An ETI Insights Report

SMARTER CHARGING – A UK TRANSITION TO LOW CARBON VEHICLES: SUMMARY REPORT

energy technologies institute

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Significant progress has been made to decarbonise UK electricity; the **same level** of progress is needed to **decarbonise transport.**

By switching to **plug-in electric** vehicles, recharged from low **carbon electricity**, the **UK can decarbonise** cars and vans.

The **ETI** has commissioned **Charging Trials** which collected **detailed journey** and charging data from 127 battery **electric vehicles** and 121 plug-in hybrid electric vehicles.

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There are currently **200,000 plug-in vehicles** on the road. In order to meet important **UK government** policy **targets** by **2030**, there will need to be significantly more than **4 million plug-in vehicles** on the road.

SMARTER CHARGING – A UK TRANSITION TO LOW CARBON VEHICLES

Plug-in vehicles are attractive to the majority of **UK drivers**, provided they cost the same over a **4-year period** as current cars, have sufficient range and **recharging** is **easy** and **cost-effective.**

Unmanaged **charging by mass-market** drivers peaks at the same time as **current electricity demand**, with potentially serious **consequences** for UK infrastructure.

Charging access through **market design** and **shaping incentives** for consumers are needed to **achieve the** most **efficient** use of existing resources.

Further **information** and results from the **Charging Trials** can be found on the **ETI Knowledge Zone**.

EXECUTIVE SUMMARY

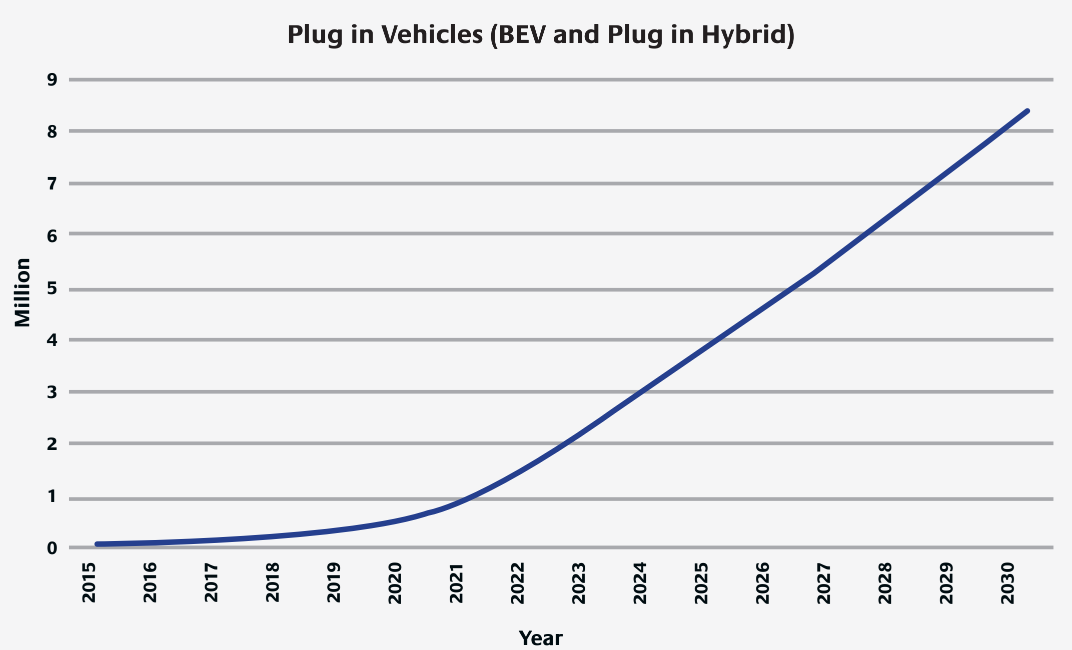
Significant progress has been made towards decarbonising the UK's electricity supply. Whilst there is more to do in this area, the same level of progress is needed to decarbonise transport, heating and industry.

Most analysts identify cars and vans as the next most economic and practical sector to decarbonise by switching to plug-in electric vehicles (PiVs), recharged from low carbon electricity. Assuming a high level of electric vehicle (EV) uptake by 2030 is both possible and indeed likely, this poses challenges and opportunities for the UK's electricity and fuels system.

This insight report has been prompted by the completion of the ETI Consumers, Vehicles and Energy Integration (CVEI) project, which included trials with mass-market consumers to test charging management and uncover range requirements. As well as the CVEI project, the report draws together key insights from across a range of recent activities by different UK and other centres of expertise. It considers which drivers and journeys will need to be converted to electric miles in order to meet UK climate goals. In order to meet important UK government policy targets by 2030, there will need to be significantly more than 4 million PiVs on the road.

We stand at the beginning of a transition to low carbon vehicles in the UK. At the end of March 2019 there were over 200,000 rechargeable cars on the road (0.6% of the total parc) and rechargeable cars accounted for 2.7% of new vehicle sales in 2018. From September 2018, Plug-in Hybrid Electric Vehicles (PHEVs) represented two-thirds of PiVs sold in the UK. Uber has announced the intention for all 40,000 of their drivers in London to be driving Battery Electric Vehicles (BEVs) by 2025, with significant progress by 2021. BMW and Daimler-Benz have announced a joint-venture in electric mobility services branded Your Now; bringing together their existing fleet access management capabilities, which have strong IT platforms, like Uber. Other OEMs have also announced their own initiatives.

Figure 1
Illustrative uptake trajectory to reach 4m+ PiVs in the UK by 2030

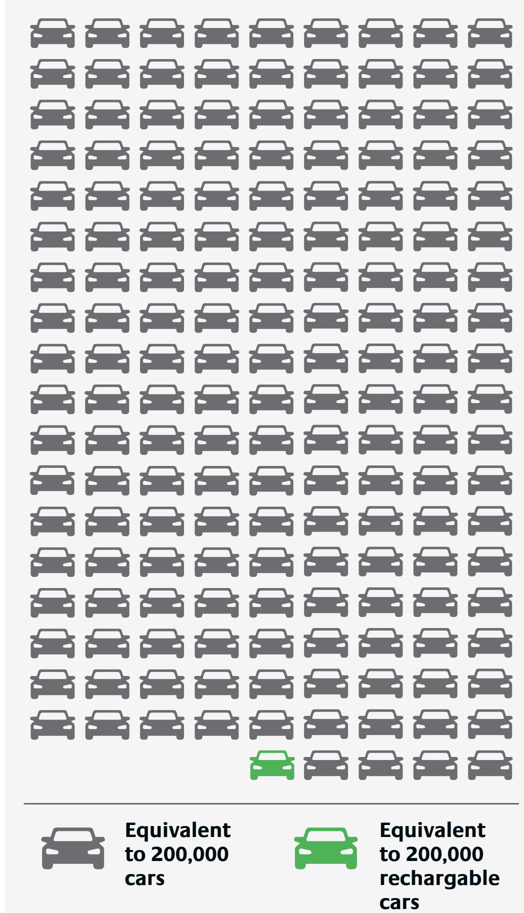


Source: SMMT

The split between BEVs and PHEVs is less important to decarbonisation and charging than the miles travelled using electricity, and the greenhouse gas emissions produced by generating the additional electricity. There are clues in the CVEI data that PHEVs are not always used in a way that maximises electric miles. The potential is there, though, and the consumer research in the CVEI project shows that PHEVs currently have a wider appeal amongst mainstream consumers than BEVs. This potential should be capitalised upon.

