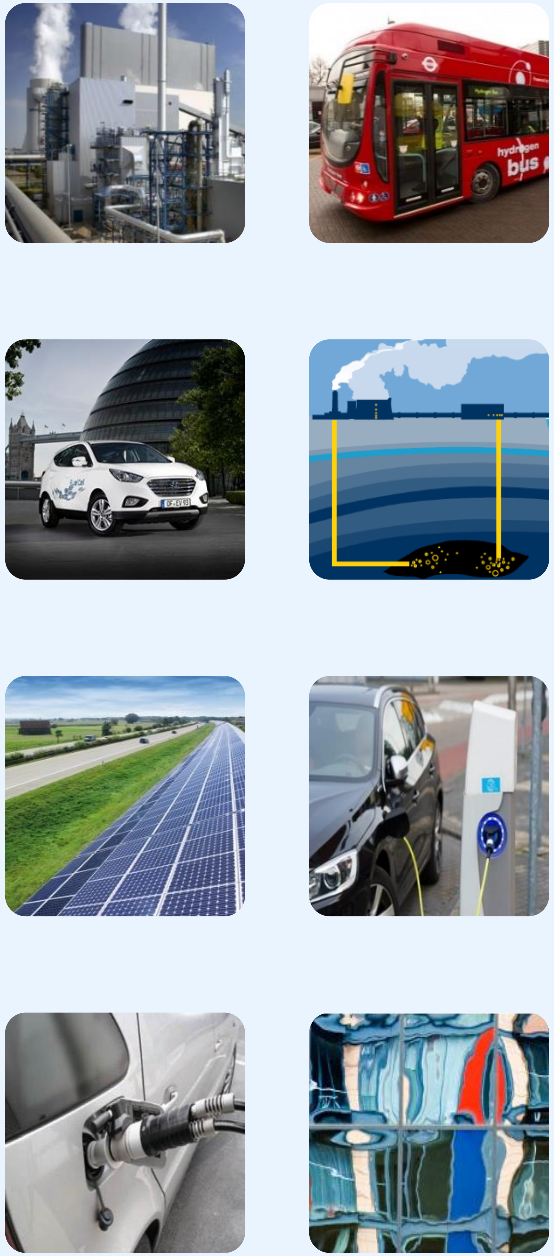

Battery electric HGV adoption in the UK: barriers and opportunities

Private charging market analysis

A report for Transport & Environment

November 2022

elementenergy
an ERM Group company

William Drake, Richard Riley, Celine Cluzel

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This work assesses the barriers and opportunities for early electrification of Heavy Goods Vehicles (HGVs) use cases that do not need to wait for a public charging network to be in place

Aims and objectives of the work

1. Analyse **HGV operations that can be electrified using depot and/or warehouse charging** and hence can be electrified early without having to wait for a public charging network to be in place.
2. Determine the **total cost of ownership (including infrastructure) for battery electric** vehicles relative to diesel across a range of duty cycles, and the associated policy implications.

Approach

1. **Interview fleet operators** and use this to develop a set of **archetypes representing different HGV duty cycles**.
2. Determine the specific infrastructure needs for each duty cycle and **when each duty cycle will reach total cost of ownership parity between battery electric and diesel vehicles**.

Key takeaway

Battery electric rigid HGVs are on the cusp of cost competitiveness for city and regional deliveries but **policy support is needed to de-risk the transition** for fleet operators.

With the right policy support, the majority of rigid HGVs and some artic HGVs can be electrified today using home depot charging only – without needing to wait for a public charging network to be in place

The immediate opportunity for early electrification of back-to-base use cases: key points

1. Between **65% and 75%[1] of rigid HGVs** can be electrified using **home depot charging only** and **battery electric HGV models already available today**. These use cases – whose duty cycles are composed exclusively of back-to-base operations – account for around **15% to 20%** of total UK domestic HGV emissions[2].

2. Combined with battery electric models already available, the **capabilities of battery electric artic HGVs entering series production** with multiple OEMs in **2024** will be sufficient to electrify between **30% and 35%[1]** of articulated HGVs with **charging at their home depot only**. These artic use cases – whose duty cycles are composed exclusively of back-to-base operations – account for a further **10% to 15%** of emissions from UK domestic HGVs.

3. With government support, large scale electrification of back-to-base HGV use cases can begin today and accelerate quickly as battery electric trucks hit total cost of ownership parity with diesel over the next 5 years. Back-to-base uses cases capture **over half of UK HGVs** and **25% to 35% of the emissions**.

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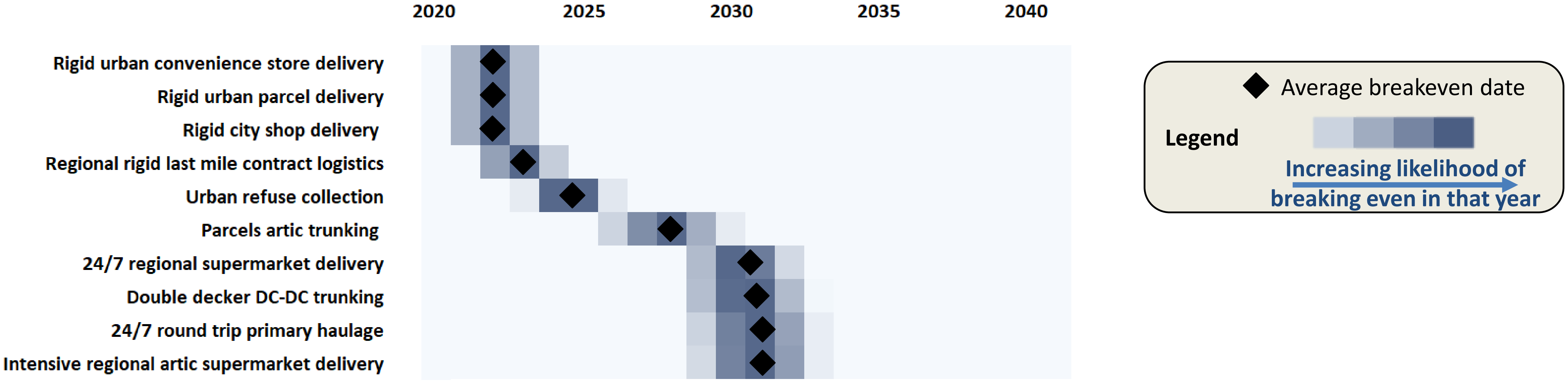
1 – Element Energy research (using first-principles energy consumption modelling) based on capabilities of current BEV models and DfT's national dataset of HGV movements https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1006775/road-freight-statistics-notes-and-definitions.pdf . 2 – OEM model capabilities for 7.5t and 12t vehicles are currently well below what is technically feasible. If models in these weight categories with larger batteries were introduced the proportion of addressable emissions would rise by approximately 5%.

Battery electric HGVs are already capable of performing a huge range of duty cycles using just depot and warehouse charging – and are already cost effective in several use cases

Key conclusions

1. Many HGV duty cycles can be **electrified today without waiting for public charging infrastructure or battery improvements**.
2. **Urban** and **regional deliveries** performed by **rigid HGVs** are **already on the cusp of being cheaper with battery electric vehicles** (BEVs) than diesel vehicles.
3. **BEVs are cheaper than diesel** on a total cost basis **across all use cases studied** by the **early 2030s** - **even with conservative modelling assumptions**.
4. **Policy support** for BEVs is needed in the short term to **de-risk the transition for fleet operators** and close the **cost gap with diesel** for the larger HGVs.

BEV-diesel TCO breakeven dates[1] for a broad sample of HGV use cases, without policy support and with conservative[2] assumptions on future improvements



HGV – Heavy Goods Vehicle; TCO – Total Cost of Ownership; BEV – Battery Electric Vehicle
Descriptions of the duty cycles involved may be found on this slide.

1 – Source: ERM TCO parity date forecasting model; 2 – see following slide.

Policy support is needed to de-risk the transition to battery electric vehicles for fleets and build scale

Why policy support is needed

- **Risk mitigation:** the cost savings from battery electric vehicles come from lower operating costs and, in some cases, increased vehicle life compared to diesel. In the short term, fleet operators may be uncomfortable taking the risk that a certain higher capital cost will be completely offset over the years following purchase by lower running costs since both of these factors are inherently slightly uncertain. This low risk appetite is compounded by the fact that fleet operators generally experience very low profit margins, and hence small cost fluctuations can cause loss of profit. Subsidies to reduce upfront capex for battery electric HGVs are therefore needed in the short term to provide a “margin of safety” for fleet operators so they can be certain that the higher capex will be offset by lower running costs in situations where this trade-off is marginal.

- **Closing the total cost of ownership gap:** for large articulated HGVs, BEVs are currently significantly more expensive on a total cost of ownership (TCO) basis than diesel equivalents. Temporary subsidies are needed in the short term to close this TCO gap, allowing the industry to scale, which will in turn bring down costs and allow subsidies to be phased out completely later. **These subsidies can be funded by a small malus payment on new sales of diesel vehicles and hence would be revenue neutral for the government.**

- **Payload and vehicle length regulations:** 44 tonne battery electric vehicles currently require an increase in vehicle weight allowance and an increase in vehicle length allowance in order to allow them to carry the same payload as diesel equivalents and provide enough space to fit batteries onto the vehicle. Avoiding payload loss is necessary to avoid deterring uptake from operators, and this is particularly true in the 32 tonne rigid and 44 tonne artic categories.

- **Grid capacity:** strategic grid reinforcements will be needed in some areas to prevent the speed of battery electric roll-out being constrained by availability of grid capacity.

The work uses conservative assumptions around the future cost and performance of battery electric HGVs, making the findings robust

Robustness of the results

- The work uses **conservative assumptions** and **careful sensitivity analysis** to ensure our key findings are robust.
- Conservative assumptions used include:
  - **No disruptive battery technologies**, just incremental improvements in existing battery technologies. No improvements in battery lifetime. Assumptions around battery energy density have been carefully checked against public data on the performance of current and future (2024) battery electric HGV models.
  - **Conservative assumptions around infrastructure costs**, chargers and grid connections
  - **No aerodynamic / vehicle mass improvements** are assumed; in reality these will likely improve the business case for BEVs by allowing smaller batteries
  - Electricity costs kept at high levels until 2030. In reality, the current **electricity market reform may cause electricity costs to fall before 2030** by decoupling the electricity price from the natural gas price. Furthermore, **fleet operators may be able to access cheaper electricity prices overnight using smart tariffs** and corporate power purchase agreements. **None of these have been assumed, making the results conservative.**
  - **No change in operator behaviour**. We assume operator behaviour remains unchanged whereas operations may change if cost reductions exceed any impact on loss of time or payload.
- Key sensitivities used to confirm the robustness of the results include
  - **Battery prices and fuel prices –** even **with the most pessimistic assumptions around fuel prices and battery prices**, **the key conclusions are not changed**: city and regional deliveries with rigids HGVs are on the cusp of being cheaper with BEVs, and BEVs reach total cost of ownership parity with diesel across all use cases studied by the early 2030s – even with the conservative assumptions mentioned above.
  - **Diesel vehicle life –** diesel vehicles are OPEX intensive rather than CAPEX intensive, and so the lifetime assumed for a diesel vehicle has minimal impact on the annual total cost of ownership.

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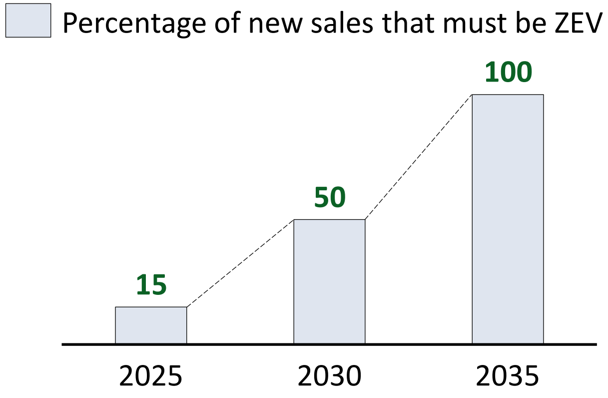
At least 50% of new Heavy Goods Vehicle sales must be zero emission in 2030 for UK emissions to remain on a path that limits global warming to 1.5 degrees. This is in line with many OEM targets

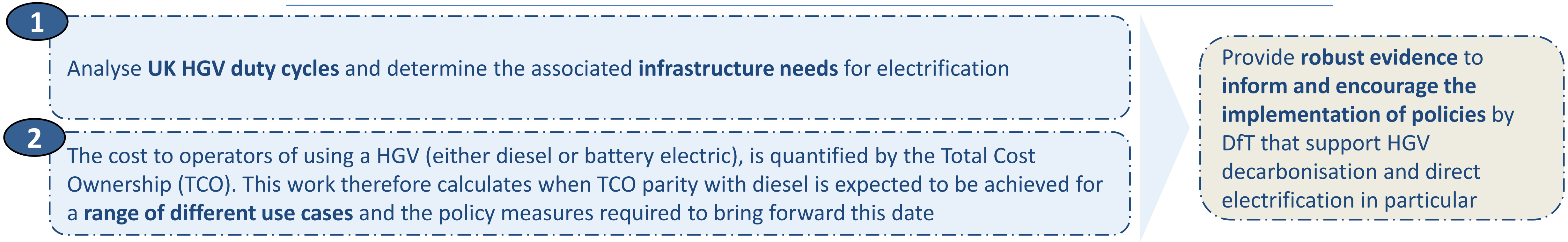
Background

- For UK transport emissions to remain on a path consistent with limiting global warming to 1.5 degrees, **50% of new Heavy Goods Vehicle (HGV) sales[1,2] must be zero emission by 2030** - including a significant number of articulated HGVs (artics). These values are close to OEM sales targets, highlighting their achievability.
- In addition, 15% of new Heavy Goods Vehicle (HGV) sales[2] must be zero emission in 2025 to stay on an emissions reduction pathway consistent with 1.5 degree warming (shown on the right). If fewer than 15% of HGV new sales are zero emission in 2025, more than 50% will need to be zero emission in 2030.
- Even this pathway assumes that decarbonisation of HGVs lags behind other transport sectors, with BEV uptake in the car market and modal shift of both freight and passenger transport making up for the shortfall
- This work focuses on the role that **battery electric HGVs** with **static charging** can play in delivering these emissions reductions, using only depot and warehouse charging – **without waiting for a public charger network**. Battery electric HGVs can achieve large emissions reductions today.

Approximate required percentages of new sales that must be zero emission for a 1.5 degree pathway[2]



Objectives



1. Analyse **UK HGV duty cycles** and determine the associated **infrastructure needs** for electrification

2. The cost to operators of using a HGV (either diesel or battery electric), is quantified by the Total Cost Ownership (TCO). This work therefore calculates when TCO parity with diesel is expected to be achieved for a **range of different use cases** and the policy measures required to bring forward this date

Provide **robust evidence** to **inform and encourage the implementation of policies** by DfT that support HGV decarbonisation and direct electrification in particular

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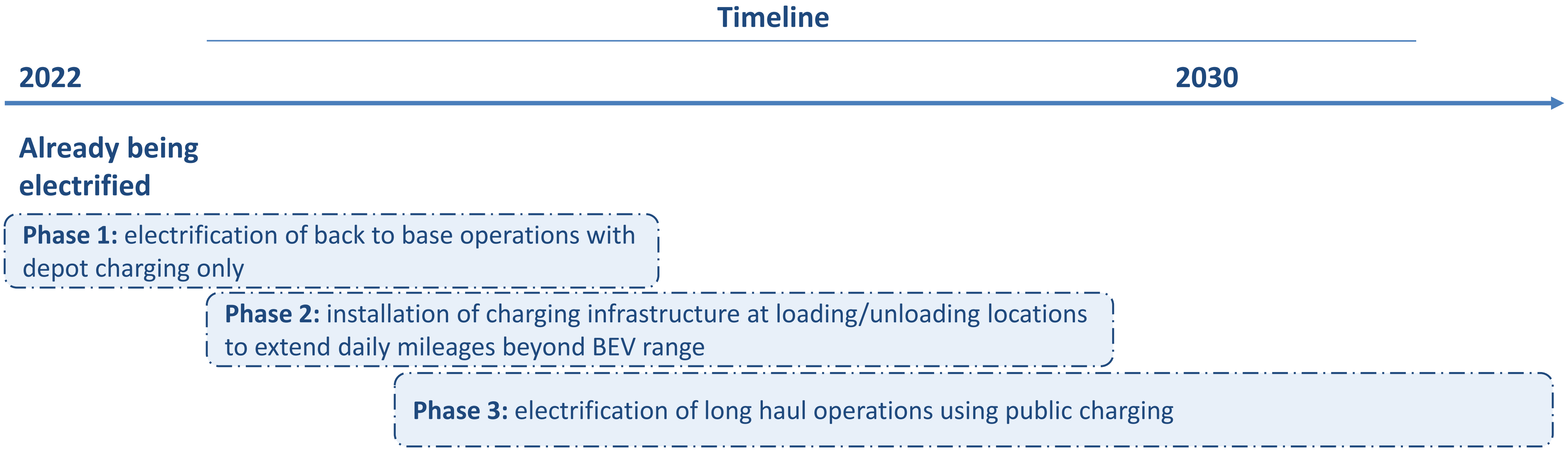
[1] – HGV refers to vehicles over 3.5t max gross vehicle weight. This 50% *does not* include 4.25t vans replacing 3.5t vans, [2] - https://www.transport.gov.scot/media/50354/decarbonising-the-scottish-transport-sector-summary-report-september-2021.pdf.

Achieving the required rate of emissions reduction requires early moves over to battery electric from duty cycles that do not need to wait for a public charging network to be in place

- Battery electric technology is the preferred technology of choice for decarbonisation of a wide range of city and regional rigid HGV operations:
  - Through detailed modelling of a wide range of real world HGV operations, this work has shown that BEVs are capable of decarbonising city and regional operations cost effectively this decade.
  - All rigid city operations – and a great number of rigid regional operations – can be performed without public charging, instead depot charging can be used as already done for buses. Use cases that do not require public charging are the focus of this report – a following report will cover use cases that require public charging.
  - Battery electric HGVs will reach TCO parity with diesel this decade across a wide range of HGV use cases.
- This report focuses on two broad categories of HGV operation:
  - **Urban and regional deliveries performed by rigid HGVs**: these can feasibly be performed using BEVs with depot charging only (as has already been done for a number of bus fleets). These operations **do not** need to wait for **a public charging network to be in place to electrify and are likely to become cheaper than diesel on a first owner, lifetime basis before 2030 for regional deliveries and around 2025 for city deliveries.** This accounts for a large proportion of all HGV operations for vehicles up to 26t gross vehicle mass and **the technology needed to electrify most of these operations is already available**. **Lack of public infrastructure is not a barrier to the uptake of BEV for these duty cycles.**
  - **Regional deliveries performed by articulated HGVs**: many of these operations can feasibly be performed by BEVs using depot charging along with opportunity charging at loading and unloading locations – mostly warehouses and large shops. These operations can largely become **cost competitive with diesel on a first owner lifetime basis around 2030**.

Discussions on the technology choice for long haul operations and those in remote rural areas should not detract from the fact that city and regional delivery operations should go electric in the short term in order to achieve the required rate of emissions reduction.

Electrification of the HGV sector can be achieved in three phases



Timeline

2022

2030

Already being electrified

Phase 1: electrification of back to base operations with depot charging only

Phase 2: installation of charging infrastructure at loading/unloading locations to extend daily mileages beyond BEV range

Phase 3: electrification of long haul operations using public charging

This work focusses on phases 1 and 2 and shows how a broad range of use cases can be electrified cost-effectively without fleet operators needing to wait for 3rd parties to put public infrastructure in place.

This work focuses on HGV use cases that can be electrified without public charging

First report – no public charging (phases 1 and 2 on previous slide) – focus of this work

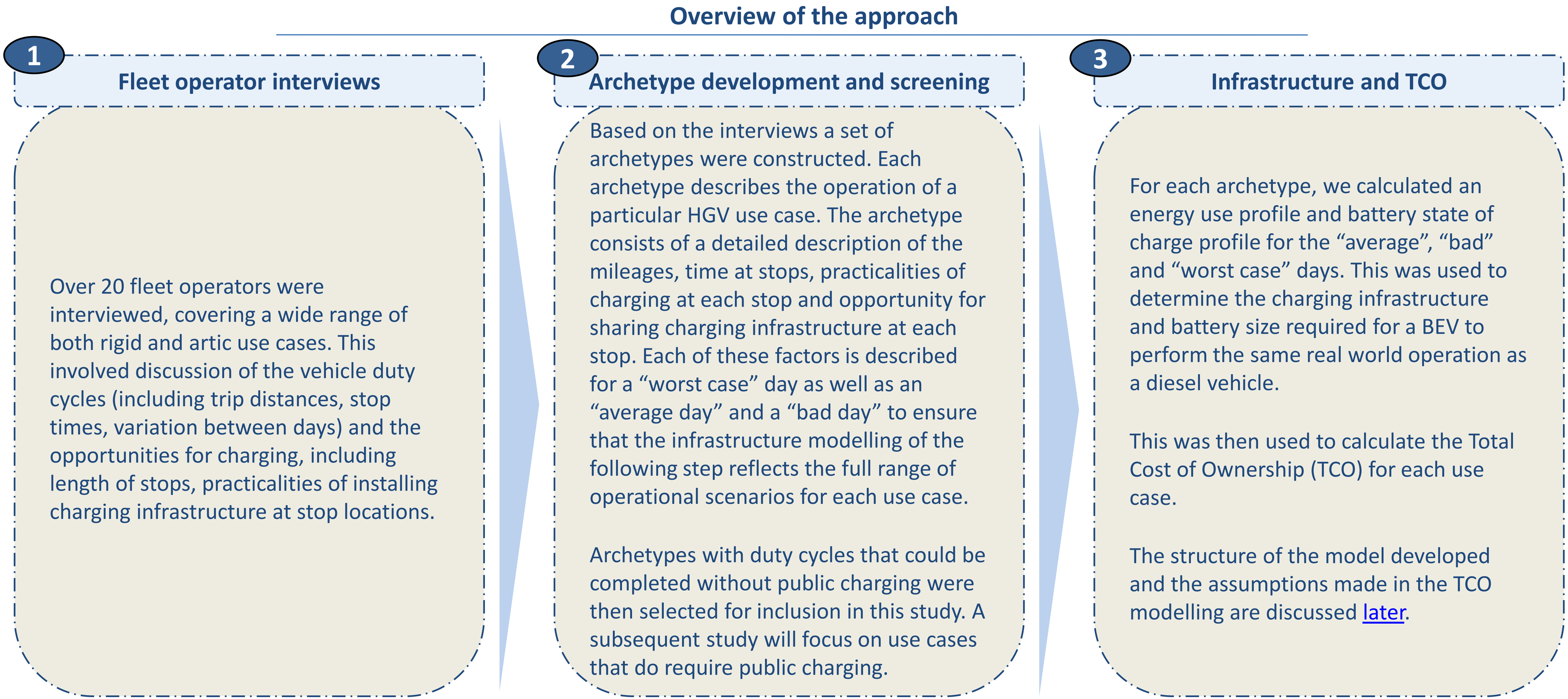
Key themes	Breadth of use cases that can be electrified **without public charging (i.e. depot and warehouse charging only)** and the policy measures required to support this
Example use cases	**Rigids on last mile deliveries, artics on shuttle runs**

Second report – public charging (phase 3 on previous slide – focus of subsequent work

Key themes	**What national public charging network is needed to electrify the long-haul fleet**
Example use cases	**Artic tramping, rigids operating in rural areas**

The second report will <u>NOT assert that BEV with static chargers is the only solution for long haul use cases</u> but will show where this option can take us

We have devised a set of archetypes based on over 20 discussions with fleet operators – these archetypes capture a broad range of HGV use cases



Overview of the approach

1

Fleet operator interviews

Over 20 fleet operators were interviewed, covering a wide range of both rigid and artic use cases. This involved discussion of the vehicle duty cycles (including trip distances, stop times, variation between days) and the opportunities for charging, including length of stops, practicalities of installing charging infrastructure at stop locations.

