Project Shift

UK Power Networks
Delivering your electricity

Summary Report – September 2021

Contents

Glossary of Terms

Coincidence Factor	**CF**
Distribution Network Operator	**DNO**
Distribution System Operator	**DSO**
Distribution Use of System Charges	**DUoS**
Electric Vehicles	**EV**
Low Voltage	**LV**
Plug-in hybrid electric vehicle	**PHEV**
Profile Class 1	**PC1**
Significant Code Review	**SCR**
Transmission Network Use of System Charges	**TNUoS**
Time of Use	**ToU**

Thank you to our collaborators

We would like to recognise the valuable partnerships with Kaluza, ev.energy and Octopus Energy on the project and insights that collaboration with them has enabled. Their contributions to the project have enabled us to develop a richer understanding of market-led smart charging, and the motivations and perceptions of customers involved.

Thank you to Baringa Partners for their continued support and analysis on the Shift project.

The 8.3 million customers and businesses connected to our electricity network are increasingly making the switch to cleaner forms of transport to reduce harmful emissions.

4.5 million
electric vehicles in 2030

62%

of EV charging occurs at home off-street

By 2030, we forecast up to 4.5 million electric vehicles will be connected to our electricity network[1], a 30 fold increase on those connected today. This acceleration is fuelled by government policy, technological advancement, and changes in public sentiment as awareness and confidence in the charging infrastructure needed to support this transition grows. This includes the government bringing the ban on sales of petrol and diesel cars forward from 2040 to 2030.

Charging at home is both convenient and cost-effective for those who have the ability to do so. In our EV Strategy[2] we estimated that 62% of EV charging occurs at home off-street. Although we project this to decrease to 38% by 2028 as more on-street charging infrastructure is deployed, we expect it to remain the largest charging segment.

As a Distribution Network Operator (DNO), we need to ensure that the distribution network is adequately sized for the expected future demand, while managing the uncertainty of when and where electric vehicles will be adopted. Seen today, most parts of the distribution network would be able to accommodate the relatively low levels of EV penetration. However, as the projected EV uptake materialises, unmanaged EV charging would soon require significant additional network reinforcement.

Previous studies have shown that unmanaged domestic EV charging could approximately double the peak demand of an average household. Accommodating that demand at network level would require widespread investment in network capacity, potentially leading to increased electricity bills for consumers. There would also be increased disruption for customers as a result of the street works needed to reinforce the network, and could impact the pace that networks can facilitate EV uptake.

Our ambition is to facilitate Net Zero at the lowest whole system cost to customers, including accommodating the electrification of transport in an efficient and timely way.

To facilitate a more cost-effective transition to Net Zero, we are rapidly developing capabilities as a Distribution System Operator (DSO). One of the integral functions of a DSO is to utilise energy flexibility to manage network capacity, establish a more resilient grid and save money for our customers. Through this transition and network innovation, we are continually developing solutions that enable us to manage capacity more efficiently as the UK transitions to Net Zero.

[1] UK Power Networks Distribution Future Energy Scenarios 2021 https://innovation.ukpowernetworks.co.uk/wp-content/uploads/2021/01/2020-DFES-Report-Final-January-21.pdf
[2] https://innovation.ukpowernetworks.co.uk/wp-content/uploads/2019/11/UK-Power-Networks-Electric-Vehicle-Strategy-November-19.pdf

19%
of the time spent plugged-in at home is used for charging

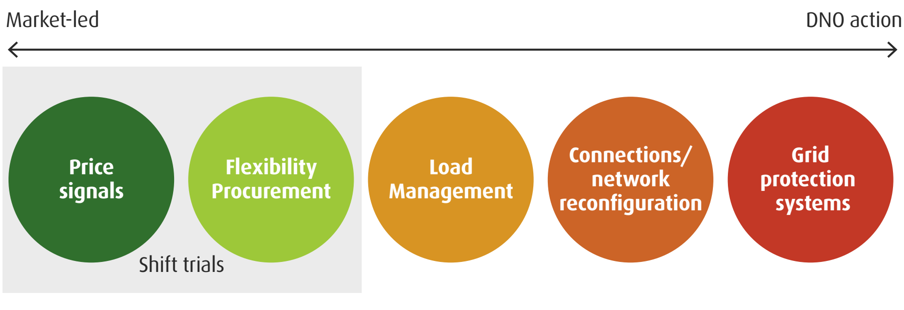
On average, EVs only charge for 19% of the time they are plugged in at home. This provides an opportunity to shift demand away from typical plug-in times when demand for electricity is already high, to times when the electricity network is less congested. This can reduce the capacity required to accommodate EV uptake on local networks, allowing capacity for other low carbon technologies and in some areas, delaying or preventing the need to reinforce the network.

Importantly, smart charging enables customers to use electricity when it is both cheaper and cleaner. Non-renewable generation is often used to meet electricity demand at peak times such as the early evening. There is also a strong correlation between the wholesale price and carbon intensity of electricity[3]. The interplay between market incentives and local network needs must be considered to ensure the best solutions are made accessible to customers. Used as part of a whole systems approach, smart charging will facilitate more renewables to connect to the network and enable the UK to reach Net Zero.

With the right market mechanisms, customers, market participants and networks should be able to share in the benefits of flexibility, such as smart charging.

The value of smart charging has been shown through previous trials such as SSEN's My Electric Avenue project and WPD's Electric Nation, both of which made use of technical solutions where the DNO controlled the charging. These projects demonstrated that customers were open to changing their charging patterns when required, so long as their mobility requirements were met. Through our Smart Charging Architecture Roadmap CAR[4] project, we established that a marked-based approach to smart charging was the preferred approach, both by us and our stakeholders.

Figure 1
Hierarchy of mechanisms for managing network capacity



[3] https://www.elgarmiddleton.com/exploring-the-correlation-between-the-carbon-intensity-of-the-uks-electricity-and-the-wholesale-price/
[4] https://innovation.ukpowernetworks.co.uk/wp-content/uploads/2019/05/UKPN-Smart-Charging-Architecture-Roadmap-Final-Report.pdf

A market led approach to incentivise smart EV charging will create a smarter, flexible network accessible for domestic consumers through:

- **Market mechanisms** between the DNO/DSOs and suppliers/service providers create a financial incentivise to use electricity when network capacity is available
- **Customer propositions** are offered by suppliers/service providers to their customers (for example through smart tariffs) to incentivise flexibility.

For widespread participation, smart charging needs to be simple, accessible and trusted, with incentives designed around real-world customer behaviour and preferences.

Engagement with a range of industry stakeholders, and independent research with 800 motorists[5], helped us to define three market mechanisms to be trialled during project Shift. To trial these in a real-world environment, we ran an open 'expression of interest' process to appoint project partners.

