


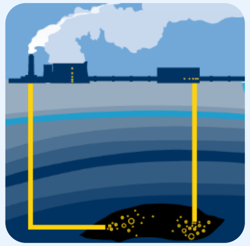



Why Great Britain’s long-distance, heavy-duty HGVs can go battery electric – and what needs to be done to achieve this

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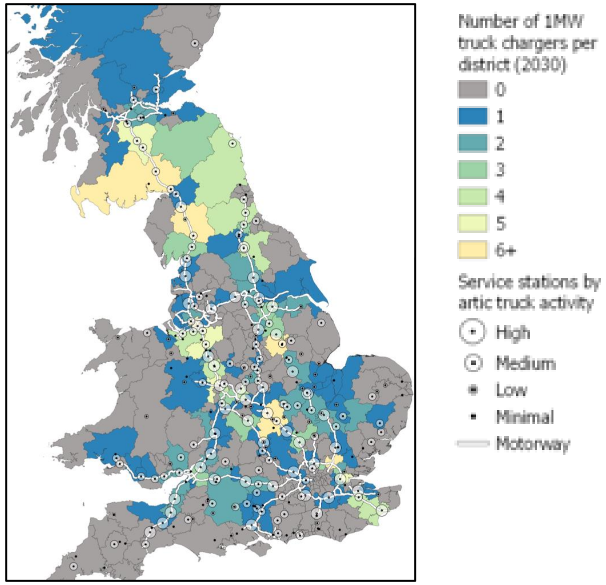
elementenergy
an ERM Group company

William Drake (will.drake@element-energy.co.uk)
Timothy Howgego (timothy.howgego@element-energy.co.uk)
Richard Riley (Richard.Riley@element-energy.co.uk)
Robert Pearce-Higgins (Robert.Pearce-Higgins@element-energy.co.uk)
Celine Cluzel (celine.cluzel@element-energy.co.uk)

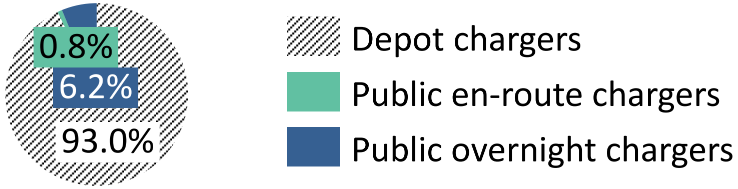
Executive summary

- **Great Britain's long-distance, heavy-duty 44 tonne HGVs will be able to perform their operations using battery electric vehicles with technology available from 2024.**
- **Battery electric HGVs will become cost competitive with diesel equivalents for many 44 tonne long-distance, heavy duty use cases around 2030, with payload and downtime taken into account.**
- **Most charging will occur at depot (including for 44 tonne HGVs), making the "chicken and egg problem" much smaller than for other zero emission technologies, but a public charging network will be needed to support long-distance, heavy-duty operations.**
  - Depot chargers will charge vehicles overnight, with high power depot chargers for vehicles that require rapid charging between shifts.
  - Public *en-route* charging will provide top-ups for vehicles in longer trips – a mixture of 350 kW and 1 MW chargers will be needed for different applications and the geographical distributions of these two charger powers will be different.
  - Public overnight chargers will serve tramping and international long-haul vehicles.
- **A simple set of policy measures could enable battery electric HGVs to significantly reduce emissions from long-distance, heavy-duty trucking by 2030.**

2030 network of 1 MW chargers required to support GB long-distance, heavy duty battery electric HGVs



Split of number of chargers required by type to electrify HGVs in GB



This report is the second in a series of two reports – the first report focussed on HGVs that could convert to battery electric with home depot charging only and this second report looks at HGVs that will need a public charging network to electrify, with a focus on 44 tonne long-haul heavy-duty

Summary of this report

- **Introduction.** This sets out the context and background of the work.
- **Chapter I: key opportunities for policy to accelerate adoption of battery electric HGVs for long-distance, heavy-duty operations.** This chapter sets out how a simple set of policies could greatly accelerate adoption of battery electric HGVs, including areas where government could support the provision of an initial national charging network.
- **Chapter II: why battery electric HGVs are an attractive option for long-distance, heavy-duty operations.** This chapter sets out how range and recharge time barriers will be tackled with vehicles arriving in series production in 2024. It also demonstrates how the lower fuel costs of battery electric HGVs allow the vehicles to become cost-competitive with diesel equivalents. All of the total cost of ownership analysis presented includes the effects of any payload losses and downtime for charging, using an approach presented in the chapter.
- **Chapter III: what infrastructure is needed.** This chapter presents a detailed analysis of the national static charging infrastructure needed to electrify GB's HGV fleet.
- **Appendix.** Further details on assumptions.

Note: this report only covers static charging and battery electric HGVs. It does not cover the Electric Road System or hydrogen. It does not assert that battery electric HGVs with static chargers are the only solution for long distance heavy duty, but the study results have indicated that this provides a cost effective and scalable solution for decarbonising GB's long-distance, heavy-duty HGVs.

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This work assesses the barriers and opportunities for decarbonisation of GB's HGVs using battery electric vehicles with static chargers and is the second of two reports

Aims and objectives of the work

1. Analyse GB HGV operations to determine the associated **infrastructure requirements for electrification**, accounting for the **major variations in infrastructure requirements between different HGV duty cycles**.

2. Determine the **total cost of ownership (including infrastructure) for battery electric** vehicles relative to diesel across the spectrum of HGV duty cycles, and the associated **policy implications**.

Structure of the work

1. **This is the second of two reports**.

2. The **first (previous) report** sets out the opportunity for early electrification of HGVs that **do not need to wait for a public charging network** to be in place. Through in-depth analysis of a wide variety of HGV duty cycles based on discussions with fleet operators, the first report showed how **battery electric rigid HGVs are on the cusp of cost competitiveness for city and regional deliveries** and how many HGV operations can be electrified using home depot charging only. The report also highlighted key areas where policy could assist fleet operators in taking full advantage of this early decarbonisation opportunity.

3. **This second report assesses the infrastructure requirements for electrification GB's HGV fleet**, and the **total cost of ownership for HGV use cases that require public charging infrastructure in order to electrify**. The work focuses on the long-distance heavy-duty 44 tonne use cases since these operations account for half of all GB HGV emissions and most of the public charging infrastructure requirement.

This report focuses on long-distance, heavy-duty HGV use cases that can be electrified with a public charging network

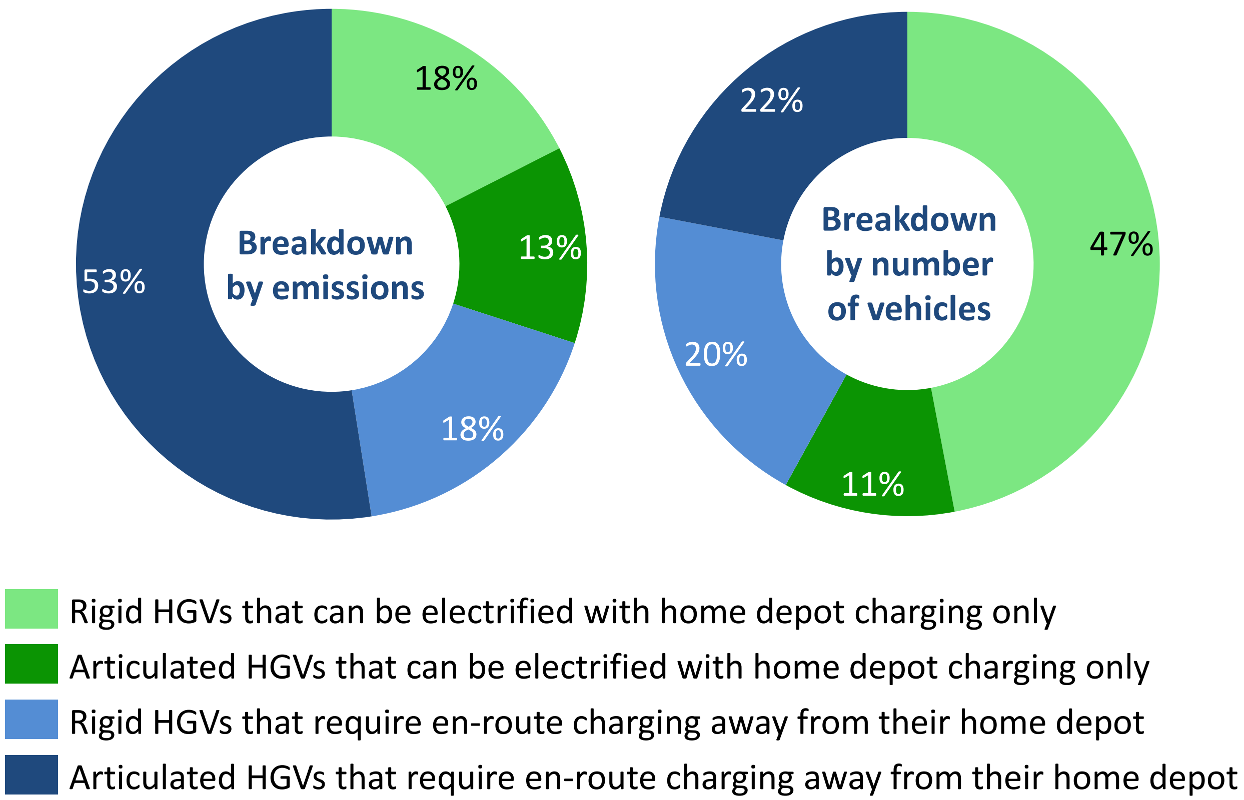
The early opportunity for HGVs that can charge entirely in their home depot

Roughly half of HGVs and one third of HGV emissions are from vehicles that can be electrified using BEVs available today (rigids) and in 2024 (artics) and *no public charging infrastructure* – these use cases were the focus of the previous report.

The need for a nationwide public charging network

Roughly half of HGVs and two thirds of HGV emissions are from vehicles that require charging outside their home depot in order to complete longer trips.

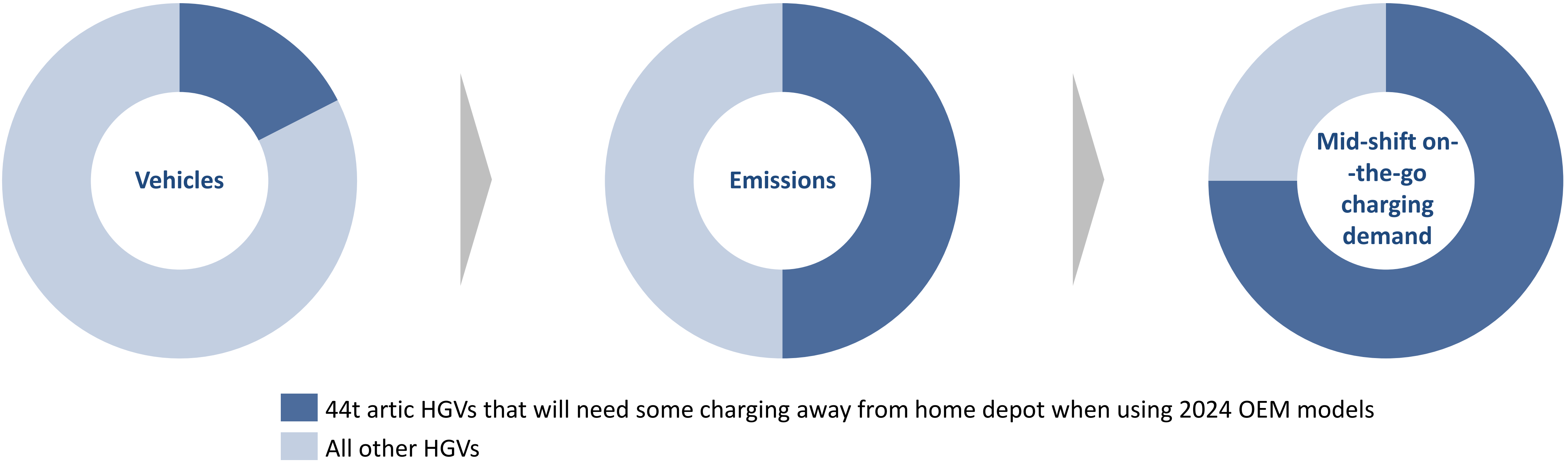
Breakdown of the GB HGV fleet by out-of-depot charging need



This report focusses on HGV use cases that require public charging infrastructure – a sector dominated by 44 tonne long distance HGVs

Public charging requirement – and emissions – are both dominated by long haul 44 tonne articulated HGVs

- **44 tonne long distance, heavy duty vehicles (i.e., those that will require some charging away from their home depot) account for just 20% of GB's HGVs, but are the hardest use cases to electrify and will define where public charging infrastructure is placed.**
  - As shown below, 44 tonne long distance, heavy duty vehicles account for around half of GB's domestic HGV emissions[1]
  - The vehicles are additionally expected to account for around three-quarters of the public charging demand from GB domestic HGVs[1]
  - These vehicles are therefore the focus of the analysis in this report



1 – Element Energy analysis based on DfT CSRGT data

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Opportunities exist in several areas for policy to accelerate electrification of HGVs in Great Britain and are explained in detail in this chapter

Summary of this chapter

- **Two small changes to the Road Vehicle Construction & Use and Authorised Weight Regulations could significantly accelerate decarbonisation of GB's long-distance heavy-duty HGVs.** A one-metre increase in allowed vehicle length and two-tonne increase in allowed gross vehicle weight would allow operators to switch from the heaviest 44 tonne diesel HGVs to 44 + 2 tonne battery electric HGVs without loss of payload deterring adoption.
- **Infrastructure.** There are several actions outlined in this chapter that could be taken by government to help ensure that initial infrastructure is in place to enable long-distance heavy-duty vehicle operation.
- **The phase out date for the sale of new, non zero emission HGVs could be brought forward to 2035 for all HGVs, not just those up to 26 tonne gross vehicle weight.** By 2035, HGVs capable of long-distance, heavy-duty operation will have been in series production from multiple OEMs for 10 years. Setting a 2035 phase out date for all non zero emissions HGVs would increase adoption during the 2020s by giving infrastructure providers the confidence to invest with demand guaranteed over an investable timeframe. This target is broadly in line with OEM plans, since most OEMs have announced sales targets for at least 50% of their vehicle sales to be zero emission 2030, which – given the exponential ramp-up in sales associated with the transition – implies close to 100% of sales in 2035 in any case.
- **A malus-funded incentive scheme could be revenue-neutral to the treasury and greatly accelerate zero emission HGV adoption.** A small additional purchase tax on diesel vehicles could be used to provide a purchase subsidy for BEVs, which could be phased out by the early 2030s as BEVs reach TCO parity with diesel across all use cases. A similar scheme has already been implemented in France.

Structure of this chapter

- This chapter begins by highlighting the changes to the Road Vehicle Construction and Use Regulations and Authorised Weight Regulations that would accelerate BEV adoption, and follows this by quantifying the economic benefits that this would bring across the 44 tonne vehicle parc.
- This is followed by a description of actions the government could take to support infrastructure roll-out.
- The chapter finishes by considering financial support and phase-out dates.