2

Archetype development and screening

Based on the interviews a set of archetypes were constructed. Each archetype describes the operation of a particular HGV use case. The archetype consists of a detailed description of the mileages, time at stops, practicalities of charging at each stop and opportunity for sharing charging infrastructure at each stop. Each of these factors is described for a “worst case” day as well as an “average day” and a “bad day” to ensure that the infrastructure modelling of the following step reflects the full range of operational scenarios for each use case.

Archetypes with duty cycles that could be completed without public charging were then selected for inclusion in this study. A subsequent study will focus on use cases that do require public charging.

3

Infrastructure and TCO

For each archetype, we calculated an energy use profile and battery state of charge profile for the “average”, “bad” and “worst case” days. This was used to determine the charging infrastructure and battery size required for a BEV to perform the same real world operation as a diesel vehicle.

This was then used to calculate the Total Cost of Ownership (TCO) for each use case.

The structure of the model developed and the assumptions made in the TCO modelling are discussed later.

HGV – Heavy Goods Vehicle, TCO – Total Cost of Ownership, BEV – battery electric vehicle

Contents

The follow chapter contains key recommendations for policymakers to drive the transition to zero emission HGVs, and for fleet operators to assist their path to adoption

- **Policy recommendations covering several key areas:**
  - ZEV supply regulation
  - Support for OEMs in delivering the transition
  - Stimulating demand by improving BEV TCO relative to diesel in the short term
  - Policies needed to ensure that sufficient infrastructure is in place
  - Changes to the Road Vehicle (Authorised Weight) Regulations and the Road Vehicle (Construction & Use) Regulations to remove regulatory barriers to BEV adoption (e.g. due to loss of payload)
  - Further policies to assist the transition
- **Recommendations for fleet operators**
  - Recommendations around vehicle specification, financing and related enablers to electrification

Contents

Sufficient supply of zero emission vehicles must be in place across all HGV categories. This requires a ZEV mandate with both an end point and intermediate target(s)

ZEV supply

- **The UK should put in place a ZEV mandate with both an end point and intermediate targets. A ZEV mandate is a policy instrument which requires 100% of OEM vehicle sales to be zero emission by a certain date, with intermediate targets for the percentage of sales that must be zero emission by earlier dates.**
- **The conclusions of this work have the following implications for the structure and timelines of a ZEV mandate for the UK:**
  - Firstly, this work shows that rigid battery electric HGVs are already close to (or at) cost parity with diesel for many city and regional delivery operations. This shows that a 2025 intermediate target for a ZEV mandate can be delivered by battery electric vehicles in these applications alone.
  - Secondly, battery electric HGVs are cheaper than diesel on a TCO basis across all use cases studied, well before 2035. This suggests that a 2035 target for 100% of OEM sales to be zero emission can be delivered with battery electric vehicles, since by 2035 operators in the use cases studied are likely to be commercially disadvantaged if they continue to operate diesel vehicles. A second study is underway examining BEV for long haul use cases and will provide the remaining evidence to confirm whether or not this is feasible.
  - The UK should examine introducing a **ZEV mandate** of **100% sales in 2035**, along with intermediate targets of **50% in 2030** and **15% in 2025**. This study shows that the 15% is feasible with BEVs on city and regional rigid deliveries alone. The 50% in 2030 aligns with OEM sales targets and the 100% in 2035 will be examined in a study following this one, looking at long haul duty cycles and rigids vehicles that may need public charging. However, any uncertainty over the exact level of feasibility of the 2035 100% sales target should not deter implementation of the intermediate 15% in 2025 and 50% in 2030 targets. Intermediate targets are needed not only to allow the final target to be achieved (the transition cannot happen overnight) but also because early adoption is needed to drive pre-2030 emissions reductions which are crucial to mitigating the worst impacts of climate change.
- BEVs will soon become cost effective across a number of “early mover” applications, creating high demand. This could cause battery electric truck sales to become supply constrained and a ZEV mandate is needed to avoid this, while also giving infrastructure investors and vehicle OEMs the confidence to invest in scaling the battery electric truck ecosystem.

The TCO of larger BEVs must be made competitive with diesel to stimulate demand: the UK government must put temporary financial support in place for BEVs

Increasing demand for zero emission HGVs by bringing forward the TCO parity date with diesel (and reducing the cashflow impact of increased capex)

- **Road charge per km with different tariff depending on CO_2 emissions and truck weight class**
  - Initially, diesel vehicles would be charged and zero emission vehicles would be exempt (at least until 2030-2035)
  - This charge could **replace the loss of fuel duty during the transition**. Once ZEV market penetration is high and TCO is lower than for diesel, the road pricing could eventually be introduced for ZEVs too, to make up for the loss of fuel duty once very few diesel vehicles are running

- **Purchase subsidies are need to stimulate early BEV uptake in many sectors, but will only be needed for a few years as costs come down. These should be funded by a bonus-malus system which would make them revenue neutral for the Treasury.** For example, if the largest BEVs require a subsidy of £100,000, and the BEV uptake is 1%, then diesel vehicles each pay a £1000 malus – added as an effective tax on the purchase cost – to fund the subsidisation of BEV.
- The magnitude of the subsidies required is indicated in the TCO section of the report.
- **Subsidies should be reviewed** annually owing to the uncertainty around future costs, particularly fuel
- **The UK should put in place a subsidy scheme for zero emission HGVs similar to that which has already been implemented in France and Germany as current support is insufficient to achieve the required rates of uptake.** A subsidy of around £50,000 is temporarily needed for rigid vehicles performing regional deliveries, and of £100,000 (which could be split between vehicles and infrastructure) for articulated battery electric HGVs on intensive duty cycles. The support could be less if other policies bridge the short-term TCO gap.
- As shown later, by the early 2030s, BEVs will be cost competitive without subsidy across the board, **so subsidies are only needed temporarily to bridge the gap in the short term.**

- **Congestion charges/zero emission zone charges** with exemptions for zero emission HGVs will help ensure that urban operations decarbonise early, which also brings co-benefits around improved air quality

HGV – Heavy Goods Vehicle; TCO – Total Cost of Ownership

Regulation must mandate and support sufficient infrastructure supply, and remove current barriers to rapid deployment of chargers. OEMs must be supported in rolling out ZEVs at scale

Infrastructure

- "Right to plug" – decarbonisation related infrastructure should go through the same accelerated permitting process as fibre cable laying for high speed internet or water mains, whereby the landowner must give consent within a fixed period of time. **Installation of critical pieces of national infrastructure must not be delayed by intransigent 3rd party landowners**
- In order to **receive planning permission**, **new warehousing must have the necessary infrastructure installed to support operation of ZE HGVs to and from the warehouse**
- **Plan and fund strategic grid infrastructure upgrades** at key motorway junctions where motorway service stations, depot districts, warehousing districts cluster together and are going to require major reinforcements. DNOs should be required by Ofgem to deliver proof that they have a plan for delivering the level of grid reinforcement needed.
- All zero emission refuelling infrastructure to count as a permitted development
- **Public charging to be covered in the next report**
- **Operators based in rural areas may face disproportionately high asset extension costs (even though upstream reinforcement costs will be covered by the DNO). Funding must therefore be made available to cover this, proportional to the difference between the asset extension cost per kW at site under consideration, and a reference value (for example the £200/kW used in this report).**

Supporting measures for OEMs

- Support for OEMs in delivering this:
  - **Enhanced capital allowance scheme** - this would allow manufacturers to deduct the full capital costs of investment in ZEV manufacturing facilities from their profits before tax (already used in other contexts)
  - Investment in **training programmes** to upskill the UK workforce for both **production and maintenance** of zero emission HGVs
  - Accelerated planning process for construction of new facilities related to ZEV manufacture/maintenance
  - Innovation grants to help small UK manufacturers bring new zero emission HGVs to market as fast as possible

The Road Vehicle Construction and Use and Authorised Weight Regulations must be updated to remove the barriers to ZE HGV adoption that they currently create

Amendments to the Authorised Weight Regulations and Construction and Use Regulations for ZEVs

- Remove or extend the **maximum length limits**, keeping just **the inner and outer turning circle regulations**
  - Longer tractor units are needed for 6x2 / 6x4 battery electric artics to allow sufficient space for the batteries
  - Currently, this would require use of a shorter trailer to keep the vehicle within total length limits – not an acceptable option for most operators as this would lead to loss of payload
  - The success of the Longer Semi Trailer trial[1], which allowed the running of vehicles 2.05 metres longer than current length limits to allow for a longer trailer, shows that longer vehicles are able to maintain the turning circle limits (the relevant quantity for safety on roundabouts and other areas requiring tight turns), through use of rear wheel steering.
  - This would allow OEMs to design vehicles with both sufficient battery packaging space and turning circle radii, for example through use of rear wheel steering

- **Increase maximum vehicle mass for ZEVs - as well as axle load and tractor unit mass limits**
  - The weight limit for ZE 6x2 / 6x4 artics needs to be increased to at least 46t. Increases in 44t artic GVM to 48t are already being trialled for transport from rail terminals[2] and this should be extended to battery electric HGVs. Some artic use cases weigh out routinely (e.g. double decker trunking, haulage of dense agricultural goods such as milk, potatoes), while others require the flexibility to carry 28t loads when needed (e.g. general haulage) – **in both cases regulation must prevent a payload penalty for switching to ZEV**
  - The weight increases can be reviewed at a subsequent date when improvements in battery (gravimetric) energy density reduce the size of the BEV payload penalty.

(1) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/933259/impact-assessment-longer-semi-trailer-trial.pdf (2) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/933312/48-Tonne-Intermodal-Freight-Trial-Impact-Assessment.pdf

A range of other policy measures are required to remove barriers to ZE HGV adoption (1/2)

Local policies

- **All diesel HGVs should be banned from all city centres in 2030. This benefits fleet operators, emissions and air quality:**
  - This work shows that urban deliveries and regional deliveries (delivering to multiple urban areas on one trip) will both be cheaper with battery electric rigid HGVs than diesel rigid HGVs well before 2030, including when using 2nd hand diesel vehicles. It will therefore be cheaper for fleet operators to operate BEVs for these deliveries than diesel vehicles by 2030 – and so operators will benefit commercially from doing so.
  - Removing diesel vehicles from city centres at this point will also help reduce deaths related to air quality as well as bringing emissions savings.
- Mandatory ZEV procurement by 2030 for public authorities. This will help achieve large scale early adoption, helping to demonstrate vehicles and contracting at scale, giving the private sector the confidence to invest.

Customer pressure

- Emissions from 3rd party logistics operations must to be included in mandatory company GHG reporting and GHG reduction targets so that **3rd party logistics operators can pass on decarbonisation costs to customers** (e.g. supermarkets)

Super tax credits

- Fleet operators could be allowed to **write off move than 100% of the capital cost of a battery electric vehicle from their profit before tax**. This has already been implemented in France and could be a convenient way for the government to support the business case for battery electric HGVs.

A range of other policy measures are required to remove barriers to ZE HGV adoption (2/2)

Driver hours

- Increased flexibility in the driver hours regulations would allow drivers to ensure that **their break occurs at a location with charging infrastructure**
- This would bring other benefits as drivers are already struggling to find rest areas in cities
- This would apply to zero emission HGVs with enhanced safety features relative to diesel

Battery warranties and sustainability

- Mandate battery warranties (covering both direct costs and cost of downtime owing to premature battery replacement) to be given by OEMs to give fleet operators the necessary confidence around battery lifetime and hence the accuracy of their depreciation assumptions.
- Copy across the EU battery regulation covering battery carbon footprint, repair/re-use recycling and responsible sourcing in UK law (or introduce UK-specific but broadly equivalent requirements)

Contents

Recommendations for fleet operators

1

Battery right sizing

The battery must be sized correctly for the operation. Batteries are the largest component of vehicle capital cost. Longer range means larger batteries and increased cost. Fleet operators can dramatically reduce TCO by using a vehicle with just the right amount of range for their operation. Using a BEV with more range than required by the operation will result in unnecessary additional cost. Several major OEMs are already offering multiple battery sizes and detailed guidance to operators in selecting the correct battery size.

2

Lifetime of the vehicle

Depreciating the vehicle over the entire battery life – which for rigid city and regional operations is likely to be longer than the typical diesel first owner lifetime – will improve the business case by reducing the TCO per year. BEV drivetrains have fewer moving parts and therefore last longer than their diesel counterparts.

3

Financing of infrastructure

Using infrastructure financing options (such as infrastructure as a service) will reduce the cashflow issues caused by the capital cost of the infrastructure, and allow the infrastructure costs to be spread over a long period and be offset by reduced fuel costs. **Agreeing a fixed electricity price with the infrastructure provider for a period of years will also remove the existing financial risks posed by fluctuations in diesel prices. This is an opportunity for operators to use BEVs to increase the predictability of their operating costs.**

4

Sharing of infrastructure

Sharing of infrastructure (for example during the day when vehicles are offsite) can dramatically improve the business case.

Recommendations for fleet operators (continued)

5

Phased transition

Parts of the fleet with repetitive duty cycles and plenty of downtime for charging can be transitioned to BEV first, with more challenging duty cycles transitioning later in the decade as technology improves further and costs reduce.

6

Driver training

BEVs offer particularly large fuel cost savings over diesel for urban operations because they are able to recover energy while braking, reducing fuel consumption for stop-start driving. Drivers should be trained to optimise use of regenerative braking to maximise this benefit.

7

Making best use of BEVs in a mixed fleet

In the transition to BEVs, fleets will pass through a phase of having a mixture of diesel vehicles and battery electric vehicles. In order to maximise the fuel cost savings from use of BEVs, they should be used as much as possible. BEVs should always be dispatched first to maximise the mileages that they do each week and hence maximise fuel cost savings. Every mile driven with a BEV is money saved compared to diesel: a BEV should be viewed by fleet operators as an asset for reducing fuel expenses – and its utilisation should be maximised accordingly. This particularly applies to rigid vehicle operations with low annual mileages.

8

Triple shifting vehicles

BEVs produce considerably less noise pollution than diesel equivalents. This allows them to perform night-time deliveries and addition to delivering during the day. Depending on the time critical nature of the delivery, this could allow triple-shifting of vehicles and hence a reduction in the total number of vehicles needed, massively reducing costs to the operator. Operators making city deliveries in particular should consider this option, which could greatly improve the business case for BEV adoption.

Contents

This chapter reviews the key features of HGV duty cycles and their implications for electrification

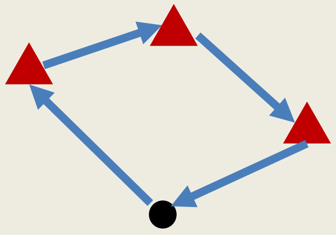
- **The chapter covers the following topics**:
  - Overview of key features of duty cycles that enable early electrification or necessitate further support to decarbonise
  - The type of use cases that can be electrified without any public charging, compared with the vehicle use cases that do require public charging to be electrified
  - The varying potential for opportunity charging across different HGV use cases
  - The influence of duty cycle repetitiveness or variability when electrifying the fleet

Contents

This report focuses on the large number of HGV use cases that can be electrified without waiting for a public charging network to be in place – these cover a broad range of applications

Below are examples of operational profiles that can either **complete all operations on a single overnight charge** or **have good opportunity charging options** at their own **depot between shifts**, or at **3rd party warehouses** while loading and unloading

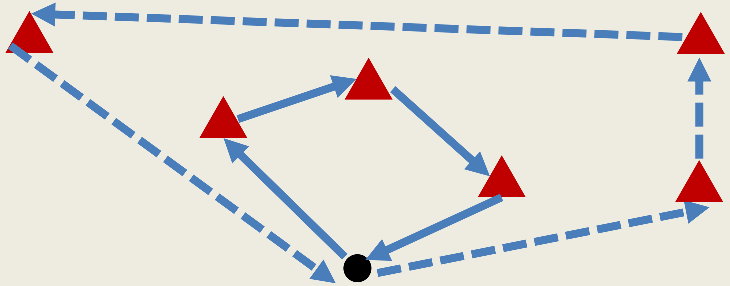
Short range last mile distribution



✓	✗	✗
Depot	**Opportunity**	**Public**

- **Short daily mileages** allow easy completion of a day's work with a **depot overnight charge only**

Regional distribution



✓	✓	✗
Depot	**Opportunity**	**Public**

- **Regional distribution** operations that can be performed using depot charging (overnight/between shifts) and at warehouses/large shops while loading/unloading

Shuttle runs

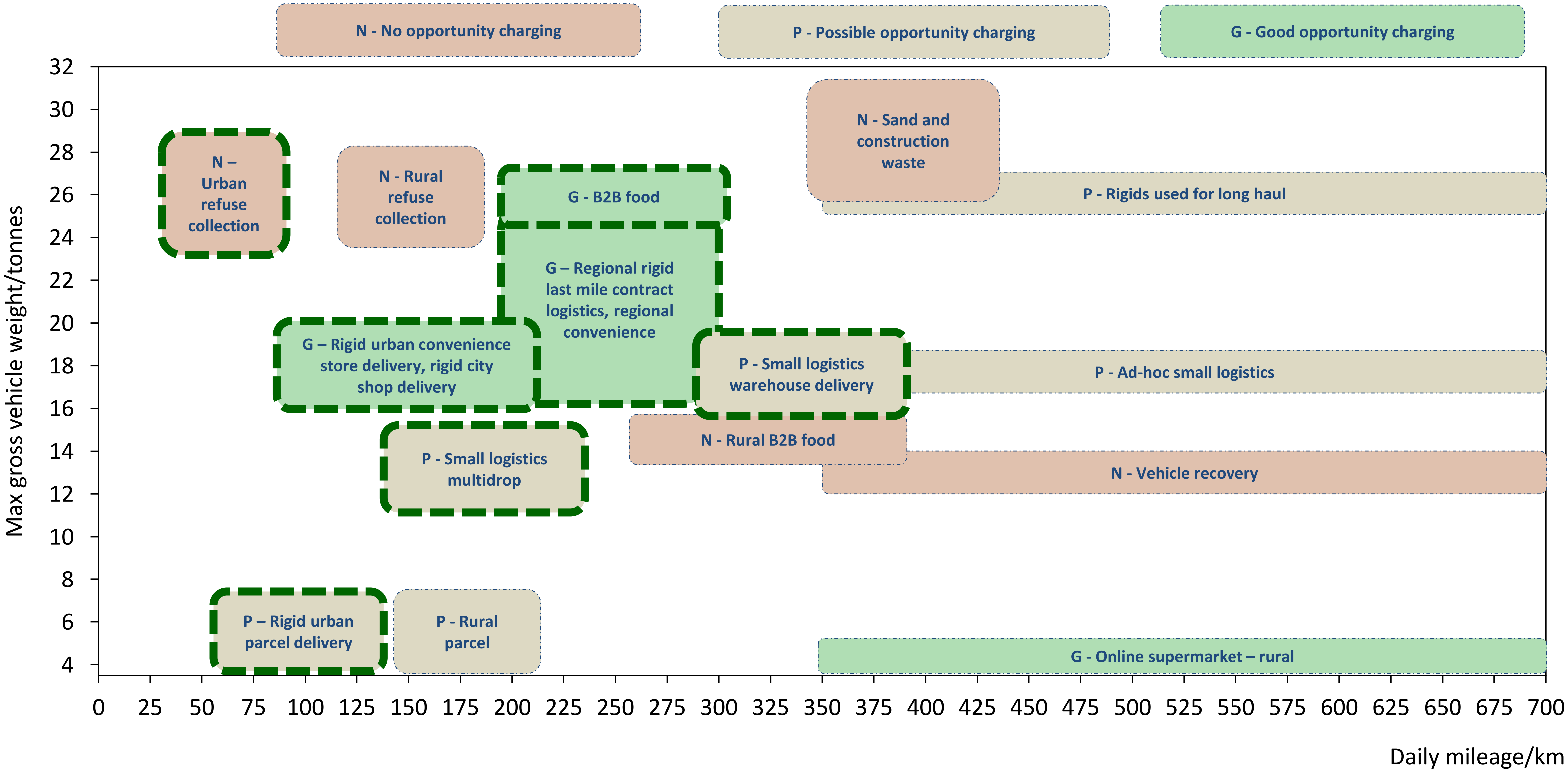
✓	✓	✗
Depot	**Opportunity**	**Public**

- **Predictable route** and opportunity to charge at warehouse while trailer unloaded/loaded mean public charging not needed