Distribution Use of System Charges or DUoS cover the costs of the electricity distribution network. DUoS charges are wrapped up into the cost of electricity for domestic consumers by suppliers who pay these on behalf of the customer.

The resulting partners for each mechanism were:

Time of Use (ToU) Distribution Use of System (DUoS) pricing	KALUZA
Capacity-based DUoS pricing	octopus energy
LV flexibility procurement	ev.energy

Figure 2
Creating market based incentives for domestic smart EV charging

[5] Customer research with those outside the Shift smart charging trials.

2,500+
domestic customers shifted their charging during the trial

248MW
capacity procured from EV batteries in our latest DSO tender

Shift stimulated a market for smart EV charging and explored the efficacy of these solutions, leading to the world's first LV flexibility tender and the UK's first contract with EV service providers.

Collaboration with customer-centric partners on Shift led to the development of several customer propositions, which were adopted by over 2,500 domestic customers during the 12 month trials to understand:

- **Can mechanisms to incentivise flexibility help DNOs manage network constraints on the low voltage (LV) network?**
- **What peak load reduction can be achieved under each mechanism, whilst delivering the customers' needs?**
- **How might these approaches interact with wider market services and electricity network needs?**

On the trial, incentives through the respective mechanisms were set to encourage charging outside of the residential peak on the low voltage (LV) network, which typically occurs around 6-9pm. The DUoS pricing structure was designed to reflect the realistic value of flexibility to the distribution network. This was done to observe how these incentives might function alongside wider market price signals and compare to investment in network capacity.

The development of these mechanisms through Shift led to the world's first low voltage flexibility tender as well as the UK's first contract with an EV service provider, which has stimulated the market to develop further customer propositions. Securing contracts directly with EV service providers, UK Power Networks has now procured 248MW of capacity from EV batteries[6] through the use of smart charging solutions. This holds the key to enable customers to access added value from their cars whilst reducing the need for costly reinforcement on the network.

In this report, we share the outcomes of Project Shift, including the findings of the trials themselves and how mechanisms can be implemented to unlock the value of smart charging to the industry and our customers.

[6] https://smartgrid.ukpowernetworks.co.uk/flexibility-hub/

1

Trial Design and Results

Trial Design and Customer Propositions

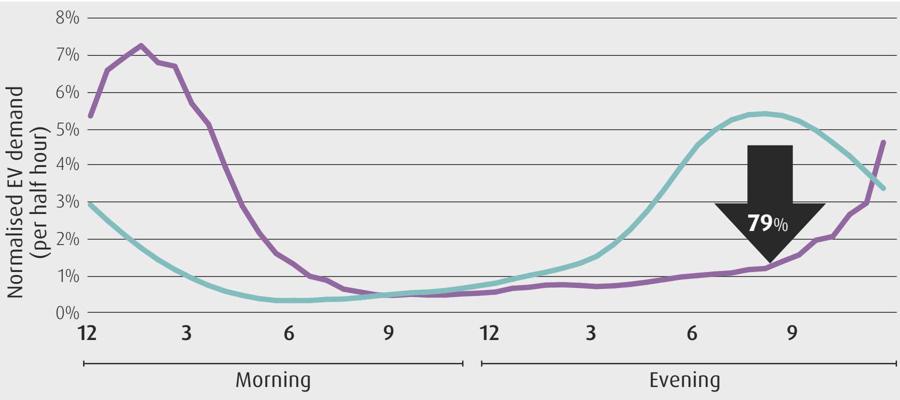
	Time of Use DUoS pricing trial (Kaluza)	Capacity-based DUoS pricing trial (Octopus Energy)	LV Flexibility procurement trial (ev.energy)
Trialled concept	ToU network charging with algorithmic optimisation of EV charging.	Capacity-based network charging, with customers managing their own EV and household consumption.	Supplier/aggregator contracted to provide LV flexibility services, and delivers algorithmic optimisation of EV charging.
Market mechanism	Two ToU DUoS shapes were trialled: 'red peak' and 'shoulder pricing', making electricity more expensive between 6-9pm. These signals were combined with wholesale and TNUoS prices which Kaluza optimised against. The ToU DUoS signal was not exposed to the end customer.	Conceptually, the supplier booked the capacity needed for a group of customers and payed penalties for capacity exceeding this. To reduce the capacity booking required per customer, the supplier incentivised demand to be more distributed by offering a time of use tariff with staggered start times.	Supplier/aggregator 'contracted' to limit the charging demand of a portfolio of customers to a predetermined level during the 'service window' based on the LV peak (6-9pm).
Customer proposition	Customers received a free or discounted smart charger before the trial. A £50 voucher was provided for joining the trial. There was no on-going customer incentive beyond this point and over half of customers were on a flat rate tariff. Customers set their charging needs via an app, and had access to a "boost" function to start charging immediately, by overriding the smart charging schedule for that evening.	A new tariff called 'Octopus Go Faster' was created for the trial. It offered customer's low cost electricity over different times of the evening to stagger charging. Low price windows varied by start time and duration across the customer base, with customers able to select these. The first 300 customers were also offered £5 for each month they participated in the trial.	Customers were rewarded for each smart charging session completed with points that could be used to claim rewards. Customers could be on any tariff. As with Kaluza, customers could set their preferences via an app and had access to an override function.
Optimisation approach	Fully automated approach, with each EV charging session optimised by an algorithm that ensured customer needs were met at the lowest cost to the customer and supplier. Optimisation was overridden when the boost function was used by customers.	As the tariff was technology agnostic, it allowed customers to enact their charging schedule via smart devices, timers in the car/charge point or undertake this manually.	Fully automated approach, with each EV charging session optimised by an algorithm that considered customer preferences, tariff and services being provided. Control could be done via the smart chargers or smart control via a 'connected car'. Optimisation was overridden when the boost function was used by customers.
Trial size	Kaluza targeted 368 existing customers to participate in the project Shift trial, of which 311 accepted.	Octopus Energy promoted the tariff to their customers as well as on their website. Customers on Go Faster tariff increased from 199 to 1182 over the course of the trial. Customer numbers fluctuated as customers moved between the Go Faster and other tariffs such as Octopus Agile, to take advantage of the best prices during the trial period.	ev.energy targeted over 3,000 existing customers to participate in the project Shift trial, of which 445 were recruited by Q2 of 2020. Since then an additional 581 customers joined the Shift proposition offered by ev.energy, bringing the total number to 1026.

Observed Peak Shift

Across all three of the trialled approaches, smart charging has successfully shifted EV charging away from the evening network peak demand.

