

A lifetime of 7 years (Drake et al.) driving 50,000 kilometres per year (Department for Transport) was used for both diesel and electric trucks.

Environmental Impact: Life Cycle Assessment (LCA)

Energy & Diesel Consumption:

The same diesel efficiency values explained in the 'Business Case' section were used for diesel, while the following energy consumption values were used for the BEV. An average of the three values were used for both diesel and BEV, to reflect a 'mixed' duty cycle. These figures use data from journeys in the BETT trial which represent a roughly 50% payload to match the diesel data, and have been adjusted to include charging losses. This means they are slightly different from the headline efficiency values given earlier in the report.

DRIVE CYCLE	BEV kWh/km
Urban	1.008
Rural	0.954
Motorway	0.943

Output Values

The critical factor when investigating how these vehicles impact the climate over their lifetime is how much carbon dioxide equivalent (CO_2e) greenhouse gas is emitted during each phase. CO_2e accounts for all such gases, not just CO_2, by applying a factor known as the global warming potential (GWP) which indicates how strongly it acts as a greenhouse gas. We have used GWP100 which accounts for the varying lifetime of gases in the atmosphere by considering their effect over 100 years.

Production Phase

The raw material acquisition and production phases consider the environmental impact of extracting the raw materials, transporting them to factories, manufacturing them into components, and finally assembling them to create the final product.

We have used detailed bill of material data provided by DAF for both types of trucks and employed the extensive databases from widely-used LCA software like OpenLCA and ecoinvent to help us gauge the environmental effects of the production phase. For the large common components and where materials or components were not available in the software, we have sourced them from literature.

The bill of materials outlined the precise basic material quantities for each part. To assess the environmental impact of every component, we used datasets specific to each material, covering the entire lifecycle from raw material extraction and transportation to manufacturing into the basic materials that then can be used for parts production (e.g. aluminium ingots or steel sheets). For accurate energy assessments during part production, literature studies, particularly Sato et al. (2020), were consulted. The exception to this was the battery and the engine/motor, which, due to their complexity, meant we based our assessment on part-specific datasets which include the energy requirements and emissions required to manufacture the entire product. A similar approach was taken for the glider, for which the impact was estimated from Hill et al. (2020).

Environmental Impact: Life Cycle Assessment (LCA)

Use Phase

For the diesel truck, the use phase encompasses emissions from the entire life cycle of the fuel it consumes. This includes the emissions from the extraction, refinement, transportation, and supply of the fuel (known as well-to-tank or WTT emissions), in addition to the emissions resulting from the combustion of this fuel in the engine (tank to-wheel or TTW emissions). Combining these two sets of emissions provides a comprehensive view of the diesel truck's impact during the use phase, known as well-to-wheel (WTW) emissions.

In contrast, the electric truck has zero tailpipe emissions so there is no TTW emissions. The use phase accounts for only the equivalent WTT emissions arising from the generation, transmission, and distribution of the electricity it consumes.

We have considered three distinct electricity grid mixes: the UK, Poland (as a current worst case in terms of grid carbon intensity), and Denmark (representing a current best case). This approach allows us to explore the varying effects of different charging locations on the environmental performance of electric trucks. The table below shows the carbon intensity of electricity generation for each of these three countries, expressed in kilograms of CO2 equivalent per kilowatt-hour (Lo Vullo et al., 2020):

COUNTRY	CARBON INTENSITY (kg CO2e/kWh)
UK	0.326
Poland	0.796
Denmark	0.076

End of Life

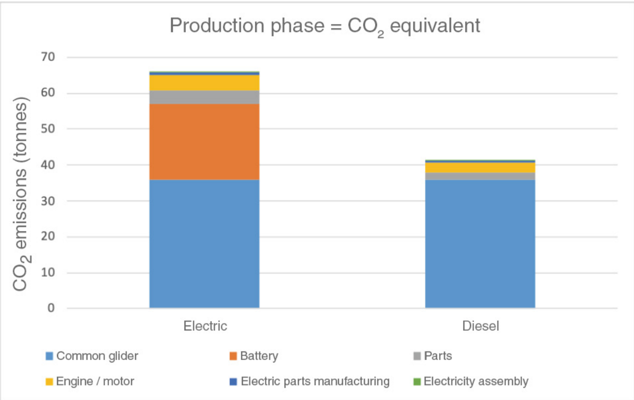
In the final phase of our LCA, we address the end-of-life (EOL) considerations for diesel and electric trucks. This phase involves disposal, recycling, and material recovery, and although it has a lesser impact on emissions compared to production, it is still significant for sustainability. Three EOL scenarios have been considered for this assessment which are based on the research of Munir (2021). In each scenario the balance between disposal, recycling, and reuse varies: a baseline scenario, a recycling-focused scenario, and a scenario with a particular emphasis on reuse. The details of these scenarios and the respective percentages are outlined in the table below:

SCENARIO	END OF LIFE		
	Disposal	Recycling	Reuse
Baseline	10%	90%	0%
Recycling	10%	79%	11%
Reuse	5%	54%	41%

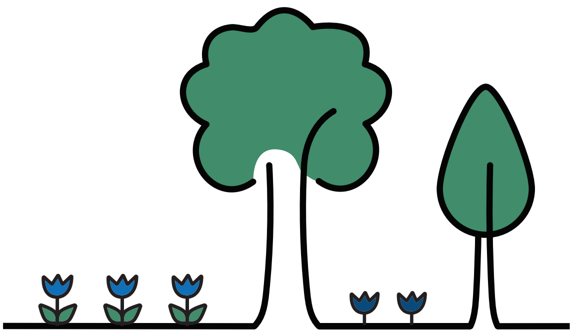
Results

Production Phase

The graph below shows the modelled emissions during the production phase comparing the electric and diesel DAF truck.

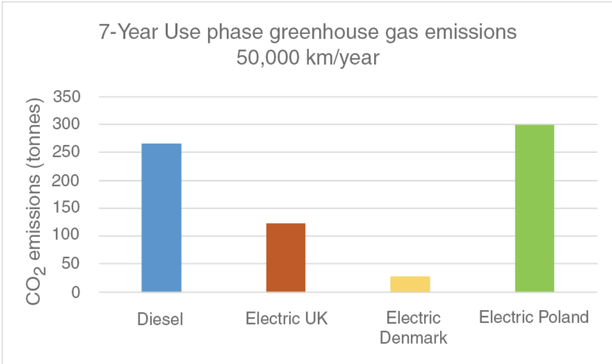


The electric truck has a 1.6 times larger environmental footprint during the production phase compared to its diesel counterpart. The main culprit here is the electric vehicle's battery, although the electric motor also has a higher impact than a diesel engine. Additionally, electric trucks are generally heavier and require more materials during production which contributes to a higher emissions output for "parts". Remember that battery and engine contributions already include energy for manufacturing these components.



Use Phase

The following graph shows the use phase emissions for all three grid carbon intensity cases for both electric and diesel units.



There are significant variations based on the location where the electric truck is charged. In the UK, where 60% of the electricity grid mix is zero carbon, electric trucks exhibit a 54% reduction in greenhouse gas emissions compared to diesel trucks. This is a clear indicator of the environmental benefits of using electric trucks when charged in regions with a cleaner energy mix.

On the other hand, in Poland, the use of electric trucks results in a 13% increase in greenhouse gas emissions compared to their diesel counterparts. This discrepancy is due to the energy mix in Poland, being more reliant on fossil fuels, leading to higher emissions from electricity generation.

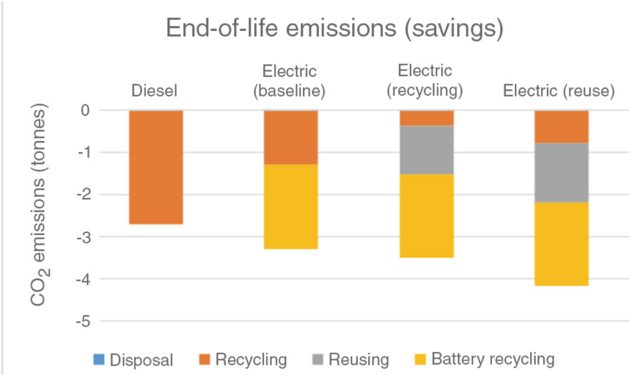
In Denmark, where the electricity generation mix is cleaner, electric trucks demonstrate a substantial 89% reduction in greenhouse gas emissions during the use phase, making them an environmentally advantageous choice in this region.

These findings emphasize the crucial role of the electricity grid's energy sources in determining the environmental impact of electric trucks during their use phase. Fleets that have access to on-site renewable energy generation, such as solar or wind power, stand to further reduce the use phase emissions of electric trucks, enhancing their sustainability.