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Two small changes to the Road Vehicle Construction & Use and Authorised Weight Regulations could significantly accelerate decarbonisation of GB's long-distance heavy-duty HGVs

- **A one metre extension of vehicle length limits would have a transformative impact on BEV adoption for the largest HGVs.**
  - The tractor units for 6x2 / 6x4 battery electric articulated HGVs will need to be around one metre longer than the diesel equivalents that they are replacing, in order 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.
  - Longer Semi Trailers are now in operation. A similar overall length derogation could be made for battery electric HGVs, allowing 6x2 / 6x4 battery electric HGVs to run on GB roads with standard trailers.
- **Allowing two tonnes of additional weight allowance for 44 tonne battery electric HGVs would improve the total cost of ownership for operators on duty cycles that are frequently weight constrained.**
  - The weight limit for zero emission 6x2 / 6x4 articulated HGVs could be increased. Increases in 44 tonne articulated HGV Gross Vehicle Weight to 48 tonnes are already being trialled for transport from rail terminals[2] and this could be extended to battery electric HGVs. A smaller increase of two tonnes would also be highly beneficial, as shown on the following slide.
  - It is important to note that, this would only increase the weight that vehicles would run at on weight constrained trips. Since these trips only form a small proportion of 44 tonne HGV trips, the increase in road wear and tear would be correspondingly much smaller than if all trips were weight-constrained (only around 10% of 44 tonne HGVs operate continuously at their maximum weight limit; see appendix). **The costs associated with the road wear and tear from allowing an extra two tonnes on the vehicle weight should be weighed up against the costs of delayed fleet decarbonisation.**

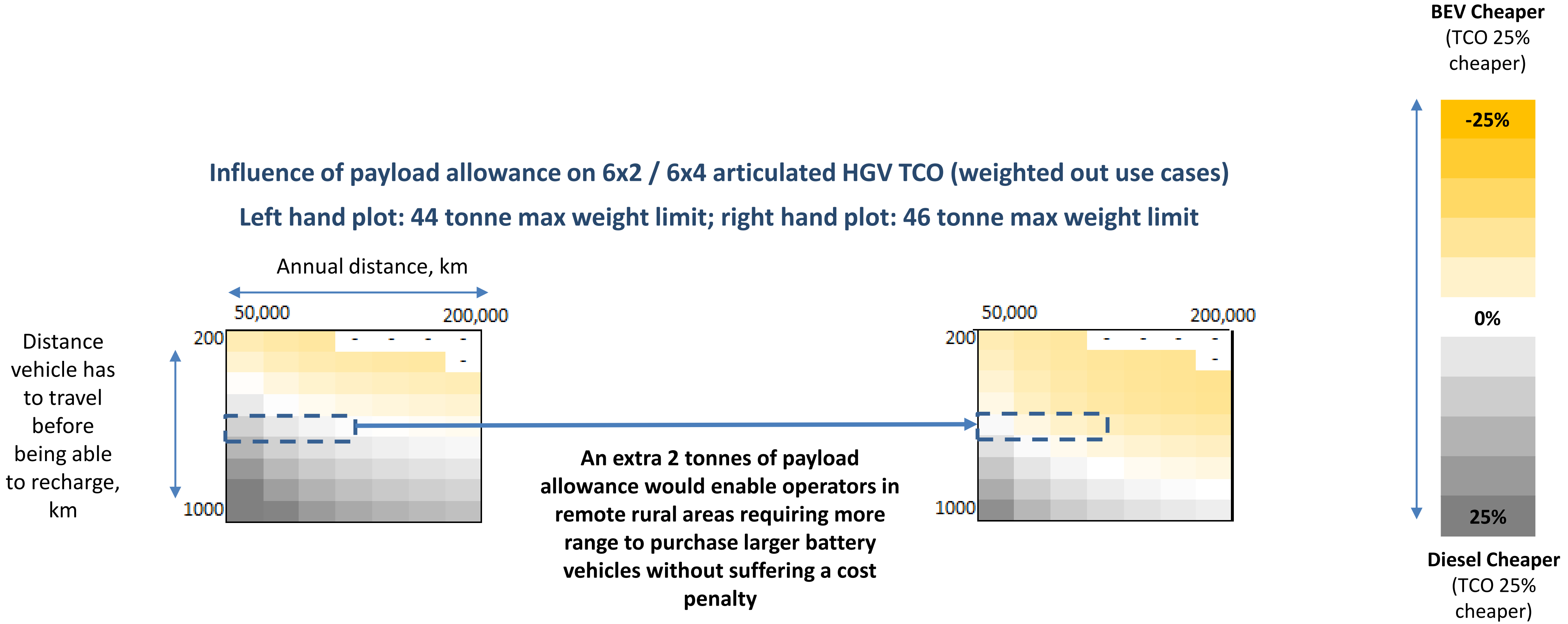
(1) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/933259/impact-assessment-longer-semi-trailer-trial.pdf (2) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/933312/48-Tonne-Intermodal-Freight-Trial-Impact-Assessment.pdf

An additional weight allowance would allow operators of HGVs in remote, rural areas with limited infrastructure to choose a longer range, larger battery BEV without payload loss

- Remote areas of Great Britain will not initially have sufficient demand to drive installation of public chargers, so operators in these areas will need longer range, larger batter vehicles to achieve the necessary operational flexibility. Additional weight allowance would be needed to enable these operators to transition to BEV without significant payload loss. As shown below, this would be particularly impactful in assisting SMEs – whose vehicles typically have modest annual mileages compared to larger operators, and hence smaller fuel cost savings from BEV operation – in transitioning to BEV.

Influence of payload allowance on 6x2 / 6x4 articulated HGV TCO (weighted out use cases)

Left hand plot: 44 tonne max weight limit; right hand plot: 46 tonne max weight limit



Several actions could be taken by policymakers to support the roll-out of infrastructure for battery electric HGVs (1/3)

- **Installation of HGV charging infrastructure at MSAs and truck stops.**
  - DfT are currently working with motorway service area operators to get at least 6 rapid charge points for cars/vans in all MSAs by 2023, with the continued electrification of MSAs supported by the Rapid Charging Fund. Similar efforts should be made to support infrastructure for HGVs.
  - As shown in chapter III of this report, **a base network of 2 x 1 MW chargers at each Motorway Service Area** would provide basic national coverage and meet most of the MW charging requirement for battery electric HGVs in 2030 (some gaps would still exist and would need to be covered after a review of national freight movements relative to the MSA locations).
- **The provision of low or zero interest loans towards installation of public charging infrastructure, with repayment rate dependent on utilisation, may help incentivise private sector investment by improving the risk-return profile.**
  - Public charging infrastructure will generally have low utilisation in the early years, with utilisation and revenues increasing dramatically over the lifetime of the infrastructure as vehicle uptake increases.
  - If private sector balance sheet investment could be leveraged against a zero/low interest loan from government, this would improve the internal rate of return during early years of low utilisation, and – if repayment rate were dependent on revenues and utilisation – help reduce the level of risk to the private investor caused by uncertainty over utilisation ramp-up rate over the later years of the infrastructure.
  - These factors would improve the risk-return profile of early stage private sector investments and hence stimulate investment.

Several actions could be taken by policymakers to support the roll-out of infrastructure for battery electric HGVs (2/3)

- **Introduce a zero emission vehicle mandate for 100% of sales (across all weight categories) in 2035, and separate 2030 intermediate targets for vehicles up to and above 26 tonnes gross vehicle weight.**
  - This may appear not be to an infrastructure policy recommendation, but in fact it is hugely important for driving investment into infrastructure.
  - This is because a fixed end point for diesel vehicle sales, along with intermediate targets for zero emission sales percentages, give investors in public charging infrastructure greatly increased certainty around the ramp up of demand and revenue that this infrastructure will achieve. This encourages investment in the public charging network and helps ensure the infrastructure is in place early on, smoothing the transition and increasing BEV uptake in the 2020s.
  - The clear definition between vehicles below and above 26 tonnes gross vehicle weight is important, because, as shown in the introduction to this report, demand for public charging infrastructure will arise almost entirely from the largest vehicles. Hence, certainty around the numbers of larger BEVs (above 26 tonnes gross vehicle weight) is the factor that provides certainty around public infrastructure utilisation for investors.
  - An aggregated target for all HGVs in 2030 does not provide this same confidence, since it would not give certainty around the split between rigids (which account for only a small proportion of public infrastructure use) and articulated HGVs (which account for the vast majority of public infrastructure use).
  - An identical 2035 target has already been proposed by a large industry coalition including Milence (a joint venture between Daimler, TRATON and Volvo), demonstrating that industry can deliver and support this target.

1 - https://milence.com/news/milence-joins-broad-business-coalition-in-calling-for-2035-zero-emissions-target/

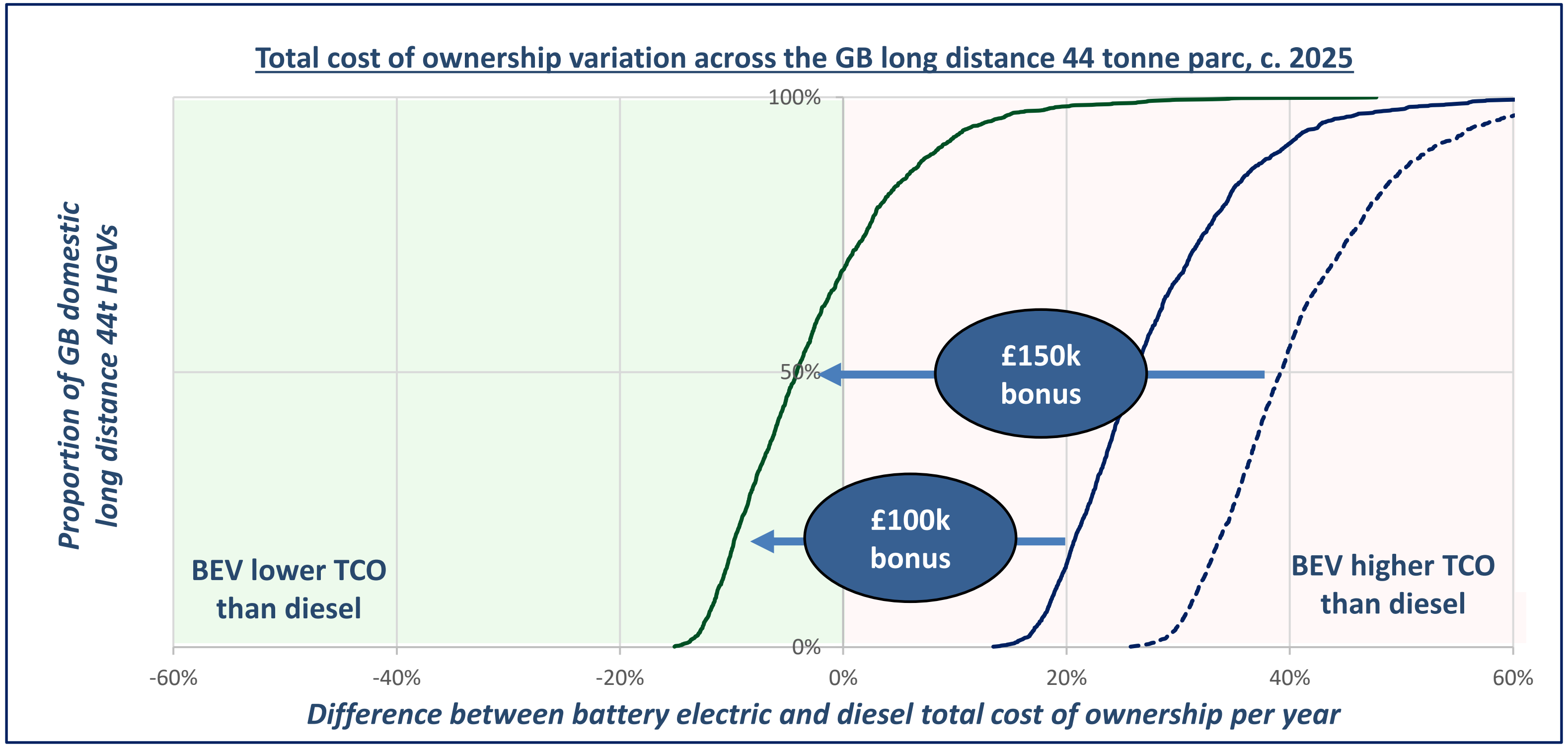
Several actions could be taken by policymakers to support the roll-out of infrastructure for battery electric HGVs (3/3)

- **Extending the Rapid Charging Fund to cover major warehousing areas would significantly enable BEV adoption.**
  - As shown in chapter III, there are concentrated demands for HGV charging in major warehousing areas, resulting from both depot charging and *en-route* charging.
  - The presence of depot charging as well as *en-route* charging in major warehousing areas will make peak power demands in some warehousing areas similar or greater than that of many MSAs, and, because of the large amount of depot charging, the ramp-up will be faster.
  - Provision of direct transmission connections to warehouses with very high concentrations of truck charging may circumvent issues caused locally by distribution level grid capacity and has precedent for other major EV charging projects in urban areas[1].
- **Policies that incentivise multiple stakeholders and landowners in warehousing areas to install infrastructure could help overcome issues caused by low land availability in warehousing areas.**
  - The installation of charging infrastructure in warehousing areas could be supported by a tax incentive scheme, whereby landowners and warehouse owners receive tax deductions for allowing publicly accessible charging infrastructure to be installed on their land. For example, they could be allowed to deduct the capital cost of the new infrastructure from their profit before tax.
- **Planning rules could be adjusted to both incentivise charge point installation and remove barriers to installation.**
  - If planning permission for new developments in warehousing areas were dependent on the developer installing publicly accessible HGV charging infrastructure, this would help provide some initial infrastructure coverage in fast-growing warehousing areas.
  - A review of planning and land rights barriers to charge point roll-out and a telecoms-style approach to removing these barriers would help ensure timely national roll-out of infrastructure[2].

1 - https://energysuperhuboxford.org/about-the-project/ 2- https://researchbriefings.files.parliament.uk/documents/CBP-9156/CBP-9156.pdf

A bonus-malus scheme for supporting the purchase of battery electric long haul HGVs could greatly accelerate BEV adoption in a way that is revenue neutral to the treasury

- **In a bonus-malus scheme, BEV purchase subsidies are funded by a small tax on new diesel vehicle purchases**
  - For example, if BEV sales are 2% and diesel sales are 98%, a £100,000 BEV purchase subsidy (bonus) can be funded by a malus tax of £2040 (c. 2% of purchase price) on each new vehicle purchased. Such schemes have been successfully implemented elsewhere (e.g. France) and can be phased out gradually over c. 5 years as BEV total cost of ownership falls.
  - The graph below shows the impact of a bonus-malus scheme applied in 2025 and demonstrates how a malus-funded bonus of £100,000 to £150,000 could allow BEV long distance 44 tonne operations to be cost competitive with diesel in 2025. Given the revenue neutrality to the treasury of the scheme, we suggest that a £150,000 bonus (with reductions as BEV costs fall) would be appropriate to drive BEV adoption in all scenarios.



Relative total cost of ownership without policy support and central battery price scenario (blue solid line) – this illustrates the relative total cost of ownership with the BEIS central commercial electricity and diesel price projections (ex VAT) as of March 2023, combined with the central battery price scenarios and other assumptions discussed in the appendix.

Relative total cost of ownership without policy support and high battery price scenario (blue dashed line) – as above, but with the high battery price scenario.

Relative total cost of ownership with bonus-malus scheme applied (green solid line) – this shows the impact of a £100k to £150k bonus (depending on battery price scenario).

Payload and downtime are both accounted for and discussed further in the following chapter on TCO.

The TCO is discussed in more detail in the following chapter.