Key ● **Depot** ▲ **Delivery point/shop/warehouse** ✓ **Regularly used** ✗ **Not used** ? **Some cases** ⟶ ⇢ **Routes taken on different days**

Many rigid use cases will not require public charging

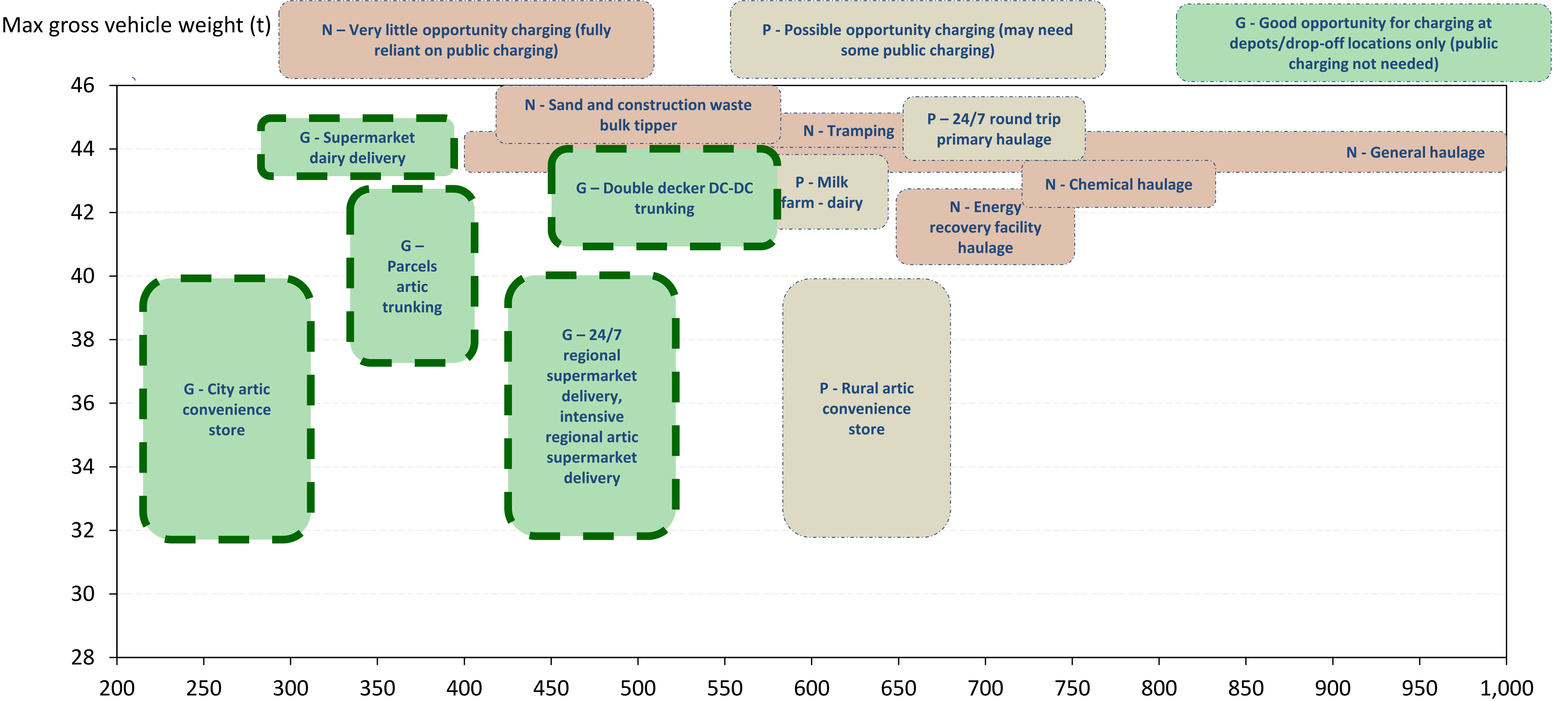
Can complete operations with no public charging – focus of this first report



RCV – Refuse Collection Vehicle, B2B – Business to Business

Some artic use cases will not require public charging

Can complete operations with no public charging – focus of this first report



A following report will focus on HGV use cases that require public charging

Contents

Opportunity charging at the depot between shifts, or at loading or unloading locations, allows battery electric vehicles to perform a wide range of operations without public charging

Example use cases	Description of charging opportunities
Rigid regional last mile contract logistics Regional B2B food	These vehicles can be charged for at least **1-2 hours at the depot between shifts**, reducing battery size requirements as the battery only needs to be large enough to complete a single multidrop driver shift.
Small logistics warehouse delivery (rigid) Regional supermarket delivery Artic primary haulage Parcel trunking	These vehicles can charge while **loading and unloading, for example at warehouses and large supermarkets**, often in addition to charging at their home depot between shifts. The impact of the utilisation of warehouse chargers on the BEV TCO is discussed later.
Sand and construction waste Rural RCV	These vehicles have **stops that are unsuitable for charging** – such as a **waste treatment plant (vehicles in moving queue or very rapidly unloading)** or a **temporary construction site.** If overnight depot charging insufficient for a full day's operations, public charging will be needed.

Contents

Duty cycle variability occurs on a vehicle, depot and company level – more variability means more reliance on public charging infrastructure

Increasing reliance on public charging infrastructure

1	Depot where **vehicles all do similar trips and trip lengths**, but it varies across the company	• Batteries and depot charging infrastructure can be optimised to meet the fleet's needs • Potential issue if company operations change and vehicle needs to be put on longer route	**Battery size can be optimised and charging can be completed mostly at the depot (overnight, or between shifts) and while loading/unloading**	**Majority of use cases**
2	Each vehicle does a similar trip every day but with **variation in trip lengths across the depot**	• Mixture of vehicle ranges needed across the depot		
3	**Each vehicle** at the depot does a **range of different trip lengths and routes**	• The vehicles could use public charging infrastructure with a small detour in the worst-case days • If the operation is highly time-constrained, range extenders may be an alternative solution	**Biggest user of public infrastructure**	
4	Vehicles that are **based temporarily away from base**	• Vehicles will need to use public charging infrastructure when away from base • Depot charging infrastructure is underutilised, which can damages the business case	**Niche**	**Minority**
5	Long haul rigids that rarely **return back to base each night**	• These vehicles are almost entirely reliant on public charging infrastructure for artics on similar duty cycles		

Contents

This chapter quantifies the TCO of battery electric HGVs operating on a range of different duty cycles and how this is expected to change in future, relative to diesel

- This chapter builds on the previous chapter's discussion of HGV duty cycles and their impact on electrification to **quantify the TCO of battery electric HGVs operating on a range of different duty cycles and the year when the annual TCO of a new battery electric HGV achieves parity with the diesel equivalent on each duty cycle**. This is done under a range of different scenarios.

- This chapter covers:
  - The key assumptions and method used in the modelling
  - A summary of the key results, showing the spread of expected breakeven dates across a range of vehicle use cases and how this can be influenced by policy, as well as a description of the reasons for the differences between use cases
  - Detailed TCO results for a few selected archetypes
  - A discussion and quantification of the key sensitivities influencing the TCO of BEVs

- The content of this chapter **feeds into the policy recommendations** of chapter II.

Contents

The model calculates the TCO from first principles and allows battery right-sizing and optimisation of the infrastructure for each archetype (1/2)

Inputs

1 Duty cycle information specific to each archetype

- Drive cycle for an **"average day"**, a **"bad day"** and a **"worst case" day**, including **distance travelled between stops**, **load carried**, **driving type** (e.g. motorway, inner city, rural B-road) and **time spent at stops**
- The **"worst case" day is used to ensure the battery and infrastructure are sized large enough to meet all operational days**, and includes the combination of **longest mileage** between stops, **shortest times for charging** and **worst weather** (headwind increasing fuel consumption and cold weather necessitating use of a thermal management system to maintain battery temperature, increasing energy use)
- Information determining the **number of times a charger is used per day** (for example, number of deliveries that a supermarket receives per day determines the utilisation of a charger at the supermarket). This determines the infrastructure cost per vehicle or equivalently the component of the electricity price needed to pay off the infrastructure cost.

2 Vehicle and infrastructure data

- **Drag coefficient, frontal area, rolling resistance coefficient and vehicle empty mass** – used to determine **fuel consumption**
- **Powertrain efficiency** of battery electric vehicles and **charger efficiency**
- Powertrain efficiency of diesel vehicles for urban and motorway driving

3 Weather

- Effective **headwind** on a windy day (used to determine fuel consumption for the "worst case" day)
- **Energy use of the thermal management system required to maintain battery and cabin temperature** on a very cold day – another component in calculating the fuel consumption for a "worst case" day

4 Cost data

- **Fuel costs** for both electricity and diesel, **under a range of scenarios** reflecting the uncertainty in future fuel costs
- Current and projected future battery pack and power electronics costs for BEVs
- **OEM transition costs**, reflecting non-component costs of the transition to BEV manufacture – this accounts for the difference between the sum of individual component costs (with markup) and the prices that BEVs are currently being quoted for
- Diesel engine costs and vehicle glider costs
- Charger and grid connection costs for BEVs
- **Calibration checks** of vehicle capital cost values for both BEV and diesel vehicles with **real world values** from fleet operators

Further details on the assumptions made in the modelling may be found on the following slides and in the appendix

The model calculates the TCO from first principles and allows battery right-sizing and optimisation of the infrastructure for each duty cycle (2/2)

Variables that are optimised by the model

Battery size

Power of charger at each stop

Varied to find the optimal combination that minimises TCO while meeting operational requirements

Calculation steps

1

Determine battery state of charge and energy use profile for an average, bad and worst case day

The fuel consumption is calculated from first principles using the **road loading equation** for each activity at every 5 minute interval during the day, and accounts for the influence of load, weather and driving type (e.g., inner city, motorway). The resulting energy use profile is combined with the charging power at each stop to create a battery state of charge profile.

This battery state of charge profiles for the average, bad and worst case day determine whether or not the battery size and charger power selected are sufficient to meet operational requirements

2

Determination of electricity price including infrastructure costs

The archetype-specific battery state of charge profiles calculated in the previous step are used to compute the total number of kWh of electrical energy dispensed by each charger for a single vehicle. This is combined with an appropriate multiplier, specific to each archetype, which specifies the number of times per day that a charger is used (described on the previous slide). The result is the utilisation of each charger, which is combined with the charger and grid connection capital costs and maintenance costs to determine the infrastructure component of the electricity cost dispensed by each charger type – or equivalently, the infrastructure cost per vehicle.

3

Determination of the TCO and optimisation of battery capacity and infrastructure

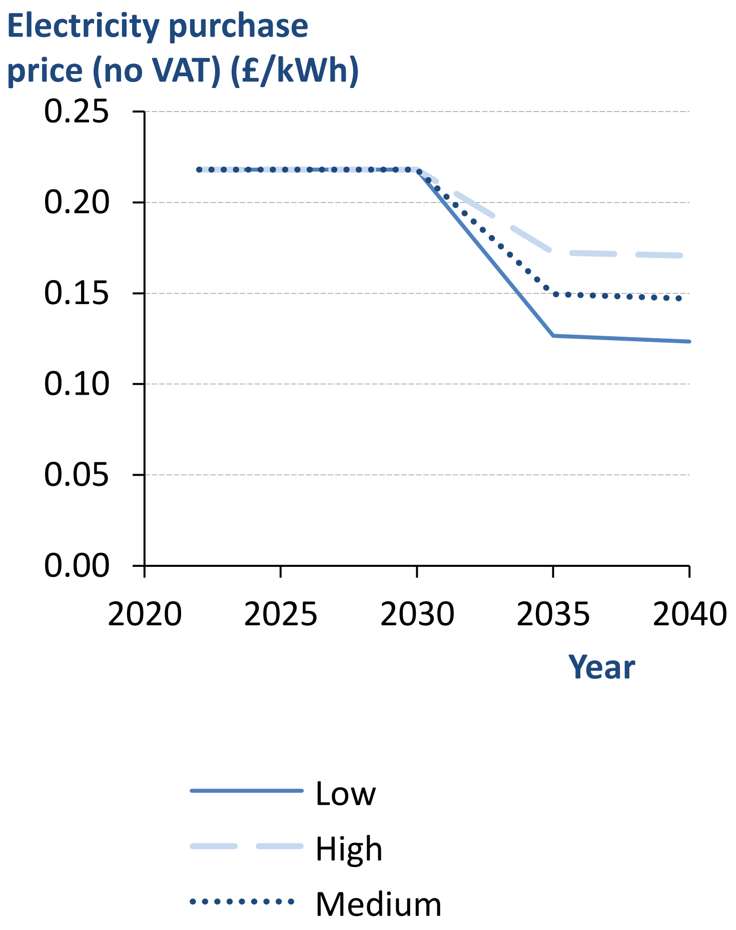
The battery size and infrastructure costs determined from the previous two steps are then combined with the remaining cost components described on the previous slide to determine the vehicle TCO.

These three steps are then repeated for a different set of charger powers and battery size in order to determine the optimal battery size and charging infrastructure that minimises TCO while meeting operational requirements.

Three electricity price scenarios are used to reflect the latest developments in electricity prices as well as the uncertainty in future electricity prices

Three electricity price scenarios are used as shown in the graph on the right:

- In all scenarios, commercial electricity purchase prices remain at their 2022 high levels (as reported by the ICCT[1]) until 2030, since gas could be the marginal generation source (and hence price setter) until this point[3,4].
- In the low scenario, prices drop off after 2030 owing to very high penetration of renewables, meeting the BEIS 2020 **high** commercial electricity price scenario in 2035.
- In the high scenario, the cost reductions post-2030 are half what they are in the low scenario. The medium scenario is the average of the two other scenarios. **Where applicable, the medium scenario is used as the baseline for the calculations on the following slides.**
- The current high prices are caused by the UK's use of gas fired power stations, alongside the current very high gas prices and the current market structure which means that the wholesale electricity price is set entirely by the marginal generator (expensive gas fired power plants) rather than cheap renewables. **If the market structure (currently under a major review[5]) is changed before this point, then electricity prices will drop earlier**. However, **it has been assumed here – conservatively – that this will not be the case**.
- Operations for which BEV TCO is already competitive with diesel generally involve charging overnight. By using an economy 7 (smart) tariff[6] – night time domestic users are currently experiencing prices of just 7.5 p/kWh[7]. There is very significant opportunity for similar smart tariffs to be applied to commercial electricity prices used for HGV charging, to the benefit of both fleet operators and the grid. Such tariffs could further insulate early-moving archetypes from the current high electricity prices. These early moving archetypes are also vehicles that will be kept for c. 8 years, so short term price volatility experienced has little impact on the TCO in any case. **None of these cost reduction methods are assumed in the TCO results, making the TCO results conservative.**
- Fleet operators can further protect themselves from high prices using Corporate Power Purchase Agreements



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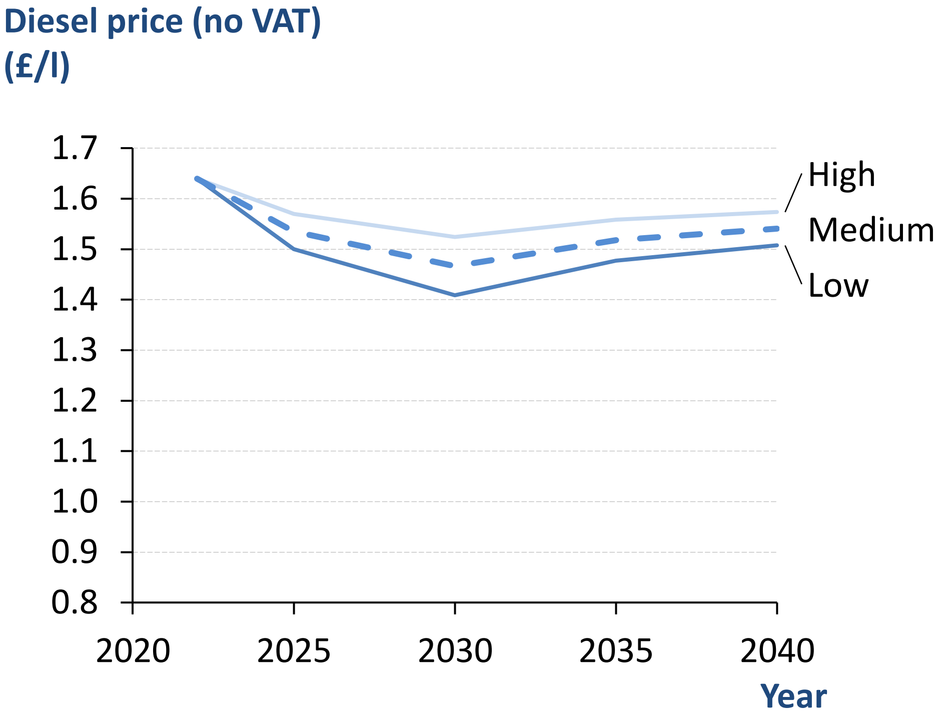
1 - https://theicct.org/wp-content/uploads/2022/06/tco-battery-diesel-delivery-trucks-jun2022.pdf 2 - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1024043/data-tables-1-19.xlsx; 3 - https://www.cornwall-insight.com/press/energy-prices-to-remain-significantly-above-average-up-to-2030-and-beyond/#:~:text=Research%20from%20Cornwall%20Insight%20looking,prices%20in%20pre%2D2021%20Summer., 4 - Plans unveiled to decarbonise UK power system by 2035 - GOV.UK (www.gov.uk) 5 - https://www.gov.uk/government/consultations/review-of-electricity-market-arrangements 6 - https://www.businessenergy.com/blog/economy-7-meters-for-business/ 7 - https://www.infinity-energy.co.uk/electricity-tariffs/

We use three diesel price scenarios

Three diesel price scenarios are used as shown in the graph on the right:

- The 2022 values for both scenarios are based on an average of a sample of June 2022 diesel pump prices
- In all scenarios, diesel prices fall from 2022-2030, reflecting the ability of diesel prices to fall faster than electricity prices owing to the greater potential for increases in European imports of oil compared to gas.
- In the high scenario, prices drop back to meet the BEIS 2020 high scenario[1] in 2030.
- In the low scenario, prices only fall by half this amount. The medium scenario is the average of the two other scenarios.
- Where applicable, the medium scenario is used as the baseline for calculations on the following slides.



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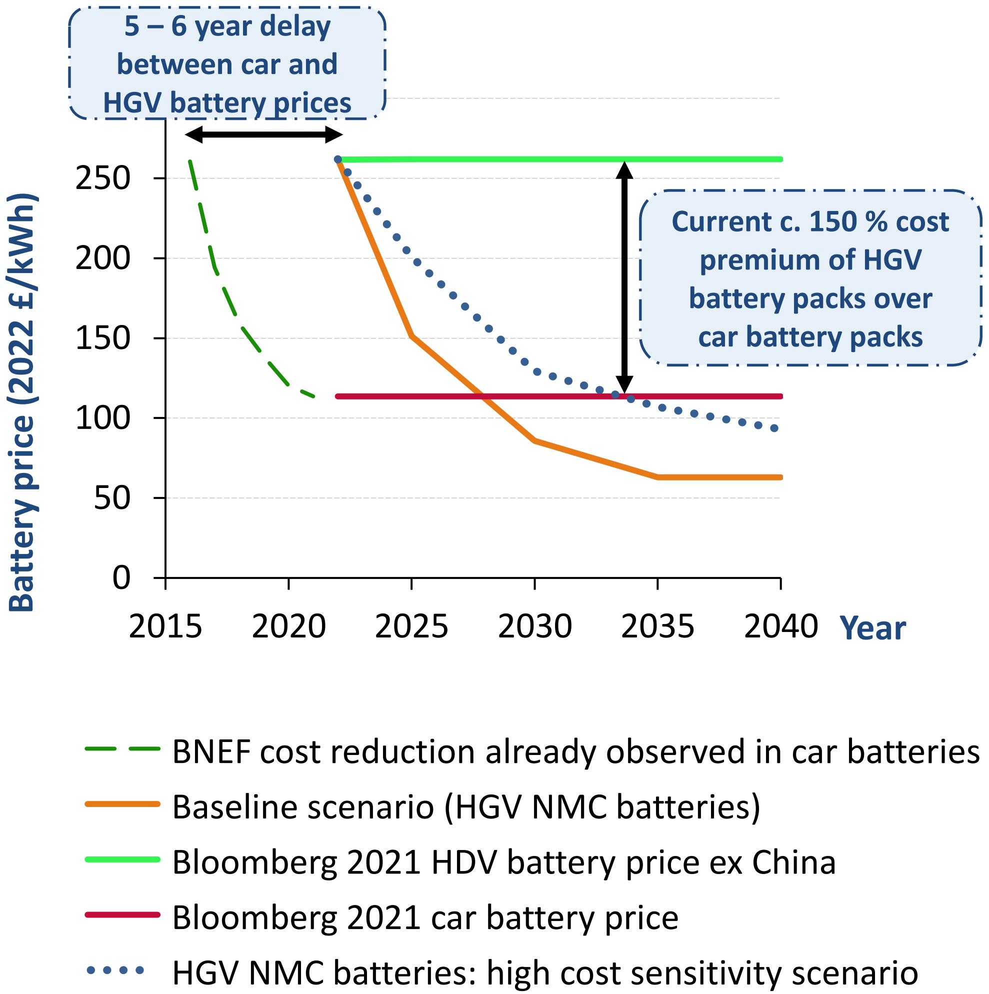
[1] - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1024043/data-tables-1-19.xlsx; 2 - https://www.autoexpress.co.uk/news/93906/record-highs-uk-petrol-and-diesel-prices-global-oil-price-rises-again; BEV – Battery Electric Vehicle; ICE – Internal Combustion Engine; TCO – Total Cost of Ownership

HGV battery prices are currently around 2.5 times higher than car battery prices but are expected to fall sharply in cost over the next 10 years, mirroring trends in the car market

- **Bloomberg NEF data shows that HGV factory gate prices are currently roughly 2.5 times higher than car prices despite the similar chemistries[1]**. This is almost entirely due to the fact that HGV manufacturers are not yet experiencing the same economies of scale in this area as car manufacturers. The expected cost curve for HGV batteries is shown by the orange line in the diagram on the right – used in the TCO results later – and is composed of two phases:
  - **Initial rapid cost reduction** (2022-2027), at a rate already seen in the car market (green dashed line). In 2027, HGV manufacturers achieve the same factory gate prices as were achieved for the car market in 2021. We expect HGV battery prices to achieve the same rate of cost reduction as already seen in the car market, for two reasons. Firstly, as described above, the premium of HGV battery prices over car battery prices is due to scale and is not related to the factors currently delaying the cost reductions in car batteries – so there is nothing to stop HGV battery prices falling rapidly to where car battery prices are currently, even if car battery prices do not fall quickly over the next couple of years. Secondly, investments by HGV manufacturers in onsite production[3,4,5,6] and purchasing alongside car batteries at a group level[4,7] are resulting in massive increase in supply and economies of scale for HGV batteries, both of which will drive down costs.
  - **An asymptotic value** of 63 (2022)£/kWh reached in 2035, 5 years behind the BNEF forecast car battery price for 2030[8]. Conservatively, no further cost reductions are assumed beyond 2035. The conclusions of this work are not materially affected by higher raw material prices in 2035. This is because firstly and as shown elsewhere, the high battery price scenario (blue dotted line on the right) results in very similar breakeven dates to the baseline battery price scenario (orange line in the diagram in the right). Secondly, new battery chemistries are highly likely to be available in 2035, mitigating the impact of raw material prices.