All three smart charging approaches trialled under Project Shift (ToU DUoS, Flexibility Procurement and Capacity-based charging) reduced the EV demand at peak times. Across the full cohort of customers on the Kaluza ToU DUoS and ev.energy Flexibility Procurement trials, the average diversified peak EV charging demand seen at 8pm was reduced by 79%[7].

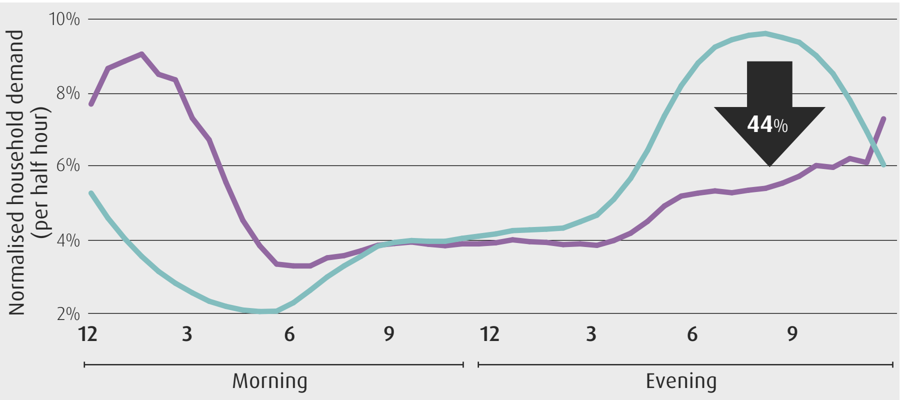
Figure 3
Average EV Charger profiles from Kaluza and ev.energy trials
(all customers across the full trial period)



Key
- Unmanaged EV charging
- Managed EV charging

At an overall household level, if we assume the underlying (non-EV) customer demand aligns to Elexon Profile Class 1 (PC1)[8], the effect of smart charging would be to reduce the 8pm peak demand (as compared to the unmanaged charging peak) by 44%. Note that during the trial period, the UK went into 'lockdown' as a result of COVID-19, which reduced driving and hence energy consumption. Although the overall energy consumption significantly reduced during this period, the shape of the normalised load profiles were relatively consistent throughout the trial.[9]

Figure 4
Average Household profiles from Kaluza and ev.energy trials



Key
- Household + unmanaged demand
- Household + managed demand

[7] Because of the trial design, the Octopus customer demand was only measured at the household level rather than the EV charge point
[8] The trial design was done on the basis of a PC1 domestic demand profile. A different profile, such as PC2 ('Economy 7') would have a different household peak, so would require different EV charging signals to smooth out demand.
[9] Comparisons of demand pre-COVID and during COVID restrictions are presented in the Shift Progress Report https://innovation.ukpowernetworks.co.uk/wp-content/uploads/2021/02/UKPN_Shift_Interim_Report_v05.pdf

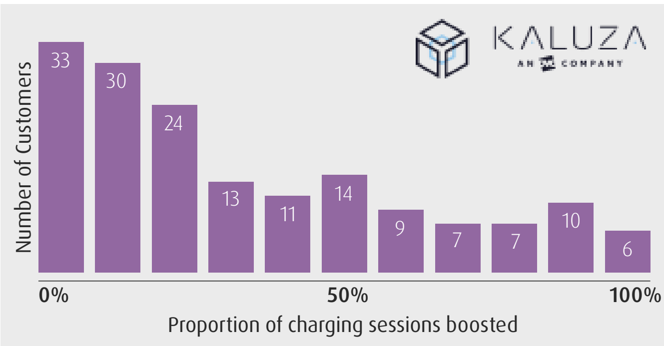
Boosting Behaviour

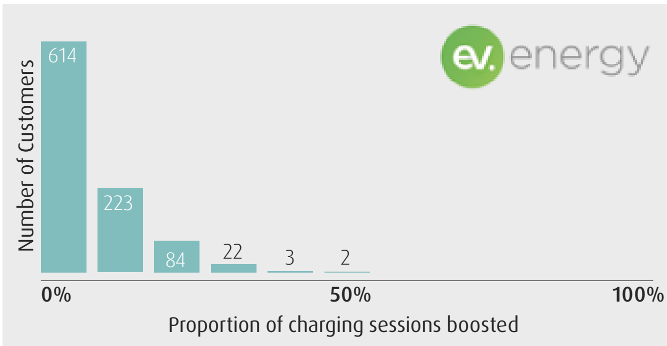
Although the 'boost' function is important for peace of mind and customer acceptance, it was only used for 16% of charging sessions during the trial.

Customers maintained control of their charging in all three trials. Charging for customers on the Octopus trial was not controlled by Octopus Energy, and so inherently customers had the option not to respond to the incentives provided through their tariff on any given day. Customers on the Kaluza and ev.energy trials had the ability to override a smart charging session and start charging the EV immediately. This was done using a 'boost' function on the charge point or app, meaning that this behaviour could be tracked and analysed.

The rewards for smart charging in the ev.energy trial gave these customers a financial incentive not to override smart charging sessions and the majority of customers rarely or never used the boost function. Boosting behaviour was more prevalent on the Kaluza trial, and a small proportion of customers used this feature frequently. However, more than half of customers on the Kaluza trial were on a single rate tariff and as the trial reward was an upfront voucher, these customers had no ongoing financial incentive to smart charge. These observations indicate that the majority of customers typically allow their EV to smart charge, and that further inducements in the customer propositions could reduce the boosting levels observed in the trial.

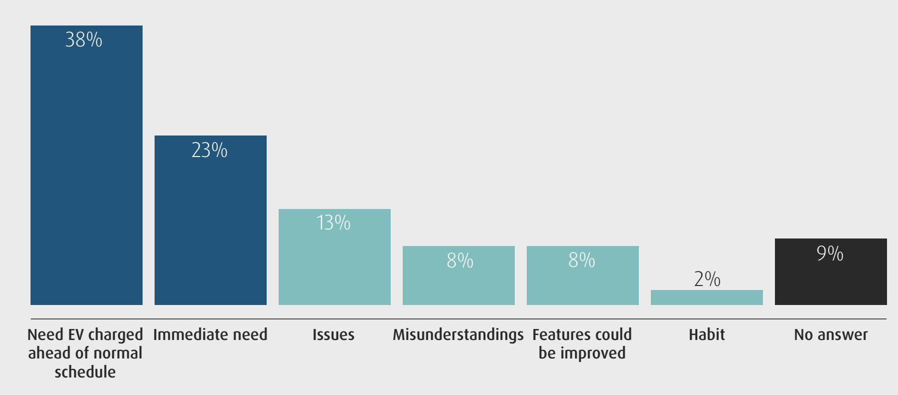
Figure 5
Boosting behaviour in the Kaluza and ev.energy trials





While the customer proposition and financial incentives appear to have had a clear impact on customers boosting behaviour, the reason most customers gave for boosting was that they needed their EV charged ahead of their normal schedule. This immediate need to charge is likely to have contributed to the greater levels of boosting observed for PHEV customers due to their smaller battery capacity.