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Why battery electric HGVs are an attractive option for decarbonising long distance, heavy duty operations 1: Range and recharge time barriers will be tackled with technology arriving in 2024

Summary of this chapter (1/4)

- **2024 OEM series production models will allow long haul range and recharge time requirements to be met with battery electric vehicles. –**
  - 2024 OEM models will have the capability to drive for 4.5 hours at full load, which is the furthest a driver is legally allowed to travel before taking a break, and then recharge fully using MW charging during mandatory driver 45-minute breaks.
  - This allows completion of long-haul operations while recharging entirely during existing downtime.
- **Most driver shifts include time spent picking up and dropping off goods, reducing distance travelled during the shift (and hence en-route charging requirements) while also often providing additional downtime for charging.**
  - 9 hours of non-stop motorway driving with only one 45-minute break in the middle represents the most demanding driver shift in terms of range and recharging time requirements.
  - However, time spent loading and unloading, combined with Great Britain's geography, mean that well over 90% of articulated HGV driver shifts do not involve two consecutive periods of 4.5 hours of non-stop motorway driving separated by just 45 minutes of downtime[1] – instead the vehicles drive shorter distances, often with more downtime.
  - This both provides more opportunities for vehicles to charge and reduces the amount of *en-route* charging needed as the vehicles travel a shorter distance before returning to depot.

1 – Element Energy analysis based on DfT data

Why battery electric HGVs are an attractive option for decarbonising long distance, heavy duty operations 2: Payload and downtime losses are small and quantifiable

Summary of this chapter (2/4)

- **Even where the vehicle operation does feature some productivity loss owing to small amounts of additional downtime for charging, the costs are small compared to the fuel cost savings from battery electric vehicles.**
  - As described later in the chapter, additional downtime costs have been included for double shifted vehicles to account for the possibility that the vehicles sometimes perform back-to-back shifts with no time in between the first driver returning to depot and the second driver leaving, or that early-stage public charging infrastructure leads to some sub-optimal stopping locations.
  - The total cost of ownership results presented include the effects of some productivity loss due to charging downtime.
- **For most 44 tonne HGV operations, payload impacts of BEV will be small.**
  - Without additional weight allowance, 2024 long haul battery electric HGVs will have a payload around two tonnes lower than diesel equivalents.
  - However, our analysis reveals that around two-thirds[1] of Great Britain’s 44 tonne HGVs operate on volume-constrained or part-load operations where the vehicle never reaches its gross vehicle weight limit and hence a two-tonne payload loss would have no impact on the operation.
  - Just 10% of Great Britain’s 44 tonne HGVs frequently or always weigh out[1] (which we define as vehicles that would receive a 5% - 8% reduction in total tonne km carried with a two-tonne max payload loss).
  - As described later in this chapter, the effects of payload loss have been included in the total cost of ownership modelling and are small compared to the fuel cost difference between diesel and battery electric. An increase in gross vehicle weight allowance for 6x2 and 6x4 articulated BEVs would enable operators of weight-constrained vehicles to decarbonize earlier by improving the total cost of ownership.

1 – Element Energy analysis based on DfT data

Why battery electric HGVs are an attractive option for decarbonising long distance, heavy duty operations 3: Battery packaging constraints can be overcome

Summary of this chapter (3/4)

- **Battery packaging constraints can be alleviated through a combination of optimised vehicle choice and extension of existing policy**.
  - Around half of Great Britain's 44 tonne HGV operations could be run with 40 tonne 4x2 vehicles with no loss of payload[1].
  - This has significant implications for the switch to battery electric, because battery packaging constraints are less challenging for 4x2 battery electric HGVs.
  - With a small (circa one metre) increase in vehicle overall length limits, 6x2 battery electric HGVs would be able to run without compromise on battery size (and hence range).
  - Such an increase has already been applied to longer semi-trailers and could straightforwardly applied to BEVs while maintaining existing turning circle limits.
  - Further details may be found in the appendix.

1 – Element Energy analysis based on DfT data

Why battery electric HGVs are an attractive option for decarbonising long distance, heavy duty operations 4: Total cost of ownership will be competitive around 2030

Summary of this chapter (4/4)

- **Battery electric HGVs provide a technologically mature path to cost competitive long haul zero emission HGV operation**.
  - Battery electric long-haul HGVs will be available in series production in 2024, enabling them to make a significant contribution to reducing emissions before 2030.
  - Battery electric HGVs can be cost competitive (unsubsidized) by 2030 for many GB 44 tonne operations under most scenarios, as shown later.
  - Battery electric HGVs will not stop improving in 2024, and further packaging and energy density improvements will ease the path to adoption further.
  - Battery electric HGVs with static chargers have received uniquely strong support from OEMs, as demonstrated by the formation of Milence[1], a joint venture by TRATON, Daimler and Volvo whereby these OEMs are investing in the construction of Europe-wide charging network for long-haul operations. Combined with strong investment in BEV from all HGV OEMs in Europe we see many of the existing batteries to large, long-range BEV HGV being effectively tackled by industry in the short to medium term.

1 - https://milence.com/

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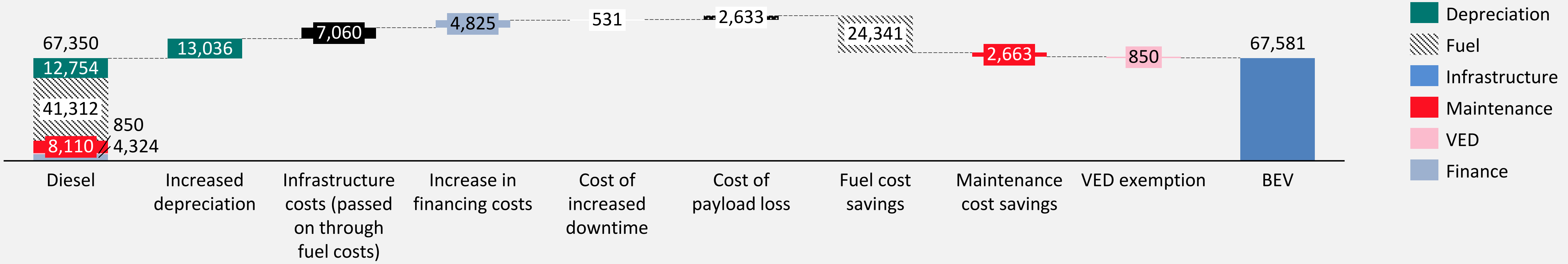
The study focuses on optimising the vehicle battery and infrastructure requirements and calculating total cost of ownership (TCO) for BEV and diesel. Key factors included are introduced below

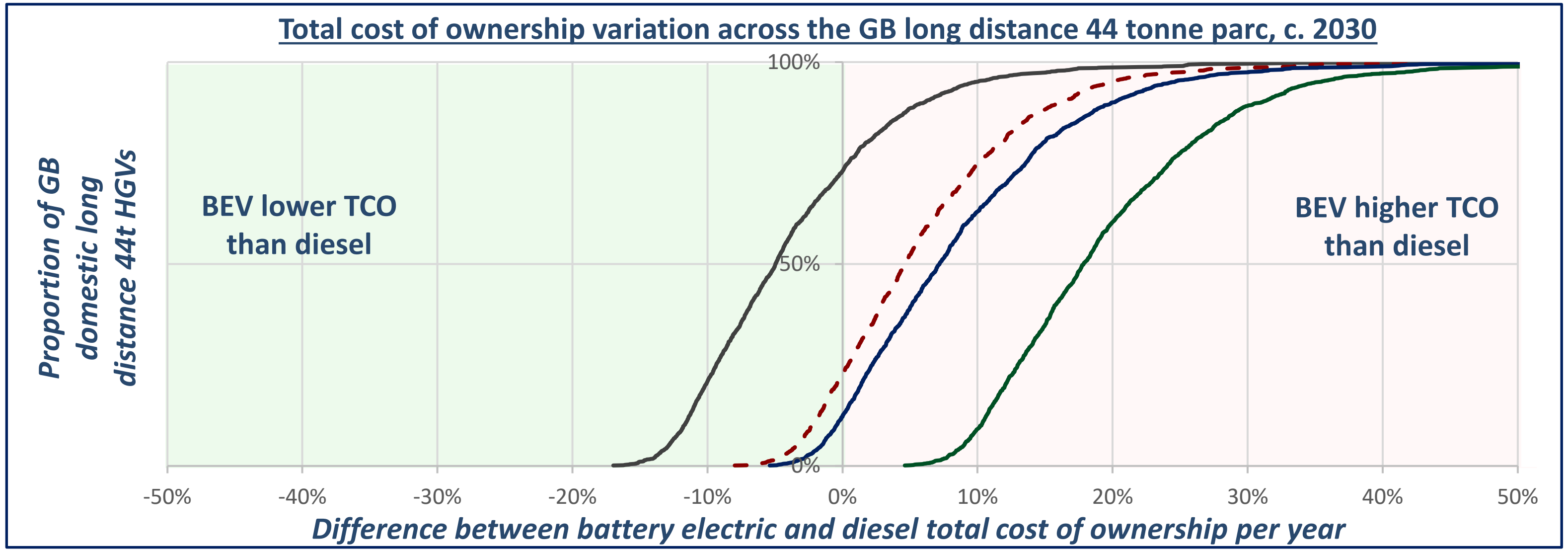
Example of a diesel – battery electric HGV annual total cost of ownership cost walk for one duty cycle in circa 2030, £ – each of the circa 2000 duty cycles considered has a different cost walk

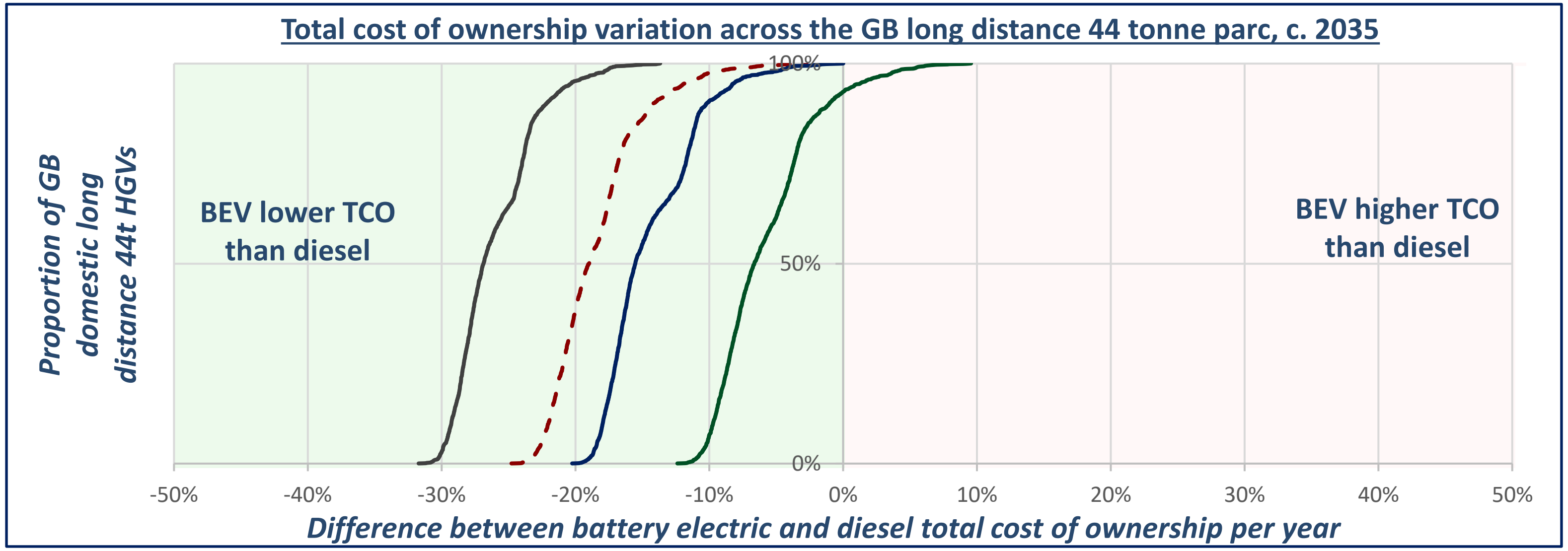


Key factors driving variation in the cost walk between duty cycles

Infrastructure cost	Higher for duty cycles that rely on early stage, underutilised public chargers and for double-shifted vehicles that require rapid charging at depot between shifts
Annual mileage	Higher mileage duty cycles have larger annual fuel cost savings (but shorter battery life and hence larger annual depreciation)
Payload	Duty cycles that often weigh out face greater economic impact from payload loss
Downtime for charging	Higher cost penalty for double shifted vehicles (e.g. due to back-to-back shifts disrupted by charging) and on vehicles highly reliant on public charging (e.g. from imperfect alignment of charging with existing downtime)

Total cost of ownership (TCO) parity between battery electric vehicles and diesel vehicles for 44 tonne long distance operations: the question is "when" not "if"





Central scenario (grey left-most line) – this represents our central case assumptions as set out in the appendix. This includes our central battery price projections and BEIS central commercial electricity and diesel price projections as of March 2023 (ex VAT).

High battery price scenario (red dashed line) – this scenario includes all the same assumptions as the central scenario but with a high battery price scenario where battery prices fall at a slower rate. The battery price scenarios are discussed in the appendix.

Low diesel and high electric price scenario (blue line) – this scenario includes all the same assumptions as the central scenario but considers the impact of **both** low diesel prices **and** high electricity prices using the respective BEIS scenarios from March 2023.

Worst case scenario (green line) – this scenario represents a worst case where battery prices decline only gradually; diesel prices are low and electricity prices are high. All other modelling assumptions are the same as the central scenario.

Scenarios unfavourable to BEV just move the TCO parity date back by a few years but do not stop cost parity from being achieved.

Assumptions and findings from the TCO analysis of the GB 44 tonne HGV fleet

- The graphs on the previous slide show the **annual total cost of ownership comparison** between **battery electric and diesel HGVs** for the most difficult-to-electrify section of GB's HGV parc, namely the **long distance 44 tonne vehicles** that will require a public charging network to complete their operations.
- The graphs were created through analysis of a **representative sample of approximately 2000 duty cycles for 44 tonne HGVs**, from DfT CSRGT data. **Downtime and payload are both considered** – further details may be found in the appendix. No changes in vehicle operation (e.g. optimisation of operation to suit BEV) have been assumed.
- **The modelling captures the range of 44 tonne duty cycles and the corresponding spread in ease of electrification**. The most cost competitive duty cycles (bottom of the charts) are volume-constrained vehicles that perform back-to-base operations and primarily use depot overnight charging, augmented by small public charging top ups.
- Several trends apply as one moves up the chart.
  - **Firstly, the proportion of mileage driven while weighted out** increases moving up the chart, corresponding to an increased economic impact of payload loss.
  - **Secondly, the reliance on public charging increases moving up the chart** – this is significant since in 2030 we expect the public charging network to have a relatively modest utilisation (we have modelled 7%) which results in high infrastructure costs per vehicle and hence high dispensed electricity costs. Use cases that source a large proportion of their electricity from an early stage, underutilised public charging network will therefore experience smaller running cost savings than their counterparts that charge entirely at depot. This factor becomes less important as public charger infrastructure utilisation increases.
  - **Thirdly, the level of additional downtime from BEV charging generally increases moving up the chart** (as an extreme example, very niche two-driver long-haul operations with two drivers in the vehicle at once site right at the top of the chart).
  - **Some of the use cases right at the top of the chart** have low annual mileages (and hence low BEV fuel cost savings), but occasionally drive long distances (and hence need large batteries and public charging). However, we note that these low mileage use cases likely correspond to **second hand vehicles**, reducing the impact on new BEV sales potential.
- **The results are shown without any subsidy or extra weight allowance, but, as discussed elsewhere and in the appendix, we note that (at least initially) 3 axle BEVs will need an extra 1 metre of length allowance to run with most common trailer types (e.g. curtain side trailers).** The are exceptions, such as bulkers, tipper and tankers, all of which are shorter than typical curtain side trailers. This is convenient, since these use cases are also some of the ones that most need 3 axle tractor units rather than 2 axle tractor units to avoid payload loss.
- **In all scenarios except for the most pessimistic, all duty cycles reach TCO parity with diesel by 2035, with most duty cycles reaching TCO parity by the early 2030s. Even in the "worst case" scenario, BEVs reach TCO parity with diesel for c. 93% of long distance 44 tonne HGV uses cases by 2035, without subsidy or extra weight allowance**. Of the remaining 7%, around one-third are performing very low annual mileages (< 60,000 km), implying a high second hand share. The remainder account for c. 5% of GB long distance 44 tonne HGVs, or c. 1% of GB HGVs, and typically represent operations that both continuously weight out and are very sensitive to downtime.