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1 – European HGV manufacturers are primarily using NMC and related chemistries, similar to those used in cars – see references 2-5 2 -https://theicct.org/sites/default/files/publications/eu-tractor-trailers-analysis-aug21-2.pdf , 3- https://www.electrive.com/2020/11/17/scania-to-build-their-very-own-battery-plant/ 4- https://www.reuters.com/article/us-volkswagen-electric-scania-northvolt-idUSKCN1SJ12L 5 - https://northvolt.com/ 6- https://www.volvotrucks.com/en-en/news-stories/press-releases/2022/may/volvo-trucks-opens-battery-plant-in-belgium.html 7- e.g. Scania and MAN are part of VW's commercial vehicle arm TRATON and are sourcing their batteries from Northvolt alongside VW passenger cars, 8 - https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/ NMC – Nickel Manganese Cobalt

We have aimed to capture the requirements of a wide range of HGV operations using a set of archetypes covering a wide range of vehicle use cases, sizes and operation types

Vehicle duty cycle	Description
Rigid urban parcel delivery	7.5t rigid vehicles delivering parcels and collecting parcels within a single large urban area. One delivery round per day of around 100 km.
Rigid city shop delivery	16t/18t rigid vehicles delivering from edge of city distribution centres to shops in large cities. 1-2 shifts of c. 60-80 km each per day.
Rigid urban convenience store delivery	Duty cycle and vehicle are similar to rigid city shop delivery, however a parasitic load from the chiller increases energy use/fuel consumption.
Regional rigid last mile contract logistics	18t rigid vehicles delivering from distribution centres to shops. 200-300 km per day if single shifted, 300-400 km per day if double shifted. Vehicle and infrastructure needs are very similar to other rigid regional use cases.
Urban refuse collection	26t refuse collection vehicles doing 2x30 km collections per day within a single large urban area. Drive cycle is very “stop-start” and vehicle has parasitic loads from crusher, leading to high fuel consumption.
Parcels artic trunking	38t cubed-out vehicles delivering parcels from spoke to hub (and vice versa) once per day; c. 200 km each way.
Double decker DC-DC trunking	44t double decker articulated vehicles, one shift per day delivering from DC to another DC. Either one long trip (250 km – 300 km each way), or two shorter trips.
24/7 regional supermarket delivery	44t vehicles operating with 2 driver shifts per 24 hour period, delivering full loads from distribution centres to large supermarkets. Each driver shift could be either a long round trip of 300-400 km, or two shorter round trips.
Intensive regional artic supermarket delivery	32t articulated vehicles delivering full loads from distribution centres to supermarkets. Duty cycle similar to 24/7 regional supermarket delivery but with reduced downtime and charging opportunities in between shifts.
Round-trip primary haulage	44t articulated vehicles performing two shifts per day from a depot with a few pick up/drops offs on each shift – often delivering from factories to regional distribution centres

Each archetype is representative of a broad category of vehicles with similar infrastructure requirements and total cost of ownership

Broad category	Example archetype(s)
Urban deliveries	Rigid urban parcel delivery
	Rigid city shop delivery
	Rigid urban convenience store delivery
Urban operations with high parasitic load	Urban refuse collection
Regional deliveries performed by rigid vehicles	Regional rigid last mile contract logistics
Regional deliveries performed by articulated vehicles, covering a wide range of operational types – particularly a range of downtime for charging	Parcels artic trunking
	Double decker DC-DC trunking
	24/7 regional supermarket delivery
	Intensive regional artic supermarket delivery
	Round-trip primary haulage

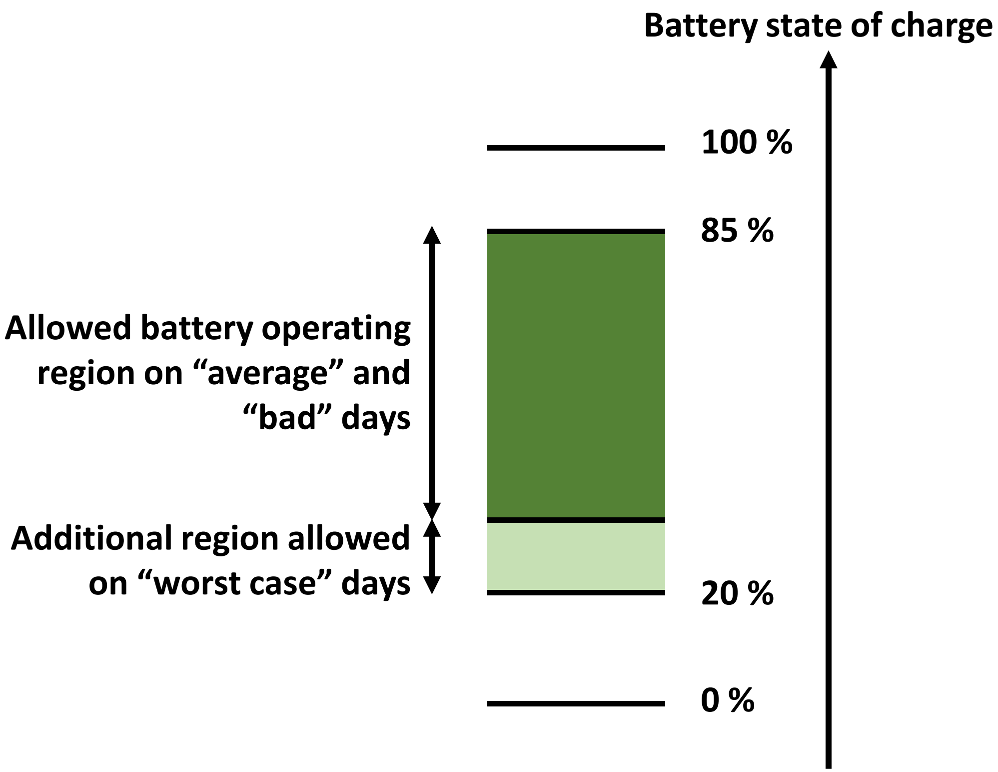
The infrastructure and battery must be sufficient when all of the vehicles in the depot simultaneously have a “worst case” days

- When modelling each vehicle archetype we have modelled the **variation between days** by considering an “average”, “bad” and “worst case” day in the modelling:
  - “Average” day – typical day and typical weather
  - “Bad” day – when the vehicle has to drive a particularly long distance
  - “Worst case” day – when the vehicle has to drive a particularly long distance and the weather is windy (increasing drag) and cold (resulting in increased energy use from the Thermal Management system for battery and cabin heating)
- It is feasible that **all the vehicles in a depot experience a “worst case” day simultaneously** (for example, all vehicles will experience bad weather at the same time). The **infrastructure and battery have therefore been sized to allow for this.**
- The utilisation of the charging infrastructure is based on a weighting of the “average”, “bad” and “worst case” days.
- The “average” day is needed to give the correct annual energy use profile and infrastructure *utilisation,* while the “worst case” day is needed to give the correct infrastructure and battery *size.*
- Further details on the modelling of a thermal management system may be found here
- Further details on the battery sizing approach may be found here and here

The battery is sized to allow for battery degradation and a conservative approach is taken to the usable state of charge window of the battery

- **The diagram on the right shows the allowed battery state of charge assumed in different situations.**
- As a base case, the vehicles are assumed to use NMC batteries, which are conservatively assumed to operate between **20% and 85% depth of discharge**
- However, over the cycle life of the battery, the **battery will degrade** to 80% of its original capacity
- The battery must be able to **remain within the 20% - 85% state of charge window** (except on exceptional days) **even when the battery is degraded** to 80% of its original capacity.
- In order for this to be the case, the battery and infrastructure are sized so that the battery only **uses a maximum of 80% of its 20% - 85% usable state of charge window on "average" and "bad" days**
- However, **variations out of the 20% - 85% depth of discharge window are allowed in exceptional circumstances**. To reflect this, the battery state of charge is allowed to **vary within the full 20% - 85% on the "worst case" days**. This means that, near the end of the battery life, when the battery capacity has decreased to 80% of its original value, the state of charge is allowed to move out of the 20% - 85% window in exceptional circumstances.

Conservative assumptions around allowed battery state of charge used in modelling for battery sizing

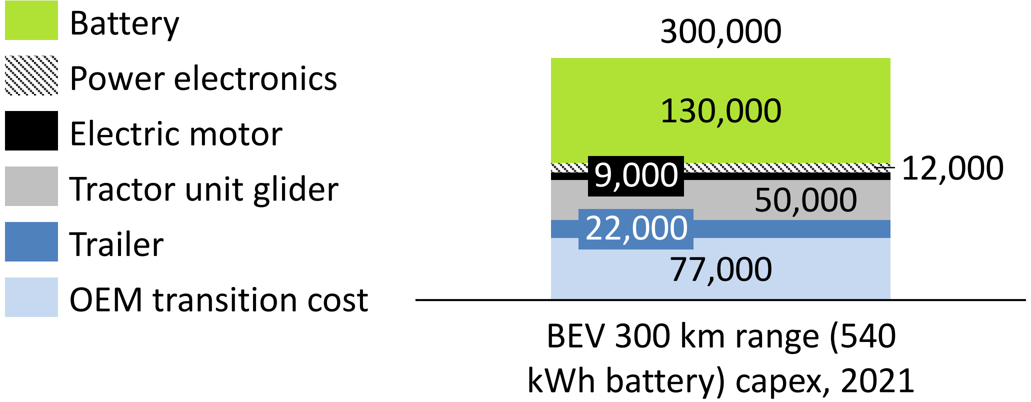


NMC – Nickel Manganese Cobalt

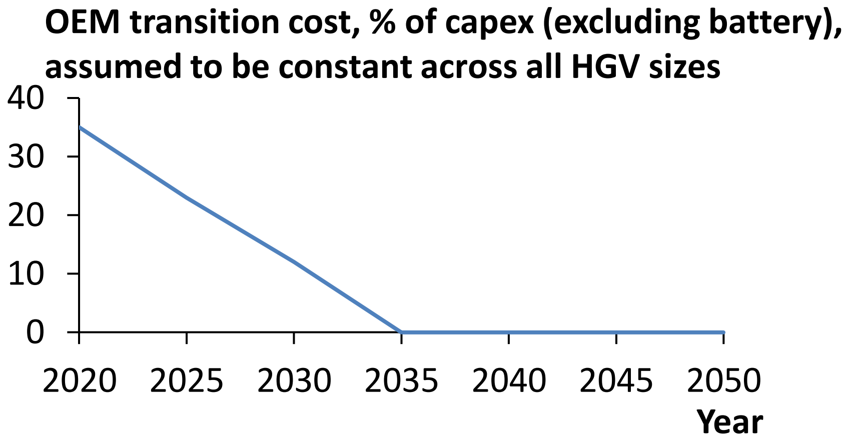
Vehicle component costs alone do not fully reflect the costs of producing a new BEV

- **OEMs face additional costs beyond vehicle component costs** when transitioning from diesel HGV manufacturing to battery electric HGV manufacturing. These include:
  - **Research and development** costs
  - **Accelerated depreciation of diesel manufacturing assets** (reduced asset lifetime)
  - **Factory retooling costs** and related costs of setting up BEV truck production
- **Small order volumes** (and the associated lack of economies of scale) mean that OEMs may be seeing higher battery prices in the very short term; and limited competition also **pushes up prices in the short term**
- We model the impact of all these costs on vehicle capex **empirically as an additional TCO cost component "OEM transition cost".**
- The **magnitude of the transition cost reflects the difference between the sum of component costs and the prices that vehicles are being sold at based on operator discussions**, and it is assumed that this cost will **decrease approximately linearly to zero from 2020-2035**.
- The vehicle glider/trailer/motor/diesel engine costs used **include an OEM markup** which is **separate and additional to** the OEM transition cost for BEVs
- The OEM transition cost is applied to all of the BEV except for the battery. For the **battery**, a **markup of approximately 40% is applied and assumed to remain in place to 2050**.
- This is shown in the diagram on the right

Vehicle capex components including OEM markup for non-component costs, 2021, £



OEM transition cost variation over time



OEM – Original Equipment Manufacturer

Across all use cases, a heat pump is needed to keep the battery and cabin warm on "worst case" days – decreasing vehicle range

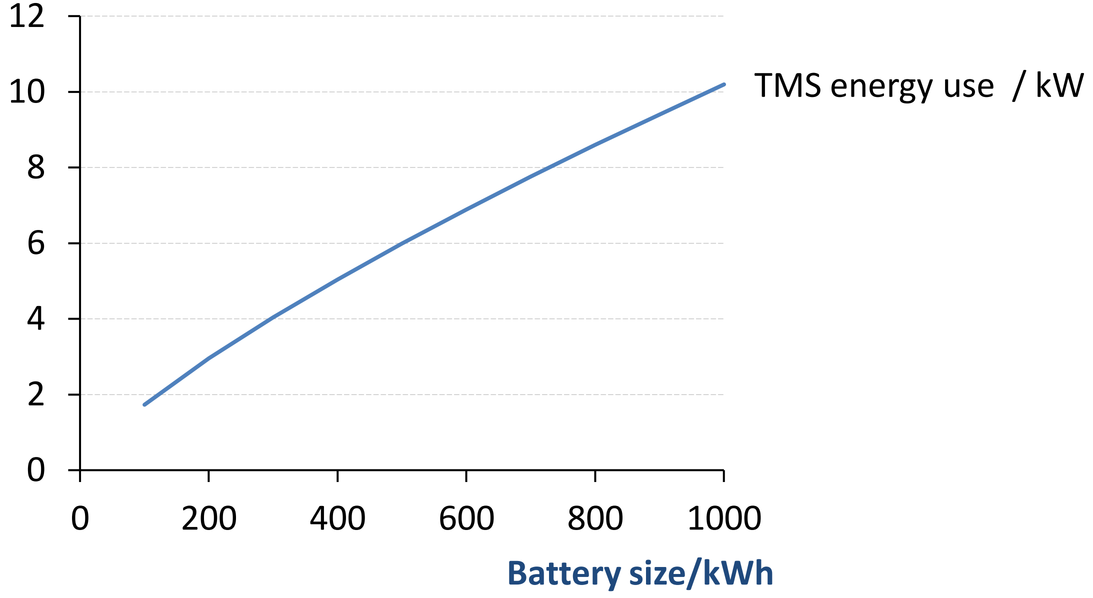
- Our modelling considers an "average day", a "bad day" and a "worst case" day of operation. The **worst-case day includes bad weather** as well as longer range requirements.

- Batteries operate within a small optimal temperature range. **Thermal Management Systems** help to regulate battery temperatures. The system may also be coupled to comfort loads (cabin heating). When plugged in to charge, battery thermal management systems can be powered by chargers, and therefore are not considered to be required when at its home depot.

- This is modelled as a **fixed power in kW** that depends on the size of the battery. Because the power is fixed, the effect is **larger on a kWh/km basis for stop-start driving** rather than motorway driving.

- Our modelling is based on data for range reductions for a motorway drive cycles as a function of battery size from ICCT modelling[1], which we have converted to a kW figure to enable application to a wide range of real-world operational profiles with stops and urban drive cycles. **The energy use is shown in the diagram on the right.**

Thermal Management System energy use/kW; cold winter day



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1 - https://theicct.org/sites/default/files/publications/eu-tractor-trailers-analysis-aug21.pdf

Battery residual values are highly likely to be maintained owing to demand for second life batteries

- Batteries are assumed to have **a residual value of 15%**[1] of their initial capex at the end of their cycle life (defined as when capacity falls to 80% of the initial capacity).
  - The batteries can then be used in **second life battery applications**, for example for stationary storage (this model has already emerged)
  - Second life batteries may prove to be particularly useful for trucks for use in reducing the required grid connection size for warehouses. The battery can be charged when not all the vehicle charge points are in use, and then discharged when all vehicle charge points are in use to reduce peak demand from the site.
- The **lifetime of the battery (i.e., the number of years before the battery reaches the end of its cycle life) is computed analytically for each use case**. This is done by:
  - determining the total discharge of the battery each day (a weighted average of the average, bad and "worst case" days)
  - combining this with the battery size to determine the number of cycles that the battery passes through each day
  - combining this with the number of days per week for which the vehicle operates to determine the number of battery cycles passed through per year
  - this, along with the battery cycle life, gives the battery lifetime in years
  - as a baseline the vehicle is assumed to be kept for one battery lifetime
- The **non-battery components of the vehicle are depreciated exponentially with annual mileage in the same way as has been done for diesel**[2] . This may be a conservative assumption, since depreciation of a diesel vehicle is largely driven by increasing annual maintenance costs with increasing age of the diesel powertrain related components, and the electric motor and other BEV powertrain components (excluding the battery) are expected to require less maintenance than a diesel engine.
- In the modelling, **the battery electric vehicle is assumed to be kept for one battery lifetime**. The lengths of ownership produced by this have been confirmed in real world examples with operators for urban delivery use cases.
- Large companies can potentially realise greater battery residual value by putting a vehicle with an older battery onto a shorter route with lower range requirements than the one for which it was intended originally.

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1 - https://theicct.org/publication/total-cost-of-ownership-for-tractor-trailers-in-europe-battery-electric-versus-diesel/ 2- Based on Kleiner & Friedrich, 2017, Maintenance & Repair Cost Calculation and Assessment of Resale Value for Different Alternative Commercial Vehicle Powertrain Technologies, https://elib.dlr.de/114666/1/EVS30_Paper_Trucks_M%26R_Resale_Florian%20Kleiner_uploaded_update.pdg

Infrastructure costs – including grid connection/substation costs – have been included

- The infrastructure is assumed to be financed over a 15 year period with a 10% Internal Rate of Return (based on conversations with infrastructure providers)
- Grid connection costs vary on a site by site basis. In view of this uncertainty, we make a **conservative assumption of £ 200/kW for the grid connection cost**, towards the upper end of values obtained from discussions with UK Power Networks.
  - Sites with good proximity to the grid can have grid connection costs below £100/kW[1], including a new substation
  - Upstream reinforcement costs will be paid by the DNO from 2023[2], rather than by the connection customer, so grid connection costs will not be increased if the site triggers upstream reinforcement. The only way in which a site can have a grid connection cost significantly higher than the £200/kW assumed is if the depot is very far from any grid infrastructure and therefore requires a very large asset extension specific to the depot under consideration.
- **Charger costs** – including capex, installation, maintenance and back-office costs – have all been included. The values used have been based on discussions with bus and truck operators who are already using this infrastructure. The values have also been sense checked in discussion with a charging point installer and through literature review.
  - Charger costs including installation are shown in the table on the right
- We have assumed a charger efficiency of 85% based on data from charger testing, and use this to account for the cost of electricity lost as heat in the modelling.
- **Chargers at shared warehouses are assumed to be used for 3.5 hours per day** – sensitivities around charger utilisation are presented later. The utilisation of other charger types (e.g. depot overnight) is determined directly from the vehicle operational profiles.

Charger capital costs including installation[3]

Charger type	Cost, £/kW
22 kW AC	145
43 kW AC	115
50 kW DC	1000
150 kW DC	575
250 kW DC and above	450

Assumed reductions in charger capital costs

Year	Charger cost, fraction of 2022 value
2022	1
2025	0.925
2030 onwards	0.85

1 – UKPN, STATEMENT OF METHODOLOGY AND CHARGES FOR CONNECTION TO THE ELECTRICITY DISTRIBUTION SYSTEMS OF EASTERN POWER NETWORKS PLC, LONDON POWER NETWORKS PLC & SOUTH EASTERN POWER NETWORKS PLC, 2021, 2- Access SCR - Final Decision (ofgem.gov.uk) 3 – costs peak at 50 kW DC because of step change in £/kW terms from adding in rectification when going from 43 kW AC to 50 kW DC

Contents

The modelling shows that many HGV operations can be electrified with chargers of only a few hundred kW – or in many cases tens of kW

Charging requirements across a range of duty cycles

Vehicle duty cycle	Depot charging requirement	Additional charging needs
Rigid urban parcel delivery	22 kW	none
Rigid city shop delivery	22 kW	none
Rigid urban convenience store delivery	22 kW	none
Regional rigid last mile contract logistics	43 kW	none
Urban refuse collection[1]	22 kW	none
Parcels artic trunking	43 kW	43 kW while waiting at hub for trailer to unload
Double decker DC-DC trunking	43 kW	250 kW while trailer is unloaded at warehouse
24/7 regional supermarket delivery	150 kW	43 kW at supermarket while trailer unloads
Intensive regional artic supermarket delivery	150 kW	43 kW at supermarket while trailer unloads
Round-trip primary haulage	250 kW	250 kW at 3rd party warehouse while trailer is unloaded or while vehicle is waiting to unload

---

1 - The large parasitic loads for the lift and crusher have been included in the modelling and the fuel consumption checked against real world data.