Figure 6
Kaluza trial customers – reasons given for boosting



Key
Factors a flexibility provider cannot influence
Factors a flexibility provider can influence

Contribution to Peak Demand and the Effect of Peak Shifting

The mechanisms trialled shifted demand to the overnight period, creating a 'secondary peak' in EV charging. This could become the dominant peak at high levels of EV uptake or in locations where there is existing overnight demand such as storage heaters.

As part of the project design, it was hypothesized that secondary peaks could become an issue under smart charging arrangements, with responses to price signals reducing the natural diversity of charging behaviour.

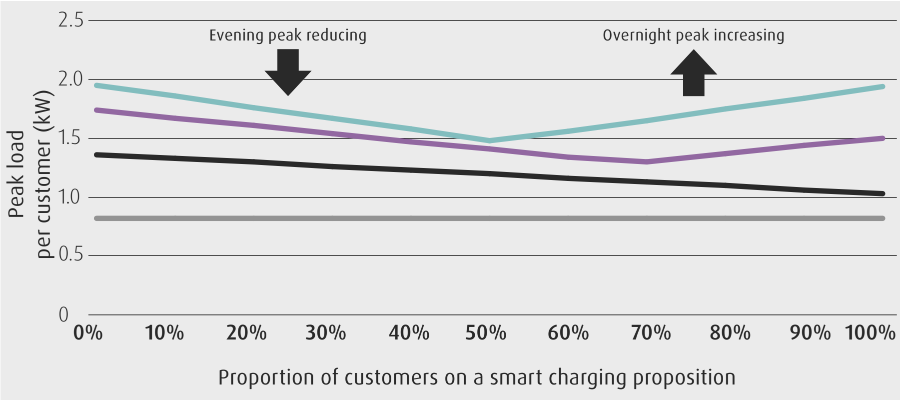
In both the Kaluza and ev.energy trials, the EV charger peak demand shifted to the overnight period. In the Kaluza trial, the magnitude of this peak was the same as the original evening peak. However, for the ev.energy trial, the peak was higher than the baseline evening peak, rising from 0.84kW to 1.08kW, as a greater proportion of demand was shifted away from the 6-9pm window. This suggests that a reduction in natural diversity is indeed a risk, but that this effect is related to the design of the customer proposition and level of response.

To further investigate the potential consequences of secondary peaks, using the ev.energy trial data and Elexon PC1 household demand, we analysed how much the diversified peak demand per customer changes as EV uptake and smart charging participation increase. For this analysis, we have assumed that there are 100 customers on the network, typical of a semi-urban low voltage network.

Initially, increased levels of smart charging are seen to reduce the average evening peak load per customer, as load is shifted to the overnight period. However, as smart charging becomes more prevalent we see an inflection point, above which the overnight peak due to smart charging becomes dominant. For very high levels of EV penetration, then, smart charging (as trialled) would only be effective up to a certain point, beyond which the overnight peak becomes the driver of network peak load.

Figure 7
Estimated peak load per customer under different levels of EV uptake and smart charging *(using ev.energy trial data and Elexon PC1 household load profile)*

Key – Customers with an EV (of 100)
- 0
- 20
- 60
- 100



The chart above illustrates what could occur if smart charging were applied to domestic EVs whilst the remainder of a household's demand continued to resemble the current typical consumption profile (PC1). It also assumes that the network area in question is populated entirely with residential customers, with large troughs in overnight demand.

However, if the same analysis is done but overlaying smart charging on a Profile Class 2 domestic household (so-called 'Economy 7') we see that smart charging increases the peak load per customer, even at low levels. This is because PC2 households already have an overnight peak, typically corresponding to electric heating load, which is being exacerbated by shifting EV charging demand overnight.

Whist these results are only indicative, they illustrate how secondary peaks have the potential to impact the effectiveness of smart charging, particularly if the underlying demand profile of a given network area is not understood. In the case of purely residential network areas, if underlying household demand remains close to the PC1 profile, the shifting of load to the overnight period is unlikely to drive additional constraints until EV penetration is high, and smart charging the norm. However, in areas with a greater level of overnight demand it will be necessary to apply tailored smart charging incentives to avoid exacerbating local overnight peaks.

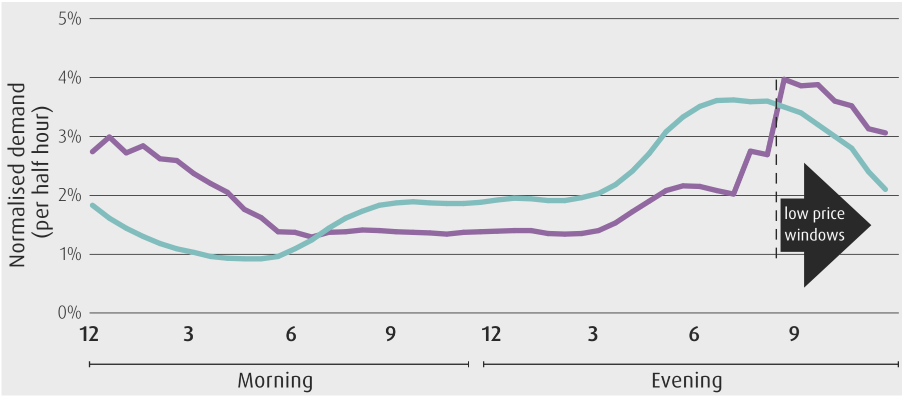
Preventing the Overnight Peak

Overnight demand can be smoothed beyond what was observed in the trials if customers can be encouraged to charge at different times.

Each of the three trials were designed to reduce demand during the evening peak. However, neither the Kaluza ToU DUoS trial nor the ev.energy LV Flexibility Procurement trial explicitly attempted to avoid the formation of a secondary overnight peak.

Capacity-based charging, which was trialled by Octopus Energy, is intended not only to reduce the contribution to the evening peak, but to smooth the shifted demand across the overnight period. In the trial design, this was to be done by offering different 'low price' windows to different customers so that their incentive to charge occurs at different times and for different durations. However, as trialled, the normalised household demand profile resulted in a managed household peak demand that was higher than the baseline.