Contents

Infrastructure availability will be a key factor determining the speed of decarbonisation of the HGV fleet (1/3)

Summary of this chapter (1/3)

- **Most HGV charging will occur at the operator home depot, including for most 44 tonne vehicles.**
  - Around two thirds of rigid HGVs can complete their operations by charging entirely at their home depot.
  - Half of 44 tonne artic HGVs will source 85% or more of their energy from depot charging (or for tramping vehicles, overnight truck-stop charging)
  - Over 80% of 44 tonne artic HGVs will source at least 70% of their energy from depot charging[1] (or for tramping vehicles, overnight truck-stop charging)
  - Depot charging predominates as there is no “chicken-and-egg” problem for depot chargers: depot chargers can achieve high utilisation immediately after installation (e.g., through being used every night for an overnight charge), making them a highly cost effective solution.
  - Public chargers require aggregation of demand from many vehicles to achieve good utilisation – and hence, in the early years, will have lower utilisation and be more expensive to charge at than depot chargers – hence operators will charge at depot as much as possible.
- **Great Britain’s geography means true long-haul operations are very rare in the GB, which is different to Europe**
  - This means depot and warehouse charging play an even stronger role in the GB than Europe.

1 – Element Energy analysis based on DfT CSRGT data

Infrastructure availability will be a key factor determining the speed of decarbonisation of the HGV fleet (2/3)

Summary of this chapter (2/3)

- **Several different types of charging infrastructure are required, each serving a distinct purpose.**
  - Relatively low power chargers (circa 20 kW – 100 kW) are required for charging vehicles in depot overnight.
  - Double shifted articulated HGVs will use high power (circa 250 kW) depot chargers to charge the vehicle quickly between shifts.
  - Public rapid (c. 350 kW) chargers – installed mostly (but not exclusively) in the vicinity of warehouses – will provide top-up charges for vehicles en-route, during driver breaks and/or while loading/unloading.
  - A complementary megawatt charging network will be needed to support the vehicles with the highest energy demands and/or lowest available time to charge.
- **There is a scalable path for battery electric HGVs to transition from small scale initial deployments up to national roll-out.**
  - Battery electric HGVs will initially operate on short distance routes that allow the vehicle to charge entirely at their home depot.
  - Over time, these routes will increase in length and require top-up charging away from depot. This will provide an initial demand for early stage public infrastructure in local regions. Some of this charging could also occur at destinations through agreements between warehouse operators and the fleets which serve them. This is seen as lower risk and more investable than true public charging helping to encourage the transition from local to national BEV operations
  - Moving forward vehicles will be able to travel between regions using public infrastructure installed in each region.
  - This provides a continuous and scalable path to electrification from short distance operations, through to regional operations and finally long haul operations. The “chicken-and-egg” problem still exists, but is smaller than might be expected.

1 – Element Energy analysis based on DfT CSRGT data

Infrastructure availability will be a key factor determining the speed of decarbonisation of the HGV fleet (3/3)

Summary of this chapter (3/3)

- **Broadly, there will be two types of charging away from the vehicle depot.**
  - 350 kW chargers and 1 MW chargers will provide two complementary charging networks with complementary functions and distinct geographical distributions.
  - This is described in detail in the 3rd section of this chapter.
- **GB infrastructure requirements are different to Europe.**
  - GB's geography means that true long haul operations – where a day consists of two back-to-back periods of 4.5 hours of motorway driving and goods are moved 700 km or more from origin to destination in a single trip – are rare.
  - In Europe, true long haul vehicles are more common. These differences are reflected in the infrastructure requirement.

Structure of this chapter

- The first section of this chapter provides an overview of the national charging network needed and the different types of infrastructure required.
- As described in this summary, depot charging will satisfy a large proportion of HGV charging demand, and this is especially true in the early years – the second subsection therefore takes a deep-dive on depot charging and describes the need for a local approach to ensuring depot charging power demands can be met by the grid in the short term.
- The third section of this chapter provides a detailed insight into the nationwide charging network required to support the out-of-depot charging needs of the vehicles.

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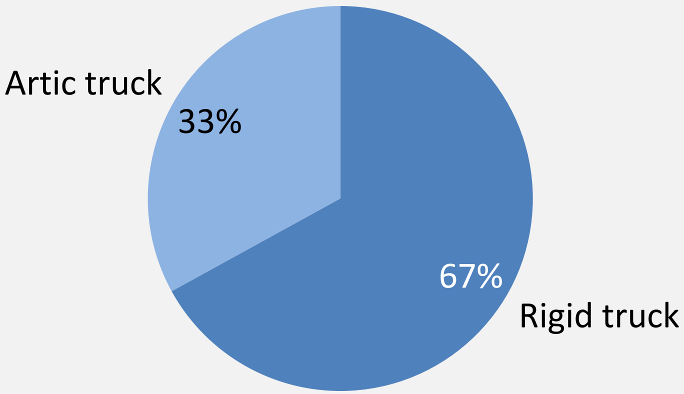
True long haul operations are rare in Great Britain – most charging will occur at depot

The majority of British trucks are rigids

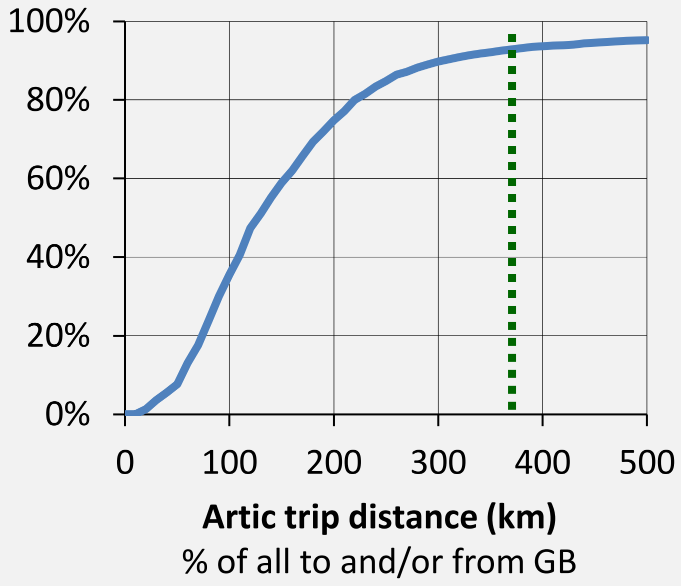
Rigids are commonly based in one locality & operate within limited range, so most will simply depot charge overnight.



British en-route truck charging need is minimal

Over 90% of artic trips from origin to destination can be completed within one 4.5 driving period – within 360km.

Where a trip can be completed within one 4.5 driving period, rest (and thus charging) breaks may be assumed to occur at start and end – not en-route.



- There are **uncertainties** about some future charging behaviour – notably long haul en-route and the pivotal role of ferries (analysed later in this chapter).
- However, over **90%** of charging requirement can be linked to fixed depot and warehouse locations – so overall allocation of demand to place is reasonably **reliable**.
- **2019 patterns of freight activity** are assumed not to change – for example, recent trends to greater home delivery are ignored.
- All trucks are assumed to ultimately use **battery electric technology similar to that currently or imminently available** – in reality, the technology of 2050 could differ.

Truck fleet split from DfT statistics. Truck journeys by distance is extracted from ETISplus modelling for 2019.

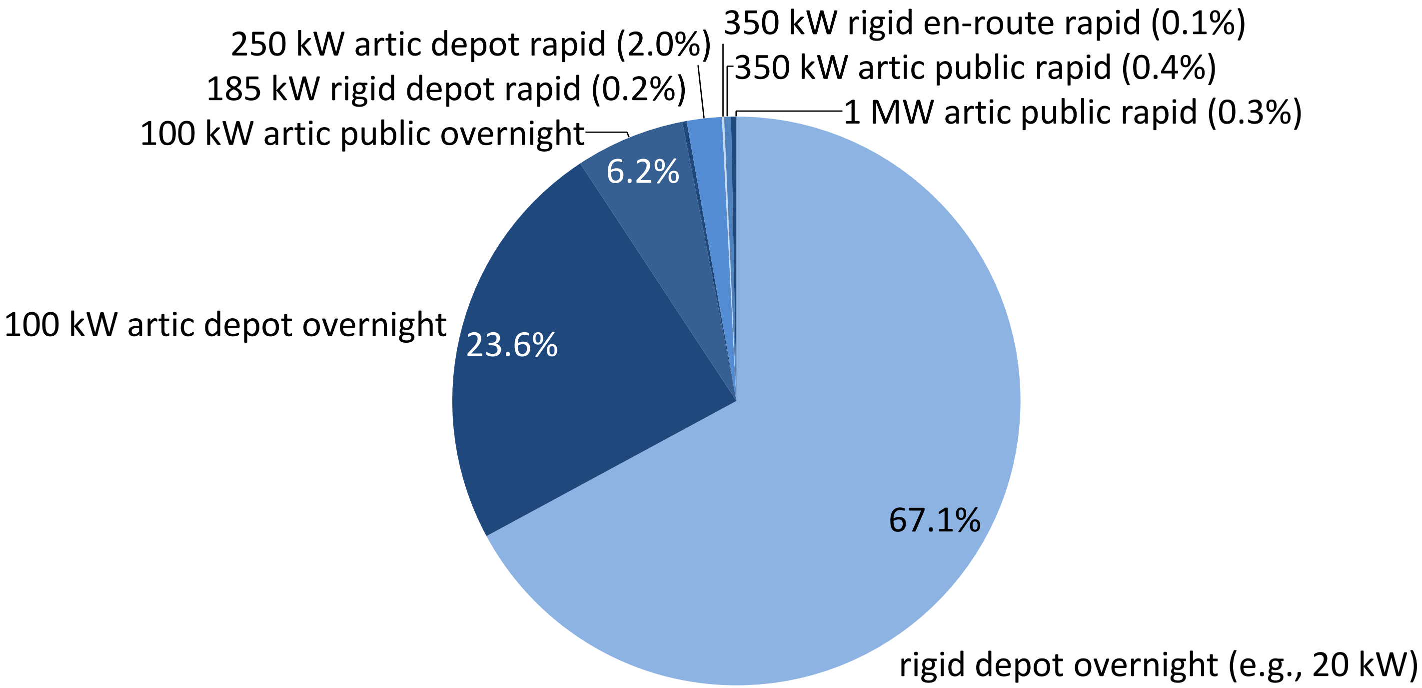
Several different forms of charging will be required

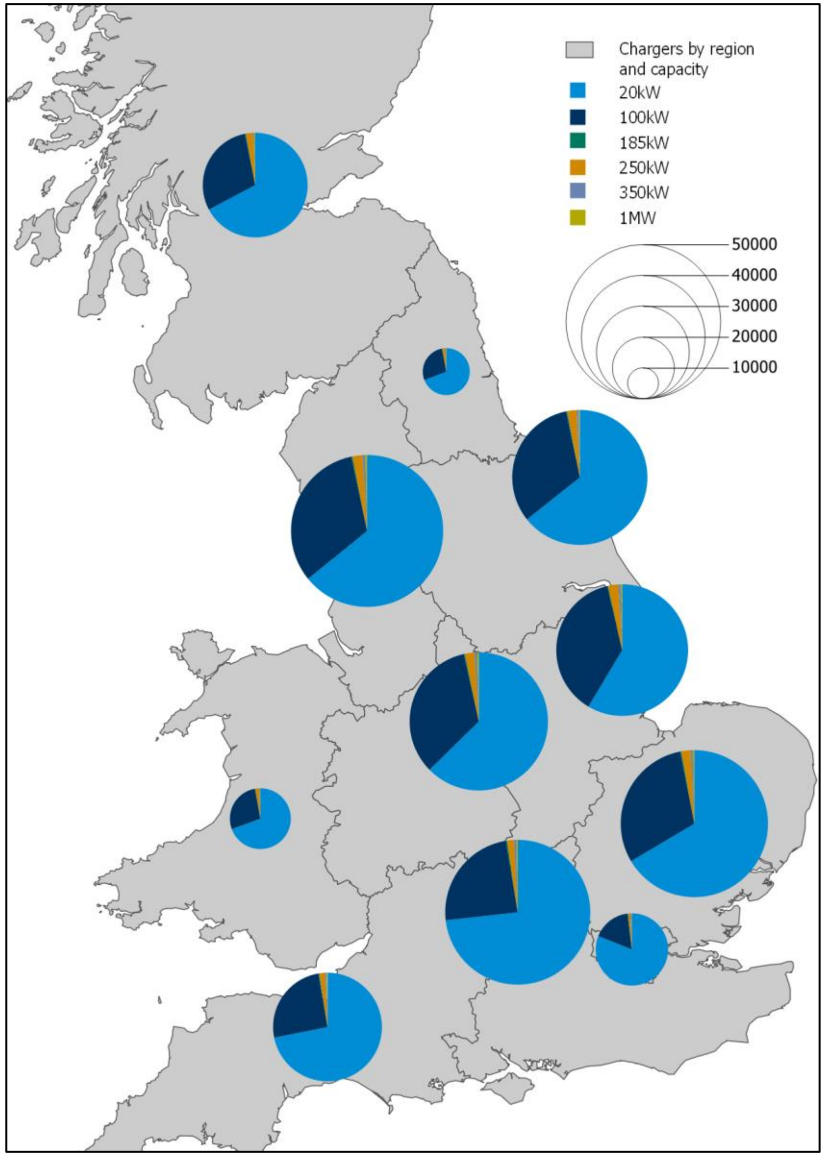
Charger type	Typical power	Use case description	Parties responsible for installation	Comment
Depot overnight	Circa 22 kW (rigids); circa 100 kW (articulated)	For vehicles that are based in the depot overnight, most charging happens in depot overnight.	Fleet operator, for example using a turnkey solution from an Infrastructure-as-a-Service provider.	Around two-thirds of rigid HGVs will only use this charging type. For most HGVs that stop overnight (except trampers) this will be the main charging type.
Depot rapid	Circa 250 kW, depending on vehicle and duty cycle	Double shifted articulated HGVs will often need to charge rapidly at the depot between shifts.	Fleet operator, for example using a turnkey solution from an Infrastructure-as-a-Service provider.	This applies to intensively used, high mileage vehicles doing two shifts per day and often in 24/7 operation.
Destination en-route charging	350 kW	**Rigids:** top-up charge on high mileage days during driver break. **Artics:** charging during 45 minute driver breaks for vehicles with modest energy demand and opportunity charging during loading / unloading at warehouses.	Pure-play infrastructure providers and warehouse owners – the latter in a joined-up approach with customers delivering to the warehouse electrifying.	Most of the demand for this charging type comes from articulated HGVs, but some rigid HGVs will also require this charging for high mileage days.
Public en-route charging	1 MW	Charging during driver breaks for vehicles with very high energy demands and/or few opportunities to charge.	Primarily pure-play infrastructure providers and Motorway Service Area / truck stop operators; warehouse owners could also participate.	350 kW charging will be sufficient for many artic duty cycles but 1 MW charging will be needed for the more demanding operations with fewer stops.
Public overnight charging	100 kW	Tramping vehicles and international long-haul vehicles charging overnight away from depot.	Primarily pure-play infrastructure providers and Motorway Service Area / truck stop operators.	The number of public overnight chargers required is much larger than the number of public en-route chargers.

