Project Shift

UK Power Networks
Delivering your electricity

Final Report – May 2022

Trialling Market Based Incentives for Domestic Smart Electric Vehicle Charging

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Glossary of Terms

After Diversity Maximum Demand	**ADMD**
Battery electric vehicle	**BEV**
Coincidence Factor	**CF**
Distribution Network Operator	**DNO**
Distribution System Operator	**DSO**
Distribution Use of System Charges	**DUoS**
Electric Vehicles	**EV**
Extra High Voltage	**EHV**
Half Hourly	**HH**
High Voltage	**HV**
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.

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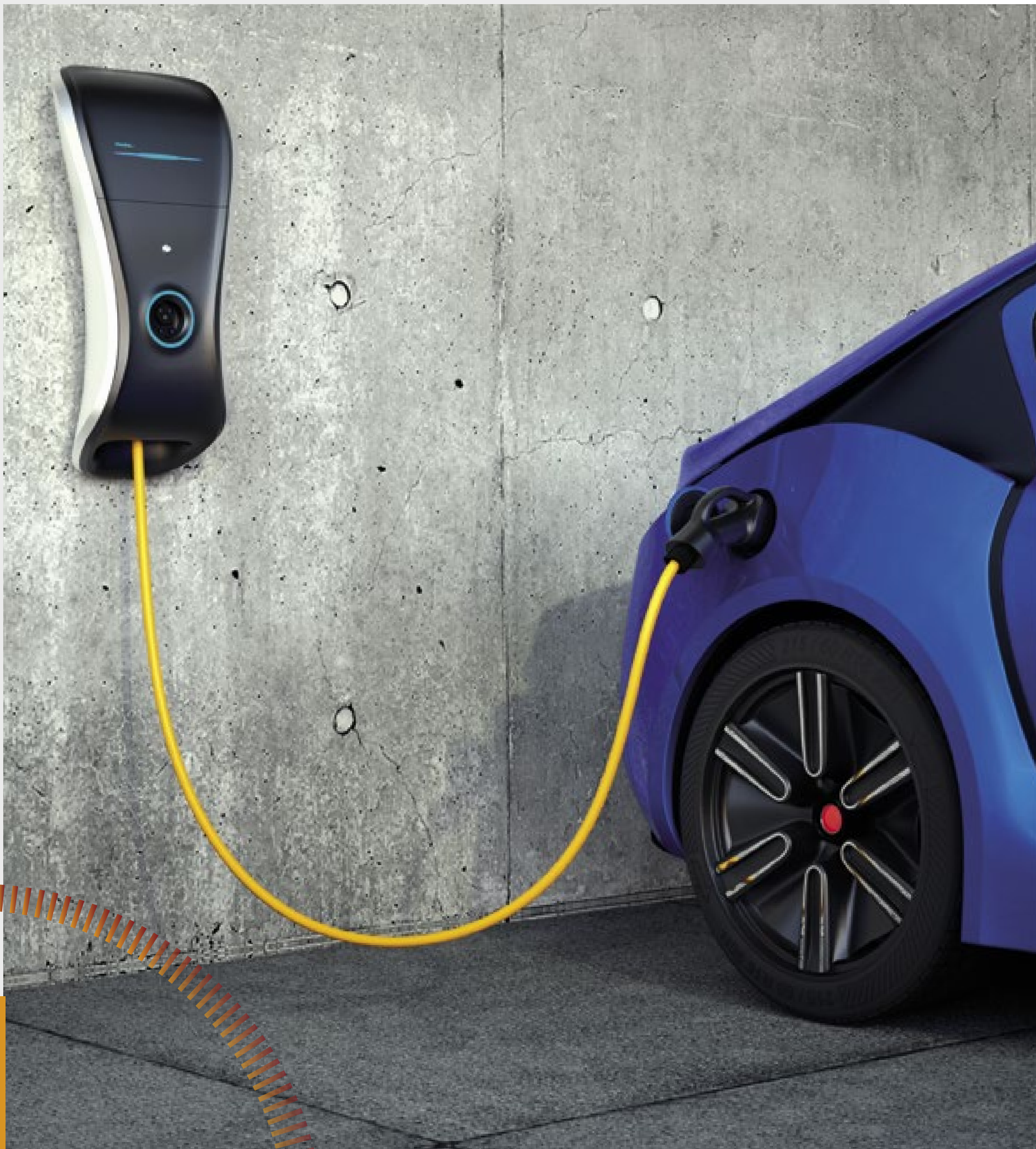
The 8.3 million customers and businesses connected to our electricity network are increasingly making the switch to cleaner forms of transport to reduce harmful emissions.