The modelling considers the impact of the uncertainty around future fuel prices on the date when battery electric HGVs will reach Total Cost of Ownership parity with diesel equivalents

- The TCO of diesel HGVs is sensitive to **diesel prices**, and the TCO of battery electric HGVs is sensitive to **commercial electricity prices**

- The **date at which battery electric HGVs reach TCO parity[1] with diesel therefore depends on how diesel and electricity prices change in future**, which is inherently uncertain especially now with current unprecedented fluctuations in energy prices

- In order to capture this**, a range of different electricity price scenarios and diesel price scenarios have been considered**, reflecting the range of possible future electricity and diesel prices. The TCO breakeven date has been determined for each combination of scenarios.

- The likelihood that the TCO breakeven date occurs in a given year is proportional to the **number of different combinations of electricity and diesel price scenarios that lead to a breakeven date within that year**

  - There are some years where there is a high probability of the TCO breaking even during that year because this happens under a wide range of scenario combinations – for example, a combination of a central electricity scenario and central diesel price scenario results in a very similar breakeven date to a combination of a high electricity price scenario and high diesel price scenario, since it is the relative TCO of diesel and battery electric HGVs that is important rather than the absolute value.

  - Conversely, very early or late TCO breakeven years are very unlikely because they require an very low electricity price scenario and a very high diesel price scenario or *vice versa*.

- In order to reflect this, on the following slide we use a heatmap **where the darkness of the square reflects the probability that the TCO will break even in that year**. This reflects the number of combinations of diesel/electricity fuel price scenarios that result in the TCO breaking even in that year.

TCO – Total Cost of Ownership (1) TCO parity refers to the first year in which purchasing a new BEV HGV would subsequently generate a lower TCO than an equivalent new diesel HGV

As confirmed in discussions with multiple fleet operators and by the modelling used for this project, battery electric HGVs will have longer lifetimes than diesel vehicles for urban deliveries

- The longer vehicle lifetimes predicted for battery electric vehicles[1] (compared to diesel) for urban deliveries have been confirmed in multiple discussions with fleet operators.

- Battery electric vehicles are CAPEX intensive while diesel vehicles are OPEX intensive**. Increased vehicle lifetimes therefore significantly reduce the total cost of ownership of battery electric vehicles** on urban deliveries (by spreading the depreciation over a longer period), but have very little impact of diesel vehicle total cost of ownership (even if they did apply to diesel vehicles), as demonstrated later.

- **This creates a significant commercial opportunity for institutions with low cost of capital to relieve operators of the vehicle lifetime and OPEX risks by financing the vehicles and offering them to operators as a Vehicle as a Service model.**

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1 – Source: ERM TCO parity date forecasting model

The following slides demonstrate how BEV can become cost competitive with diesel – however policy support is needed to de-risk the transition to battery electric vehicles for fleets and build scale

Why policy support is needed

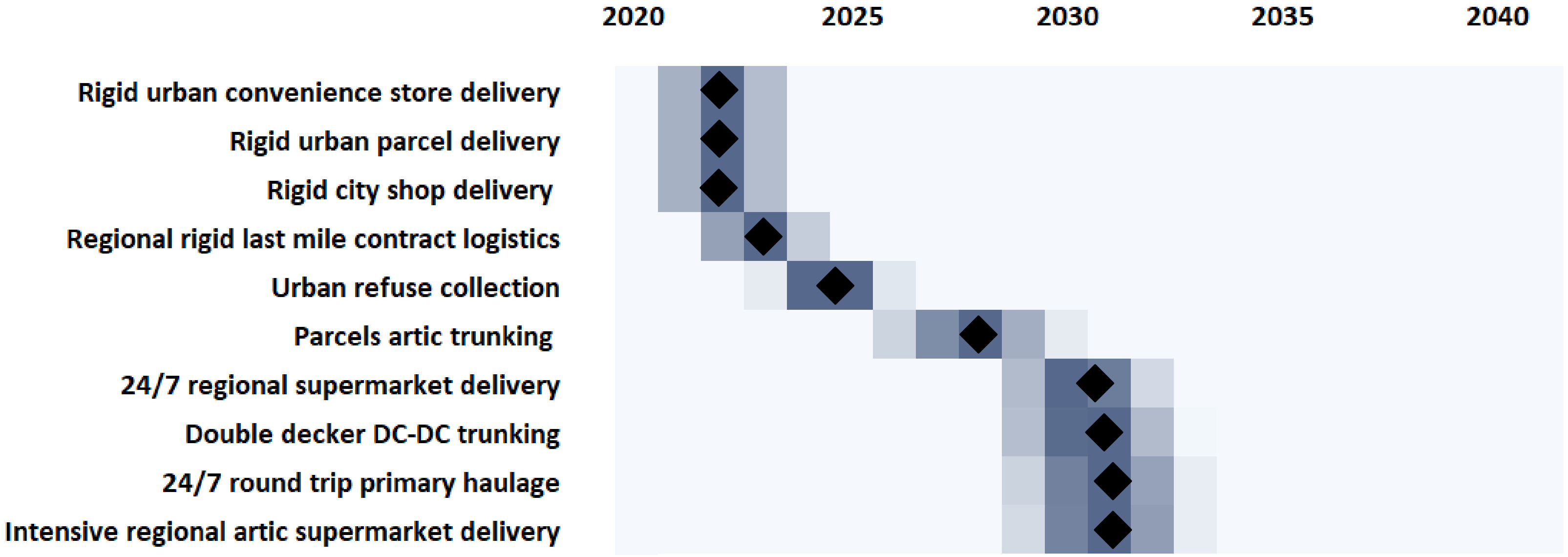
- **Risk mitigation:** the cost savings from battery electric vehicles come from lower operating costs and, in some cases, increased vehicle life compared to diesel. These cost savings are already sufficient to offset the increased capital cost of a battery electric vehicle for some duty cycles. In the short term, fleet operators may be uncomfortable taking the risk that a certain higher capital cost will be completely offset over the years following purchase by lower running costs and increased vehicle life, since both of these factors are inherently slightly uncertain. This low risk appetite is compounded by the fact that fleet operators generally experience very low profit margins, and hence small cost fluctuations can cause loss of profit. Subsidies to reduce upfront capex for battery electric HGVs are therefore needed in the short term to provide a “margin of safety” for fleet operators so they can be certain that the higher capex will be offset by lower running costs in situations where this trade-off is marginal. Subsidies are also needed to help reduce the cash flow impact of increased vehicle and infrastructure capex.

- **Closing the total cost of ownership gap:** for large articulated HGVs, BEVs are currently significantly more expensive on a total cost of ownership (TCO) basis than diesel equivalents. Temporary subsidies are needed in the short term to close this TCO gap, allowing the industry to scale, which will in turn bring down costs and allow subsidies to be phased out completely later. **These subsidies can be funded by a small malus payment on new sales of diesel vehicles and hence would be revenue neutral for the government.**

- **Payload and vehicle length regulations:** 44 tonne battery electric vehicles currently require an increase in vehicle weight allowance and an increase in vehicle length allowance in order to allow them to carry the same payload as diesel equivalents and provide enough space to fit batteries onto the vehicle. Avoiding payload loss is necessary to avoid deterring uptake from operators, and this is particularly true in the 44 tonne category.

Even without policy, BEVs will be cost competitive with diesel across a wide range of HGV duty cycles by 2030. Further policy is needed to ensure sufficient sales by 2030.

BEV-diesel TCO break even dates[1] for a sample of HGV use cases under a range of fuel price scenarios (without policy)



Legend

◆ Average breakeven date

Increasing likelihood of breaking even in that year

See here for details on how to interpret the heat map

Description

1. **Urban deliveries** with predictable daily mileages **reach TCO parity first** – batteries are small and can be right sized, reducing vehicle capex
2. **Regional deliveries** with **significant downtime** reach TCO parity around the end of the decade – this **includes some artic duty cycles with large downtime which achieve TCO parity well before the more intensively used artic use cases.**
3. **Intensive regional artic duty cycles** benefit from increases in battery energy density and hence vehicle range over time, reducing need for top up charging during the day and hence infrastructure costs

These dates assume battery and infrastructure right-sizing – choosing a BEV with more range than is needed by the operation results in a higher cost and delays the TCO parity date. OEMs are already offering a range of battery sizes.

These parity dates are achieved with conservative assumptions, including no aero improvements, only incremental improvements in existing battery technology and conservative infrastructure cost assumptions. Assumptions on battery energy density and vehicle performance have been carefully checked against the specifications of current and future announced (2024) OEM models and found to agree very well.

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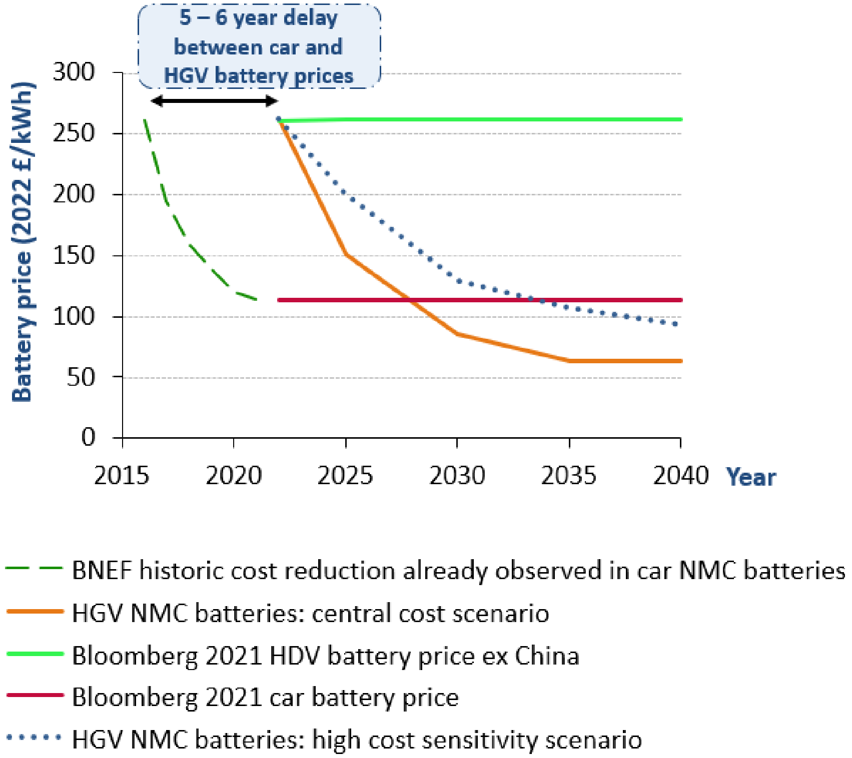
1 – Source: ERM TCO parity date forecasting model. Duty cycles described on this slide.

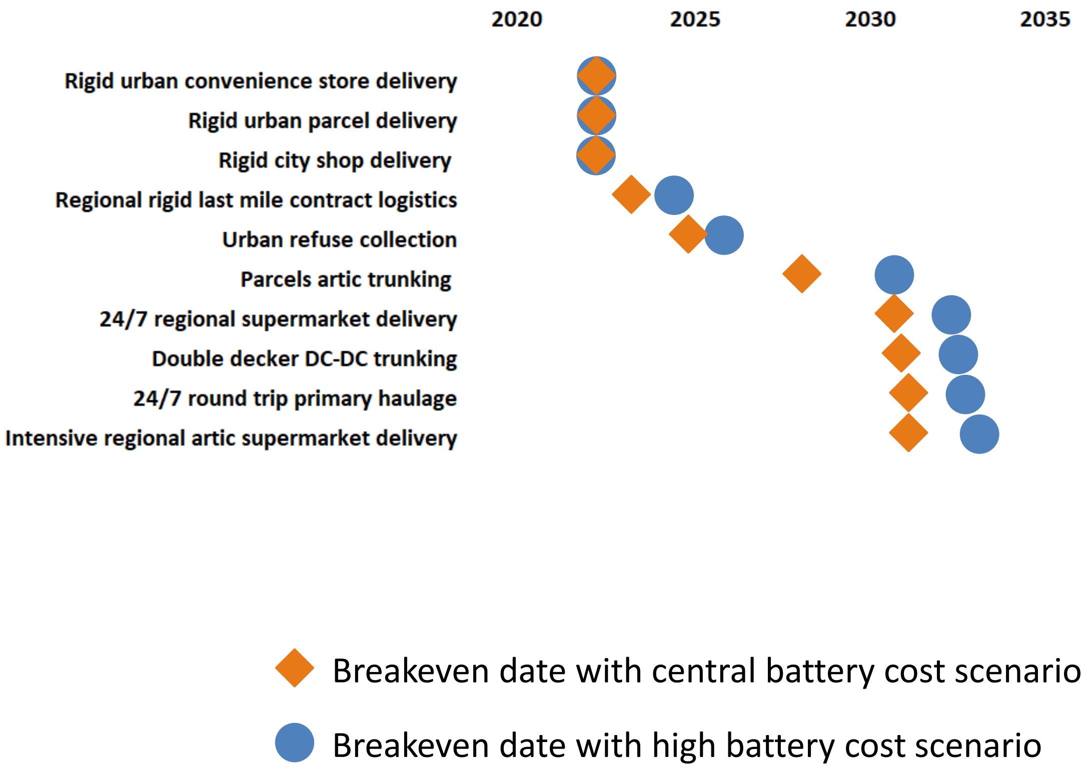
Even with significant delays in battery cost reductions, BEV achieves TCO parity with diesel across the board by 2035, and in rigids performing city and regional deliveries by the mid 2020s

Battery price scenarios



More details on battery prices on this slide and heatmap interpretation on this slide

BEV-diesel TCO break even dates without policy under the baseline battery price (orange diamond) and high battery price scenarios (blue circle)



Even with greatly delayed battery cost reductions and pessimistic fuel price scenarios, BEV cost competitive with diesel across the board by 2035 and for most rigid use cases by mid 2020s

Repetitive duty cycles with plenty of downtime for charging reach TCO parity with diesel first

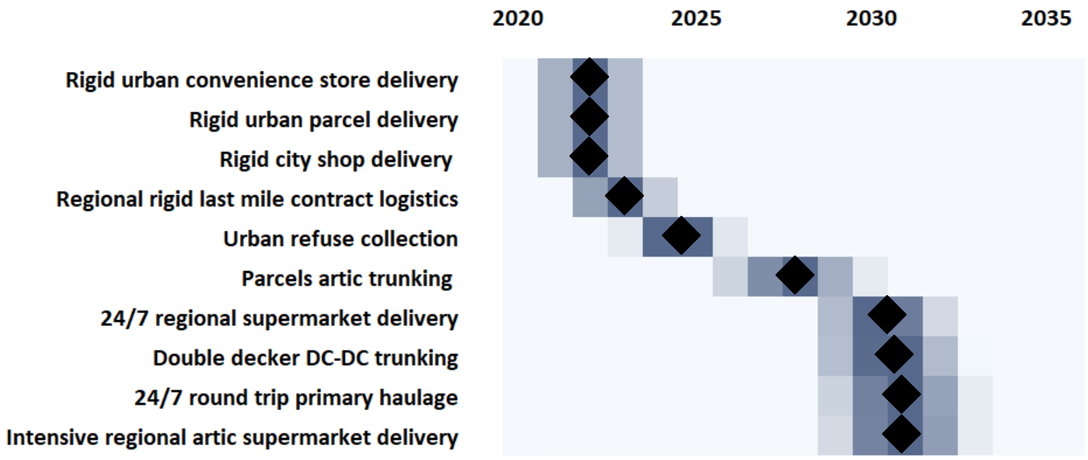
Key drivers influencing BEV-diesel TCO break even dates

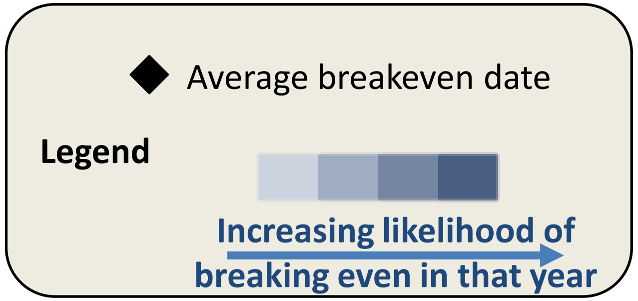
Range needs	The increase in battery capex and associated financing costs more than offsets the increased fuel cost savings as mileage increases
Downtime	High downtime in the operation allows all charging needs to be fulfilled with AC charging which greatly reduces infrastructure costs
Variability	Predictable duty cycles allow both the battery and infrastructure to be right sized and well used, maximising value for money
Drive cycle	Stop start urban driving results in greater fuel cost savings for BEV vs diesel owing to regenerative braking & higher efficiency at low speeds
Special components	Integration of bespoke components (e.g. crusher/lift for refuse collection vehicles) generally increases BEV capex relative to diesel

The following sections cover detailed TCO results for selected archetypes and key sensitivities affecting the TCO

A German-style subsidy scheme could unlock rapid uptake for both rigids and artics on back-to-base operations; it could be funded by a malus on diesel vehicles and gradually phased out

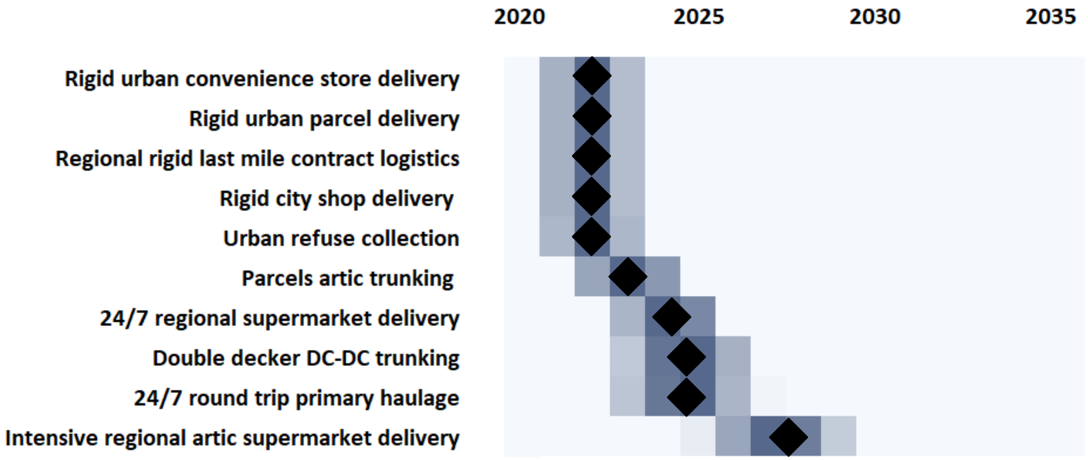
BEV-diesel TCO break even dates for a sample of HGV use cases (without policy)





See here for details on how to interpret the heat map

BEV-diesel TCO break even dates for a sample of HGV use cases (with policy)



Policies (all of these applied)

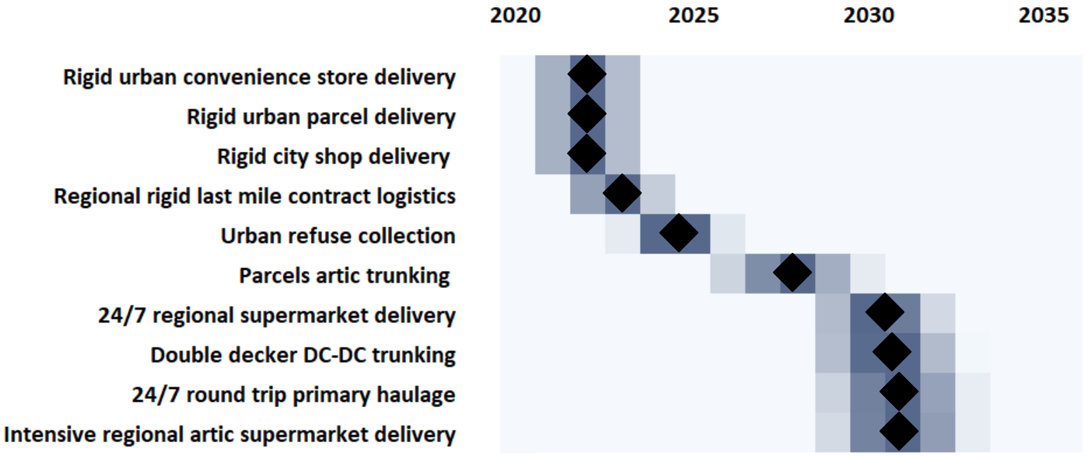
Vehicle class	BEV capex subsidy, £
Articulated HGVs	125,000
Rigids over 7.5t	45,000
Rigids up to 7.5t	1,000

Subsidies can be gradually phased out and are just needed to kick start adoption – since as shown on previous slides all use cases studied are cost competitive without subsidy by 2035.

Duty cycles described on this slide.