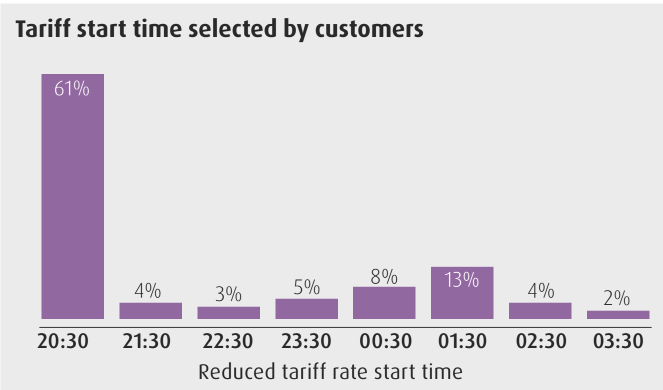
Figure 8
Octopus Go Faster trial household demand profiles

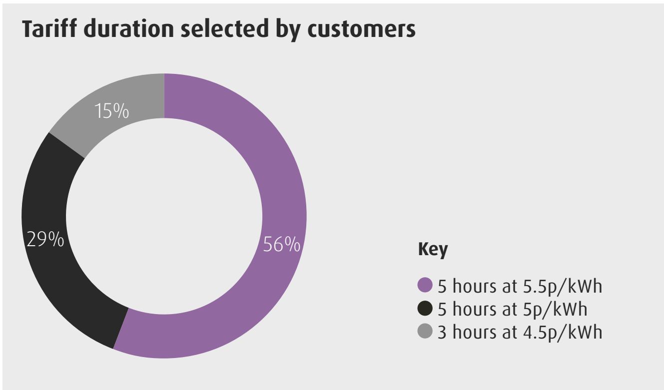


Key
- Household + unmanaged demand
- Household + managed demand

This peak occurred at 8.30pm, which corresponded to the first of these 'low price' windows. Some of the Octopus Go Faster customers were therefore incentivised to begin charging, and using their other domestic appliances, from 8.30pm, which they did either manually or using their own devices' smart capabilities. Furthermore, this 8.30pm cohort represented a significant majority of the customers on the Octopus Energy trial.

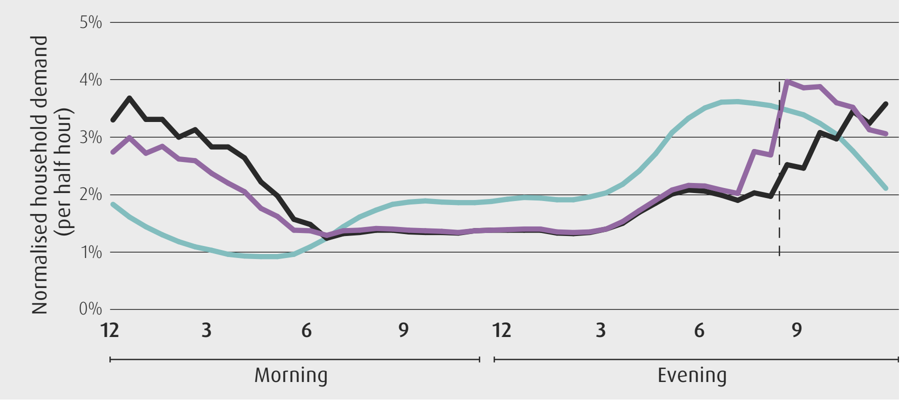
Figure 9
Octopus Go Faster customer breakdown by low-price start time and low-price window length





Subsequent analysis, however, showed that altering the distribution of customers across the start times results in different demand profiles. We have shown an illustrative example of how recruiting customers evenly across the different low-price tariffs reduces the evening peak and smooths the shifted demand across the overnight period. There could be further opportunity for smoothing by optimizing the proportion of customers on each tariff.

Figure 10
Estimated Octopus Go Faster profile if customers are averagely distributed compared to trial household demand profiles



Key
- Household + unmanaged demand
- Household + managed demand
- Averagely distributed profile

On the trial, the Octopus Go Faster customers were free to choose their preferred tariff, and many opted for the earliest available start (8.30pm). Customers were not incentivised to opt for later low-price windows. However, Octopus Energy did test whether customers would be willing to move to different low-price windows, and there was early evidence that some customers were willing to make this change.

There is reason to believe, then, that there is further opportunity to smooth shifted demand beyond what was observed during the trial period. The specifics of how this would work for each trial design, and how this may affect uptake and customer acceptance, however, may require further investigation.

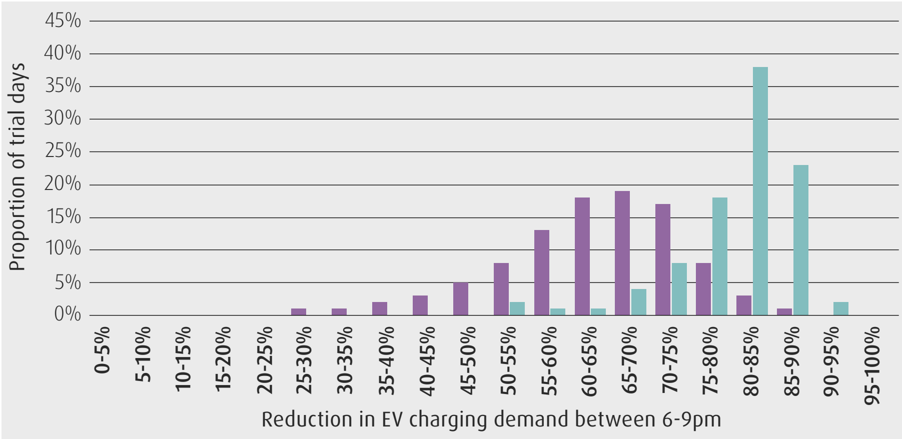
Reliability and Diversity

Demand turn-down proved to be reasonably reliable, but DNOs may need to plan for occasions when the response is less than anticipated.

A DNO needs to consider the reliability of the demand turn-down response. Even if the average peak reduction is substantial, if it does not consistently manage capacity, the benefit to the electricity network is limited.

The median peak reduction for ev.energy was 82%, but was 65% for Kaluza. The Kaluza trial observed a wider distribution of percentage peak turndown. This is likely to be a result of the particulars of the Kaluza trial design (not disincentivising boosting, and not measuring state-of-charge) rather than an inherent difference between the use of ToU DUoS compared with Flex Procurement. We need to work closely with suppliers to ensure that any schemes are implemented in a way that achieves robust and reliable results.