As batteries continue to reduce in cost and improve in range and charging rate, BEVs will become attractive to a larger proportion of car owners. PHEVs are important in the medium term as they can travel a high proportion of miles on electricity, with a much smaller battery than the driver would require in a BEV. This, coupled with their wider appeal amongst mass-market consumers, means the availability of PHEVs opens up miles to electrification that would otherwise be driven by a pure fossil fuel vehicle. In terms of decarbonisation, BEVs and PHEVs are complementary, not competitive, certainly until BEVs are capable of providing the ranges consumers desire at costs they find appealing. Drivers will choose vehicles which meet their needs. PHEVs are likely to become an important mass-market gateway to later BEV purchase, as battery costs and performance improve. PHEVs, or range extended electric vehicles (RE-EVs), may

Figure 2
Proportion of PiVs on UK Roads



Source: SMMT

continue to be important for those very high mileage drivers.

The Committee on Climate Change (CCC) and National Grid both anticipate high levels of UK electric vehicle uptake by 2030 in scenarios in which carbon budgets are met – towards 70% of sales[1] and 9M in the fleet[2]. This is partly in recognition of the current momentum and partly to compensate for slower progress in other areas, principally electricity generation. ETI scenarios show a similar pattern[3] and the

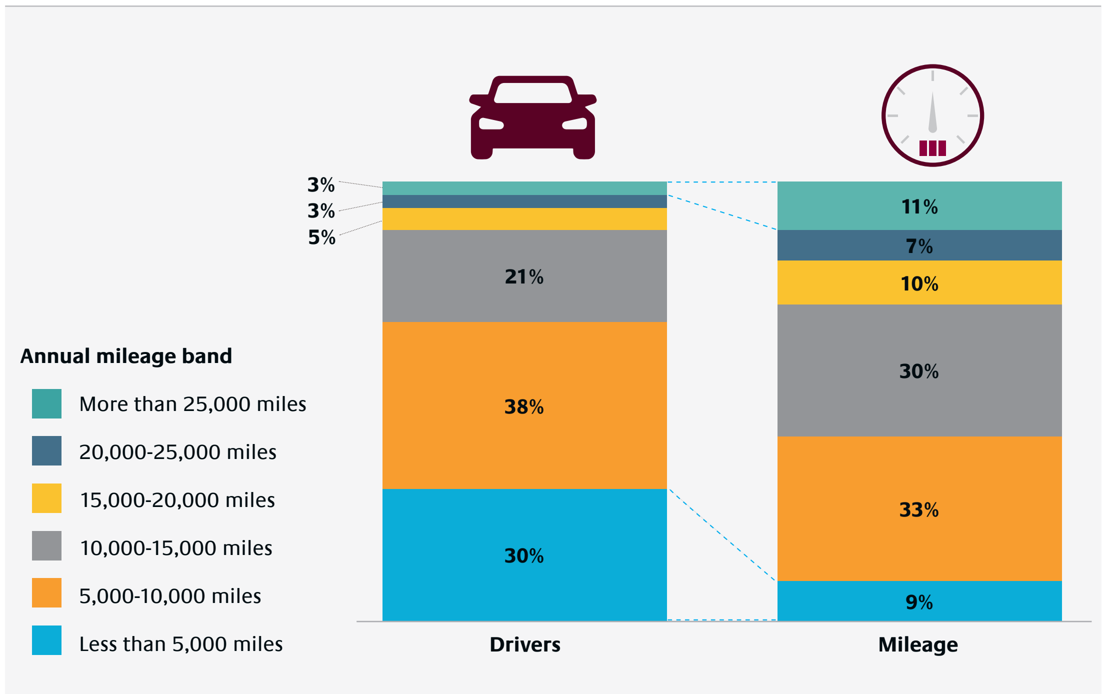
[1] An independent assessment of the UK's Clean Growth Strategy, the Committee on Climate Change, January 2018
[2] Two Degrees, Future Energy Scenarios 2017, National Grid
[3] Options, Actions, Choices: Updated, Milne, ETI, October 2018

CVEI project also examined which combination of policies might be needed to achieve these levels of uptake[4].

Implicit in these levels of uptake is an assumption that large numbers of people buy and use PiVs. Crucially, this will only happen if the PiVs meet their needs. The needs of average and higher than average mileage drivers are particularly important, as they drive the majority of miles in the UK (70% of drivers drive 91% of total miles). This insight therefore considers what a 2030 world would look like for PiV purchase and use to be at the levels foreseen in typical scenarios, where it would be possible to end the sale of pure fossil fuel vehicles by 2040 or earlier.

New cars sold in the UK in 2017 had nominal fleet average emissions of about 200 gCO_2e per mile[5]. Electric vehicles would have similar emissions if charged with electricity with a carbon intensity of 600 gCO_2e per kWh. In practice the carbon intensity of the electricity used varies throughout the year and over the course of the day. The evidence from the CVEI trial supports the view that without intervention EVs would naturally and predominantly charge in the early evening[6]. In 2018, despite being a record-breaking year for renewables and low carbon generation overall[7], the carbon intensity of electricity during this evening period still averaged almost 250 gCO_2e per kWh during the summer and reached over 450 gCO_2e per kWh[8] during the winter. UK fleet average carbon savings from switching from today's fleet to a fleet of vehicles running on low carbon electricity would be around 1.5 tCO_2e per vehicle per year. However, an organic energy system response to meet additional demand from vehicle charging at times of peak electricity demand would likely result in gas turbine back up generation being deployed. That might reduce the savings to as little as 0.2-0.4 tCO_2e per vehicle per year. Some of the increased demand will need to be managed away from the peaks to mitigate this effect.

Figure 3
Proportion of drivers by annual mileage and their contribution to total mileage



[4] https://www.eti.co.uk/programmes/transport-ldv/consumers-vehicles-and-energy-integration-cvei
[5] https://www.smmt.co.uk/industry-topics/emissions/facts-and-figures/
[6] https://www.eti.co.uk/programmes/transport-ldv/consumers-vehicles-and-energy-integration-cvei
[7] Renewables generated a third of the UK's electricity in 2018 and over half of electricity came from low carbon generation (renewables or nuclear) https://www.renewableuk.com/news/444033/New-annual-wind-energy-record-shows-wind-power-taking-central-role-in-UKs-modern-energy-system.htm
[8] https://carbonintensity.org.uk/

As well as implications for CO_2 emissions, electric vehicles represent a new kind of load for the electricity system. Currently the only domestic loads which are so large, and that demand several hours of continuous supply, are night storage radiators, used in a small minority of households, typically in areas with high capacity local networks. The potential for disruption and significant increased investment in supply and networks has been validated by multiple vehicle trials. Avoiding significant electricity cost increases and maximising emissions savings will require charging to be managed, a new concept for domestic electricity supply, going beyond the concept of off-peak tariffs.