Results

End-of-Life

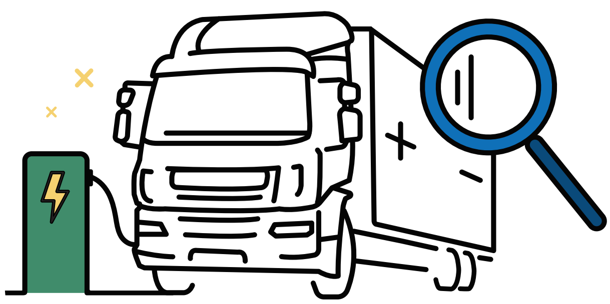
The following graph shows the comparison in end-of-life emissions between the diesel and the electric vehicles.



Due to the larger volume of materials used in electric trucks, particularly the battery and related components, there is more opportunity for recycling and reusing materials.

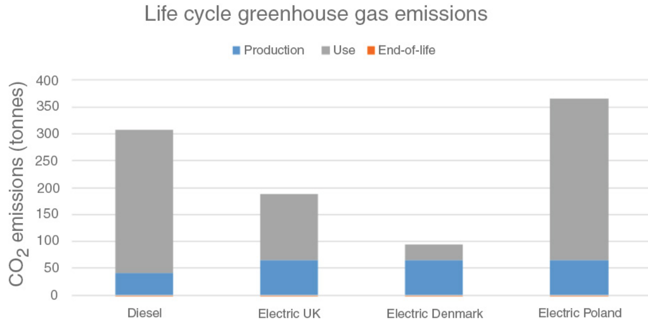
The potential for end-of-life benefits is directly tied to the quantity of materials available for recycling and reuse. While the end-of-life phase may not be the main source of emissions, it underscores the importance of efficient material recovery and recycling practices, particularly in the context of electric trucks in order to offset the greater environmental impact in the production phase. This ultimately contributes to a more environmentally friendly transportation industry.

While end-of-life impact was measured via the CO2 emissions, other ways of measuring its environmental contribution may include resource availability in terms of circularity.



Life Cycle Results

In summary, the overall results of our life cycle assessment show some compelling insights. The total greenhouse gas emissions are shown in the following graph.