Figure 11
Distribution of daily peak turn-down responses between 6-9pm

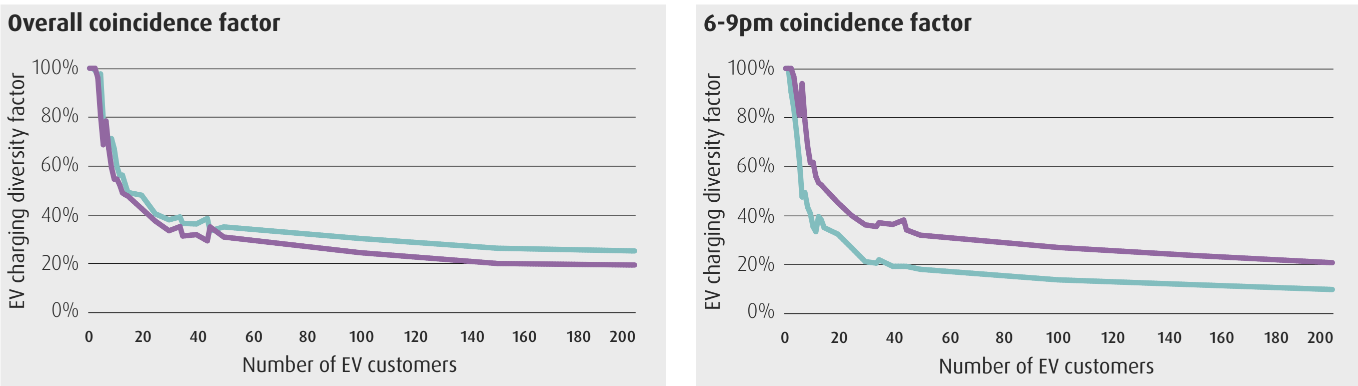


Key
- Kaluza
- ev.energy

Diversity assumptions may break down for small numbers of EVs, or when clusters of EVs charge simultaneously in response to system price signals.

Where there are small numbers of EVs, DNOs need to plan conservatively for the possibility that those EVs will be charging simultaneously. As more EVs are connected, the expected average peak demand per EV tends to fall, as represented by the 'coincidence factor'.[10]

Figure 12
EV Charging Coincidence Factors across the day and focused on the evening peak



Key
- Baseline
- Managed

[10] 'Coincidence Factor' (CF) is a measure of the extent to which different EV customers tend to charge at the same time. It is calculated by dividing the maximum demand of a group of customers by their theoretical maximum demand (i.e. if all were charging simultaneously). The value ranges between 100% (full coincidence) and a number less than 1, which represents the level of diversity in peak demand amongst members of a group. Typically, more customers leads to a lower CF, as the probability that their peak demand coincides reduces. However, 'clustering' behaviour can increase the CF if, for example, EV demand is linked to system-wide price signals.

Where a substation supplies a large number of households, the EV portfolio can be treated as fully diversified. Based on the trial data, this appears to occur once the number of EVs gets above 150-200. Below this number, a DNO will need to assume that the peak demand per EV is higher than the fully diversified curve would imply.

Both the reliability of turn-down and the diversity assumptions could break down in future as customers become increasingly exposed to the same price signals, and as those signals become more volatile. For example, as the capacity of solar and wind generation increases, we expect to see more instances of low or negative wholesale prices in the future, which may well result in EV charging being focused on those periods.

DNOs will need to anticipate such events, and determine whether the appropriate response is to attempt to counteract such price signals, or whether it is better from a 'whole system' perspective to reinforce the distribution network to ensure that renewable generation does not need to be curtailed.

2

Implementing Smart Charging

Steps to unlock the benefits of smart charging are underway but as EV uptake increases, the market will need to evolve to ensure that the whole electricity system is planned and operated efficiently.

The Shift trials have demonstrated the value of collaboration with market participants. They have provided valuable insights into the different market mechanisms that could be employed to incentivise smart charging and manage network capacity more efficiently, and that these market mechanisms can be translated into credible customer propositions.

We need to ensure that the cost and carbon savings from smart EV charging (e.g. from reduced reinforcement and from having less need for high carbon peaking generation) can be achieved. We have therefore considered how these mechanisms might be implemented in practice – first in the short- to medium term, before considering what further investigation and potential reforms (to regulations, systems and processes) may be needed in the longer-term.

Short to Medium-term Implementation

Over the course of the project, we have taken steps to implement project learnings and stimulate a smart charging market in collaboration with our project partners. Before the project started, there were very few smart charging propositions at the domestic level, with most customers facing flat prices across the day. Flexibility procurement by DNOs was in the early stages, was limited to the higher voltages, and did not include EV charge points.

Today, smart charging propositions are becoming increasingly popular, and suppliers can settle domestic customers on a half-hourly basis. By implementing the LV flexibility procurement product developed for Shift in our April 2020 tender, we became the first DNO in the world to procure services on the LV network and the first DNO in the UK to procure flexibility from EV service provider. The value of these services continues to rapidly grow, demonstrated by the 248MW of flexibility procured from EV batteries in our March 2021 tender round.

Incentivising Smart Charging within the Current ToU DUoS Charging Regime

The Kaluza trial demonstrated that a ToU DUoS signal (either a single red band or a red band with shoulder pricing) combined with TNUoS and the wholesale electricity price can reduce the evening peak. Whilst more locationally granular ToU DUoS signals would allow us to target constraints more efficiently, this would require regulatory change and a more widespread visibility of network conditions at the low voltage level.

Although we are planning to undertake work to improve LV visibility through RIIO-ED2, there is still a case for applying ToU DUoS at a network area level. Although not optimal, it has been shown to deliver benefits, and it can be done using existing systems, processes and regulations.

Making Use of LV Flexibility Procurement to Address Residual Constraints

Where the price signal incorporating ToU DUoS at DNO level does not sufficiently manage local constraints, LV flexibility could be procured to manage capacity. Combining existing ToU DUoS arrangements with Flexibility Procurement would have a number of advantages:

- **Proven approach:** This approach is already Business as Usual today, with the potential to be improved and expanded using capabilities that are already being factored into UK Power Networks' RIIO-ED2 plans;
- **Administrative burden:** Static DUoS signals involve relatively low administrative costs when applied to a customer type, rather than a specific location, whilst managing the majority of the evening peak constraints that EV uptake would otherwise cause;
- **Targeted flexibility procurement:** Flexibility procurement can be targeted where and when it is needed (including managing the secondary peaks);
- **Equitability and tariff consistency over time:** The use of Flexibility procurement avoids imposing costs on consumers in a 'postcode lottery', which could result in a high degree of uncertainty for customers regarding the cost of their electricity in the future. Instead, by using flexibility procurement in a targeted way, a direct benefit is given to those who can participate, as well as an indirect benefit to other customers through a reduction in DUoS charges; and
- **Triggering reinforcement:** Flexibility procurement provides clear commercial signals to indicate to DNOs when it is economically efficient to reinforce the network.