3.6 million
electric vehicles in 2030

Introduction



1

62%
of EV charging occurs at home off-street

1.1 Context

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.

By 2030, we forecast up to 3.6 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 forward 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 this is projected 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.

1.2. Our EV strategy

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.

[1] UK Power Networks ED2 Business Plan https://ed2.ukpowernetworks.co.uk
[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

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.

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 of, and carbon intensity of, electricity[3]. The interplay between these incentives and local network needs must be considered to ensure the best whole system 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.

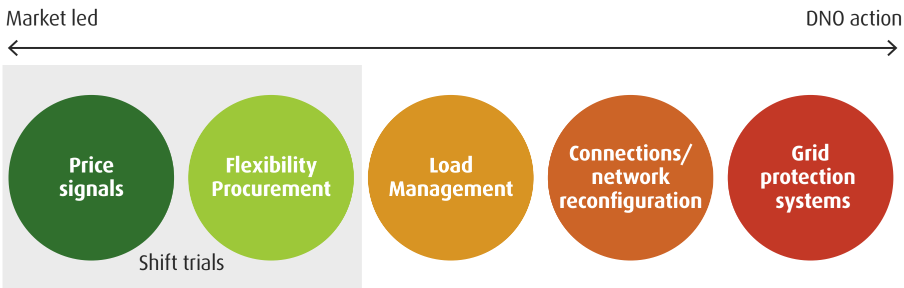
1.3. Project Shift overview

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 (SmartCAR)[4] project, we established that a marked-based approach to smart charging was the preferred approach, both by us and our stakeholders, in contrast with direct DNO action. The range of potential mechanisms is illustrated in Figure 1.

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 incentive to use electricity when network capacity is available
- **Customer propositions** are offered by suppliers/service providers (for example through smart tariffs) to incentivise flexibility.

This relationship is summarised in Figure 2.

Figure 2
Creating market based incentives for domestic smart EV charging

1.4. Market mechanisms and Project Partners

For widespread participation, smart charging needs to be simple, accessible and trusted, with incentives designed around real-word 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**
- **Capacity-based DUoS pricing**
- **LV flexibility procurement**

[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

1.5. Trial questions

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 could be implemented to unlock the value of smart charging to the industry and our customers.

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

Pre-trial research and engagement

2

2.1. Stakeholder engagement

Alongside our work with the Shift partners, we also conducted additional stakeholder engagement to test our position with a range of parties and use their feedback to shape the trials. The stakeholders who contributed to this process are shown in Figure 3.

Figure 3
Stakeholders engaged as part of Shift

Through this engagement, we identified the following key messages:

- **Use real-world propositions:** Stakeholders agreed that a key overarching objective for these trials should be the investigation of market-led approaches to smart charging, through real-world customer propositions.
- **Focus on peak turn-down:** Stakeholders agreed that, whilst it would be of value and interest to trial a range of potential services, we should focus on the provision of a demand turn-down service at peak times, as this is a high-value area and allows for a simpler trial which can focus on core learnings;
- **Align with future regulatory review:** Stakeholders agreed that we should align our commercial product design with a set of principles that are broadly aligned to Ofgem's direction of travel in the Access & Charging review, in order to ensure that our approaches are realistic.
- **Study flexibility, Time of Use (ToU) pricing and Capacity charging:** Stakeholders agreed with our proposal to trial flexibility procurement, ToU DUoS, and a capacity-based charge to inform Ofgem's thinking in the Access & Charging review. There were mixed views as to the appropriateness and potential effectiveness of these methods, but all agreed that this was for the trials to investigate. We designed the incentives carefully, and based values on the real-world network costs, to ensure that findings generated are reflective of real-world conditions.
- **Focus on customer impact:** Stakeholders raised that it would be paramount to understand the impact that the trials have on customers, and not just to focus on the outcomes for the network. As a result, we calculated settlement of the charges under the new arrangements (whilst in reality, they were settled via their current arrangements), and we conducted customer surveys to understand their experience.
- **Keep offerings simple:** In general, stakeholders felt that propositions would need to be simple, transparent, and automated, in order to develop customer trust and have the desired impacts. However, as part of this trial we looked to our trial partners to design propositions that they thought fit to enact the required services.