Households that drive a lot of miles on electricity, and charge mostly on electricity from low carbon supplies, will be critical to meeting UK climate targets. If current dual fuel[9] households were to drive all their miles on electricity, charging their cars on average would require nearly as much electricity as all their other domestic electricity uses put together. In some households, electricity for mobility will be significantly higher than for other uses.

The UK needs a strategy to provide enough capacity, with enough intelligence to meet drivers' needs, while avoiding risks to the electricity infrastructure or additional investment in high-carbon peak generating capacity. This will involve the electricity and vehicle industries working with different tiers of government.

Solutions for dense urban areas may be different to solutions in dispersed rural regions. A business car driver in rural Leicestershire is very different from a driver living in a London suburb without off street parking and commuting by train or bicycle. Understanding driving patterns and needs and providing appropriate infrastructure will need national policies and standards to support local plans and investments.

The scale of charging at or near homes is likely to be far larger than elsewhere. For the more than 60% of homes with off-street parking[10], charging at home will represent the most convenient and affordable option. Even for those without off-street parking, a good proportion may well seek to charge near home over the same period. The amount of electricity used to recharge vehicles represents both a major opportunity and a significant challenge for many households, where it will be similar to or even greater than current domestic electricity consumption.

Providing mechanisms for managing charging at or near home is a critical issue. If charging at or near home can be managed, the overall effect of vehicle electrification on the electricity industry could be significantly positive. It seems that drivers can be engaged through managed charging, provided it is designed around their needs, and aligns the capabilities of the supply-side to cater to those needs in an effective way.

This is not to say that charging away from homes is not important and the provision of charging elsewhere will be valuable. The importance of fast charging infrastructure along major routes has already been highlighted[11] and may even warrant Government support to de-risk investment. In general, other forms of charging represent commercial opportunities for businesses and places of work to attract customers or staff.

[9] Dual fuel means heating is by gas, oil or LPG, rather than electricity
[10] An affordable transition to sustainable and secure energy for light vehicles in the UK, Batterbee, ETI, November 2013
[11] Plugging the gap: An assessment of future demand for Britain's electric vehicle public charging network, Conolly et al, CCC, January 2018

Efforts to address charging provision in densely populated areas need to bear in mind other travel related changes that may arise, such as levels of car ownership and the emergence of integrated travel solutions. This may lead to a variety of localised solutions best suited to particular urban areas.

If we reach a situation where there are many hundreds of thousands of cars and vans incompatible with smart charging management standards, it will be difficult to recover consumer confidence. Now is the time to lay the foundations for extensive access to vehicle charging, and effective and customer-focused charging management, to prevent charging becoming a barrier to mass-market uptake. Further dramatic reductions in fuel sales, driven by greater vehicle efficiency, electrification and other factors, will also have implications for fossil fuel availability and prices[10].

There are some clear conclusions from ETI's research alongside other organisations:

PiVs are attractive to the majority of UK drivers, provided they cost the same (over a 4-year period) as current cars, have sufficient range, and recharging is straightforward and cost-effective.

- PHEVs will gain significant traction in the private market when their typical effective electric range is 50 miles[12].
- BEVs will gain significant traction in the private market as the second vehicle in a household when their typical effective range is 150 miles and for the primary vehicle when it is 200 miles, and up to 90% will consider a BEV if the range is 300 miles.

[12] Similar to the nominal 69 miles threshold for government support

Figure 4a
Electric range appeal amongst mass-market consumers

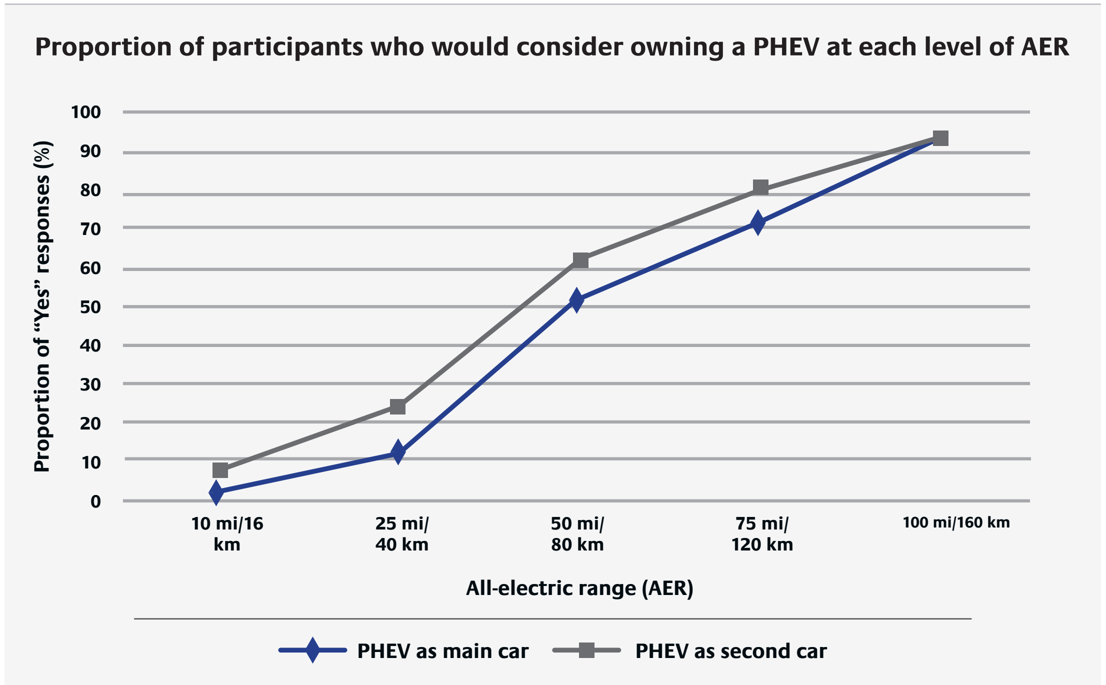
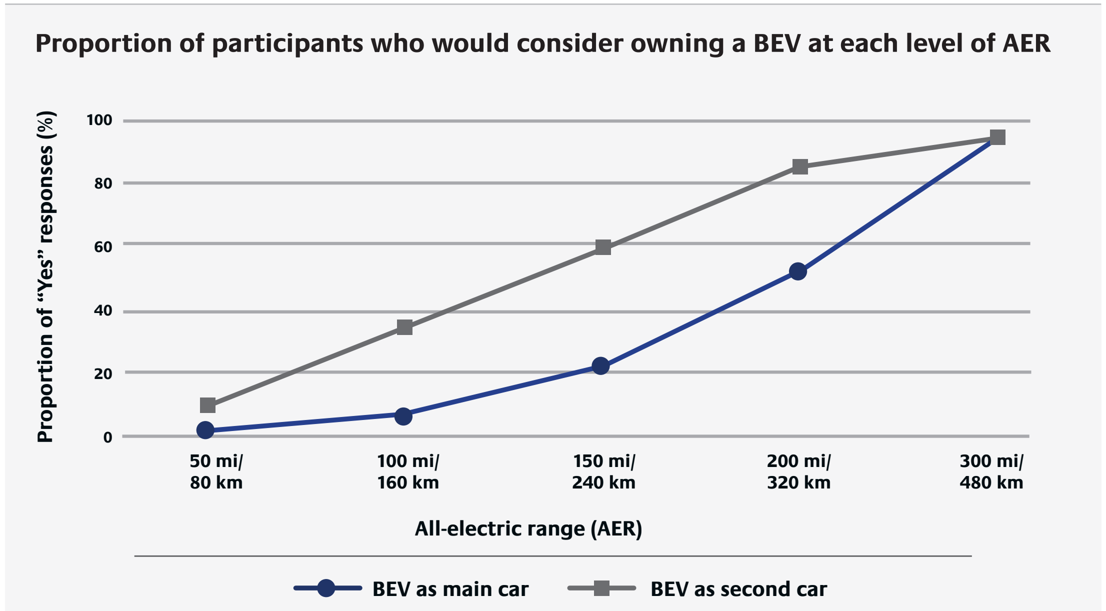