Depot chargers and public overnight chargers deliver the majority of the charging needs, but en-route chargers are a critical enabler of long distance operations including most 44 tonne artic operations

A total of about 400,000 truck chargers are expected in Great Britain by 2050 serving HGVs taxed as goods vehicles[1]:

- 93% of chargers will be within depot sites
- 97% of chargers will be 100 kW capacity or less, for overnight charging





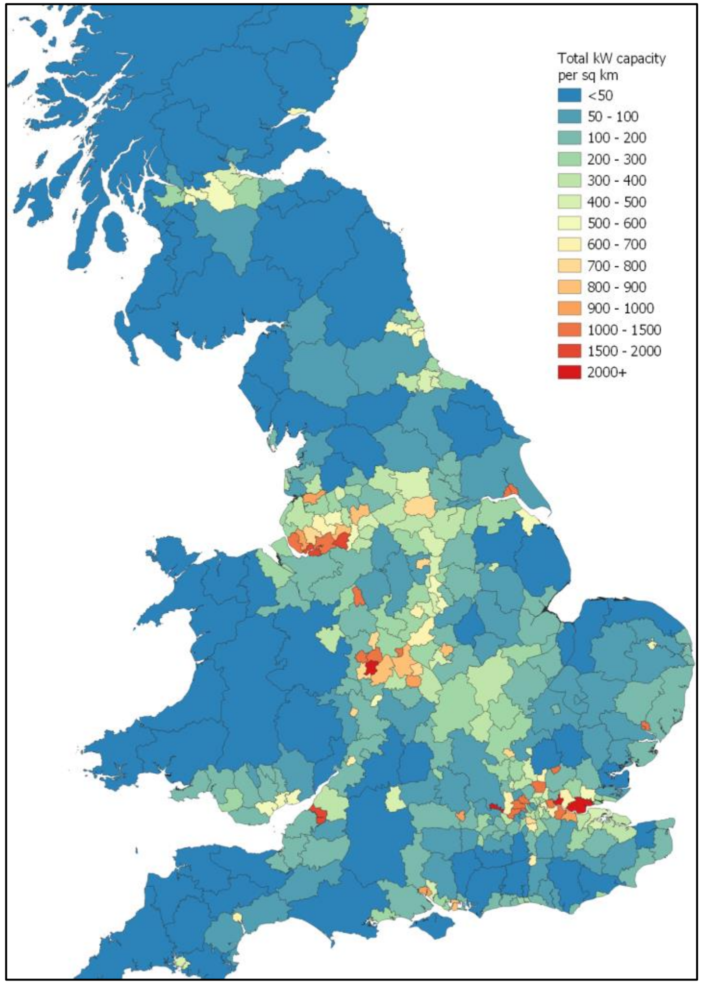
There are regional differences (illustrated right) in the balance of charger type, for example, above average proportions of higher powered chargers in the East Midlands

1 – this work focusses on freight vehicles, and did not include vocational HGVs such as fire engines, street sweepers, sewer cleaners, horseboxes, recording vehicles

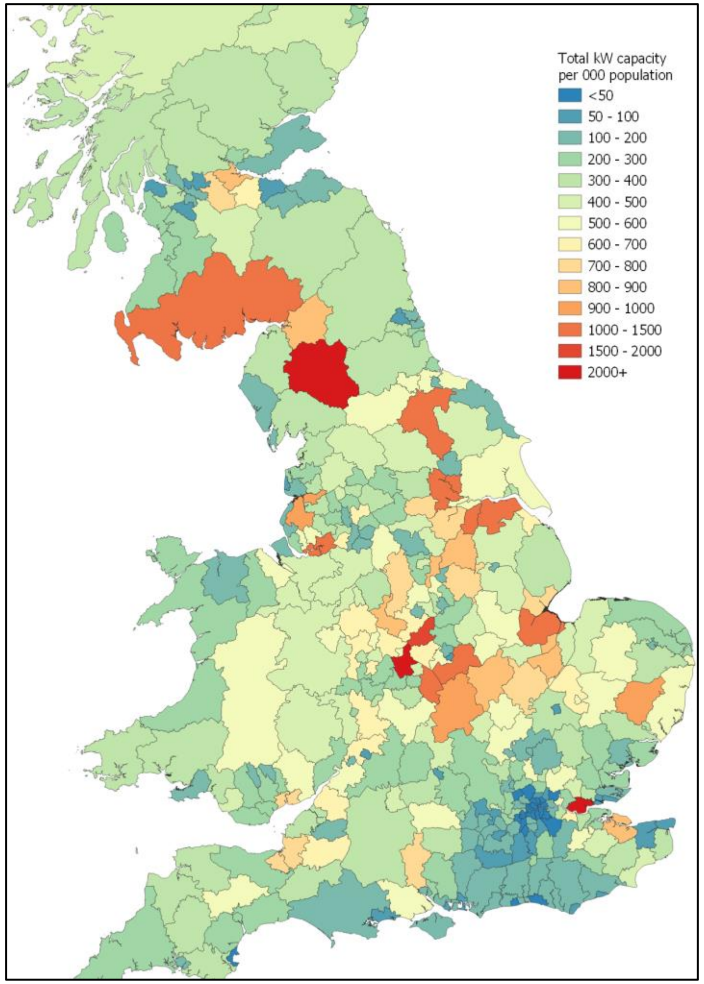
Total installed charger capacity required varies greatly by region, with high concentrations around London, Birmingham and Manchester

- **The greatest density of charging capacity (near right map) is expected in relatively industrial edge-of-city districts, primarily in the London-North West axis.**
  - These are places where the existing electricity grid tends to be strongest, such as Barking & Thurrock in east London, Sandwell in the West Midlands, and Halton & Trafford in the North West.
- **Comparison of kW charging capacity to local population (far right map) highlights places where truck power requirements most vary from underlying domestic needs.**
  - For example, Eden, in Cumbria, is sparsely populated but hosts several long-haul truck-stops.
  - Some other hotspots reflect pure intensity of logistics activity in the local economy, especially in the southern East Midlands.
- **Most of the installed capacity is depot charging, which is the subject of the following section.** This section examines some of the areas which will see early high demands from depot charging.

Total installed charger capacity per square km, for each local authority district, 2050



Total installed charger capacity per thousand population, for each LA district, 2050



LA = Local Authority

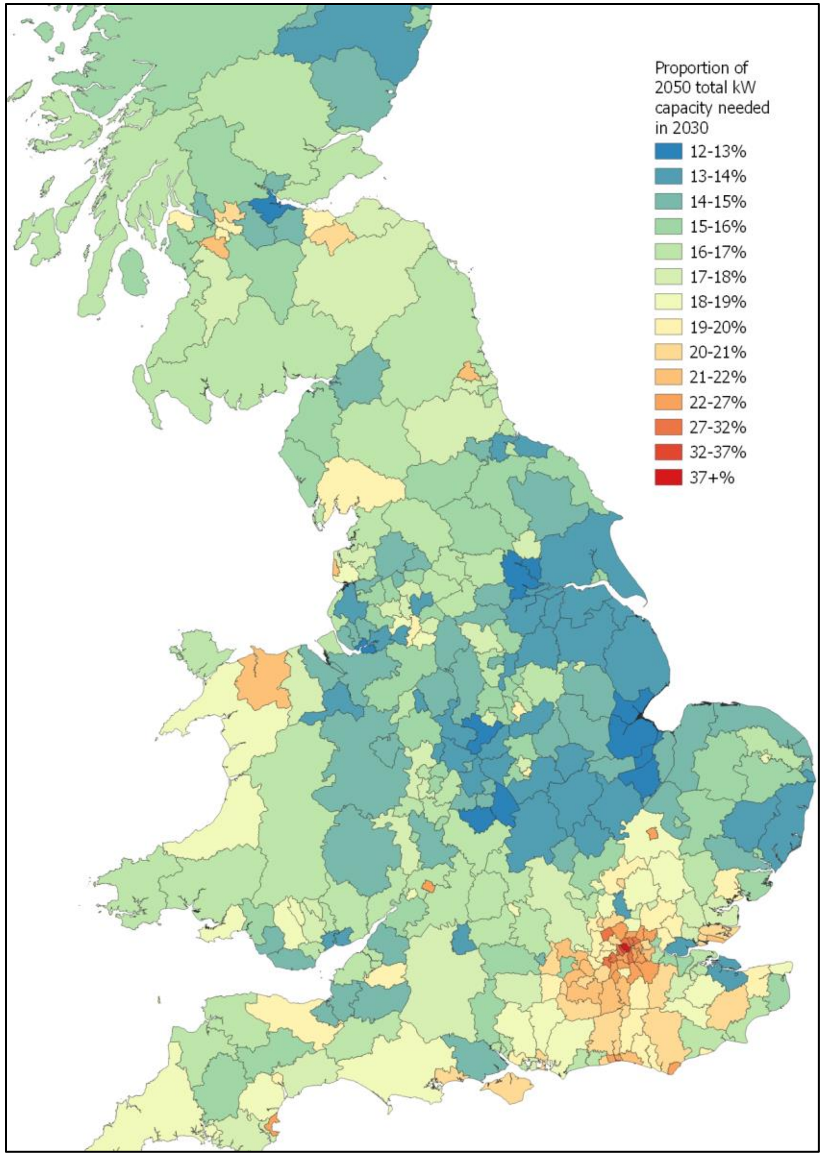
Contents

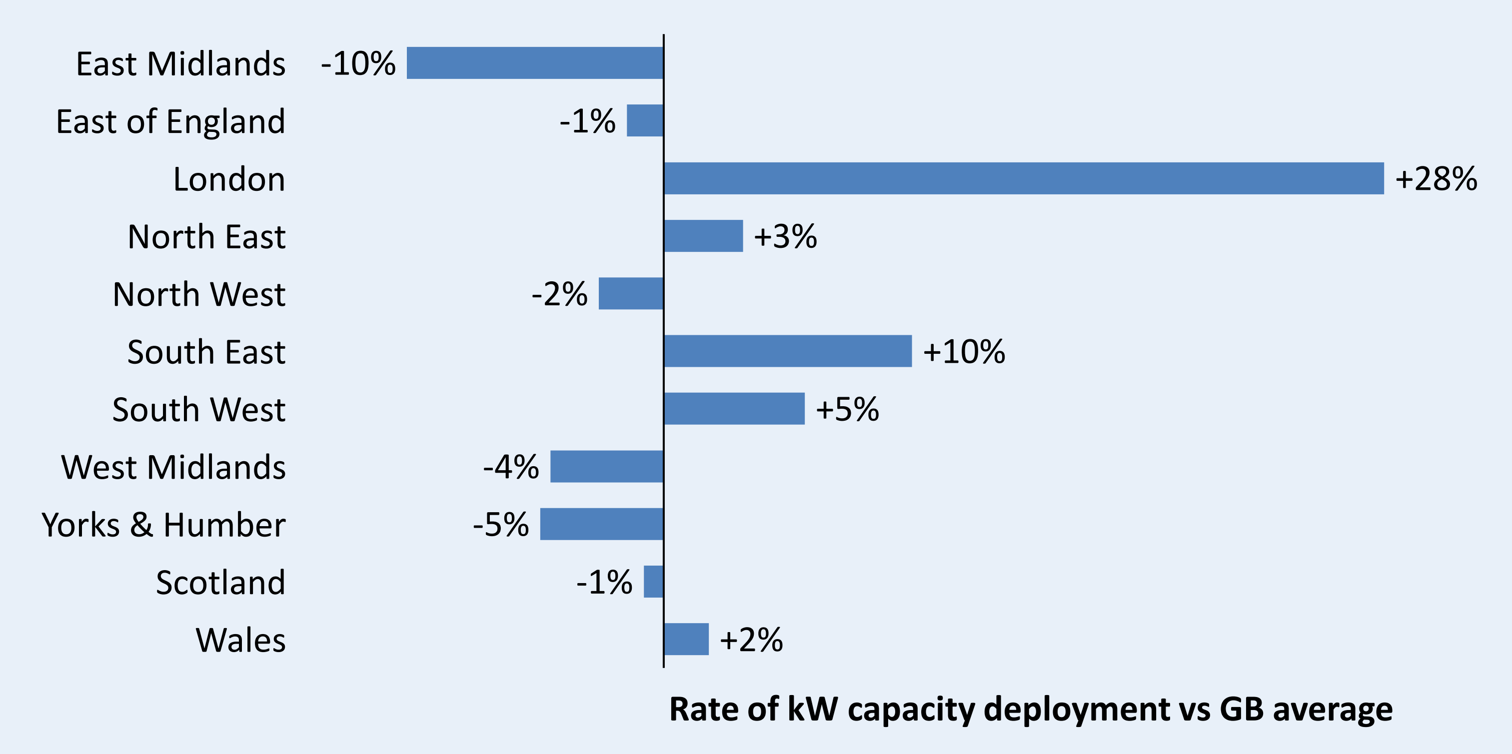
Most HGV charging will initially occur at home depots

Summary of this section

- **The first HGV operations to electrify (primarily rigids) will charge entirely at their home depot.**
  - This is because these short distance back-to-base operations do not need to wait for a public charging network to be in place in order to electrify, and also have the most competitive total cost of ownership with diesel, as discussed in the first report.
  - As a result, the fastest ramp-up for charging demand will occur in areas with a high concentration of rigid vehicle depots, leading to regional variations in the pace of demand increase, as shown on the following slide. Over time, articulated HGVs could also electrify, bringing higher demands – particularly during the day – from the use of rapid charging.
- **It is important that grid capacity is in place ahead of time so that grid capacity availability does not limit the speed of electrification for early movers.**
  - National level strategic planning is possible but determining exactly the timeframe and nature of reinforcements that will be needed requires understanding of the local circumstances, i.e. exactly which parts of their fleet each depot operator proposes to transition when, and how the vehicles will behave.
  - Ofgem regulation would need to enable the DNOs to invest ahead of time to make this possible.
- **Depot charging will need to be complemented by an en-route charging network to enable longer distance operations – this is the subject of the next section.**

Areas with a high proportion of rigid HGVs – particularly London – will require a higher proportion of their infrastructure to be in place by 2030, owing to the higher uptake expected for rigid HGVs in the 2020s





- Rigids will tend to switch to battery electric sooner than artics.
- That pattern favours disproportionate early investment in charging infrastructure in London, and to a lesser extent, the south.