Policies that encourage OEMs to place the transition cost on diesel vehicles rather than battery electric vehicles help bring forward the TCO parity date of "early mover" archetypes

BEV-diesel TCO break even dates for a sample of HGV use cases (with OEM transition cost and 40% battery markup)



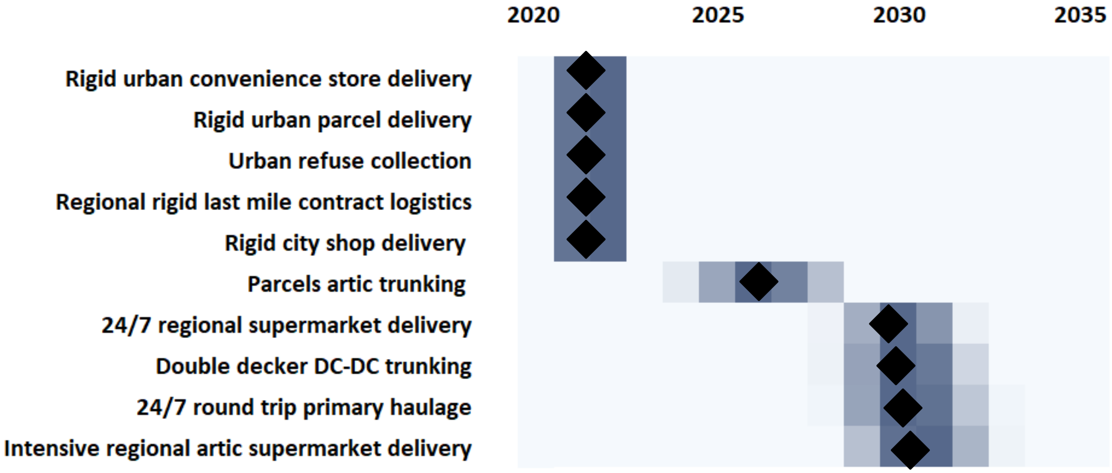
◆ Average breakeven date

Legend

Increasing likelihood of breaking even in that year

See here for details on how to interpret the heat map

BEV-diesel TCO break even dates for a sample of HGV use cases (without OEM transition cost and with battery markup reduced from 40% to 30%[1])



Simultaneously shifting the OEM transition cost from BEVs onto diesel vehicles, and reducing the markup applied by the OEM on the battery from c. 40% to c. 30%, brings forward the TCO parity date of the *early mover* use cases by around 2 years.

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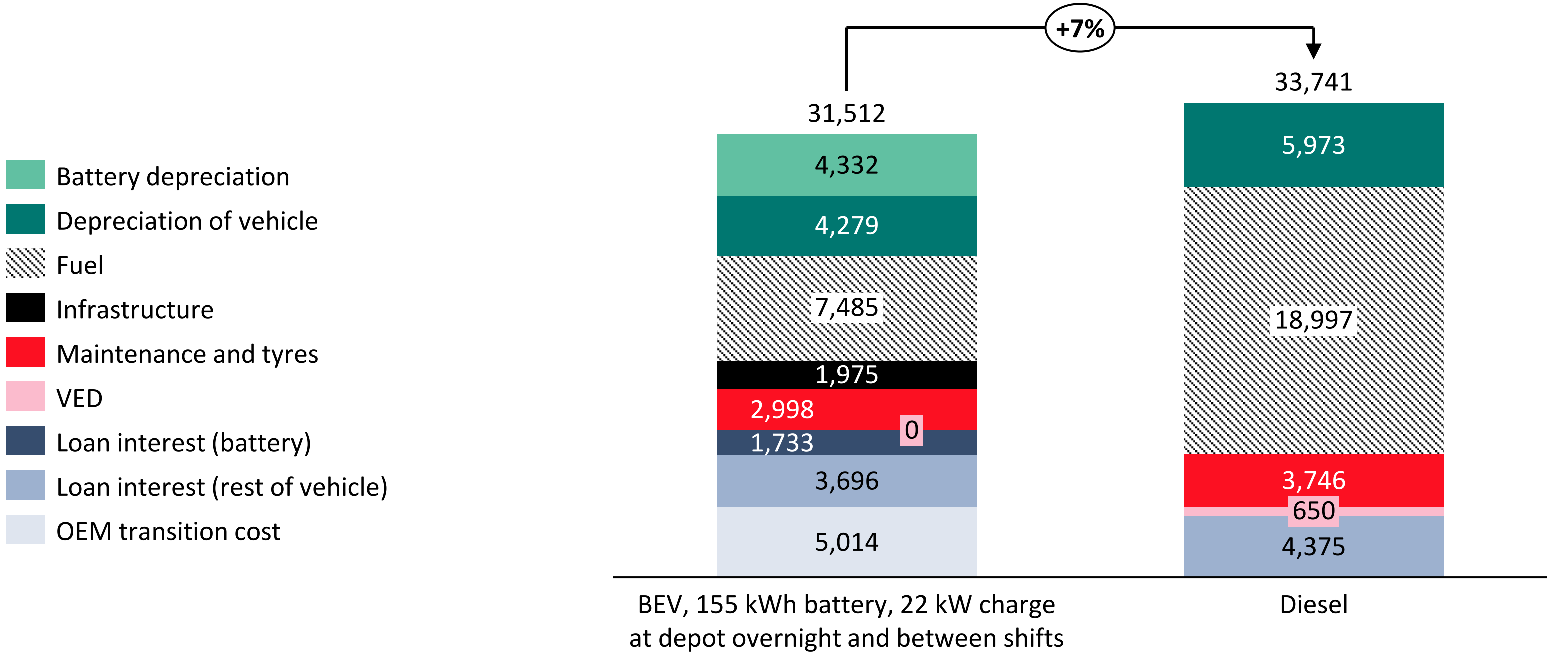
1 – The cost is removed from BEVs. In reality a very small increase in diesel vehicle costs resulting from this would bring breakeven year slightly earlier. In some cases it causes the breakeven date to be in the past, where it is just shown as 2021 for simplicity. Duty cycles described on this slide.

Contents

For rigid urban deliveries, large fuel cost savings and increased vehicle life mean that BEVs can already offer slightly lower total costs than diesel equivalents

Average Total Cost of Ownership per year (annual TCO) of an 18t diesel vehicle and 18/20t[1] BEV bought new in 2022, for large city convenience store delivery, £



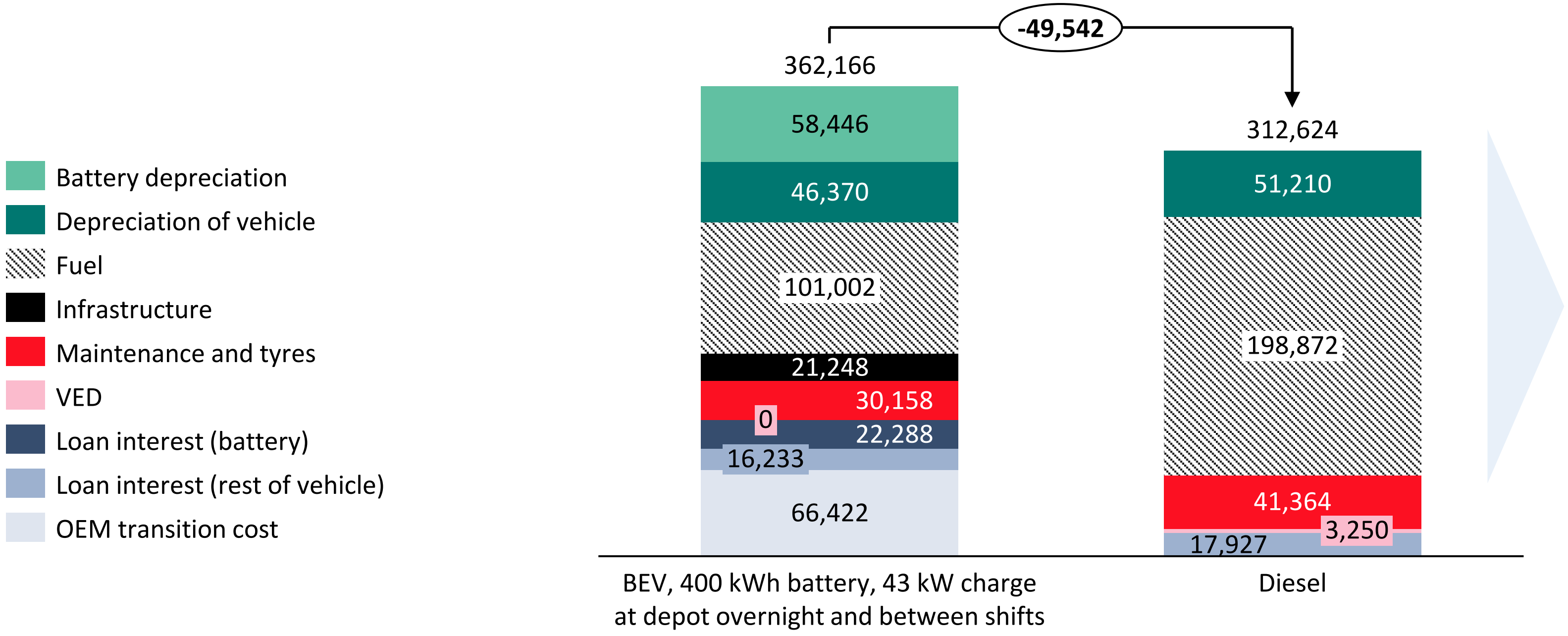
Even with an OEM transition cost that is the same percentage of vehicle capex as for articulated HGVs, battery electric HGVs are already cost competitive with diesel equivalents for urban deliveries, provided that the batteries are sized appropriately.

This is driven by particularly large fuel cost savings for BEVs performing urban driving (stop-start urban driving leads to large amounts of energy recovery through regenerative braking, more so than for motorway driving). The increased vehicle life – around **8 years for BEV as opposed to 5 for diesel in this use case** – creates further cost reductions. The use of low power AC charging results in modest infrastructure costs, reduced further by managed charging overnight to reduce the site's peak power demand.

1 – additional 2t weight allowance under consultation. Likely to be more than sufficient for this particular use case.

Rigid BEVs performing regional deliveries have larger batteries than urban delivery BEVs, so require subsidy in the short term to achieve cost parity with diesel - this will not be needed later in the decade

2022 Total Cost of Ownership over a 5 year period[1] of an 18t diesel vehicle and 18/20t BEV bought new in 2022, for regional deliveries, £



£50,000 subsidy required to allow BEVs to reach TCO parity today with diesel equivalents, over a 5 year period.

Total Cost of Ownership of BEVs for regional deliveries is less favourable than for urban deliveries because the fuel cost savings are proportionately smaller (less potential for regenerative braking power recovery) and the battery requirements are large, increasing vehicle capex.

However, as shown in this work by first principles modelling based on real world duty cycles, BEVs are still operationally well suited to regional deliveries with current technology and represent an important area for large emissions savings now if given policy support.

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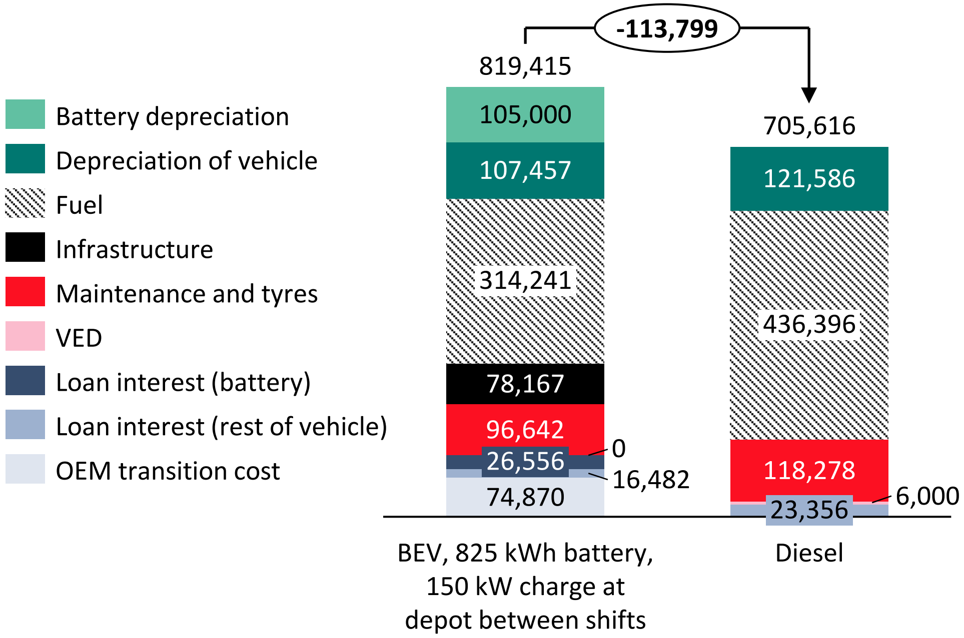
1 – our modelling indicates that, as observed in real world examples for urban deliveries, BEV lifetime will in fact be slightly longer than for diesel equivalents (5 years); here 5 years is shown for BEV as well

24/7 double shifted artic last mile deliveries (such as supermarket deliveries) will be unlocked by 2025 OEM series production models[1] and do not need to wait for a public charging network to electrify

2025 Total Cost of Ownership over a 5 year period for supermarket deliveries, £



BEV artics in series production in 2024/25 will be operationally capable of many supermarket deliveries (and similar duty cycles) using depot charging only. Many artic supermarket deliveries can therefore be electrified in 2025 **without having to wait for a public charging network to be in place**.

However, a malus-funded capex subsidy of around £100,000 will likely temporarily needed to bridge the short term TCO gap, assuming that supermarkets source electricity at around 22 p/kWh (excluding VAT) at this point**. With funding by a malus on diesel vehicles, this subsidy would be revenue neutral to the Treasury.**

An additional weight allowance of around 2 tonnes is needed to allow the longest range BEVs to carry the same payload as diesel equivalents on weight limited trips. The UK Government should therefore increase the weight allowance for 6x2 / 6x4 BEVs above 44 t, for example by extending the **48t GVW allowance for the intermodal freight trial to cover BEVs as well.** An additional circa 1.1 m in length allowance[1] is needed to allow space for batteries on the 6x2 tractor unit without loss of trailer space – discussed elsewhere in the report. The increase in length already permitted following the Longer Semi Trailer trial should therefore be extended to BEVs.

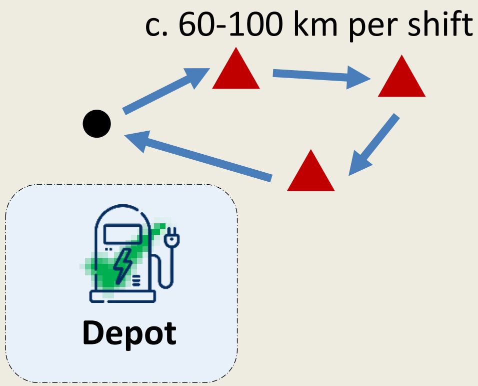
[1] - https://www.scania.com/group/en/home/newsroom/news/2021/Scanias-electrification-roadmap.html, https://www.autoweek.com/news/green-cars/a40445645/mercedes-eactros-longhaul-electric-semi-iaa-hannover/, https://insideevs.com/news/535982/man-long-range-electric-trucks/ 2- Element Energy analysis

Contents

Large city convenience store delivery (18t/20t GVW[1])is an archetypal short range rigid delivery operation

Duty cycle and charging opportunities overview

Journey profile and charging opportunities

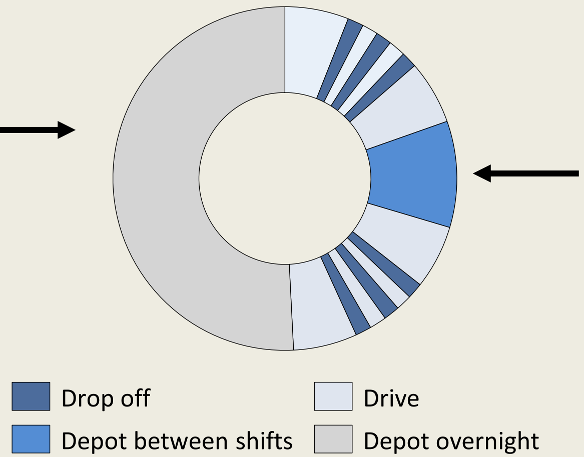


- One or two shifts per day from distribution centre to a few convenience stores
- Urban driving mostly
- 5-year diesel (lots of engine stop/start) but 8-year electric (battery lasts a long time)

Key ● **Depot** ▲ **Convenience store**

Time spent during the day

Chance for long slow charge overnight



Chance to charge for c. 2 hours between shifts

- Similar routes each day; vehicle payload c. 6t (no loss of payload)

---

1 – Gross Vehicle Weight; increased weight allowance of 2t for BEVs

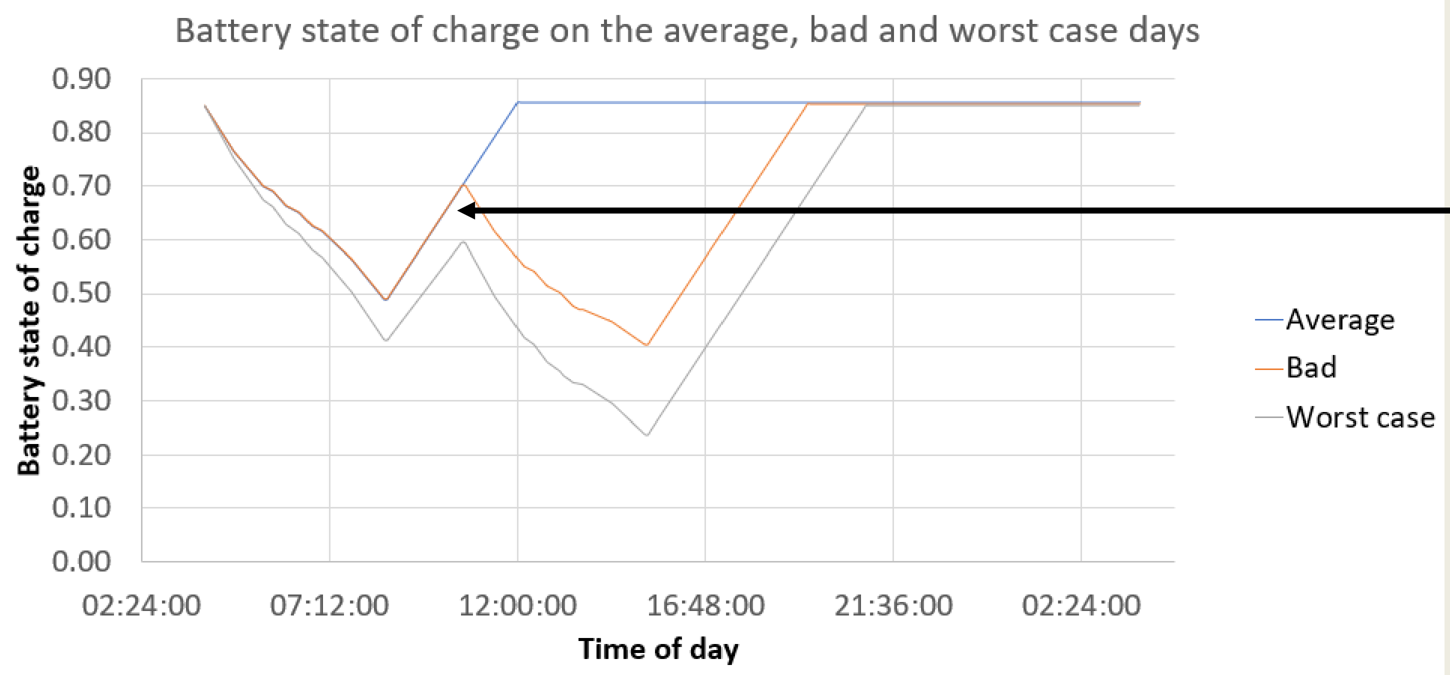
The whole duty cycle can be completed using AC charging only

Battery state of charge, energy use overview and charging power overview

Battery state of charge profile during the day

Fuel consumption average (including parasitic loads)

7.3 mpg diesel[1]   0.9 kWh/km electric



Slow, mid range SOC (hence linear) charge between shifts

Key fuel consumption points

Stop/start urban driving leads to very high diesel fuel consumption and large BEV regenerative braking energy savings

A 6 kW fridge is included as a parasitic load

Battery/infrastructure size combination

155 kWh battery   22 kW charge at depot overnight   22 kW charge at depot between shifts

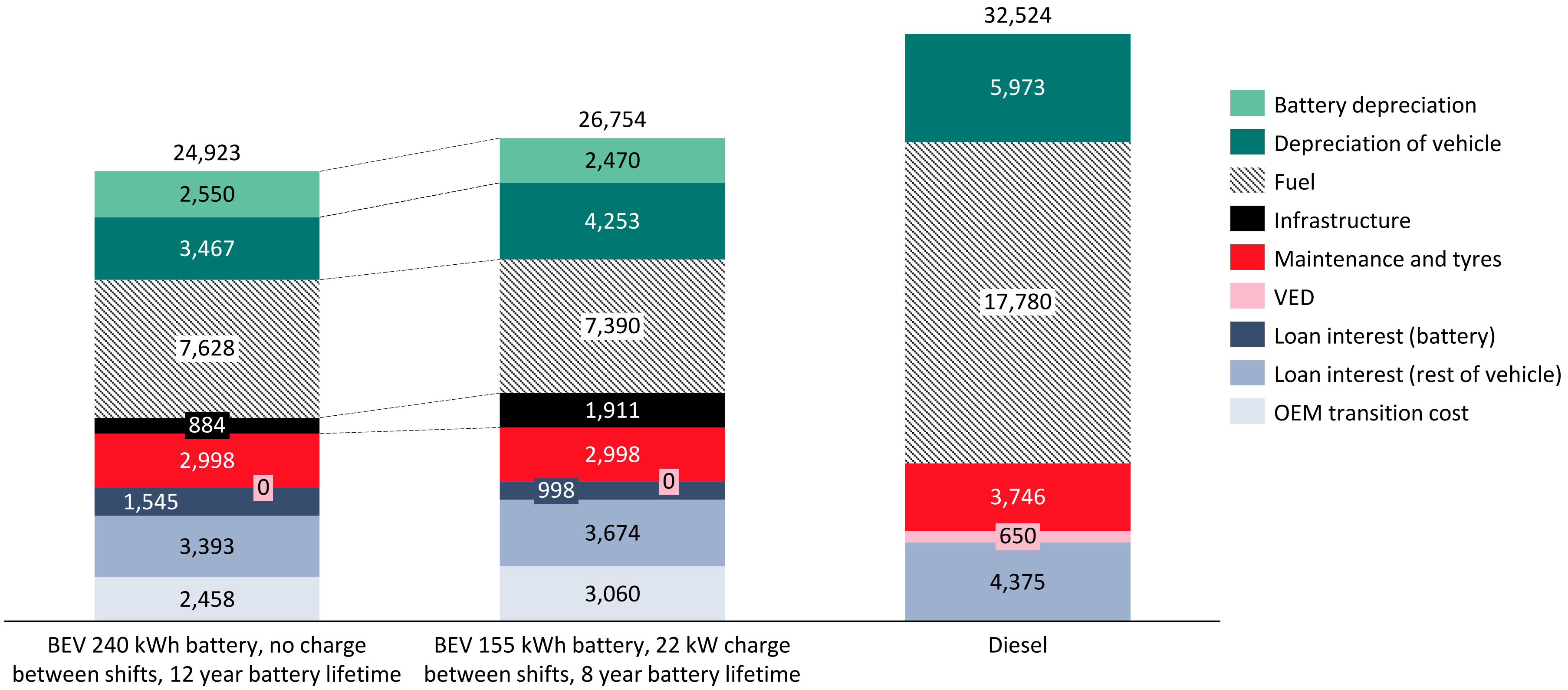
---

[1] - high diesel fuel consumption due to stop-start driving and parasitic load

Key TCO components

Annual TCO comparison of two BEV options and diesel in 2025

Fuel cost savings **for BEV over diesel increased for urban driving** because of energy savings from regenerative braking



Low duty of battery means that the modelling shows that battery will last 8 years, in line with fleet operator discussions which revealed that some operators already planning to keep **BEVs for 8 years** on this duty cycle, whereas diesel vehicles are kept for 5 years.