The forecast volume of substations and circuits that are likely to have residual constraints, once accounting for smart charging, is quite low in the short-term, and therefore would be manageable via this method. As the energy transition progresses, increased volumes of EVs and other clean technologies will impact the underlying demand profiles on the network. As these changes occur, the design of price signals and flexibility products will also need to adapt, so that we can continue to deliver the best whole systems solutions for our customers.

The Need for LV Visibility

One prerequisite for deploying flexibility on the LV network is to have sufficient real time visibility of the local network conditions, in order to both identify the need for flexibility and procure it, and also to then be able to dispatch contracted assets when needed. The majority of LV networks have not traditionally needed to be monitored to this level, and so limited monitoring is currently in place. We have plans to accelerate visibility of the LV network during RIIO-ED2 as part of our role as a DSO and we are developing innovative solutions through our Envision[11] project to increase visibility as efficiently as possible; for example through the use of smart meter and other third party data where available, in combination with software and advanced analytics, rather than deploying physical monitoring devices in all cases.

Ongoing Limitations and Future Challenges

Whilst we anticipate that a combination of static ToU DUoS and flexibility procurement will be able to manage EV uptake effectively in the short-term, Project Shift has identified ways in which this approach could become strained in future. We anticipate the following trends:

- **Interactions with other price signals will change over time**, impacting smart charging behaviour. For example, this could be due to increasing volatility in wholesale prices (mediated by their supplier or aggregator) and, potentially, participation in the provision of system balancing services;
- **Automation** of smart charging and other domestic consumption is likely to increase, which will simplify the provision of flexibility, but could exacerbate the tendency of charging to cluster around particular times of the day in response to price signals;
- **Secondary peaks** are likely to become more of an issue as EV uptake and smart charging participation increases particularly if managed under static ToU DUoS mechanism due to the factors above;
- **Location-specific constraints** will become more prevalent in areas with less typical demand profiles than the static ToU price signals are based upon, driving up the need either for other smart solutions such as LV flexibility procurement or LV reinforcement;
- **Domestic demand profiles are likely to change** as customers increasingly adopt clean technologies (such as electric heating, behind-the-meter generation and storage solutions) and the price signals under static ToU DUoS may not reflect the network conditions in these locations.

In principle, LV flexibility procurement should be able to ensure that distribution network constraints are managed despite these expected developments. While wider network pricing reforms are being considered, LV flexibility procurement will allow networks to manage the system more dynamically while creating opportunities for domestic customers to contribute to a smarter energy system.

[11] https://innovation.ukpowernetworks.co.uk/projects/envision/

Longer-term Potential Mechanisms

Evolving DUoS Charging

The way DUoS charges are applied to customers across the network could be modified in several ways to address the challenges above. The impact of different DUoS mechanisms is currently being reviewed at a wider network level through Ofgem's Access and Forward-looking Charging Significant Code Review (Access SCR), which will determine how these charges will evolve in the medium term.

Looking further into the future, ToU DUoS charges could be set more dynamically or at a more local level so that the cost of electricity at a specific time or location more accurately reflects the associated cost of distributing it as described below:

- **Location granularity:** At present, ToU tariffs are set at the DNO licence area, meaning they do not account for location-specific constraints. Theoretically, a more locationally granular price signal would result in more effective constraint management.
- **Dynamic DUoS:** Rather than imposing network charges on terms set ahead of time, it could be possible to set DUoS prices dynamically. They would be high when the distribution network (or the specific LV area) is constrained, and low when there is sufficient headroom, allowing for much more targeted pricing signals, and avoiding demand turn-down occurring when it was not required.

Both these developments would depend on having increased visibility of the LV network, through physical monitoring and enhanced modelling capabilities drawing on network and third party data such as smart meters. As charges would reflect local network conditions, if the capacity of the network were upgraded, the price signals would reflect that change as well. Unlike LV monitoring for LV flexibility procurement which can be deployed on a site by site basis, wide-spread LV network visibility is a prerequisite for implementing a dynamic and locational DUoS tariff in this way. Additionally, networks would need to develop systems capable of generating and publishing DUoS charges for granular network locations, and market participants would need to develop systems capable of consuming these charges and turning them into customer propositions.

An important consideration highlighted by the Shift trials is that both the commercial incentive and the design of the customer proposition impact customer behaviour, and that the end customer may not be exposed to the price signal set by the network. For example, if suppliers were to absorb the variability in the DUoS price across the day (perhaps to create a more simple set of tariffs, or to address concerns of fairness and equitability between its customers) this could neutralise the responsiveness of customers to those dynamic price signals. Reforms, therefore, need to consider how the design of market mechanisms may be interpreted through the lens of commercially viable customer propositions.

Capacity-based DUoS Charging

Capacity-based charging encourages the smoothing of customer demand and avoids secondary peaks by design.

The Octopus Go Faster trial and subsequent analysis showed that a capacity-based DUoS charging approach can shift demand away from the evening network peak and smooth it across the overnight period, provided the supplier builds a customer proposition that incentivises customers to spread their demand across the day.

Under the capacity-based charging mechanism, there is a financial incentive for the supplier to evolve the customer proposition to prevent increases in peak demand (all else being equal). This approach is intended to prevent peak shifting (a disadvantage of ToU DUoS) and instead incentivise peak smoothing.

Exposing market participants to this incentive could promote greater innovation on the supplier-side to deliver the desired objective for the network. This also enables market participants to assess any trade-offs that can be made against other signals and incentives, providing a more optimal response for the whole system, and providing a signal to increase capacity where required.

A number of different 'capacity charging' approaches were considered in the trial design, with two candidates emerging:

1. **Capacity booking**, under which the supplier calculates the expected capacity required for its full customer portfolio in each period (e.g. across the week, month or season), 'buys' that capacity up-front, and then pays a penalty if its portfolio utilises more than the booked capacity.
2. **Predefined capacity price bands** set by the DNO ahead of time, with suppliers paying less when their portfolio is using low volumes of energy in a particular half-hour, but more if the aggregate demand in that half hour increases into higher priced capacity bands.