Figure 4b
Electric range appeal amongst mass-market consumers



Drivers interpret effective range in terms of journeys that they take, rather than a nominal drive cycle.

- Effective range therefore depends on the nature of the journeys and driving styles and will be uncovered through the socialisation of many individual experiences.
- It is typically less than headline range figures given by vehicle manufacturers.
- There are clues in the trial results that support an alternative model, with more limited BEV range but widespread access to very rapid charging, and battery technologies that can withstand high volumes of charging.
- The cost-benefit ratio of this approach is untested, especially in terms of infrastructure.
- There are early signs that market actors will set out to test it.
- This could be very important to the ~40% of households which don't have off-street parking.

Unmanaged charging by mass-market drivers peaks at the same time as current electricity demand, with potentially serious consequences for UK infrastructure.

- This is consistent with the charging behaviours observed in large samples of very early adopters, such as the Electric Nation project.
- Drivers are very open to managing their own charging against fixed time-of-day tariffs or letting their supplier manage charging, provided that the proposition is made attractive, easy and credible – and they have

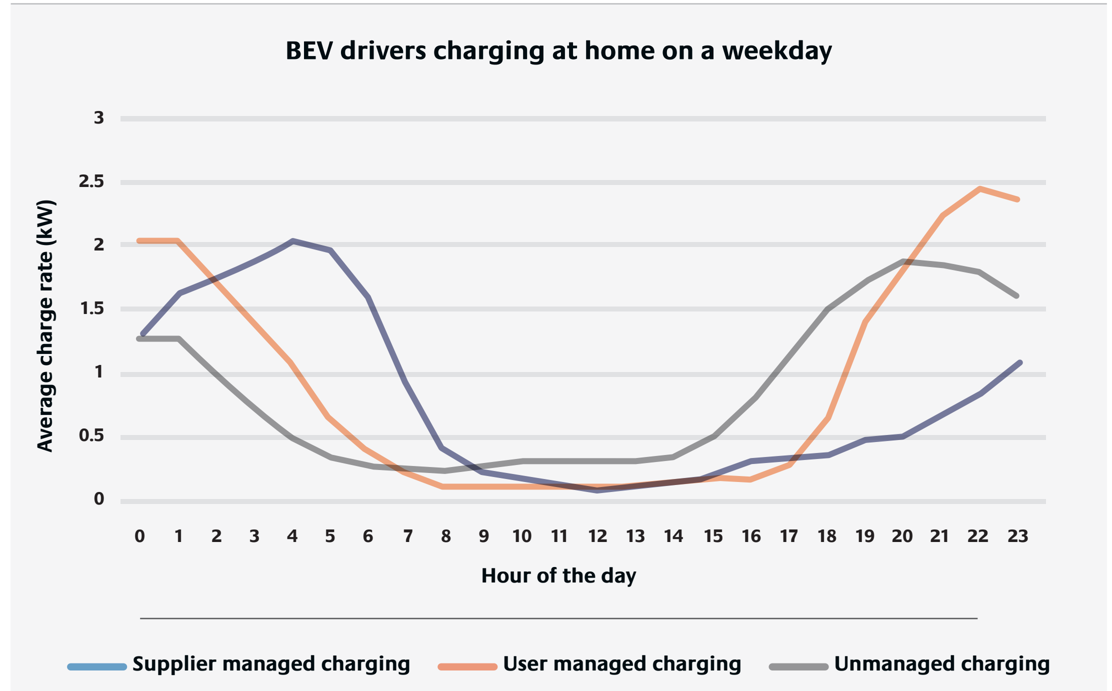
the ability to override it on the occasions they need to.

- Fixed time-of-day tariffs risk creating super-peaks, shortly after the low tariff period starts[13]; this becomes a problem once many drivers own PiVs.

High conversion rates of fossil fuel to electricity miles by 2030 will require uptake amongst the two-thirds of drivers who currently drive between 5,000 and 25,000 miles per year.

- This group drives almost 80% of the total UK car mileage
- Just under 3% of drivers have an annual mileage in excess of 25,000 miles. This group drives more than a tenth of all miles driven and will be very challenging to convert to electricity for some time.
- 30% of drivers drive 5,000 or fewer miles annually and account for less mileage than the high mileage 3% population.
- Many low mileage drivers would be better served by shared access to electric vehicles, and other modes of travel.

Figure 5
Average charging power for different charging management schemes throughout the day



[13] See CVEI D5.3 Consumer Charging Trials Report, for evidence from the charging trial

The CVEI project has collected very detailed[14] journey and charging data from 127 BEV and 121 PHEV drivers whose journeys, age and gender distribution, and geographic locations are a very good match to the core two-thirds of drivers; each driver had the car for 8 weeks; this data is rich in information.

- The data covers over 52,500 trips with a total distance in excess of 440,000 miles.
- 80MWh of electricity were used in 10,500 charging events, of which 8,700 were at home.
- This data has potential to support detailed modelling, after further analysis.

Some CVEI participants with a PHEV drove a modest number of miles on electricity – even less than company car drivers with PHEVs, have been observed to do[15] – although many achieved a high fraction of electric miles.

- Low electric mileage seems to have been caused by using the engine to recharge the battery.
- Evidence from the trial suggests that changes to vehicle design and user interface, combined with changes to the social environment, could dramatically increase average electric miles.
- High levels of conversion are possible, where drivers choose not to recharge from the engine, as the data shows.