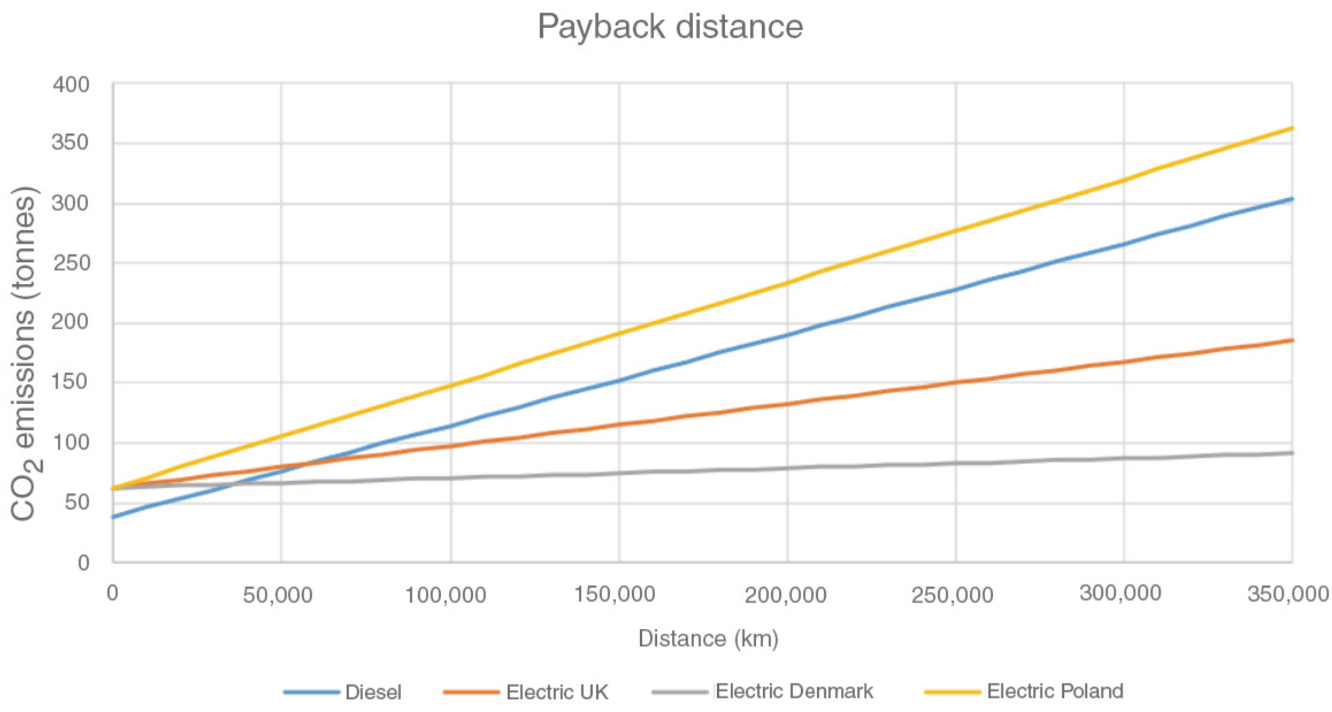


The most notable feature is that for a diesel vehicle the environmental impact of the use phase dominates the total impact and dwarfs that of the production phase. Even though the impact of the production phase is significantly greater than a diesel equivalent, in most cases this is still true for electric vehicles.

Nevertheless, unlike with a diesel vehicle there is scope to reduce the impact of the use phase with low carbon electricity generation. Over the entire life cycle, the electric truck has a 39% reduction in emissions compared to its diesel counterpart in the baseline scenario (UK charging and baseline end of life). Charging the electric truck with the cleaner Danish electricity grid results in an impressive 69% reduction in emissions, highlighting the advantages of cleaner energy sources. On the other hand, when the electric truck is charged with the Polish electricity grid mix, there is a 19% increase in emissions compared to the diesel truck. This disparity demonstrates the critical role that the energy grid's composition plays in determining the environmental performance of electric vehicles.

Results

Another key parameter to consider is the “payback time”, or in this case “payback distance”, which is the distance a truck must travel to equalise the emissions between the electric and diesel counterparts. This is shown in the following graph.



In our baseline analysis (UK grid charging), this threshold is reached at around 59,000 kilometres (or just over 1 year of operation at 50,000 km per year) after which the electric and diesel trucks have emitted a similar amount of CO2e. Notably, driving beyond this point puts the electric truck in a more favourable environmental position. With the Danish electricity grid mix, the payback time decreases significantly to just over 35,000 kilometres (less than one year), emphasizing the benefits of clean energy in extending the electric truck’s environmental advantage. In Poland, the vehicle will never pay back the higher production emissions due to the use phase emissions being higher than diesel. These results underline the importance of not only choosing electric trucks but also considering the source of electricity used to charge them. Making an informed decision based on the electricity grid’s environmental impact can significantly enhance the overall sustainability of electric transportation and help us reduce our carbon footprint on the road.

Conclusions

Trial statistics

- The BETT project collected data covering 287,000 km of driving with a combined duration of 1 year on the road, across 21,000 individual journeys. Around 2.5 years of telemetry data were recorded in total when including charging and idling.
- The average distance travelled each day was 95 km and an average daily operation time of just under 3 hours. However some vehicles were used significantly more with 400 km regularly exceeded in a day. The furthest driven in one day was 573 km.

Factors affecting range

- Regenerative braking was an important factor in achieving the range in urban and rural drive cycles, with more than 20% of energy being recovered.
- The total combined efficiency across all vehicles in all conditions was 1.08 km per kWh, giving a potential range of 270 km from the 250 kWh battery.
- More than 300 km was achievable in rural conditions, but this dropped to 225 km in urban due to the energy required for repeated accelerations and braking.
- The vehicle payload is one of the largest factors that affect the efficiency, which has an especially large impact on urban driving again due to its start-stop nature.
- Ambient temperature also had a very strong impact on efficiency, with the range dropping by around 30% between the warmest and coldest days.