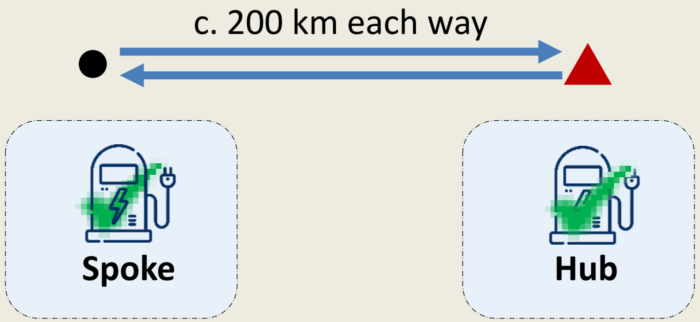
22 kW chargers are low cost, so the **additional infrastructure cost of a 22 kW charge between shifts at the depot is small**, even if it is assumed (as here) that this uses different infrastructure to overnight charging. If the 22 kW overnight charger can also be used between shifts, the TCO would be almost identical in the small and large battery cases, but the former would give a faster payback time.

Contents

Parcels artic trunking from hub to spoke is a repetitive artic duty cycle with modest range requirements, allowing it to be completed by BEV without public charging

Duty cycle and charging opportunities overview

Journey profile and charging opportunities

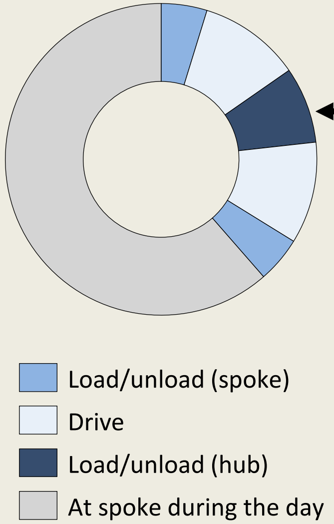


- **One journey per day** carrying parcels from hub to spoke and back
- **Same journey every day**
- **Driving mostly along motorways**
- **6-7 year ownership period**

Key ● **Spoke** ▲ **Hub**

Time spent during the day

Chance for long slow charge during day with vehicle parked at spoke for c. 16 hours



Chance to charge for c. 2 hours while trailer unloaded at the hub

- **Vehicle cubed out – can reliably run on 4x2 / 38t**

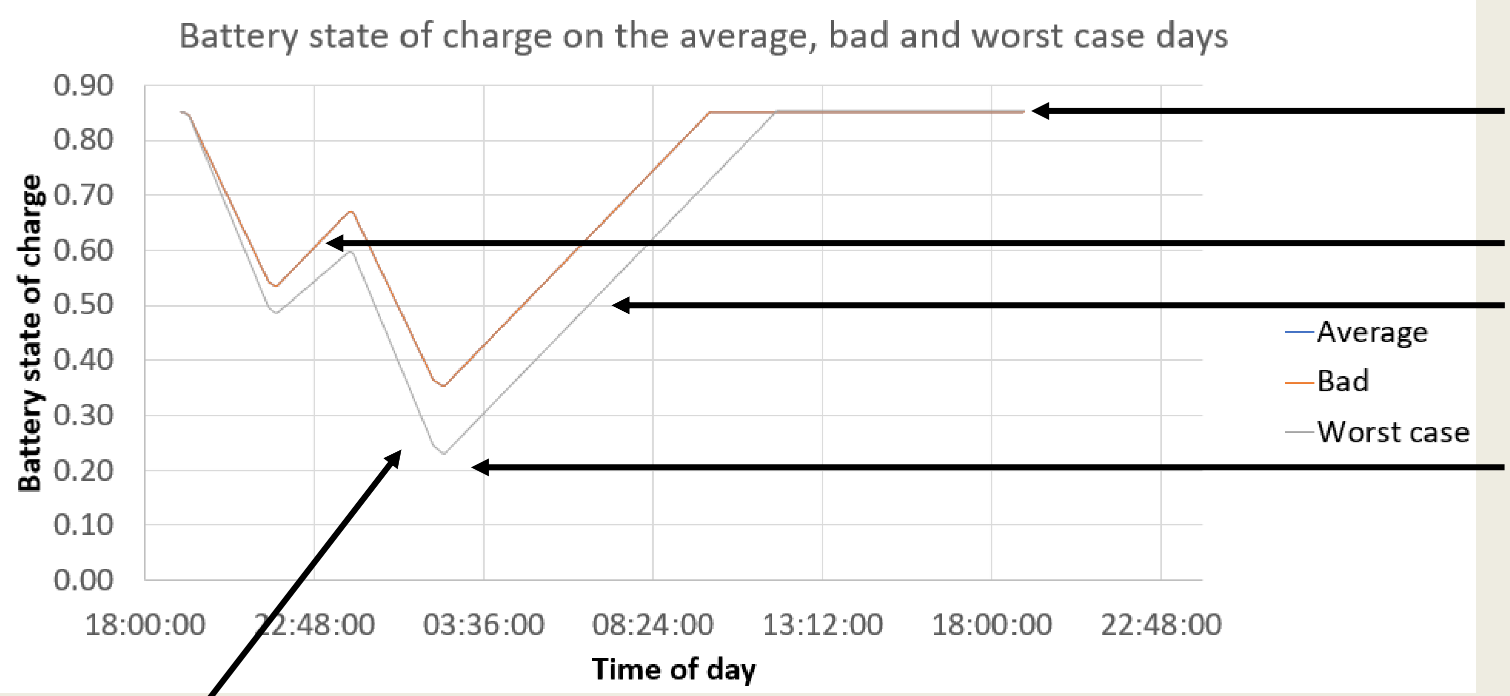
The whole duty cycle can be completed using AC charging only

Battery state of charge, energy use overview and charging power overview

Battery state of charge profile during the day

Fuel consumption average

9.8 mpg diesel 1.3 kWh/km electric



c. 60% diversity factor for spoke charging (based on fraction of available time used)

Slow (hence linear) charge at hub

Slow (hence linear) charge at spoke

Energy use higher on worst case day even though mileage is the same, due to energy use for battery and cabin heating, and wind increasing drag

Battery SoC allowed to drop to 20% on worst case day

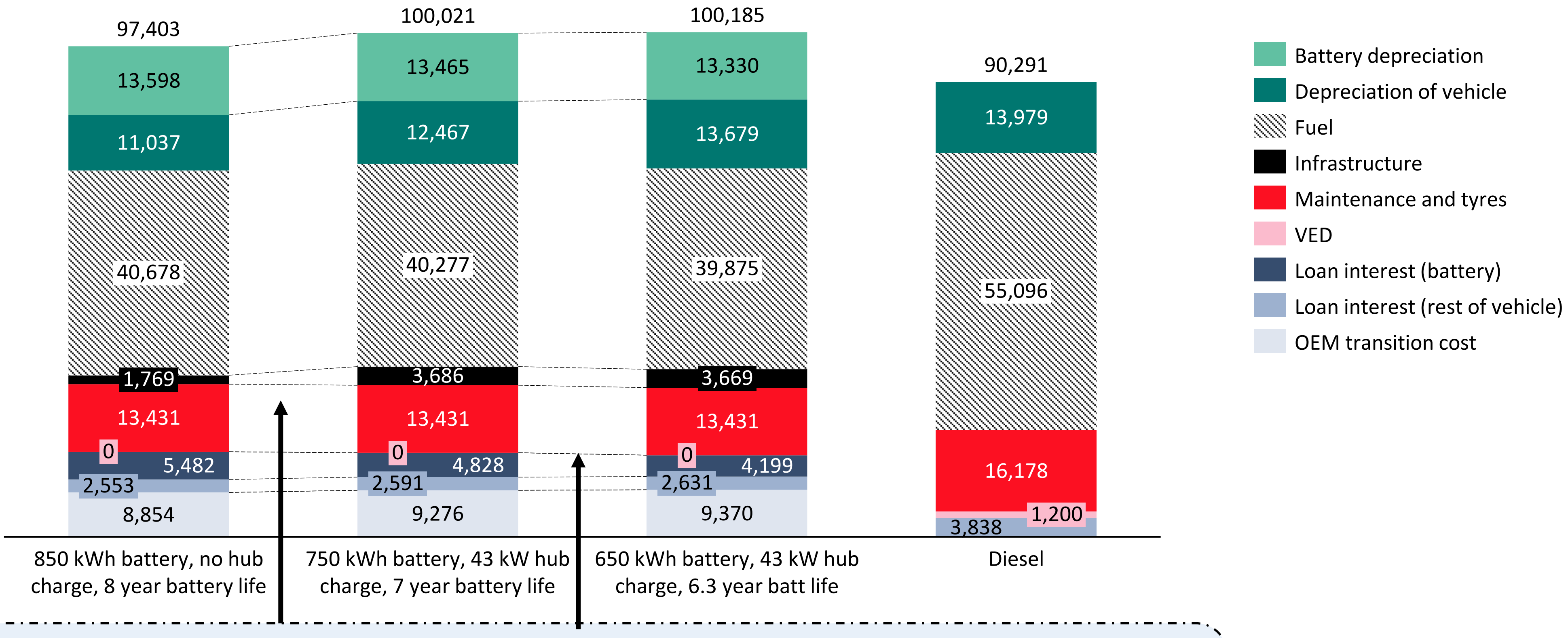
Optimal battery/infrastructure size combination

2022: 750 kWh battery (limited by chassis battery packaging space) 43 kW charge at hub 43 kW charge at spoke

2025: 850 kWh battery (improved energy density); 43 kW charge at spoke only (no hub charge needed)

Key TCO components and optimisation

Annual TCO comparison of three BEV options and diesel in 2025, £



Larger, more expensive batteries will last longer and require less infrastructure, which offsets the additional battery capital cost. Nonetheless, as can be seen above, the various BEV options all have very similar annual costs and these are similar to diesel in 2025.

Contents

Urban and regional last mile deliveries, often performed by 18t rigids, have similar duty cycles but with larger mileages in the regional case

Key ● **Depot** ▲ **Shop**

Comparison of *examples of* urban and regional rigid last mile distribution

Urban

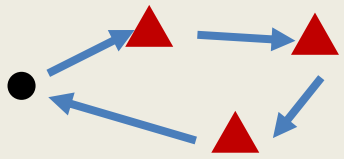
Journey profile and charging opportunities

c. **60-100 km** per shift; **1-2 shifts per day**

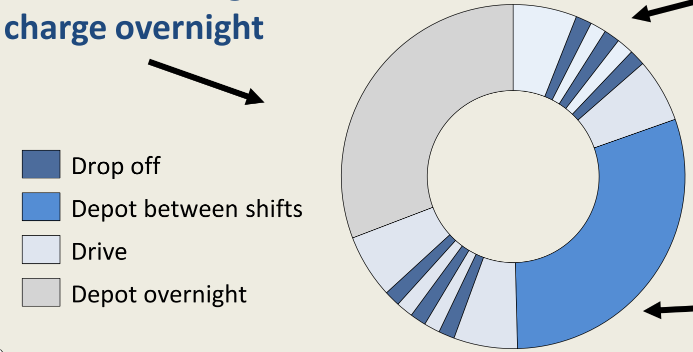
2-3 drops per shift within a single large city

Stop-start, city based driving

Depot



Time spent during the day



Chance for long slow charge overnight

First shift before shops open

Possible second delivery after shops close

Regional

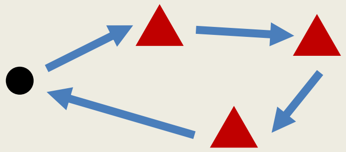
Journey profile and charging opportunities

c. **200-250 km** per shift; **1-2 shifts per day (max 400 km per day)**

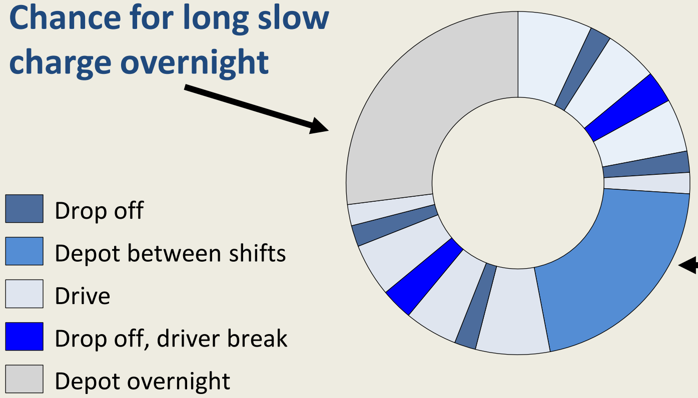
2-3 drops per shift in 2-3 urban areas

Rural A/B road driving between towns

Depot



Time spent during the day



Chance for long slow charge overnight

Chance to charge for c. 5 hours between shifts

Rigids performing both city and regional deliveries are both likely to be significantly cheaper to operate than diesel by 2025

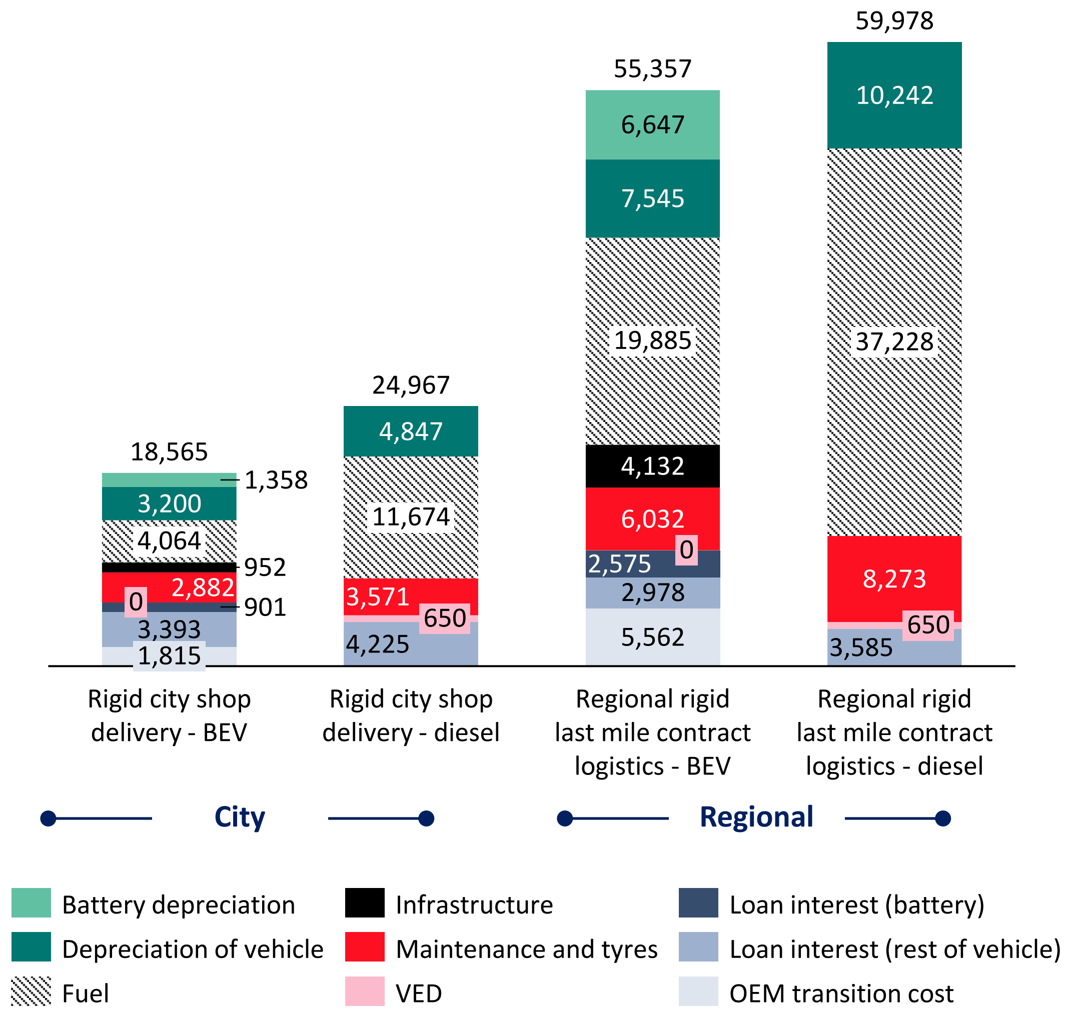
Key drivers

1 **Battery size** – if the battery is **sized correctly for the duty cycle**, the **battery size required for rigid city shop deliveries is very small**. Regional deliveries require a **larger battery size** – this increased capex more than offsets the increased fuel cost savings from the larger annual mileages in the regional case. Furthermore, the city delivery duty cycle completes fewer battery cycles per year compared to the regional counterpart, so the battery **depreciates more slowly**.

2 **Infrastructure capex** – the city delivery duty cycle requires only overnight 22 kW depot charging. The large amount of time spent in the depot allows managed charging to reduce the grid connection capacity and grid connection costs. Regional deliveries require 43 kW charging both overnight and between shifts, with less potential for managed charging. Infrastructure costs can be reduced below those shown here if overnight charges can also be used between shifts – this depends on depot layout.

3 **Fuel cost savings** – the **stop-start nature of city driving means that very large amounts of energy can be recovered by regenerative braking**. This means that the fuel cost savings over diesel, per km driven, are significantly higher for battery electric vehicles in city driving than rural driving. The effect is compounded by the fact that electric motors are very efficient at all speeds, whereas diesel engines are very inefficient at low speeds and hence perform poorly for urban drive cycles.