2.2. Customer research

In addition to the stakeholder engagement that we conducted, independent research carried out by Delta EE during the research phase of Shift engaged over 800 motorists, including EV drivers and non-EV drivers. The objectives of the research were broken down into two primary aims:

- Provide customer insight to inform and **shape the design of Shift** including insight into how customers will respond to smart charging as a concept as well as the different elements of a market-led smart charging proposition.
- Gather primary evidence on **customer perception of a market-led approach** to smart charging, to understand both the value of this approach (as there is no consensus on this amongst all UK electricity system stakeholders), and gather insight on how customers engage with the complex concept.

The research involved the following activities to gather insights:

- **Focus groups and co-creation workshop**: This included three focus groups with 20 prospective[7] and 20 current EV drivers and a co-creation workshop with five prospective EV drivers and five current EV drivers.
- **Customer survey:** An online survey with 750 participants and ~30 questions. Participants included 236 current EV drivers, 414 prospective EV drivers with off-street parking and 100 prospective EV drivers with on-street parking.

The research provided valuable insight into customers' attitudes towards smart charging. Extensive learnings were captured from these activities, which we have summarised and published on our website[8]. In summary, the survey research revealed that:

- The majority of EV and non-EV drivers preferred a market-led approach over a load management approach.
- The vast majority of BEV drivers surveyed had typical daily journeys of 60 miles or less and more than two-thirds only feel the need to charge their EV when the battery has 50 miles or less of range left.
- 75% of all participants were 'quite' or 'very' happy with the idea of a third party managing their vehicles charging outside of peak times under the condition that their mobility is not affected.
- A small proportion of EV and non-EV customers surveyed were not open to the idea of smart charging and indicated no level of reward would incentivise them to allow a third-party organisation to manage their EV charging.
- More than two-thirds of all participants would allow an organisation to manage their EV smart charging for £4 or less a month.
- More than a third of all participants indicated they did not require an incentive to allowing smart charging to occur. Non-EV drivers and those living in rural and semi-rural areas were more willing to allow smart charging to occur for no compensation.
- 85% of participants would trust their DNO to act in an emergency on the grid: they prefer third party intervention to a possible power outage, with the preferred intervention method for 6 out of 10 being the pausing of one's EV charging.

[7] Looking to purchase an EV within 5 years
[8] https://innovation.ukpowernetworks.co.uk/projects/shift/

- The need to provide customers with 'peace of mind' when it comes to meeting their mobility needs was reinforced by 9 out of 10 participants rating the ability to override the smart charging process as important. Charging customers to be able to override smart charging is a contentious issue for customers, and something a majority will not pay additionally for.
- Customers would like their service provider to make smart charging recommendations to them. These should provide insight on which smart charging tariff/package is best suited to the customer, as well as providing best practice advice for smart charging.

The customer research activities were conducted with a separate group of people to those involved in the smart charging trials. In addition, the project partners carried out surveys of their customers actively participating in the trial. The outputs of these engagement activities have been used to draw insights from the trial data to further understand customer behaviours, and will be used to understand how applicable the insights of the trial are to our customers, both now and in the future.

2.3. Market review

Our view is that appropriate smart charging mechanisms need to provide a high level of market freedom and optimise across markets and customer needs, with the DSO procuring services from market players to deliver the best outcomes for customers. Within the Shift project, we developed three commercial products that would enable EV customers to access this value through a free market. These were developed in collaboration with energy market specialists from Baringa and subject matter experts in our smart grid, income management, and regulation teams.

To design these products in such a way that would be valuable to the network customers and the market, we initially reviewed the network needs and explored the conflicts and synergies between existing products on the market.