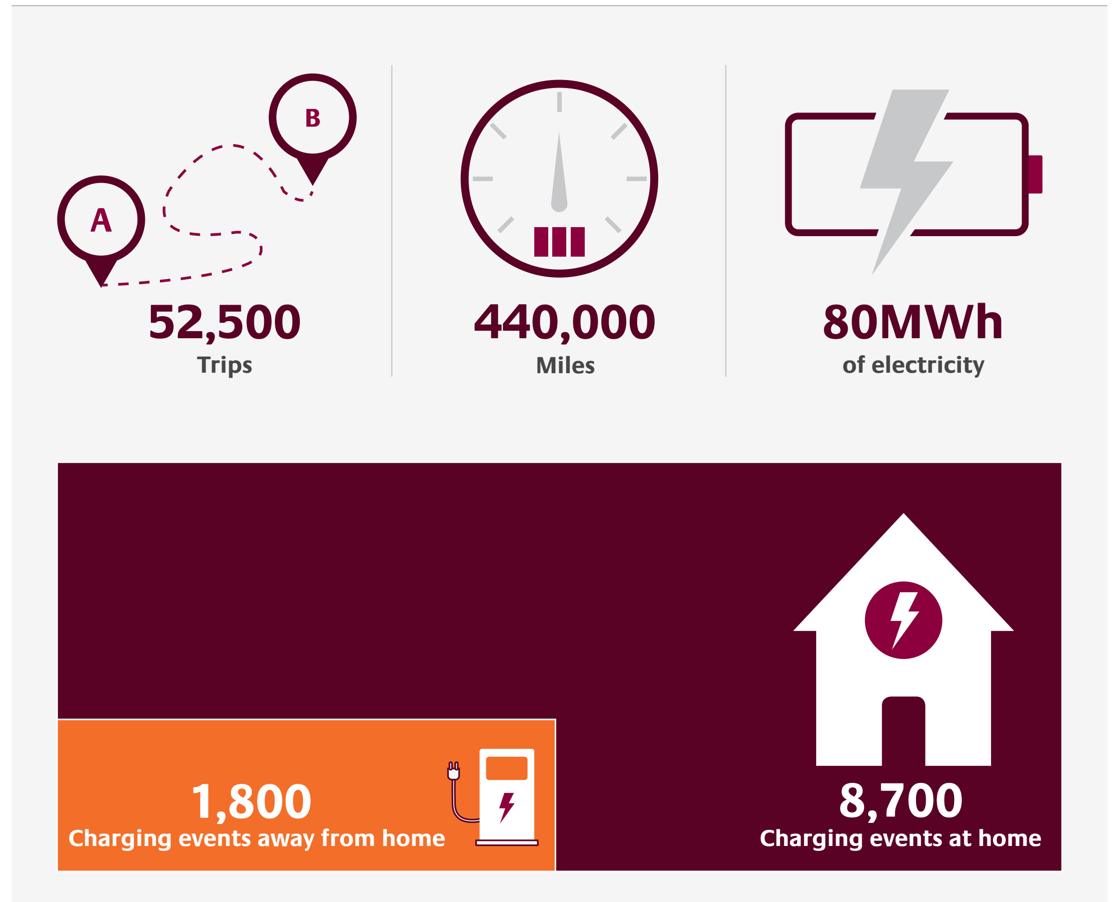
More than half of all new cars are currently bought by fleets.

- This proportion is likely to rise, as the total number of new car sales falls.
- Given the low electric miles fraction driven by many fleet PHEV drivers[16], incentives should focus on electrification of miles, rather than vehicle purchase.
- Fleets are therefore a critical target for policy, to ensure that second-hand vehicles entering the UK parc are suited to higher mileage drivers and that the socio-technical environment is increasingly supportive of maximising miles on electricity.
- Workplace charging will be part of this, given that it is the second largest charging opportunity, after the home.

ETI deliberately chose to study mass market drivers, since they are critical to 2025 and 2030 targets.

- It is right that the needs and behaviours of the earliest adopters are also being studied (by others), since they are an important step on the pathway.
- Although the focus of the CVEI project was vehicle uptake and charging management, detailed analysis of the data poses some important questions for attracting different people, with different needs, in different locations to use electric vehicles.
- Access to travel on demand through a combination of different modes will increase in many cities. This will combine public transport, cycle rental, Uber style taxi. services and occasional car hire, as a packaged offer.
- The pattern of vehicle ownership and use may change significantly by 2030, with many current low mileage drivers deciding not to own a car.
- Supporting the charging of high mileage taxi and ride hailing BEVs around the centres of these cities will be a new type of load on the electricity supply.
- The aim should be to attract visitors to these cities to park & ride style integrated travel services, thus reducing visitor fossil fuel mileage.

Figure 6
Summary of data from the CVEI consumer charging trials



[14] Typically key GPS and vehicle parameters at 1s frequency
[15] See for example data from The Miles Consultancy on real-world fleet PHEV performance

RECOMMENDATIONS

Overview

The UK stands at the end of the first phase of vehicle electrification. Measures to encourage the early uptake of electric vehicles and the provision of public charging points have been effective. Evidence from this early uptake, and related trials, points towards the issues for the next phase.

Attention is now turning to the framework for continued progress in an effective and robust way, especially a transition from push by focused point support mechanisms to a more commercially led series of activities. This can be where policy support stimulates private investments and innovations within a broadly technology neutral and competitive environment.

This policy environment is still developing, so there is a need to describe its potential outline as a backdrop for specific recommendations on knowledge and capability development. Over time, the body of evidence from real-world commercial activities will become the main contributor to policy development and policy mechanisms will therefore build in collection of evidence as an integral part of their design.

The ETI does not have the experience to make policy recommendations and the following policy backdrop is intended to only illustrate the issues. Within the next phase, it is expected that the main issues will be vehicle uptake, electrification of miles and overall fossil fuel use decline, and providing cost effective private and public charging access. Decline in fossil fuel use will reduce greenhouse gas emissions but has implications for tax revenues and the availability of petrol stations. Ensuring that the electricity used for recharging is mostly low carbon is likely to be a challenge for a later phase that should be considered today in the technical standards for charging management. ETI's recommendations are focused on the more technical challenges, which will support the interpretation of real-world data and especially its use for planning by businesses and policy makers.