Contents

Two main types of en-route charging will be required (1/3)

Summary of this section: description of the two different types of *en-route* charging (1/3)

- **Both 350 kW and 1 MW chargers will be needed.**
  - Based on our modelling of the expected sizes of energy top-up needed on HGV trips[1], we estimate that around half of the energy delivered by en-route charging can be delivered by 350 kW chargers, while the remainder of the en-route charging energy is delivered by 1 MW chargers.
- **The main HGV stopping locations are at destinations (mainly warehouses) followed by motorway truck stops[2,3].**
  - HGV drivers are already very good at aligning their breaks with existing downtime at stops. This means that for many drivers there is no long 45 minute stop along the motorway between a pick up and a drop off. To make use of existing downtime charging therefore needs to work around pick up and drop off activities.
  - Most of the warehousing is close to motorway junctions and can be used as destination chargers but could also be opened up as en-route chargers if public access can be agreed.
- **The distinct roles played by 350 kW and 1 MW chargers are reflected in their geographical distribution.**
  - 350 kW chargers are distributed more towards warehouses, while 1 MW chargers are distributed more towards truck stops.
- **The reinforcements required for 350 kW charging near warehouses will also be needed to support depot charging near warehouses and can be performed at the same time.**
  - This reflects the fact that the majority of HGV depots are near warehousing locations[1]. Forward planning could allow for the sharing of grid assets as night time depot charging and day time 350kW top up charging at warehouses clearly peak at different times

1 – Element Energy analysis based on DfT CSRGT data 2 – Element Energy analysis based on ACEA data: https://www.acea.auto/figure/interactive-maps-electric-trucks-stop-locations-central-europe/ 3 – Element Energy analysis

Two main types of en-route charging will be required (2/3)

Summary of this section: description of the two different types of *en-route* charging (2/3)

- **350 kW and 1 MW charging play distinct roles.**
  - 350 kW chargers will provide small top-ups during loading and unloading at warehouses, as well as top-ups during driver 45 minute breaks for regional delivery vehicles (which includes many 44 tonne articulated HGVs) – such breaks also often occur near warehousing areas.
  - 1 MW chargers will serve vehicles with high out-of-depot energy demands and limited downtime (long haul vehicles).
  - 1 MW chargers will also play a role for vehicles performing deliveries and collections at small sites (such as farms) that will not be able to support charging infrastructure, meaning that the vehicle cannot "sip" charge during trailer loading / unloading and instead will need to charge just once in the middle of the shift, during the driver break.
  - The total cost of ownership modelling presented in an earlier chapter includes some productivity loss to account for the possibility of imperfect alignment between driver breaks and charging stops.
  - 1 MW chargers will play an important role for international road freight, because although these vehicles account for only a small proportion of HGVs present in Great Britain at any one time, they are much more reliant on public charging than domestic HGVs because of their long haul duty cycle.
- **The total number and spatial distribution of 1 MW chargers required in 2030 broadly corresponds to two 1 MW chargers in each Motorway Service Area and truck stop.**
  - DfT could support the implementation of this infrastructure in the same way that DfT is supporting the installation of at least 6 high powered charge points for cars at Motorway Service Areas by 2023[1].

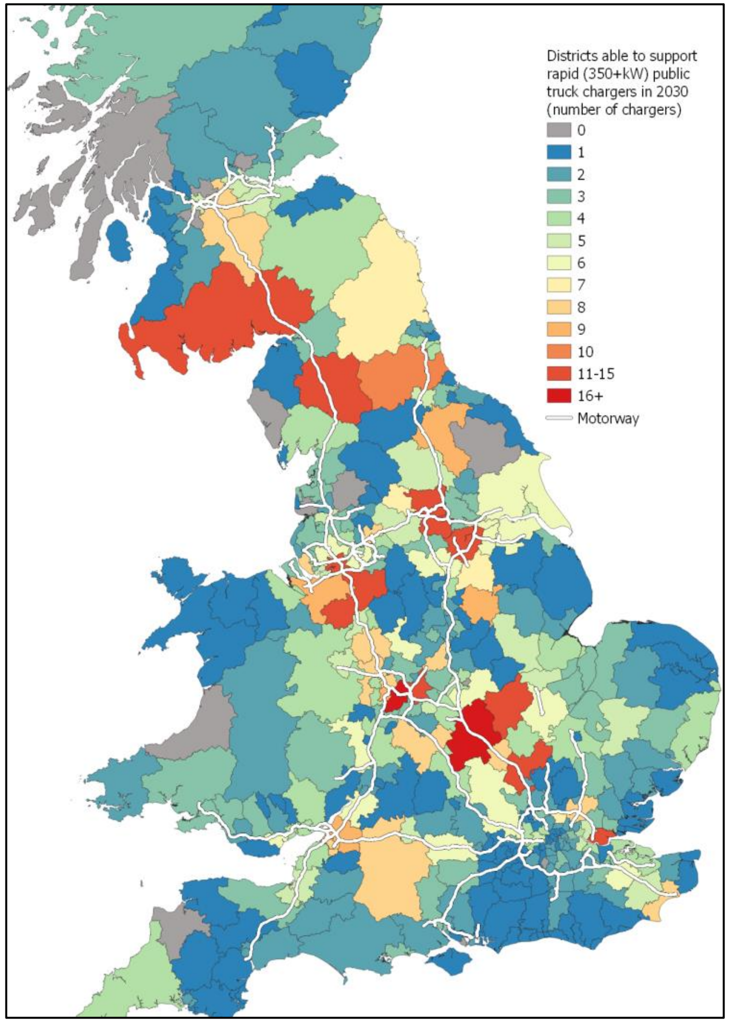
1– Government vision for the rapid chargepoint network in England - GOV.UK (www.gov.uk)

Contents

350 kW charger requirements are national, but concentrated near major warehousing areas

- **The map shows numbers of 350 kW chargers required by local authority district.**
- **350 kW charger demands are concentrated into areas with large amounts of warehousing.**
  - This can be seen by the large concentrations in areas such as Birmingham and Bristol.
  - We estimate that around 800 x 350 kW chargers will be required to meet 2030 charging demand, based on an estimated circa 30% of rigids and 8% of artics being battery electric by this point.
  - We expect this number to rise to around 2000 by 2050 as the full vehicle parc electrifies and charging infrastructure utilisation increases.
- **350 kW charging will primarily occur at destinations and this is reflected in the geographical distribution.**
  - For example, note that Cornwall has significantly higher requirement for 350 kW HGV charging than Devon – reflecting the fact that most goods entering Cornwall will pass through Devon, but the drivers will not need to stop in Devon (for example because the drive from Bristol to most parts of Cornwall can be done in under 4.5 hours).
- **The map on the right shows charger allocation with fixed utilisation nationally – in some areas with high demand (e.g., Daventry), chargers may be fewer in number than shown but achieve higher utilisation.**
  - This will lead to vehicles operating along the strategic road network between London, Birmingham, Leeds, Daventry, Liverpool and Glasgow achieving total cost of ownership parity before vehicles operating into the South West of England, Wales, East Anglia and the North of Scotland, which require a higher vehicle uptake to achieve high charger utilisation.

Estimated required 350 kW charger numbers by local authority district, 2030



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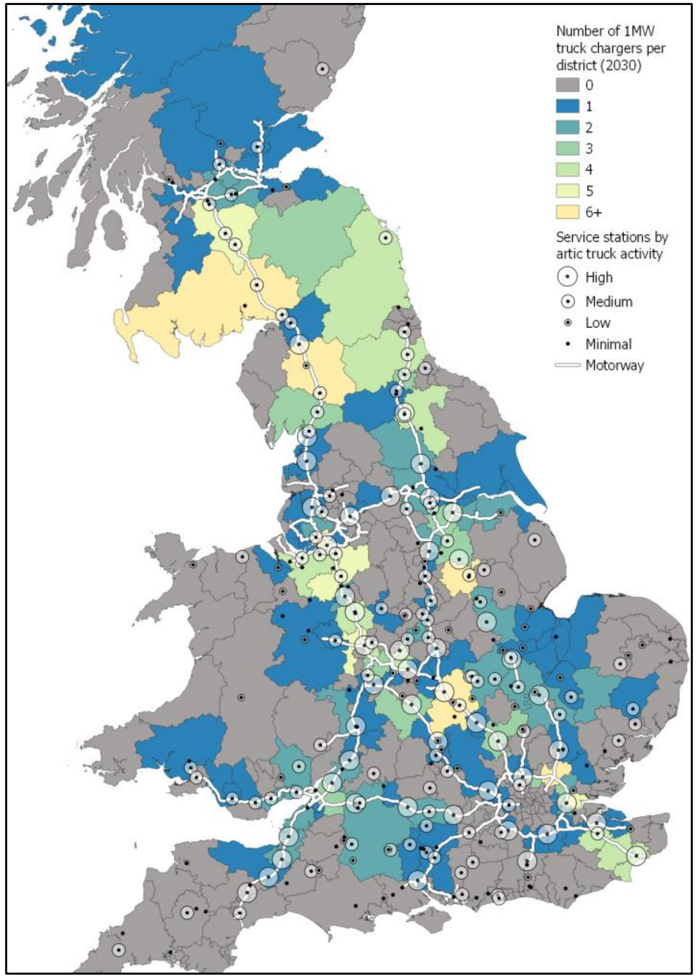
The number and distribution of 1 MW chargers required in 2030 broadly corresponds to one to three 1 MW chargers in each Motorway Service Area and truck stop, depending on site size

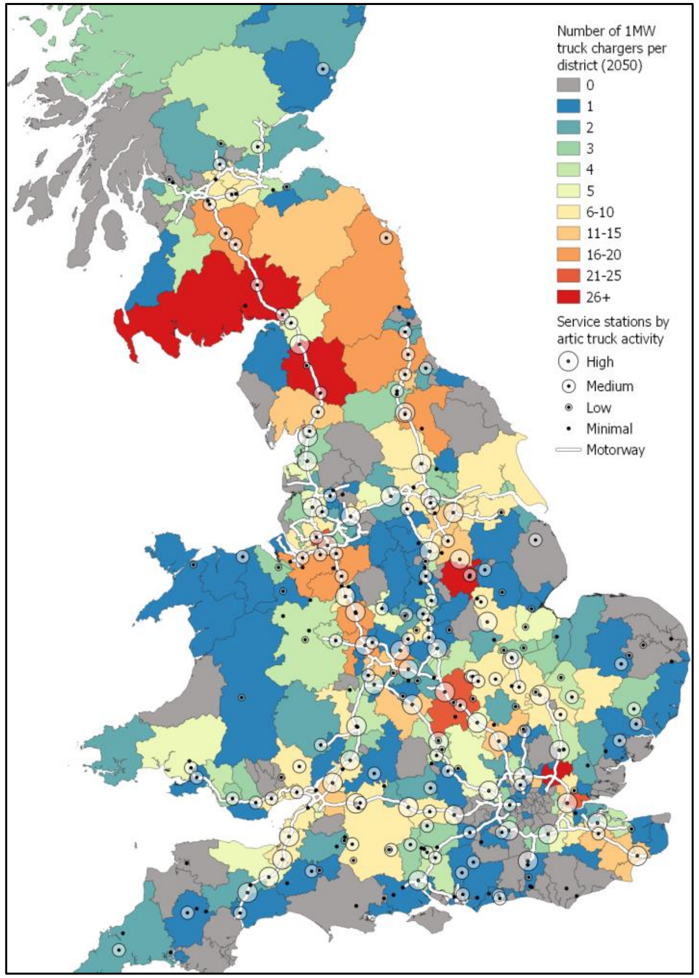
Estimated required 1 MW charger numbers by local authority district, 2030



2030		2050
c. 300	Total 1MW chargers	c. 1200

- The map on the left shows the expected distribution of 1 MW chargers required in 2030, while the map on the right shows the corresponding network in 2050. Circles on the maps show Motorway Service Areas.
- The maps illustrate that the required national MW charging network required in 2050 will likely consist of a core network of hubs (mostly busy MSAs), each with 5 – 10 x 1 MW chargers, and a complementary network of sites with 1 – 3 x 1 MW chargers each in more remote areas.
- In 2030 a site will typically need 1 – 3 MW chargers.
- In 2050 a site will typically need 1 – 10 MW chargers, corresponding to a peak demand of no more than about 6 MVA – the size of routine industrial grid connections.
- Analogously to the situation explained on the earlier slide covering 350 kW charging, areas in red and orange on the right will likely achieve high utilisation earlier, hence vehicles operating between these areas are likely to achieve total cost of ownership parity with diesel first.

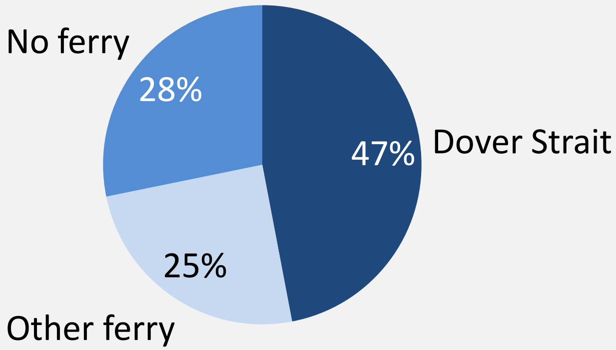
Estimated required 1 MW charger numbers by local authority district, 2050



1: Assumes 1MW chargers are used for all 45 minutes breaks by trucks travelling more than 360km, patterns based on ETISplus with facilities at least every 70km, where all one-stop trips stop for 45 minutes, and half of 2+ stop hauls stop for 45 minutes (the remainder overnight).

Over 70% of long-distance trips in Great Britain (covering over 360 km) involve a ferry crossing
In future, EU patterns *or* trailer-only crossings could dominate

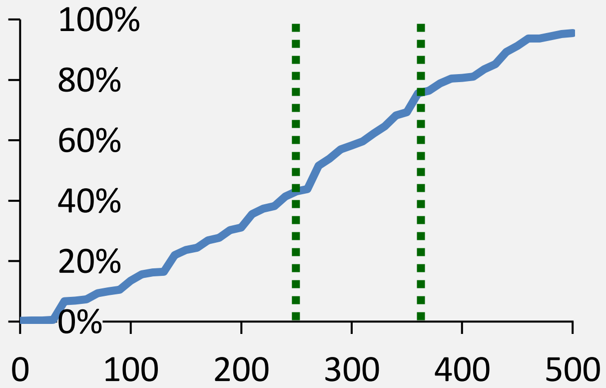
GB long-hauls (over 360km) primarily use ferry crossings – so rest breaks may not naturally align to charging opportunities



Truck (artic) trips over 360km
% of all to and/or from GB over 360km

- Predictions of enforced en-route truck charging thus depend largely on future behaviour around ferries
- Our modelling assumes rests breaks on ferries, but this may not be a valid assumption for battery electric charging, as it is for journeys within Britain

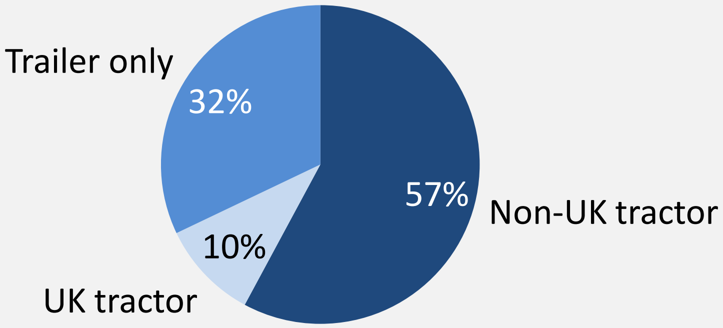
1/2 trucks arriving on the ferry have over 250km further to go before their destination, with 1/4 needing charging before next rest



KM driven to GB destination after ferry
% of all to GB from non-GB

- A quarter of trips (on average, those travelling between 250 & 360 km from the port) would need to stop to charge before the driver's next logical rest break (assuming no in-transit charging & a 500km range battery electric truck)
- It may be more efficient to switch tractor & driver via a trailer-only ferry crossing