2.3.1. Network needs and services

At the start of the project, we developed a preliminary cost-benefit analysis (CBA) tool that produced a high-level assessment of the value of LV smart charging to networks (in terms of network reinforcement deferral) to inform the design of the LV flexibility products, the volume of flexibility required and what proportion of required flexibility EVs can contribute. The outputs of the trial have been used to produce an updated CBA, and will feed into UK Power Networks' ongoing planning activities. To some extent, the findings of the trials have already begun to inform our LV Flexibility procurement, which is now Business as Usual. As we develop new flexibility services, we will use the trial outcomes to understand how EVs and households on smart tariffs can participate.

2.3.1. Conflicts and synergies

We did a market scan to understand the context of DSO services in relation to other market services that are already established such as wholesale and ancillary services. We aimed to understand the potential conflicts and synergies between DSO products and those in other markets. The interactions that an LV network reinforcement deferral service would have with other markets are as follows:

- **EHV/HV Constraints:** The extent to which these can act in synergy depends on the overlap of the windows in which the response is needed.
- **Frequency Response:** The frequency services are generally mutually exclusive with DSO services. If the DSO window overlaps Electricity Forward Agreement blocks the flexibility provider would have to forgo the income from two Firm Frequency Response (FFR) windows. Additionally, there may be some operational restrictions given the nature of the frequency response products as there may be requirements on the level of charge in the batteries.

- **Wholesale market arbitrage:** If high wholesale market prices correspond with LV network peaks then flexibility providers will shift charging to cheaper periods. This could provide a complementary incentive to shift demand away from peak times but also means that if the EV was not charging at that time they would not be able to respond to a turndown request by the DSO. In addition, if low wholesale market prices correspond with LV network peaks, this could further exacerbate the constraint.
- **System price:** The price of the Balancing Mechanism (BM) is more volatile compared to the Wholesale market. It can reach high positive prices or even negative as it tracks closely how short or long the system is. In this context, the DSO flexibility services for EVs could interact with the BM pricing during the evening charging period of EVs. This interaction could either take the form of a strong alignment, i.e. a high BM price discourages charging at peak times, or of a conflict, i.e. a negative price can incentivise charging and amplify a local constraint.
- **Capacity Market:** Unless service providers have an exemption from delivering on their Capacity Market (CM) obligations when a DSO service is required, it is unlikely that providers will try to stack these services, particularly as the penalties for non-delivery in the CM are high. However, providers receive 4 hours warning of a Capacity Market stress event and so may opt into both services if the DSO service has a flexible approach (i.e. provision for the CM takes priority).

The advantage of implementing a price- or capacity-based solution to managing distribution constraints is that it avoids some of the contractual conflicts that could restrict participation in providing flexibility in markets where it is needed. The disadvantage is that the flexibility response could be less reliable for the purpose of network planning and investment.

For the Shift project, therefore, we designed several market mechanisms, including price-based, capacity-based and contractual signals. Each of these were designed to ensure that they could meet the need to manage our own network constraints. The trial results reveal the scale and reliability of response that could be achieved under each approach. We have also given further consideration to how these different mechanisms might behave when deployed in practice – both today and as the electricity system evolves.

3

Trial Design

3.1. Introduction

Each of the three trials were designed to test a different mechanism for incentivising and commercialising managed EV charging. The following sections describe, for each trial, the underlying mechanism, how that was translated into a customer offering, and the recruitment of customers.

3.2 Trial Design and Customer Propositions

	Time of Use DUoS pricing trial KALUZA AN OVO COMPANY	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 paid 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.

3.3. Time of Use DUoS trial (Kaluza)

3.3.1. Product overview

This product was based on exposing suppliers to a ToU DUoS price signal, such that the cost of network capacity access to customers is subject to peak/off-peak price bands at different time windows in a day. In the trial, the ToU pricing was tested at the supplier level, rather than at the individual consumer level – that is, the time-varying costs are exposed to the supplier, with trial customers remaining on their original tariff.

In the Kaluza trial, the arrangement being tested was that the DNO would publish a static peak pricing shape. This would be similar to the way DUoS charges are currently published but at a more granular level. The objective of this mechanism is to incentivise service providers to shift demand away from the peak price bands of the ToU DUoS signal.