Human factors

- Fleet managers saw the biggest strengths of electric trucks in the following areas: environmental benefits, operational benefits, cost reduction, positive driver feedback, marketing impact, and energy efficiency.
- Fleet managers indicated the following as the biggest challenges: impact of ambient temperature, reliability and availability of charging infrastructure, range anxiety, maintenance, and the need for specific BEV training.
- Truck drivers reported that two categories significantly exceed pre-trial expectations: acceleration, both rolling and from a standing position, and the ability to handle steep inclines. On the other hand, truck reliability was the only category in which the experience was worse than the expectations.
- According to drivers, the categories that have performed the best at the end of the trial are acceleration, both rolling and from a standing position, engine noise and vibration, overall driving comfort (refinement, cabin noise, cabin comfort), and environmental performance. The only category that underperformed compared to diesel at the end of the trial is range on full charge.
- The level of anxiety about not making the destination due to restricted range is a common experience, with 48% of drivers indicating their anxiety is high to very high. Anxiety levels about the vehicle's performance have remained low to medium indicating that most drivers have the confidence that the BETT truck can perform the job, outside of the issues with restricted vehicle range.

Conclusions

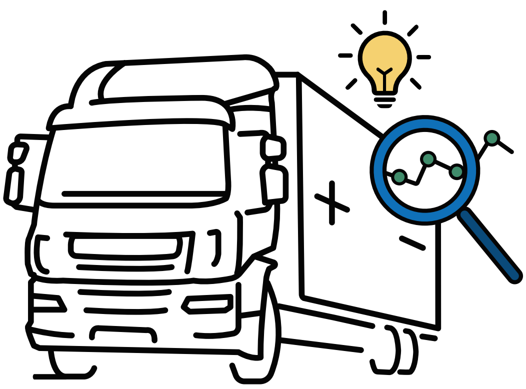
Business case

- The baseline scenario includes one stop per day at public chargepoints, which currently have tariffs that can be twice as expensive as depot charging, which increases BEV OPEX significantly. The baseline scenario provides negative BEV savings of £10,000 per year and vehicle. Even though maintenance and taxes are smaller for the BEV, the larger CAPEX and especially larger fuel costs are the reasons for the negative savings.

- To achieve TCO parity with diesel, public charging would need to cost 29p/kWh, assuming 'medium' values of depot charging at 30p/kWh and a diesel price of £1.28/L (all excluding VAT).

- Out of the top 10 variables with the largest impact on BEV savings, 5 are 'External', 4 are 'Operational', and only 1 is 'Policy' related. This means that fleets still have some control over their economics if they operate their vehicles efficiently, but there are still many external factors that have a large impact, mostly related to fuel/electricity prices.

- In a new baseline scenario with only depot charging, BEV savings are increased to minus £2,000 per year and vehicle. TCO parity with diesel can be achieved with a 'medium' depot electricity price (30p/kWh) and a 'high' diesel price (£1.42/L).



Environmental impact

- The electric trucks have an approximately 1.6 times larger environmental footprint during the production phase compared to their diesel counterparts, mainly due to the impact of producing the electric vehicle battery.

- There are significant variations in the use phase emissions depending on the location where the electric truck is charged. In the UK, where 60% of the electricity grid mix is zero carbon, electric trucks exhibit a 54% reduction in greenhouse gas emissions compared to diesel trucks. On the other hand, in Poland, the use of electric trucks results in a 13% increase in greenhouse gas emissions, while in Denmark electric trucks demonstrate an 89% reduction.

- Over the entire life cycle, the electric truck has a 39% reduction in emissions compared to its diesel counterpart in the baseline scenario (UK charging). However, charging the electric truck with the Danish electricity grid results in an impressive 69% reduction, highlighting the advantages of cleaner energy sources. If the electric truck is charged with the Polish electricity grid mix, we see a 19% increase in emissions compared to the diesel truck.

- In most cases use phase emissions dominate the overall environmental footprint. Production and end of life emissions make a smaller contribution.

- The payback distance, defined as the distance a truck must travel to equalize the emissions between the electric and diesel counterparts, is 59,000 km in the UK and 35,000 km in Denmark. These distances can be achieved by 19t trucks in most duty cycles in around a year. In Poland, an emissions payback cannot be achieved due to the high carbon content of their energy grid mix.

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Contact

BETT was managed by DAF Trucks. Cenex were responsible for research, study aspects and dissemination. If you would like to find out more about the DAF Truck range, then please contact DAF on the details below.

If you have any comments or questions on the study aspects, this website or the fleet tools then please contact Cenex.

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DAF is the only major commercial vehicle manufacturer producing trucks here in the UK, with their factory in Leyland producing over 15,000 vehicles every year. Almost every DAF vehicle registered in the UK, is built here in the UK.

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Cenex focuses on low emission transport & associated energy infrastructure and operates as an independent RTO and consultancy, specialising in project delivery, innovation support and market development.

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