Policy backdrop

Fleets

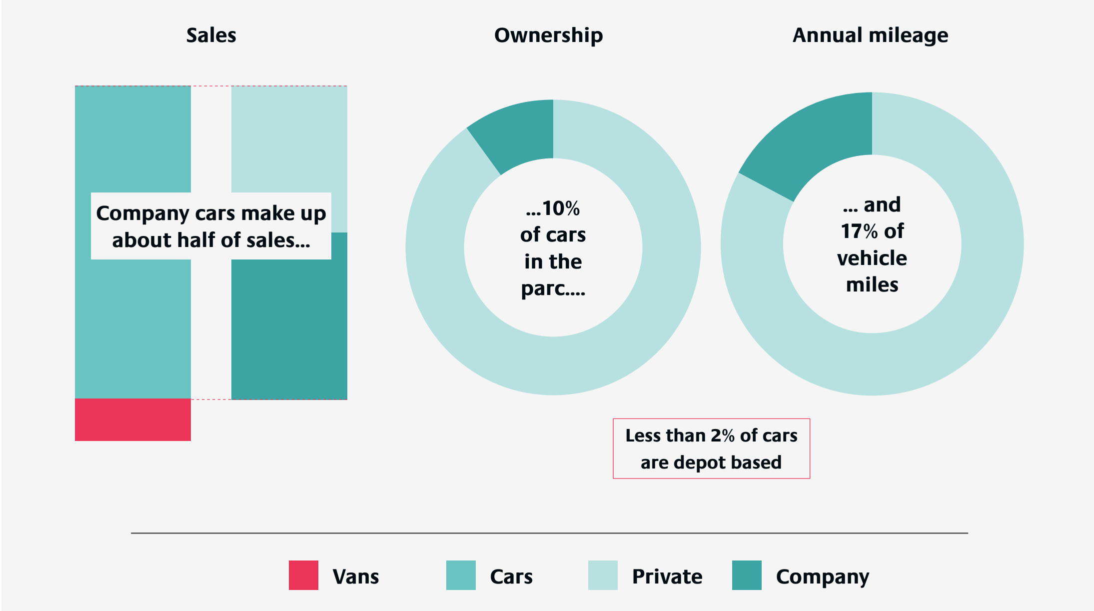
This is a very important group, both for the introduction of new vehicles into the UK parc, and also the electrification of miles. Over half of all new cars are bought by fleets which they sell on after first use. The market for used PiVs will therefore be led by vehicles purchased originally by fleets. Company car drivers, and other drivers with similar journey patterns, represent a large fraction of UK miles. Private hire taxi vehicles represent an important special case, especially given the strategies of companies like Uber. Fleets are therefore a critical target for policy. Fleet managers and their supply chains, including vehicle manufacturers, represent a large body of skill, experience and ingenuity. Within the right environment they can and will deliver considerable reductions in fuel usage and electrification of miles. The technical and social environment for cost-effective electrification and fuel use reduction will develop around lead fleet users and spread out to others.

Managing recharging, paying for recharging electricity across multiple sites and providing workplace charging will also be on the agenda of fleet managers.

It is imperative to incentivise electric miles (or disincentivise non-electric miles), not just PiV purchase. One might anticipate two elements to policy: taxation support for fleets which deliver targets for fuel use per mile and use of electricity, and minimum vehicle standards. The main driver of progress will be the benefits, supported by lower fuel bills and (in the case of BEVs) less maintenance. Minimum standards are intended to avoid low performing vehicles entering the used car market and also to set market expectations. Significant price support to vehicle manufacturers for PiV sales to fleets will probably diminish; support would be mainly through the fleet level tax benefits. Minimum standards might include a minimum electric range for PHEVs.

Once vehicles in a fleet meet the minimum standards, the fleet as a whole becomes eligible for tax benefits. Vehicle mix selection,

Figure 7
Contribution of company and private cars to UK sales, car ownership and annual mileage



operational factors, driver training and motivation will be the responsibility of fleet managers. In order to receive the tax benefit, they will provide an auditable return to Her Majesty's Revenue and Customs (HMRC) stating that they have met the minimum standards and providing evidence of levels of fuel and electricity use per mile. HMRC has considerable experience in developing appropriate requirements for auditable returns and supporting records.

It is likely there will be multiple bands of benefits, for example tiers 1 to 3. The lowest tier (1) would represent a realistic aspiration at the beginning of a company's journey and the highest tier (3) would represent an aspiration for the highest performing fleets, whose performance would provide role models and a source of industry wide learning. Over time, the requirements for fuel efficiency and electric miles for tier 2 would become those for tier 1, etc., so that the performance of the whole industry would move forward. Even fleets not yet at tier 1 would benefit from the availability of vehicles and approaches to minimise their fuel use and therefore their costs.

Analysis by Her Majesty's Government (HMG) of tax return data and case studies provided by the industry will provide a rich source of evidence for policy development and business planning. Undoubtedly, these analyses will prompt the development of research designs for combinations of social and technical research to explain important features of this real-world data. The process for collecting this data should deliver high quality results, without additional interventions and cost. Data collection is an inherent part of the process.

Private first purchasers

Current policy is focused on price support to vehicle manufacturers for first sale of BEVs. This seems entirely appropriate. BEVs are likely to be most attractive to lower mileage drivers who represent a large cohort within the population of UK drivers. Maintaining momentum in this segment is also socially and economically important, even if it turns out that electrification return on public investment is less than for fleets. Support for PHEVs is currently limited to those with a nominal electric range that corresponds to the CVEI target effective range (of 50 miles). Although this might seem restrictive, it does mitigate against the risk that PHEVs are driven in low electric miles fractions. As evidence emerges on progress with PHEV fossil fuel consumption reductions, the most appropriate support for PHEV purchase can be reviewed. How efficiently range extension is achieved is also important. There will also be a segment of somewhat higher mileage drivers who can afford a long-range BEV. Although price support will probably be important to them, their decisions are not primarily driven by economics and there is a risk that relating price support to range would exceed what is required to stimulate purchases by this segment.

Electricity and fuel use

Government statisticians have developed methods to collect data on fuel use. The challenge for electricity used for recharging vehicles is to untangle it from electricity for other uses.

An underlying assumption is that recharging is a new load class that will require management separately from other uses, probably with a different cost structure. There are a variety of reasons that could be summarised as providing incentives to make best use of existing generating and network capacity by reflecting costs appropriately. This is especially so for incentives to make best use of low carbon generating capacity.

These incentives are important because recharging vehicles has a much higher degree of flexibility than other load classes (as we have evidenced in the CVEI project) and it is a very large energy requirement, not dissimilar to existing domestic consumption (on a per household basis).

Provided that the right technical standards and data collection requirements are developed, extensive data on vehicle recharging will be collected from fleets and individuals. The primary driver for collecting this data will be operational and investment planning by the electricity industry and charging businesses. Analysis of this will, however, be invaluable for policy development and business planning.
There will be a significant need to explain characteristics of charging behaviour through a combination of social and technical research.

Charging access

In one sense, this has already moved from a support push phase to a more commercial phase. Businesses are showing a great deal of interest in investing in charging technologies and charge point locations. Government is providing innovation support for understanding current charging patterns, Vehicle-to-Grid technology development, and using Smart Meters to ration local network capacity through connecting their Auxiliary Load Control to the charge point.

However, this market is only emergent. Whilst vehicle design, performance and choice will improve and more PiVs will be bought and driven differently, the existing network capacity may be used up quickly and inefficiently. Market design and market shaping incentives are needed if the most efficient use of existing resources is to be achieved.