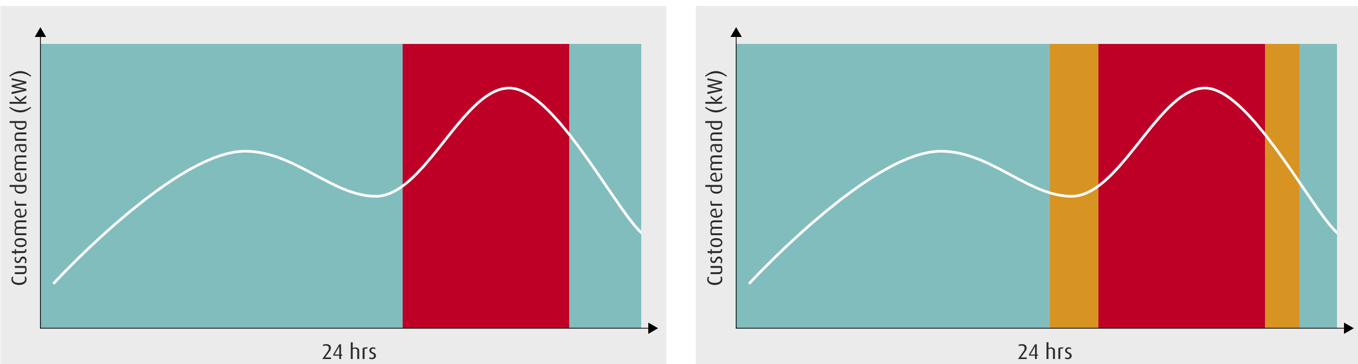
In the design of this mechanism the static price shape sought to better reflect LV network constraints. This ToU DUoS signal would then be aggregated by Kaluza with other costs of electricity supply such as TNUoS and wholesale prices, to create a price signal reflective of both the cost to supply and the local network conditions. Against these aggregated price signals, the service provider would seek to optimise EV charging schedules for its customers, while meeting their mobility needs.

3.3.2. Product design

The trial's aim was to test different shapes for a ToU signal that better reflect LV constraints and their impact on the reduction of peak demand from EV charging. The outcomes of the trial were intended to inform Ofgem's Significant Code Review (SCR) on Network Access and Forward-Looking Charges, and therefore the price signals were designed to be consistent with the direction of travel of this review.

A key risk of a ToU signal is that it might serve to coordinate EV charging, with multiple EVs beginning to charge at the end of the red band period, thus creating a secondary peak and exacerbating network constraints. To investigate potential mitigations to this risk, two variants of the price signal were designed with different shapes – one a simple red band (Group 1) in and one designed with 'shoulders' or amber bands either side of the central red band (Group 2), shown in Figure 4.

Figure 4
Indicative ToU DUoS pricing



Group 1 **Group 2**

The prices for the red peak band DUoS were based on those for the Eastern Power Networks (EPN – effective 1st April 2020), with the times adjusted to better align with times of peak demand at LV level. This is opposed to the existing red band DUoS, which is based on the probability of peaks occurring within the band at all voltage levels.

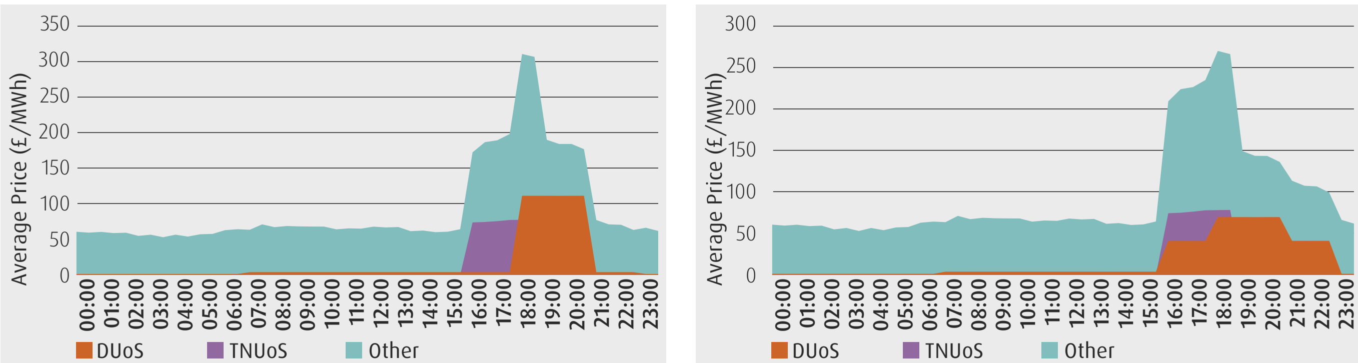
The shoulder pricing option introduced a high amber band rate on either side of the shifted red band. The red band charge was reduced so that an equivalent cost was recovered through the high amber band (set according to the expected demand profile). These prices are shown in Figure 5.