Majority of haulage is powered and owned outside GB – this structure could change if ferry rest breaks cannot be used to charge



Ferry crossing road traffic by onwership
% of all RoRo leaving GB

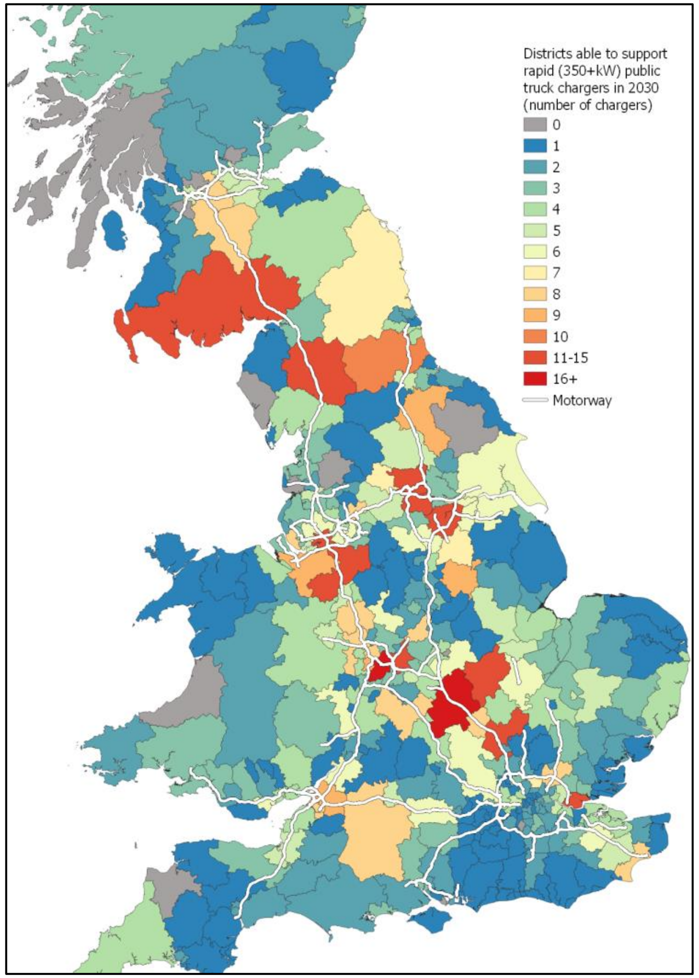
- Shortest crossings are most likely to be with tractor & trailer – matching crossing to rest break is important to efficiency
- Dominance of non-GB traction implies EU decarbonisation will strongly influence GB en-route decarbonisation
- Eurotunnel in-transit charging could be a game-changer

RoRo: Roll-on Roll-off (trailer-based maritime traffic). Dover, RoRo and "ferry" statistics all include Eurotunnel. Trip analysis via ETISplus modelling for 2019. RoRo ferry traffic by power from DfT statistics for 2019. Eurotunnel currently conveys 40% of Dover Strait truck crossings – but in-transit charging would grant further competitive advantage.

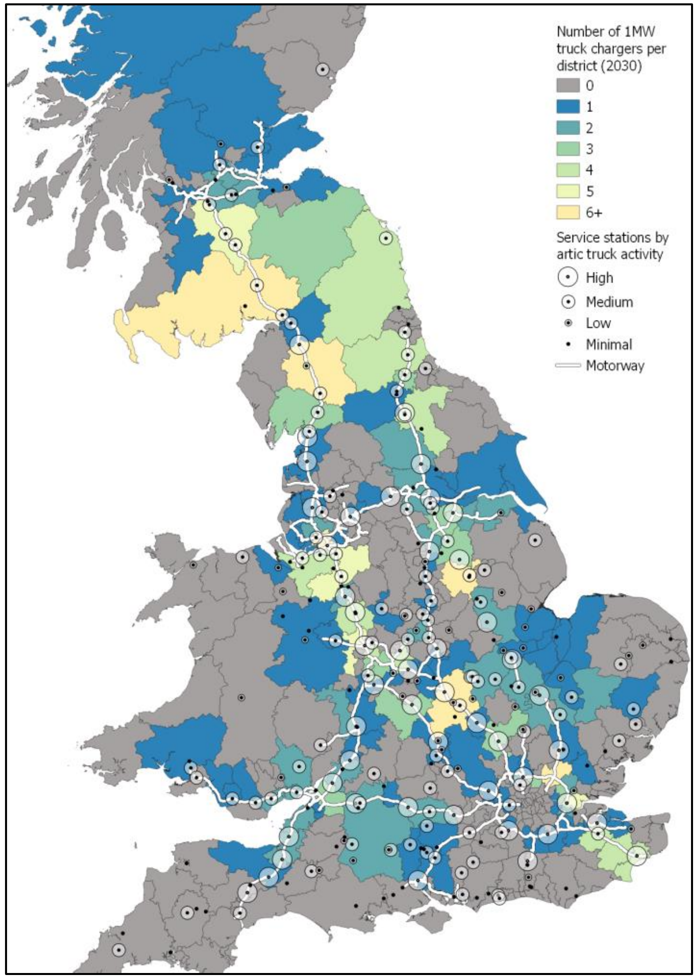
Similarities and differences exist between the 350 kW and 1 MW charging network

- **The figures on the right show the expected patterns of demand for 350 kW charging and 1 MW charging in 2030.**
- **Similarities exist between the patterns.**
  - MSAs adjacent to major destinations / warehousing areas will need a mixture of 350 kW chargers and 1 MW chargers (for example, the area around Daventry will see high demand for both charging types).
- **Differences exist between the patterns.**
  - A higher proportion of 350 kW charger network will need to be in place in 2030 and 350 kW chargers are likely to provide the destination charging for vehicles visiting remote parts of the country such as parts of East Anglia, Wales and the Cornwall.
  - 1 MW charging dominates more in MSAs primarily serving trucks on the way between an origin and destination that are far apart. For example, the A1 in North Lincolnshire / South Yorkshire is a major area for short stops but not warehousing areas – hence, it is among the top areas for MW charging, but not 350 kW charging.
  - For major warehousing areas in Birmingham the reverse is the case and 350 kW charging dominates.

Estimated required 350 kW charger numbers by local authority district, 2030



Estimated required 1 MW charger numbers by local authority district, 2030



Contents

Loss of payload and time have a finite and quantifiable impact on total cost of ownership

Concerns are regularly raised about the issues of losing payload or losing time due to charging

The total cost of ownership presented represent the full picture of BEV ownership:
Penalty costs have been added to BEVs to account for these operational losses

Loss of payload

- Around two thirds GB artic HGVs[1] rarely or never use their full available payload, so **will not be affected**.
- For those which are affected, **payload losses will be below 10%,** and these are significantly offset by lower running costs.
- Payload capability is not a "black or white" situation: it is one of several quantifiable factors in the total cost of ownership that can be outweighed by savings in other cost components. Modelling approach explained here.

Loss of time

- 2024 battery electric HGVs will be able to drive for 4.5 hours and charge in 45 minutes: co-location of infrastructure with driver rest breaks therefore eliminates charging downtime; in this analysis we have assumed an *imperfect early stage charging network* that does not fully eliminate downtime.
- Charging downtime cost has been carefully included, but is just one component of the total cost of ownership – and for most duty cycles a very small one, dwarfed by other factors such as fuel cost savings. Modelling approach explained here.

BEVs will be attractive to operators if the lower running costs outweigh the small operational penalties:
Operational losses do **not** mean that BEVs are unsuitable for a given duty-cycle

[1] Element Energy analysis based on DfT data

Charging downtime is included but largely overcome by MW charging

Cost of lost time has been calculated as the cost of an additional vehicle and driver to cover the time lost within a day

If a (hypothetical) vehicle in 24/7 operation were to lose 1 hour per day due to charging:

1 extra vehicle and driver for every 23 diesel vehicles added into total cost of ownership to make up for lost hour.

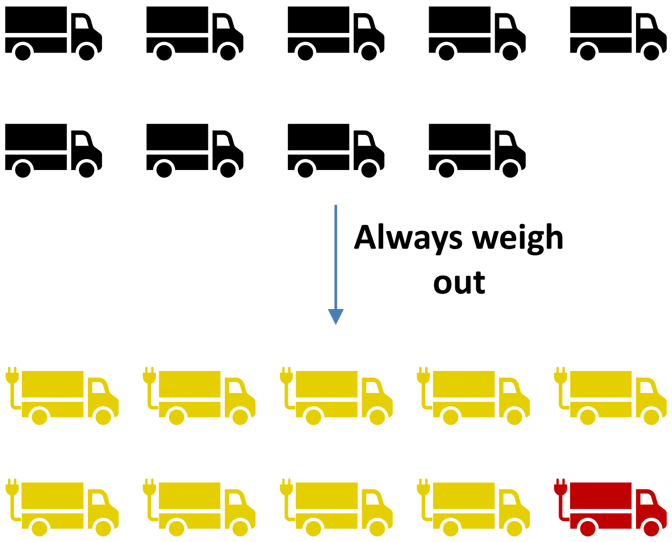
The total cost of ownership of the BEV is increased to account for these additional vehicles **and** the cost of a driver's salary is also added

The cost of reduced payload has been included in the TCO analysis by adding extra vehicles to carry the lost payload

Loss of payload has been incorporated by calculating the cost of an extra partial vehicle and driver in order to achieve the same level of payload

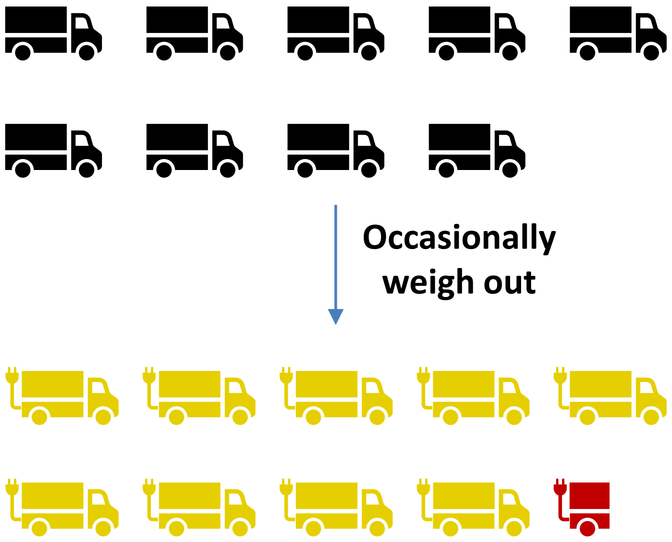
For a *hypothetical, illustrative* scenario where the BEV has 10% less payload than diesel:

Vehicle always weighs out



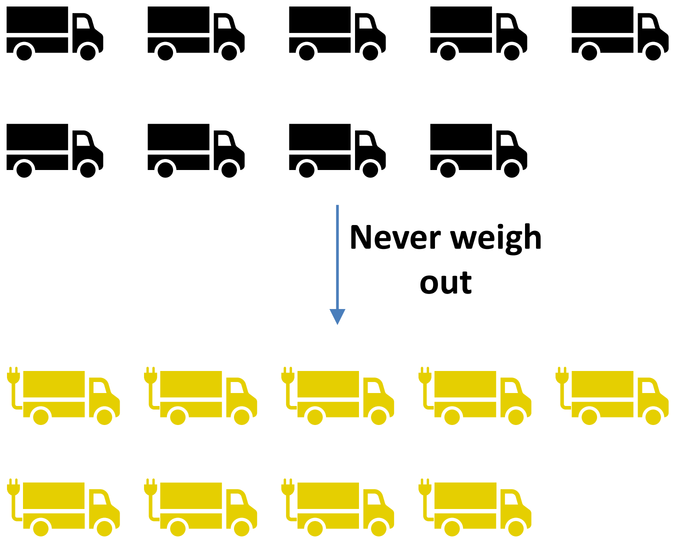
The TCO of the BEV is increased by 11% to account for this additional vehicle (11% of a driver's salary is also added to drive the extra vehicle)

Vehicle occasionally weighs out



The TCO of the BEV is increased by **less than 11%,** as the extra payload capacity is not always required

Vehicle rarely/never weighs out



The TCO of the BEV **does not increase**, as the extra payload capacity is never/rarely required

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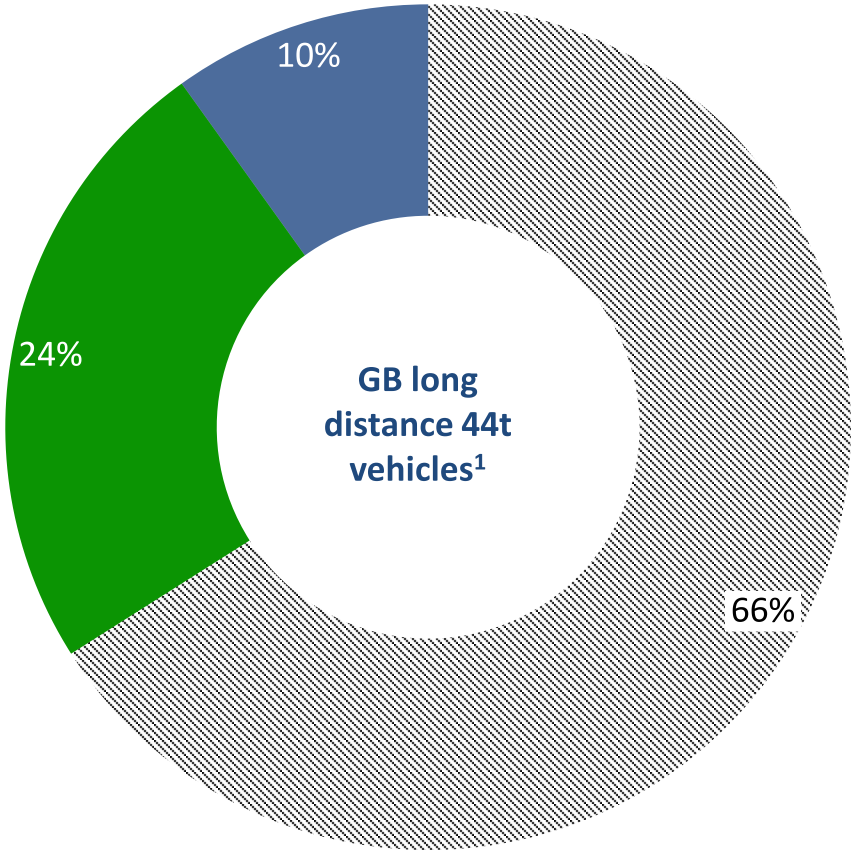
Most 44t HGVs don't weight out frequently



- When considering the impact of a two tonne payload loss on their operation when switching to BEV, operators should assess how frequently this two tonne loss will have an impact – in many cases the impact is inconsequential.
- If the government were to permit an extra two tonne weight allowance for 44t battery electric HGVs, the weight of most vehicles would be unchanged, as only the minority of cases that are weight limited would run up to the higher weight allowance – this would limit any wider impacts.