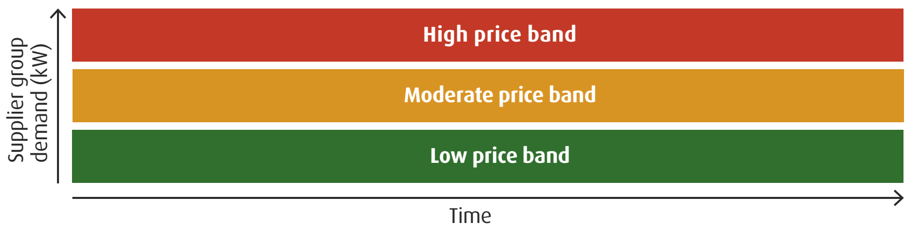
There are conceptual advantages associated with having suppliers 'book' capacity. When applied at a granular level, this approach would signal when additional capacity was required, giving a strong signal to the DNO of when to create additional capacity.

There are, however, limitations to this approach. If this were to be applied at a less granular level, this relationship between capacity booked and the network constraint becomes less direct, since the amount of headroom within a network area will vary depending on where each customer is located. A booking approach is also administratively burdensome, requiring the DNO to set penalty prices, manage the booking process, and create a new DUoS settlement system to account for the booked volumes and penalty prices. It is particularly challenging to relate the mechanism to actual network constraints, particularly on highly meshed networks, such as London.

A capacity booking approach could also lead to barriers to entry for suppliers in areas in which they have fewer customers, thus inhibiting retail competition. At lower customer numbers, the coincidence factor for EV charging is greater, which would result in suppliers with lower customer numbers having to book more capacity per customer, thus incurring greater DUoS costs. To prevent this bias, the capacity would need to be booked at primary substation level or across a catchment area of a sufficient size, which would dilute the locational benefit of the mechanism for networks.

A simpler approach, that could conceptually deliver similar benefits to capacity booking at a regional level, would be to set DUoS capacity bands. Under this approach, the existing ToU DUoS bands could be replaced with escalating price bands based on the volume of consumption in a suppliers' portfolio consumed in each capacity band. This approach would not relate capacity to constraints in as direct a way as would capacity booking, but would provide an incentive to smooth the demand of customers within their portfolio.

Figure 13
Illustration of network charging based on capacity bands



While this approach would not address all locational constraints, it could be used in conjunction with flexibility procurement in the near-term, and evolved in the longer-term through considerations similar to those outlined for a ToU DUoS price signal.

Our experience through this trial suggests that a simple DUoS capacity band approach, applied at a supplier or regional level, could have some advantages. Creating an incentive for suppliers to reduce their overall peak load regardless of time better reflects capacity as the driver of network costs and removes the need to tailor ToU signals which will become increasingly dynamic and less predictable in a smarter, more flexible energy system.

Conclusions and Next Steps

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Conclusions

It is clear to us that smart charging is going to be a key enabler for the rapid uptake of EVs, whilst minimising network costs, as well as enabling domestic customers to provide flexibility services to the electricity system.

Industry stakeholders told us that a market-based approach to smart charging should focus on real-world propositions designed around customer behaviour. Project Shift was intended to develop three such propositions to understand whether these approaches could work, and how they might be implemented in the future.

Returning to our trial questions:

Trial question	Conclusion
Can mechanisms to incentivise flexibility help DNOs manage network constraints on the low voltage (LV) network?	A number of different mechanisms can successfully help DNOs manage network constraints. Significant peak demand reduction was demonstrated across a range of approaches, with different types of network signal, different forms of customer proposition, and different levels of automation and control.
What peak load reduction can be achieved under each mechanism, whilst delivering the customers' needs?	Whilst demand between 6–9pm was successfully reduced across all three trials, the daily reduction in EV demand at this time varied between 25% and 95%. In all trials, customer feedback was positive. The ability to override the smart charging controls ('boosting') was seen as an important element of the approach, but the trials showed that this could be accommodated, and minimised with the appropriate use of incentives.
How might these approaches interact with wider market services and electricity network needs?	Static ToU charging has been shown to be effective, but as market signals evolve, and as more customers become exposed to those signals, the ability of this approach to manage LV constraints may diminish. For example, very high or very low (or negative) wholesale prices could become the dominant driver of smart charging behaviour in the future. The complementary use of LV flexibility procurement is working well today to address these residual constraints, but the current approach would need to evolve as the uptake of EVs (and other low carbon technologies) increases. The move to more locational and/or dynamic DUoS could improve the interactions with wider market services, but would require significant system and process changes. Capacity-based DUoS charging has the merits of incentivising market participants to use capacity efficiently between their customers, whilst allowing them to assess trade-offs between network charges and other price signals across the whole energy system.

Both the electrification of transport, and the integration of new forms of flexibility onto the electricity system, are going to be key parts of the UK's Net Zero ambitions. The Project Shift trials, and our experience with flexibility procurement, have demonstrated that there is significant potential in ensuring that EV charging is managed effectively.

Key Messages

Based on these trials, and our engagement with stakeholders, we have identified the following key messages:

Trial Learnings

Customer acceptance

- Customers were open to smart charging, so long as their mobility requirements were met
- Just 20% of the time spent plugged in at home is needed to meet customers charging needs

Shift in demand

- EV demand during the evening peak reduced by an average of 79% due to smart charging
- Customers chose to smart charge for 85% of all charging sessions

Reliability of response

- Ongoing financial incentives increased the reliability of response compared to one off incentives
- The median daily reduction in EV demand between 6-9 pm was 82% with ongoing incentives, compared to 65% without

Network capacity

- By achieving a significant reduction in the evening peak, a peak in demand forms overnight
- Secondary peaks should not be used as a reason not to smart charge as new products, increased network visibility and development of market mechanisms could be deployed over time to prevent these in the majority of locations

Scaling Up

Customer propositions

- Automated smart charging propositions can respond to changes in market mechanisms through optimisation, reducing the need to incentivise changes in customer behaviour as network conditions and price signals evolve
- Product development paired with collaborative innovation will continue to deliver more flexibility

Market mechanisms

- Flexibility procurement can create opportunity for domestic consumers to avoid location specific constraints while wider reforms take place
- Greater visibility of the low voltage network is required to enable more sophisticated mechanisms in future that more efficiently address local network constraints

Next Steps

Smart EV charging is going to be critical to enabling the electrification of the transportation sector in a way that minimises costs for consumers. The Shift trials have provided a number of insights into how smart charging behaviour could evolve, and the viability of creating credible customer propositions.

There are a number of open questions around how the market will evolve, and how supplier propositions and customer behaviour will change. In particular, we need to understand how price events in the future could drive LV network peaks, and how the relationship with network price signals may evolve.

Through RIIO-ED2 and beyond, we will work closely with suppliers, flexibility providers, other DNOs and Ofgem to address these open questions. At the same time, we have plans in place to develop our network modelling, procurement, and dispatch capabilities to ensure that we are able to operate in a rapidly evolving environment.