These ToU DUoS price bands were combined with other prices, including TNUoS and Wholesale charges, to make up the overall price signal against which EV charging was to be optimised, displayed in Figure 6.

Figure 5
Shift ToU DUoS Charges

DUoS		Red	High Amber	Amber	Green
Shifted LV peak red band	Monday to Friday	18:00-21:00		07:00-18:00 21:00-23:00	00:00-07:00 23:00-24:00
	Charge (p/kWh)	15.238		0.486	0.135
Shoulder pricing	Monday to Friday	18:00-21:00	16:00-18:00 21:00-23:00	07:00-16:00	00:00-07:00 23:00-24:00
	Charge (p/kWh)	8.842	5.204	0.486	0.135
All options	Saturday and Sunday				00:00-24:00
	Charge (p/kWh)				0.135

Figure 6
Average weekday prices for Kaluza Red Peak (Group 1) and Shoulder pricing (Group 2) DUoS trial *(prices from Nov '19 to May '20)*



3.3.3. Customer proposition

Kaluza offered a £50 incentive to their existing customers to sign up to the Shift trial. The invitation encouraged customers to sign up to help them understand how they can better help protect the electricity network. This was combined with the customers' original smart charging incentive which was received upon first signing up to the Kaluza product, which included free or discounted charge points, and for customers on a dual-rate tariff – a saving on their electricity bill (depending on the tariff).

The customer could enter their mobility needs into an optimisation app at their discretion. This could include their charging ready-by time schedule (e.g. "I need my car to be ready and fully charged by 7am"), their tariff (i.e. off-peak, or peak times), and their EV's charging needs (i.e. battery capacity). The Kaluza algorithm used these customer charging needs, together with the trial's price signal to optimise the EV portfolio consumption.

Customers using optimisation apps to set smart charging preferences could also override scheduled charging events, also known as 'boosting'. This could be done via the platform provider's app or on the physical charge point. When a session was overridden, the EV would charge at the maximum rate until the battery was full or the customer stopped the session.

3.3.4. Charging control and optimisation

The control approach was third party managed (fully automated) and included an override option. The Kaluza platform itself ran a fully-automated algorithm that managed customer charging on a minute-by-minute basis against a combined price signal. A breakdown is shown in figure 7.

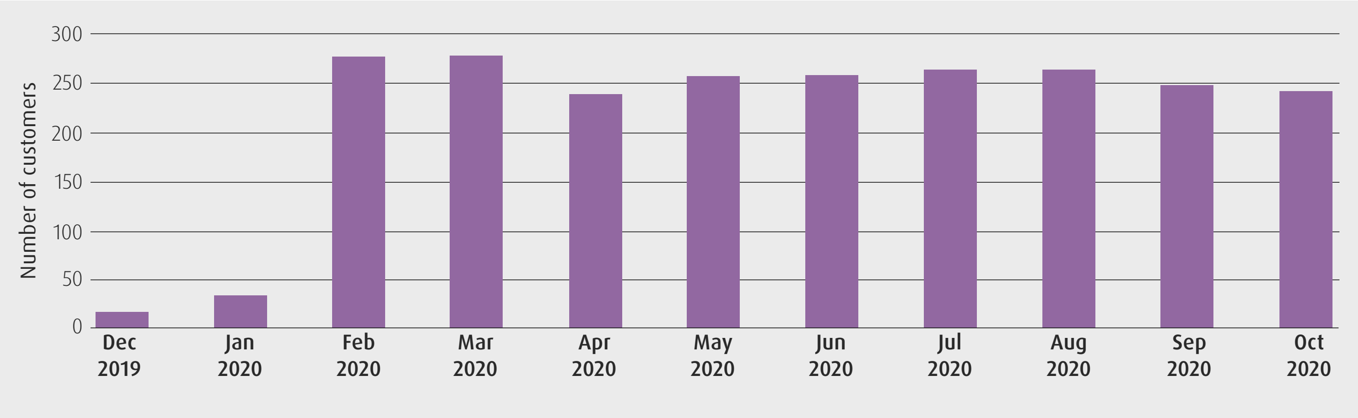
Figure 7
Optimisation data for Kaluza trials