The emergent nature of the market is exemplified by the competition between battery technologies that can withstand rapid charging and those that are less resistant, which has only just started. The network implications for supporting this competition are considerable.

The main challenge is to collect and analyse complex evidence to support policy and planning, rather than new policy development.

There will be a significant need to explain characteristics of charging behaviour through a combination of social and technical research.

Against the backdrop of these perspectives on possible policy approaches, the ETI recommends:

Area Models

Tools are required which combine simulation of drivers and transport patterns with the location of charging and its impact at the scale of a regional distribution system. Key challenges for these tools include modelling driver behaviour on a Monte Carlo basis, together with the impact of charging loads on the local network. It is important that these tools should provide sufficient granularity in time and space, since system failure is due to random combinations of localized events, as shown by Infield[16]. The models need to include the data, communications and control activities in the system (for example the Smart Meter infrastructure) and the operation of different actors. Actors include drivers, building occupants and suppliers, with some representation of the wider energy system, including the Electricity System Operator (ESO).

The ETI has funded the Energy Systems Catapult (ESC) to carry out research and prototyping on modelling building occupant behaviour and network loading for low carbon heating. This research showed that these kinds of models may be tractable and provide a platform for further development. These capabilities should be expanded to include journeys, drivers and charging away from home.

National Models

There are a number of significant system control challenges involved in managing charging, when drivers are responsive to supplier managed charging as seems likely from our CVEI project. Area models can give some sense of how many drivers are likely to be plugged in and available for a variety of responses, ranging from Enhanced Fast Frequency Response through to load shifting. Dispatch modelling at an ESO scale is required to understand how the addition of a large and complex "Demand Response" system might impact system design and operation.

The ETI recently commissioned an extension to its Energy System Modelling Environment (ESME) tool, by Baringa Partners, to include system flexibility and dispatch analysis on a multi-vector basis[17]. Learning from Area models could be used to calibrate the demand response profiles of both vehicle charging and heat-pumps. Vehicle charging is the clear priority.

Consumer Trials

The EA Technology Electric Nation project has gathered charging data from drivers who have purchased a PiV (i.e. very early adopters), including data on charging management. The starting point was to test methods of managing rationing of network capacity, investigating both the technical and consumer aspects. This work is important to network companies and should continue. These drivers could also be used to test responses to different charging management propositions, whilst recognising that these earliest adopters do not predict mass market behaviours and attitudes.

There should also be further trials of charging management with mass market consumers, looking at supplier managed charging. Although CVEI has met its objectives and has shown that mass market consumers are open to managed charging, there are many detailed aspects relating to this which require further research.

One approach might be to leave this proposition development and segmentation work to commercial companies. However, the potential economic value to the UK, the barrier to innovation presented by the cost and complexity of consumer trials, the need for the trial design and analysis to be strongly coupled with the operation of the wider energy system and the pace of policy development required to implement in time, all argue for a set of trials with outputs that are more openly available.

[16] Markov Chain Monte Carlo simulation of electric vehicle use for network integration studies, Wang & Infield, International Journal of Electrical Power and Energy Systems, 99, 85-94
[17] As with ESME, this is now hosted by the Energy Systems Catapult (ESC)

Technical Standards and Governance

If vehicle charging is to be managed effectively, a whole range of standards and codes will need to be developed or modified, and adopted within the system governance, including any primary or secondary legislation.

Examples include:

- Communication between charge points and vehicles.
- Communication between charge points and Smart Meters.
- The basis on which Smart Meters can be used by multiple suppliers.
- Standards for monitoring network loading.
- Standards for preventing network overload by communicating with charge points.
- Market structures to implement incentives and rewards for suppliers to manage charging to allocate network capacity, minimise additional systems costs and minimise additional systems carbon emissions.

There will also need to be agreement amongst the energy and automotive industry as to the form that managed charging should take and how it should evolve over time. To inform these decisions, the impacts should be assessed using the aforementioned Area Models, National Models and Consumer Trials.

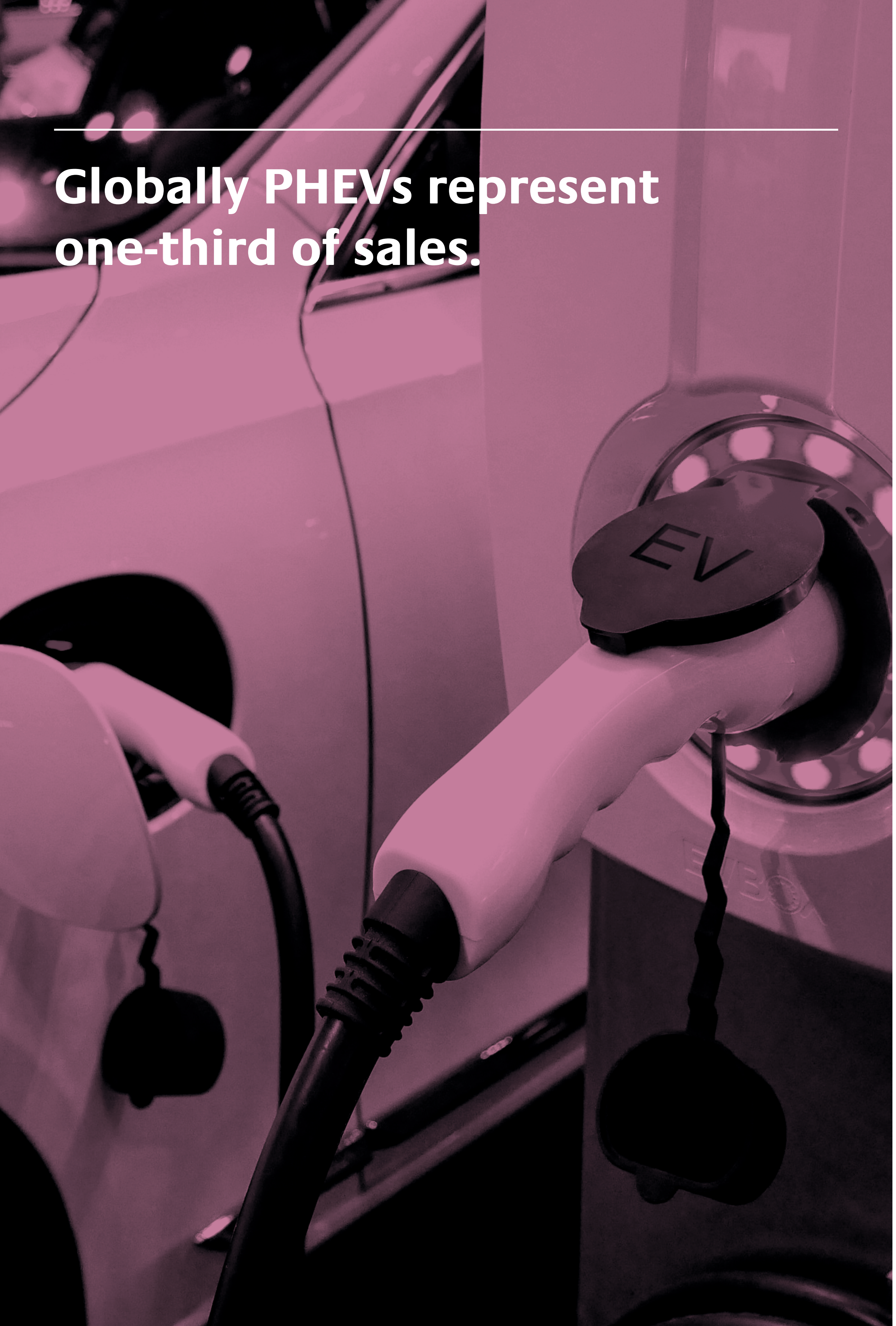
What is the CVEI project?