Annual TCO comparison in 2025 for city and regional delivery[1]



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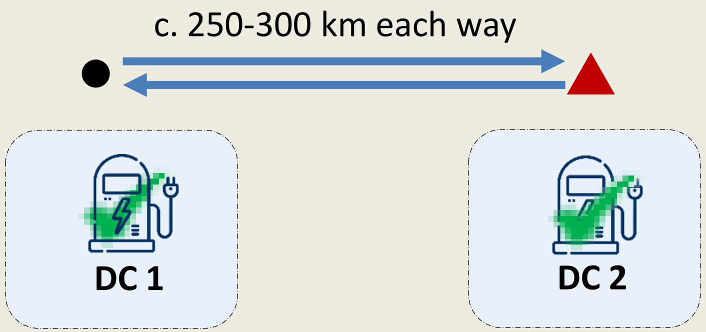
[1] –duty cycles shown on previous slide

Contents

Double deckers performing DC-DC trunking will require a rapid top-up charge in the short term, but improvements in battery energy density will change this, reducing TCO

Duty cycle and charging opportunities overview

Journey profile and charging opportunities

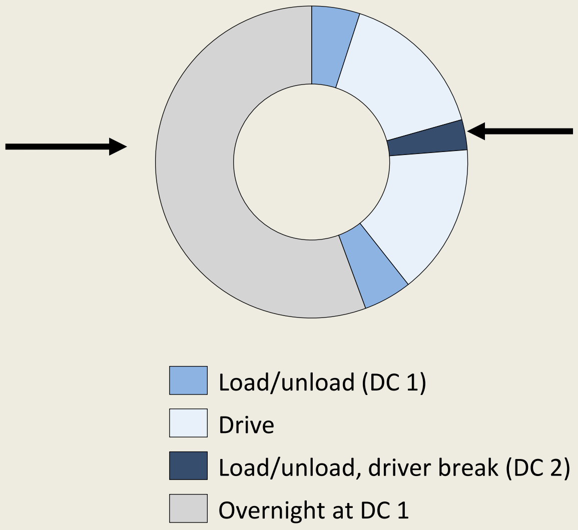


- One long 500-600 km round trip or two shorter trips
- 44t weighted out double decker
- Driving mostly along motorways
- c. 7-year ownership period for diesel

Key ● **DC 1** ▲ **DC 2**

Time spent during the day

Overnight charge at DC 1



Chance to rapid charge for c. 45 minutes while trailer is unloaded and driver has break at DC 2 – need in 2025, but not in 2035 due to increased vehicle range

- Vehicle weighted out – increased weight allowance needed to allow for extra weight of battery electric powertrain

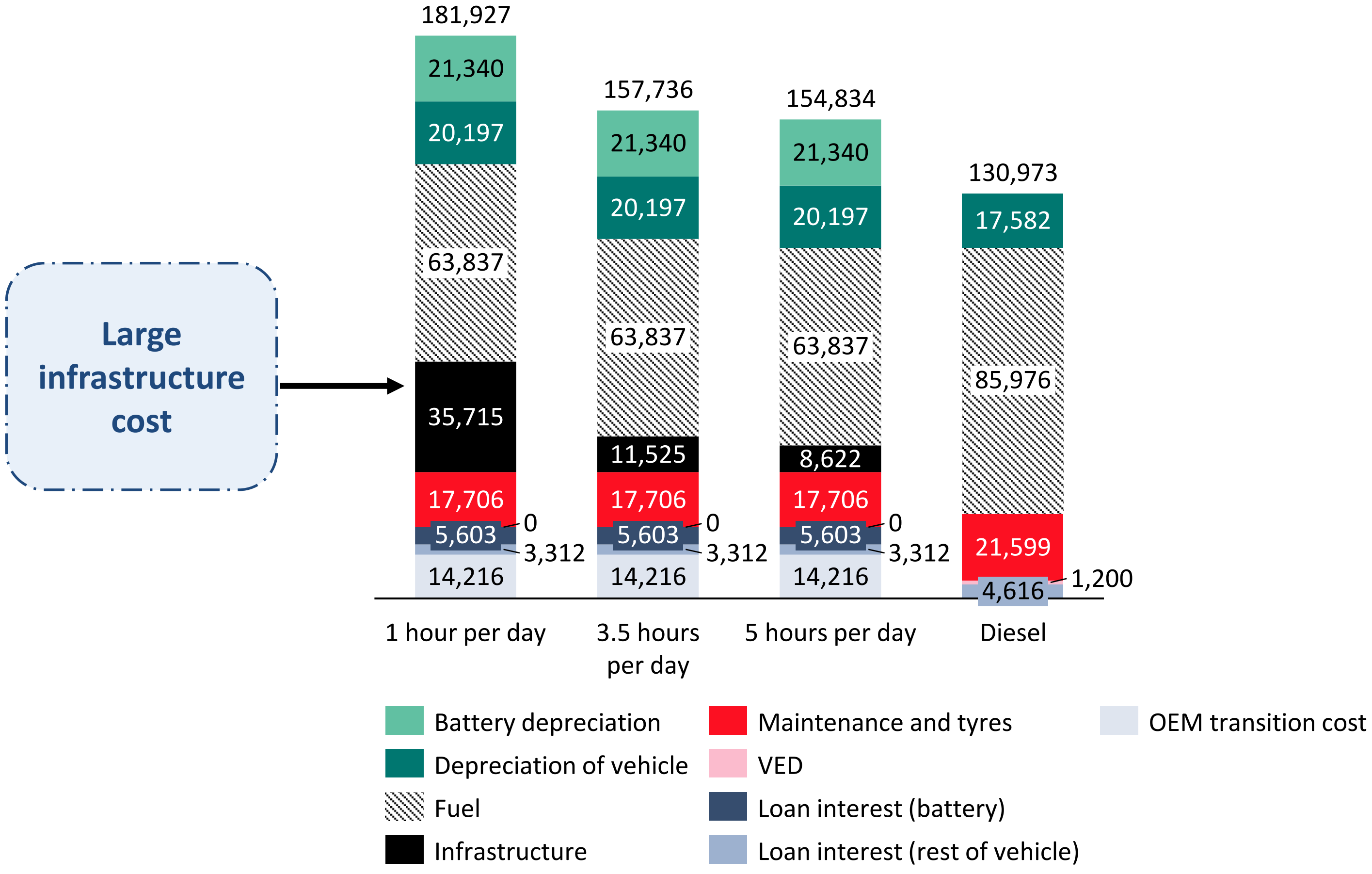
Further discussion related to this on the following slide

DC – Distribution Centre

Sharing of rapid chargers at warehouses can make BEVs cost competitive with diesel several years earlier – and is an important enabler of electrification

- Artics performing DC-DC trunking operations, such as the example shown on this slide , will in many cases require **rapid charger top-ups** while unloading during the middle of a shift.
- As shown in the diagram on the right, if this rapid charger is only used for one hour per day it represents a **major TCO component** and the infrastructure cost delays the TCO break-even date
- The diagram on the right shows how **sharing warehouse charging infrastructure** between many fleets can **bring forward the date at which BEVs become cost competitive** with diesel by several years

2025 annual TCO components for artic double decker trunking, for different warehouse charger utilisation rates (hours per day)



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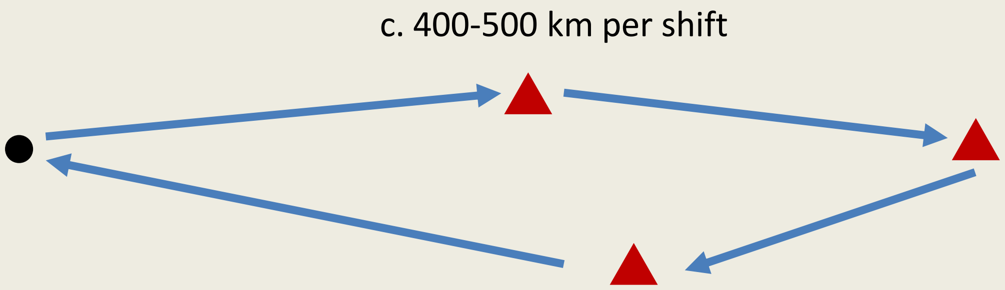
Some charging at warehouses will be needed to enable electrification of 24/7 primary haulage

Duty cycle and charging opportunities overview for 24/7 primary haulage

Journey profile and charging opportunities



- **Two separate driver shifts per 24 hour period, both starting from the same depot**
- **Each shift 3-5 pick-up/drop offs**
- **3 year vehicle life**
- **Opportunity to charge for around 20-25 minutes at each warehouse**
- **Driver break mid shift – it is assumed that public charging is not available**
- **Shifts are staggered, allowing 2 vehicles so share the same rapid chargers for charging between shifts, reducing infrastructure costs**

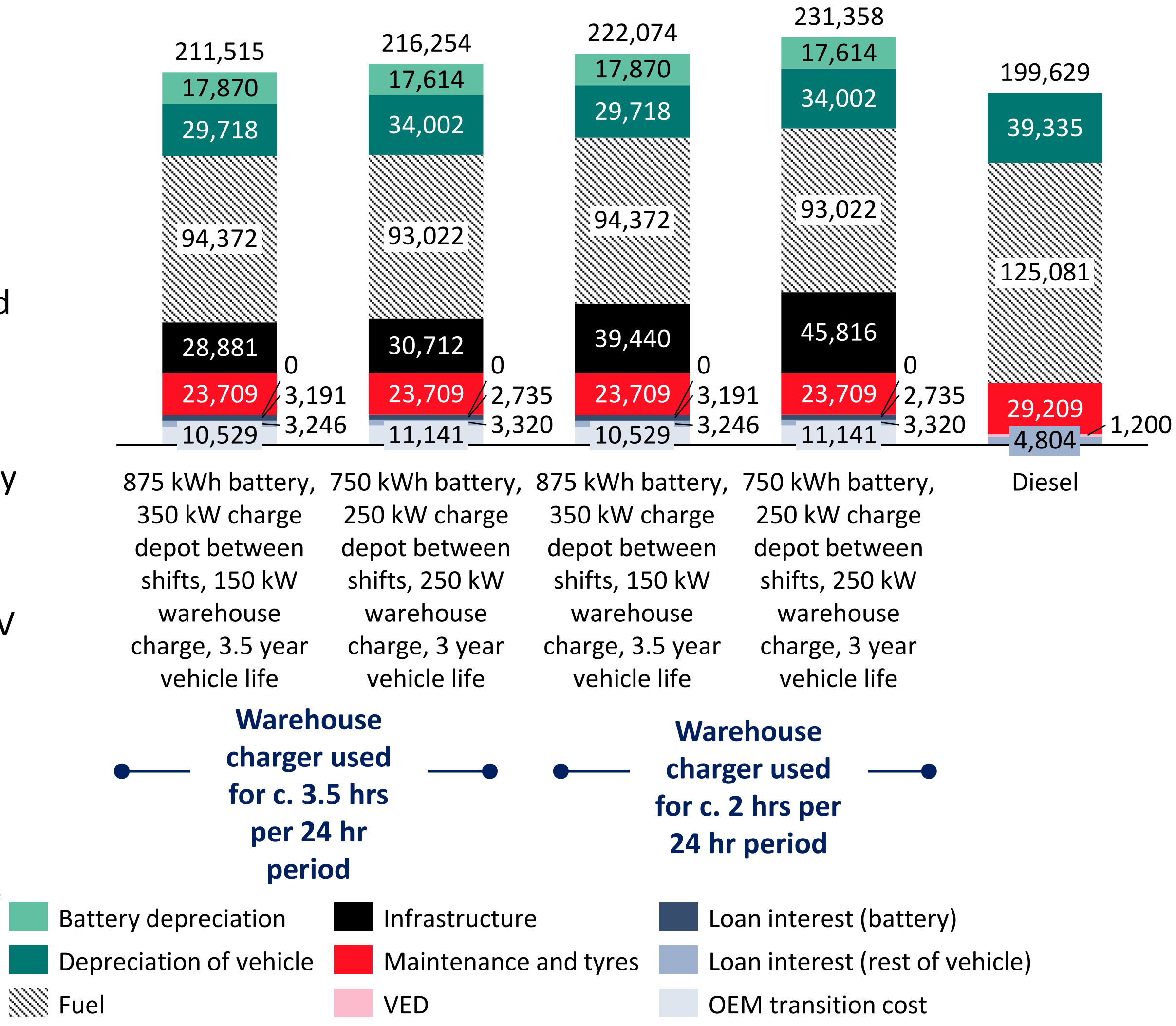
Key ● **Depot** ▲ **3rd party warehouse/factory/DC**

DC – Distribution Centre

Primary haulage requires opportunity charging at warehouses – and even with conservative assumptions (such as no aero improvements) is close to diesel parity in 2030

- Primary haulage operations require **opportunity charging at warehouses** that the vehicle visits, either while **waiting to go onto a loading bay**, or while the trailer is being **loaded or unloaded**.
- It is conservatively assumed that there is a **25 minute charging opportunity** at each warehouse – in reality this is likely to be the minimum amount of time available to charge.
- Warehouse charging continues to be needed even as vehicle range capabilities improve (owing to improvements in battery energy per unit volume and hence the amount of energy that can be stored on the vehicle). However, from around 2030, the limiting factor will likely be the mass of the battery rather than the battery packaging. Even though very long range vehicles will be possible, operators may prefer slightly shorter range vehicles with lighter batteries and hence improved payload. For this reason, it is assumed that the battery capacity for this duty cycle will not increase beyond around 875 kWh, even after 2030.
- The results on the right show that:
  - **Maximising infrastructure utilisation** at warehouses is key to reducing BEV TCO, so sharing of warehouse charging infrastructure brings strong commercial advantages for BEVs.
  - 350 kW charging between shifts, supplemented by 150 kW charging at warehouses, is likely to be the cost optimal infrastructure solution for this duty cycle, and strategically places the higher cost, higher power infrastructure where it can be immediately utilised well (in depot) and the lower power, lower cost infrastructure at warehouses where there is a higher risk of lower utilisation.

Annual TCO in £, 2030, for various charging options



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BEVs will reach cost parity with diesel for rigid vehicle regional deliveries during the 2020s – even if battery price reductions are heavily delayed

Rigid regional duty cycle used for the purposes of these sensitivities

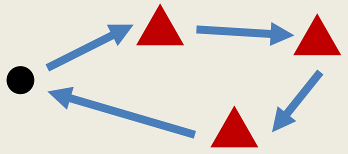
Journey profile and charging opportunities

c. **200-250 km** per shift; **1-2 shifts per day (max 400 km per day)**

2-3 drops per shift in 2-3 urban areas

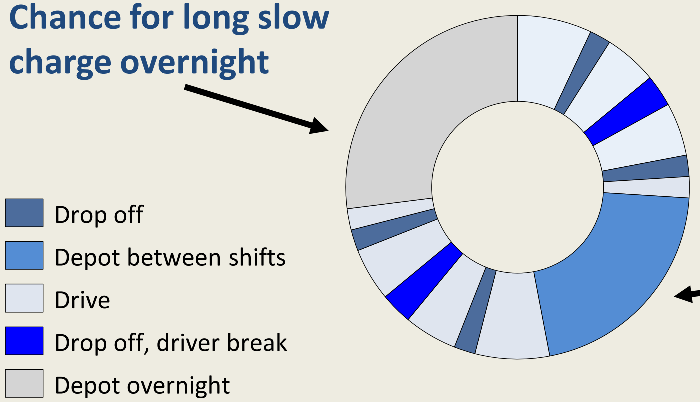
Rural A/B road driving between towns

Depot



Time spent during the day

Chance for long slow charge overnight



Chance to charge for c. 5 hours between shifts

Key ● **Depot** ▲ **Shop/site of delivery/loading/unloading**

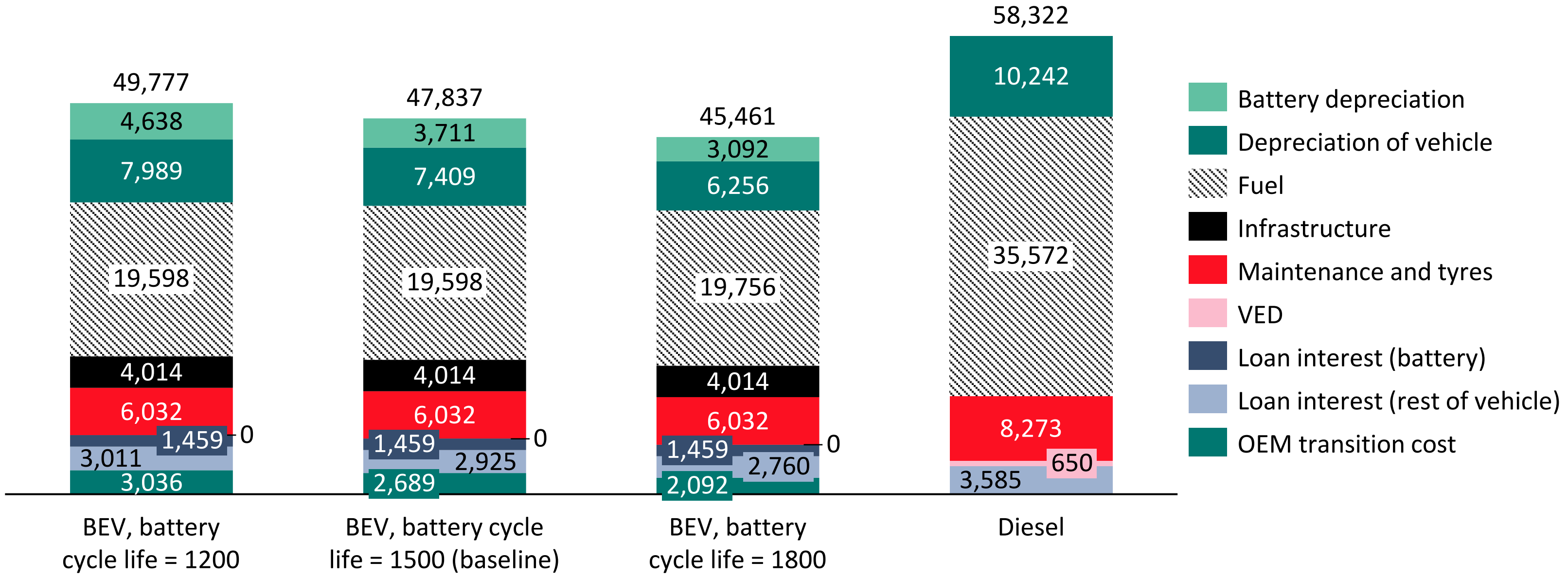
18t rigid vehicle, 5 year lifetime diesel, 7 year lifetime BEV
350 kWh battery, 43 kW charge both overnight and between shifts

Key sensitivities may be found on following slides:

- Battery lifetime
- Diesel vehicle ownership period

Further improvements in battery cycle life by 2030 are likely to allow increased vehicle lifetime and drive further TCO reductions

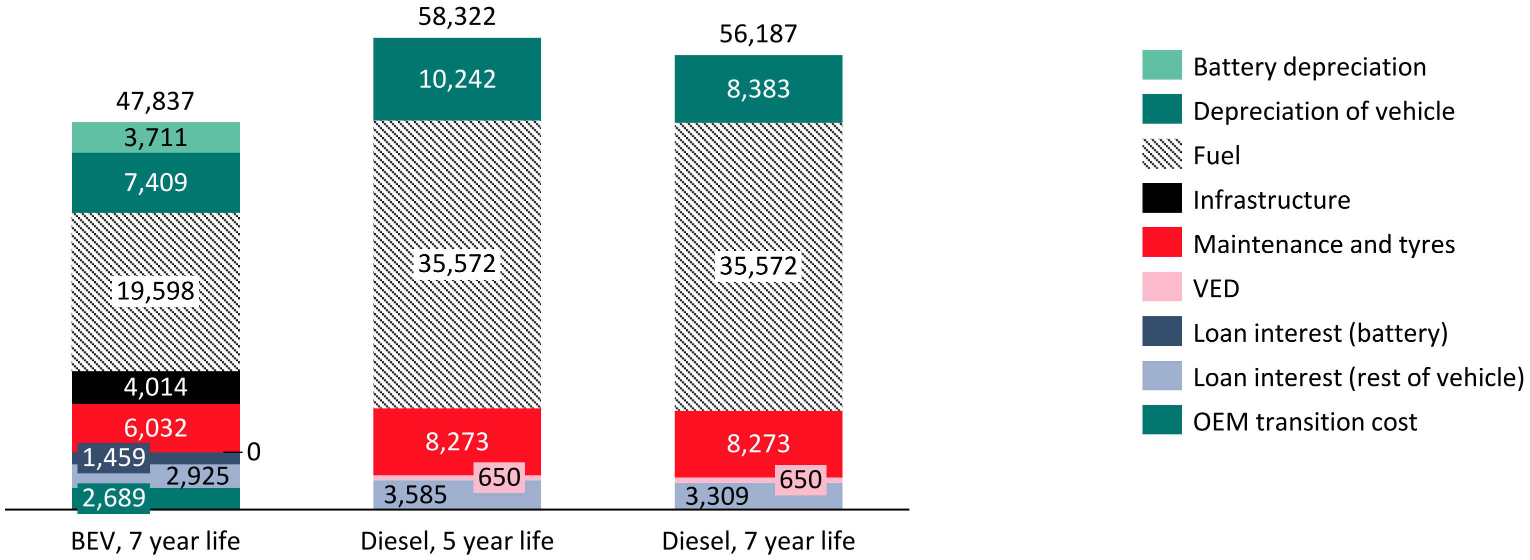
Annual BEV TCO compared to diesel, 2030, for different battery cycle lives – rigid regional deliveries



As a conservative baseline, battery cycle life in 2030 is taken as the same as today – 1500 cycles. It is assumed that the vehicle will be kept for one battery life. For the baseline cycle life, this allows the vehicle to be kept for over 7 years. If – as is likely – battery cycle life improves to around 1800 by 2030, the vehicles could be kept in operation for 9 years, with decreased annual TCO. Even if intensive use results in battery cycle life decreasing to 1200 cycles, this only slightly increases the annual TCO, which remains below that of diesel.

Even if (hypothetically) diesel maintenance costs do not increase after the 5th year, the annual TCO is only slightly improved by a 7 year as opposed to 5 year diesel vehicle life

Annual BEV TCO compared to diesel, 2030, for different vehicle lives[1]



The BEV/diesel annual TCO comparison is insensitive to the exact life assumed for the diesel vehicle. This is because most of the diesel vehicle costs are OPEX and hence don't change with vehicle life, whereas BEVs have high capex, and hence the reduced annual depreciation from increased vehicle life does have a significant impact on annual costs.

1 – BEIS 2020 central electricity and diesel price scenarios

Contents

The mass and volume of batteries create implications for vehicle payload and length which require policy amendments to prevent BEVs being disadvantaged

Key considerations

Payload

The large mass of the batteries can cause combinations of **axle loadings, tractor unit gross vehicle masses and whole vehicle gross vehicle mass** limits to be exceeded.

Some 44t artic use cases **weigh out routinely** – such as double decker trunking and agricultural haulage (milk, potatoes, grain), while others **require the flexibility to run up to 44t when the need arises** – such as in general haulage, where loads are unpredictable.

32t rigids carrying products including construction waste, sand, gravel and concrete frequently weigh out.

Vehicle length

The **current tractor units most commonly used for diesel 44t vehicles do not have sufficient space available for batteries – longer tractor units will be needed**, increasing vehicle length.

Existing legislation

Existing legislation[1] allows a **Gross Vehicle Mass increase of 1t for the two axle (18t diesel) and three axle (26t diesel) rigid vehicles with low carbon powertrains**.

However, this **does not extend to the 32t rigid and 44t artic categories** which weight out far more frequently than the smaller rigids, which typically cube out.

Policy recommendations to address these crucial issues are made on the following slides

(1) https://www.legislation.gov.uk/uksi/2017/881/pdfs/uksiem_20170881_en.pdf

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Key assumptions: battery performance

Key assumptions

Cathode	Anode	Depth of discharge	C-rates	Cycle life with 80% capacity retention
Nickel Oxides e.g. NMC variants, NCA	**Graphite**	20% - 85%; **but see note below**	0.8 (20% - 72% SOC); 0.4 (72% - 85% SOC)	1500

Residual values	All batteries are assumed to have a residual value of 15%[2] of the initial capex at the end of their first life (once capacity has faded to 80% of its initial value)
Usable state of charge	**To allow for battery degradation, the vehicle is assumed to only be able to use 80% of its usable state of charge to allow for this capacity reduction, except on worst case days**

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1 – this will vary between min and max SOC so is an approximation for the purposes of our modelling; 2 - https://theicct.org/publication/total-cost-of-ownership-for-tractor-trailers-in-europe-battery-electric-versus-diesel/