Automated optimised charging	Yes
Optimisation granularity	Minute-by-minute
Charging session data collected	Yes
HH household meter data collected	No

3.3.5. Overview of recruitment and trial customers

Kaluza originally targeted 368 customers, with 304 customers ultimately taking part in the trial and having their charging sessions tracked. The number of customers actively participating in the trial varied over time, as shown in Figure 8. Of the customers, 154 were exposed to the red peak DUoS price (Group 1) and 150 were exposed to the shoulder pricing DUoS (Group 2).

Figure 8
Number of Kaluza trial participants over time



Kaluza undertook a customer survey amongst their trial customers to better understand their motivations to smart charge, perceptions of smart charging and the drivers of customer behaviour. The research included 122 survey responses, with surveys collected between 21st August and 22nd September 2020.

Across these four categories, the survey results revealed the following key insights across the Shift trialists surveyed:

- **Motivations to smart charge:** customers were primarily driven by cost savings (43%) and secondly by environmental reasons (34%).
- **Perceptions of smart charging:** 70% of responses were deemed to understand the core functionalities of the smart charging algorithm; 76% of customers understood how the 'boost' function worked; 78% of customers were able to correctly identify times of peak grid constraint.
- **Drivers of customer behaviour:** most customers surveyed rely on home charging – it is a necessity, not a luxury. For 96% of respondents, their EV is the car they use the most, 84% fully rely on their EV for transport, and 78% almost always charge at home.

Figure 9 provides an overview of the customers involved in the trial, taken from a mid-trial snapshot.

Figure 9
Customer characteristics from the Kaluza trial

Tariff type	163 single-rate 74 multi-rate 74 unknown
Vehicle type	55.5% BEV 37.5% PHEV 7% unknown
Average EV battery capacity	38 kWh
Charging point rating	7 kW for BEV 3.6 kW for PHEV

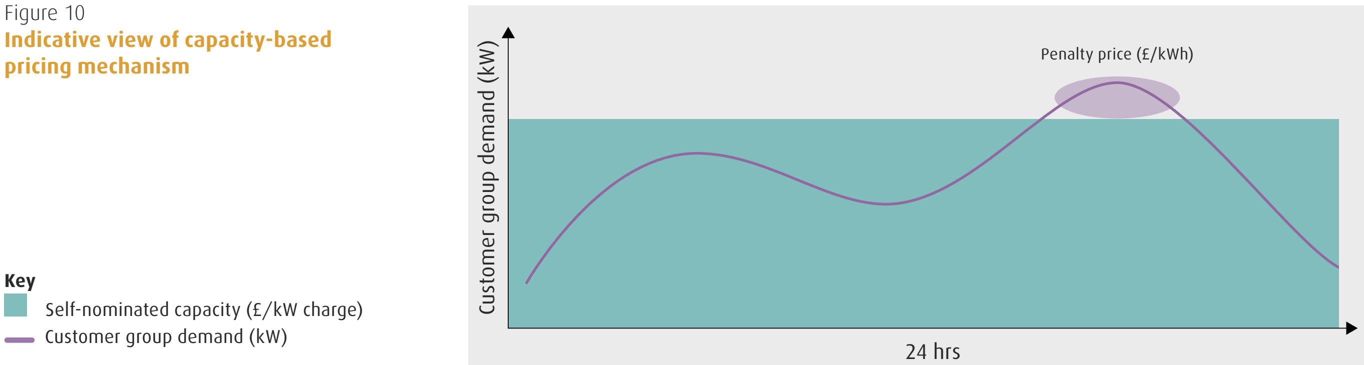
3.4. Capacity Based DUoS Pricing Trial (Octopus)

3.4.1. Product overview

This product was based on payment for access to network capacity, with suppliers charged for the total aggregate maximum demand for their customers (kW), rather than via a volumetric charge. The primary objective of a capacity-based price signal was to incentivise service providers to spread load throughout the day, thus 'flattening' the demand curve, rather than simply shifting it to another time band as per the ToU DUoS signal.