Rarely or never weigh out (no reduction in tonne km carried from the two tonne BEV payload loss)
Sometimes weight out (1% - 4% reduction in total tonne km moved from two tonne BEV payload loss)
Frequently weight out (5% - 8% reduction in total tonne km moved from the two tonne BEV payload loss)

1 – Element Energy analysis based on DfT data

Contents

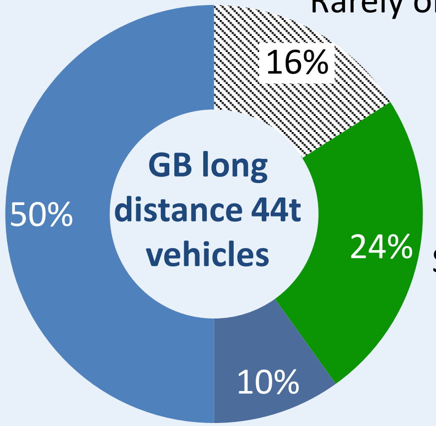
We have analysed a representative sample from DfT of over 2000 real-world 44 tonne operations to understand the impacts of payload and packaging considerations

Battery packaging onto artic tractor units

4x2 articulated HGV (max 40 tonnes as a diesel)

6x2/6x4 articulated HGV (max 44 tonnes as a diesel)

The payload and packaging issues for GB 44 tonne HGVs – with no length or weight allowance



Rarely or never weigh out as a 6x2 (but small payload loss if switched to 4x2)

BEV payload *BEV length*[1]

Could switch to 4x2 with no payload loss

BEV payload *BEV length*

Sometimes weight out

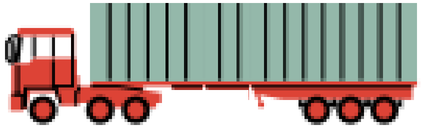
BEV payload *BEV length*[1]

Frequently weight out

BEV payload *BEV length*[1]

1 – see following slide – this is addressable with a small extension of existing regulation

A one-metre vehicle length increase, <u>smaller than has been allowed for Longer Semi-Trailers</u>, would <u>eliminate</u> the battery packaging issue and is an urgent policy request for DfT (1/2)

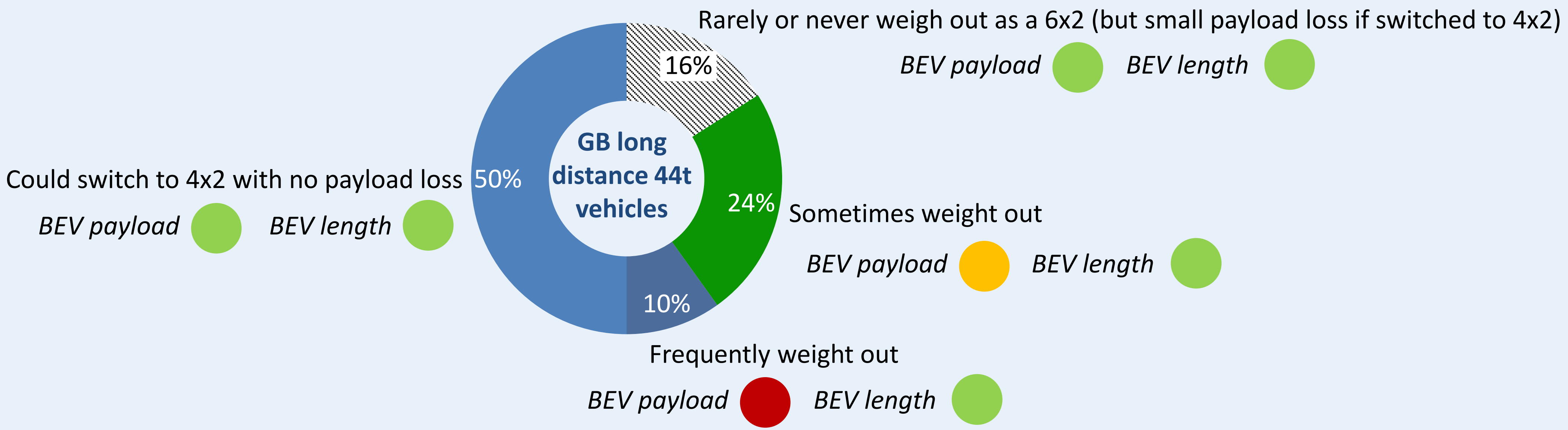
		Length increase over standard configuration	*Turning circle limit obeyed[1]?*	*Allowed under current GB regs?*
Standard 44 tonne artic and most common trailer		**0 m**		
Standard 44 tonne artic and with longer semitrailer		**2.05 m**		
BEV 44 tonne artic and most common trailer		**c. 1 m**		

A 1 metre length increase is assumed in the TCO, but no weight increase is assumed unless stated

1 – assumes the use of rear-wheel steering, as well-documented in the LST trial

A one-metre vehicle length increase, smaller than has been allowed for Longer Semi-Trailers, would eliminate the battery packaging issue and is an urgent policy request for DfT (2/2)

The payload and packaging issues for GB 44 tonne HGVs – with 1 metre length allowance but no weight allowance



A 1 metre length increase is assumed in the TCO, but no weight increase is assumed unless stated

Contents

Modelling and assumptions deep dive (1/3)

- For all scenarios, an OEM markup of c. 30% is applied on battery pack factory gate price in 2030/2035 and c. 40% in 2025.
- The scenarios account for potential additional downtime associated with BEV operation. For public charging, it is assumed in 2025 and 2030 that half of public charging is disruptive – for example, if a vehicle uses public charging for 45 minutes each day, it is assumed that in 2030, this 45 minute charge completely misaligns with the driver break on half of the days. This is conservative, since use BEVs will be accompanied with use of route planning software that enables careful planning of charging breaks within existing downtime. For double shifted vehicles, we account for the fact that sometimes these vehicles are turned around immediately between shifts by assuming that, in 2030, 45 minutes of disruptive charging occurs between shifts on every other day of operation for double shifted vehicles.
- By 2035, infrastructure density will be higher, so misalignment of charging with driver breaks will be less likely. Charging speeds will also be higher. For these two reasons, the economic cost of lost time in 2035 is taken as one-half of the 2030 value. In reality, with appropriate planning software for scheduling of charging, and appropriate infrastructure coverage, the downtime impact of BEV is likely to close to zero for most operations – but we have adopted a conservative approach here.
- The TCO penalty of additional downtime is calculated, as set out in the appendix, by adding in the cost of extra vehicle(s) and driver(s) in the fleet to cover the downtime. This results in significantly higher penalties for additional downtime than the alternative revenue loss approach, and hence represents a conservative method.
- The modelling accounts for loss of payload of two tonnes for BEV in 2025 and 2030 – consistent with both Element Energy modelling and OEM public announcements for 2024 models. We note that since the focus here is on 3 axle tractor units, rear axle loading does not present an issue and gross vehicle weight is the limiting factor determining payload. For each of the c. 2000 duty cycles analysed, we have determined the economic impact of payload loss by costing in additional vehicle(s) and driver(s) to deliver the lost payload. This, as for downtime, is a more conservative approach than the revenue loss approach. We note that while some vehicles (e.g. bulkers, tippers, tankers, supermarket double-deckers) weigh out routinely, these are relatively rare. General haulage vehicles typically only weigh out part of the time, and so receive a correspondingly lower TCO penalty for payload loss than those that weigh out constantly.

Modelling and assumptions deep dive (2/3)

- 2030 vehicle capabilities are conservatively assumed to be the same as those already announced for 2024. For 2035, payload loss is reduced to around 1 tonne, corresponding to a roughly 25% increase in battery specific energy (and no improvements in powertrain or vehicle efficiency). We hence conservatively assume that the pace of battery improvement is significantly slower over the next ten years than over the past ten years, and conservatively assume that no improvements in vehicle aerodynamics or powertrain efficiency are made between 2023 and 2035.
- We assume that the mean utilisation of on-the-go chargers increases from 7% in 2025 and 2030 to 20% in 2035. This is consistent with exponential uptake of BEVs from 2030, following creation of an initial nationwide under-utilised charging network, and describes a situation where the network is built out from 2025 to 2030 (with increases in number of chargers roughly cancelling the increases in number of vehicles leading to roughly cancelling out to give roughly constant utilisation), but from 2030 national coverage is broadly achieved and utilisation increases rapidly as vehicle uptake increases exponentially. This mean utilisation is lower than our modelled 2050 values and takes into account real-world factors such as the variation in demand over the course of the day, and chargers not operating continuously at full power when in use. Charger loses of 5% are included in the TCO calculation. The public charger price factors in a variety of costs associated with construction of a public charging hub, such as land (£1 million / hectare) and tarmac for constructing a new site (as well as chargers and grid connection). For 2030, these result in an uplift of c. 20 p/kWh of the public charging price above the base electricity price, using a 15 year lifetime and 10% IRR.
- Conservative charger costs (including installation) of 400 £/kW in 2025/2030 and 300 £/kW in 2035 are used, on top of a grid connection cost of 200 £/kW. These translate through to c. 3 p/kWh and c. 6 p/kWh for overnight charging and depot rapid charging respectively (15 year lifetime, 10% IRR for financing), dropping slightly in 2035.
- Battery cycle life is taken as 1500 in 2025, 1750 in 2030 and 2500 in 2035.

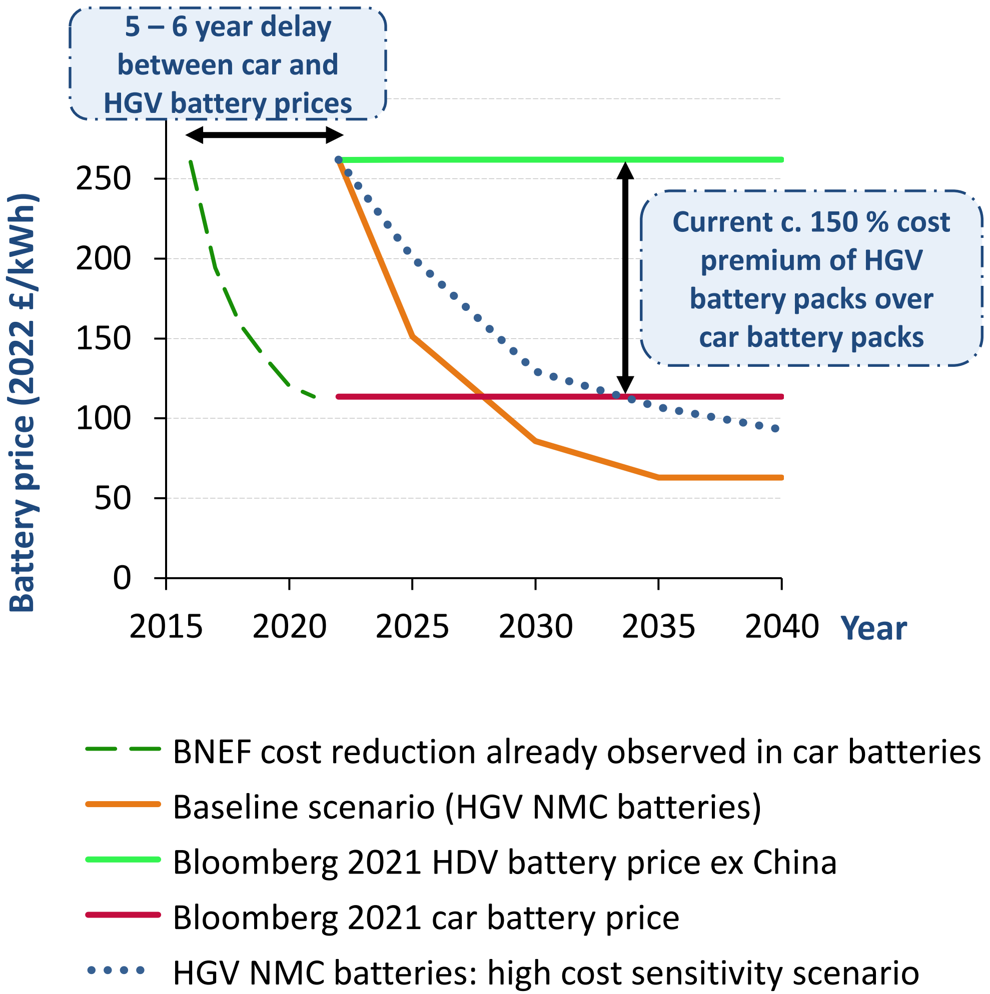
Modelling and assumptions deep dive (3/3)

- Fuel consumption has been calculated using the road loading equation for a representative balance of motorway and dual carriageway driving (based on DfT data) and benchmarked against OEM data for both diesel and BEV. As an illustrative example, for a vehicle that runs continuously at 44 tonnes, the fuel consumption is 0.32 l/km for diesel and 1.58 kWh/km (2030/2035) and 1.74 kWh/km (2025) for BEV (including a conservative charger efficiency of 86% in 2025 and 95% in 2030 and 2035). Vehicles that do more rural driving and driving on hilly terrain experience greater cost savings from the switch to BEV from those running mostly on motorways (owing to regenerative braking); however these cost savings have conservatively not been taken into account in the analysis.
- No diesel vehicle cost increases from Euro VII have been assumed. Diesel infrastructure costs have not been included, which is conservative from the point of view of BEV cost competitiveness. The results are not sensitive the exact capital cost (c. £100,000) of a diesel long-haul 44 tonne tractor unit, or the exact diesel vehicle depreciation rate[1], since diesel vehicle TCO is dominated by fuel costs.
- Battery electric vehicle lifetime is determined by battery life, with high mileage duty cycles thereby depreciating faster owing to shorter battery life (high mileage duty cycles also have larger annual fuel cost savings from BEV operation, however). Battery residual value (driven by second life applications) is taken as 15% of initial capex[2] (conservatively entirely writing off OEM markup); the results are not sensitive to this.
- Slightly reduced vehicle range in cold weather has been taken into account.

1 - https://elib.dlr.de/114666/1/EVS30_Paper_Trucks_M%26R_Resale_Florian%20Kleiner_uploaded_update.pdf 2 - https://theicct.org/publication/total-cost-of-ownership-for-tractor-trailers-in-europe-battery-electric-versus-diesel/

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 – 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.

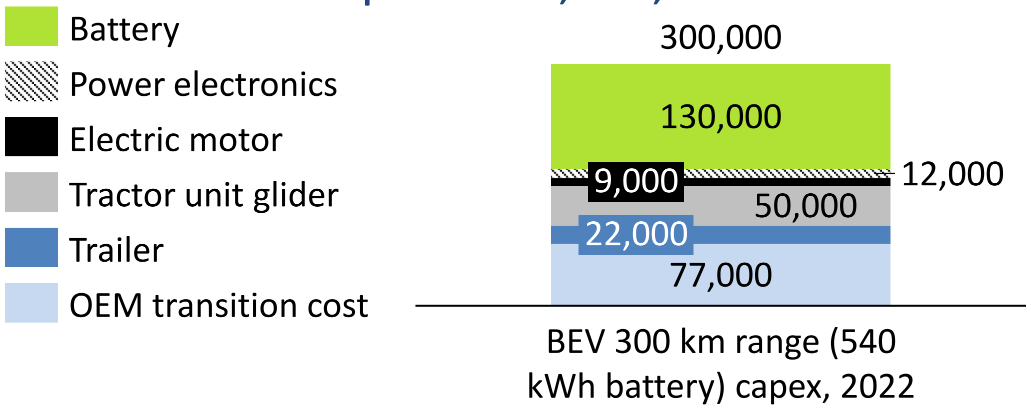


1 – European HGV manufacturers are primarily using NMC and related chemistries, similar to those used in cars – see references 2-5 2 -https://theicct.org/sites/default/files/publications/eu-tractor-trailers-analysis-aug21-2.pdf , 3- https://www.electrive.com/2020/11/17/scania-to-build-their-very-own-battery-plant/ 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

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. Battery markups are discussed elsewhere.
- This is shown in the diagram on the right.

Vehicle capex components including OEM markup for non-component costs, 2022, £



OEM transition cost variation over time