- The CVEI project has generated a wealth of detail, models, data and analysis based on vehicle uptake and charging consumer trials with mass-market consumers. This insight uses data from CVEI, in combination with other analysis, to consider the implications for decarbonization of the UK energy system out to 2030. The key reports from CVEI are available in the ETI Knowledge Zone and the tools and data can be accessed through the Energy Systems Catapult. The project Summary Report is a good starting point[18]. The CVEI project had a broad mission, covering a wide range of factors involved in vehicle uptake to 2050.

Other ways to decarbonize transport

- Whilst it appears likely that PiVs will be the dominant low carbon technology for cars and vans, it is less clear what the solution might be for other vehicles. It might still be that hydrogen wins out for light vehicles in the long run, and we should keep this option open, at least until battery-electric light vehicles represent a significant fraction of the UK parc.
- There are signs that walking, cycling and mass-transit are all likely to play a greater role in personal mobility across the UK in future, especially in, around and between cities. Although they will have a significant impact in these locations, there will still be extensive car and van usage across the UK. There are many benefits to an increase in these modes of travel and it is encouraging to see examples of serious and well-organised efforts to support them.
- On average cars currently spend less than 5% of their time on the road. More than 40% of cars are driven less than 4,000 miles per year. The social and individual return on the higher upfront investment in a replacement electric vehicle for low mileage cars is quite low. Arguably these journeys would be better served by some combination of shared access to cars, car rental, better public transport, cycling and walking, especially in integrated public and private transport systems.
- Different ownership models and autonomous vehicles may transform vehicle use in future. Much higher utilisation of cars would change their design parameters, making the up-front cost of the vehicle a lower element of cost per mile and changing the basis of competition, for example between electric and hydrogen vehicles. Refuelling requirements would change, because of the reduced availability of “charging windows”.

[18] Available at: https://www.eti.co.uk/programmes/transport-ldv/consumers-vehicles-and-energy-integration-cvei



Globally PHEVs represent one-third of sales.

How the UK compares

- The latest report on vehicle electrification from the International Energy Agency[19] shows a wide variation across different countries in PiV sales and provision of public charge points. Norway and Sweden stand out on the journey to vehicle electrification, although the Netherlands has a large stock of Plug-In Hybrid Electric Vehicles (PHEVs) from a period when there were business tax incentives for their purchase. Annual PiV sales in the Netherlands reached nearly 10% market share at the peak but have since fallen back, due to changes in the business tax regime.

- The split between pure Battery Electric Vehicles (BEVs) and PHEVs varies widely between countries, but globally PHEVs represent one-third of sales. PHEVs are a slight majority of sales outside China. Provided that PHEVs are driven in order to use their battery, the exact split between BEVs and PHEVs is not important to decarbonisation, but both are required in the UK to achieve 2030 decarbonisation goals.

- Public charge point availability on a global basis is slightly more than the EU target of 10% (1 charge point per 10 PiVs). There is no obvious pattern to public charging point provision, apart from countries with higher penetration of PiVs managing successfully with lower provision than the EU target. Fast charging is at an early stage, except in China and Japan. The UK is third in terms of fast charger penetration. The Netherlands has the highest public charge point provision, but relatively few are fast chargers[20].

- Looking at trends in each country over the last few years, the impression is of a rapidly developing picture, with country specific factors, but underpinned by economies of scale arising globally in both battery cell manufacture and battery pack size. Different factors interact to deliver battery pack cost and performance[21].

[19] Global EV Outlook: towards cross-modal electrification, IEA, May 2018
[20] Less than 3% have a charge rate greater than 22kW, https://www.eafo.eu
[21] BatPaC: A Lithium-Ion Battery Performance and Cost Model for Electric-Drive Vehicles, Argonne National Laboratory, http://www.cse.anl.gov/batpac/index.html

What the Charging Trials have told us

- Within the Charging Trials undertaken in the CVEI project, mass-market consumers were monitored to see how they used and charged BEVs and PHEVs, whilst being provided with different varieties of managed charging[22].
- Both a Time-of-Use form of managed charging and a more sophisticated variant, where the consumers provided information about their needs and delegated control of the charging to a third-party, were tested; alongside a Control group who did not have managed charging.
- The trials provided evidence that mass-market consumers do in fact predominantly charge at peak times of electricity demand, when not using managed charging. This would have significant, challenging consequences for energy supply and the cost of energy that could be delivered if EVs were widespread. By contrast both forms of managed charging, were shown to be effective at shifting charging away from typical peak times of electricity demand.
- Following their experience of using and charging an EV in the trials, the consumers were asked which of the three forms of charging they would choose. Across the experimental groups, between 76% and 96% chose one of the two variants of managed charging. This shows that managed charging offerings can be designed to appeal to mass-market consumers.
- The attitudes of the consumers in the trials were further explored through choice experiments to uncover their underlying preferences. This revealed broad characteristics of managed charging offerings that would enhance their appeal. For example, consumers highly valued the presence of an override function, to charge straight away, even though they only used that feature in the trial infrequently.
- Looking deeper into the data, further lessons can be drawn. The Time-of-Use form of managed charging resulted in charging coalescing at the start of the cheapest period of the tariff. This poses a system level risk at high levels of EV uptake where a new super-peak could emerge. It also points to the need to have a more intelligent form of managed charging, such as the delegated control variant that was tested in the trial, in place before that arises. Fortunately, the consumers in the trial who had experienced this more sophisticated variant of managed charging – where they merely indicated when they next needed the car and how full they wanted the battery – were more likely to choose that than the Time-of-Use variant. This suggests there is the potential for a more intelligent form of managed charging to gain traction and deliver greater savings across the energy system, ultimately lowering electricity costs for all electricity consumers.
- Further information and results from the Charging Trials can be found in the Consumer Charging Trials Report on the ETI Knowledge Zone[23].

[22] The term “managed charging” is synonymous with the term “smart charging”
[23] https://www.eti.co.uk/programmes/transport-ldv/consumers-vehicles-and-energy-integration-cvei

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