In the conceptual design of this mechanism, suppliers would be required to book a nominated capacity level for their customers, with a charge per kW, and would be subject to additional peak pricing for any volume of demand that breaches the booked capacity level, as illustrated in Figure 10.

Figure 10
Indicative view of capacity-based pricing mechanism



3.4.2. Product design

For the trial, the nominated capacity price was calculated to determine the capacity price that recovers the same net revenue per customer group as the existing DUoS charges, based on the LV Network Domestic tariff for the EPN region. This tariff was used for consistency with the ToU DUoS pricing mechanism, which was also based on recovering the costs under this tariff.

The capacity price assumed that if suppliers take a risk-averse approach and book the maximum capacity per customer, aggregated for their group of customers (i.e. the ADMD per customer) then the DNO will still recover the same costs as under the current charging regime. However, if the supplier can reduce the capacity booking with minimal usage in the penalty zone then they can reduce their DUoS bill.

The penalty price imposed additional costs on a supplier if the aggregate consumption of their customers rises above the booked capacity for that group of customers (for the trial, a group of customers was expected to be the supplier's customers under a feeder). This was intended to incentivise a flattening of the supplier's aggregate load profile for that group, and booking of a capacity level that is highly utilised, with minimal consumption above that booking.

Octopus Energy has performed analysis to understand the relationship between the penalty price and the optimal level of capacity for a supplier to book, as well as the way that this changes for different numbers of customers. This is summarised in Appendix A.

In the trial design, prices for nominated capacity would be set regionally (i.e. per licence area), to reflect the long-run cost of reinforcement and follow a similar approach to the current DUoS regime. Penalty prices could then be varied locally to provide sharper signals in areas facing higher constraints.

Nominated capacity would be booked by suppliers for their customers at a local level (i.e. feeder level) and would therefore provide a valuable and granular forward view of capacity requirements to the DNO. The service provider would be responsible for understanding their customer needs and coordinating EV charging in order to minimise its costs whilst delivering the customers' mobility needs.

The prices for the trial were determined based on EPN DUoS and are shown in Figure 11.

Figure 11
Capacity-based trial prices

Nominated capacity price	71 £/kW
Penalty prices	2-40 £/kWh

3.4.3. Customer proposition

Octopus Energy designed a new tariff (Octopus Go Faster) based on their Octopus Go EV tariff and offered it to their existing customers, marketed as a research project. Customers were offered £5 off their overall bill for each month that they participated in the trial. Octopus Energy continued to offer the Go Faster tariff to customers not involved in the trial without the £5 credit.

Octopus Energy customers selected both a duration for the reduced rate and a start time for that rate to apply to of:

- 3-hour Go period at a reduced rate of 4.5p/kWh – 20:30, 21:30, 22:30, 23:30, 00:30, 01:30, 02:30, 03:30
- 4-hour Go period at a reduced rate of 5p/kWh – 20:30, 21:30, 22:30, 23:30, 00:30, 01:30, 02:30
- 5-hour Go period at a reduced rate of 5.5p/kWh – 20:30, 21:30, 22:30, 23:30, 00:30, 01:30

During the trial, there were several periods with low wholesale energy prices over the summer and negative plunge prices for charging. This led to a number of customers moving between the Octopus Go Faster tariff being trialled and the Octopus Agile Tariff to take advantage of the best offering. It is important to acknowledge that this switching is in part due to the current market context, which would be different under a capacity-based pricing DUoS mechanism which incentivises smoothing of demand.

3.4.4. Charging control and optimisation

The control approach was customer managed and therefore the level of automation was dependent on any devices that the customer chose to use, such as built-in timers or a smart cable.

Figure 12 provides an overview of the optimisation data used by Octopus Energy in their capacity-based DUoS pricing trial:

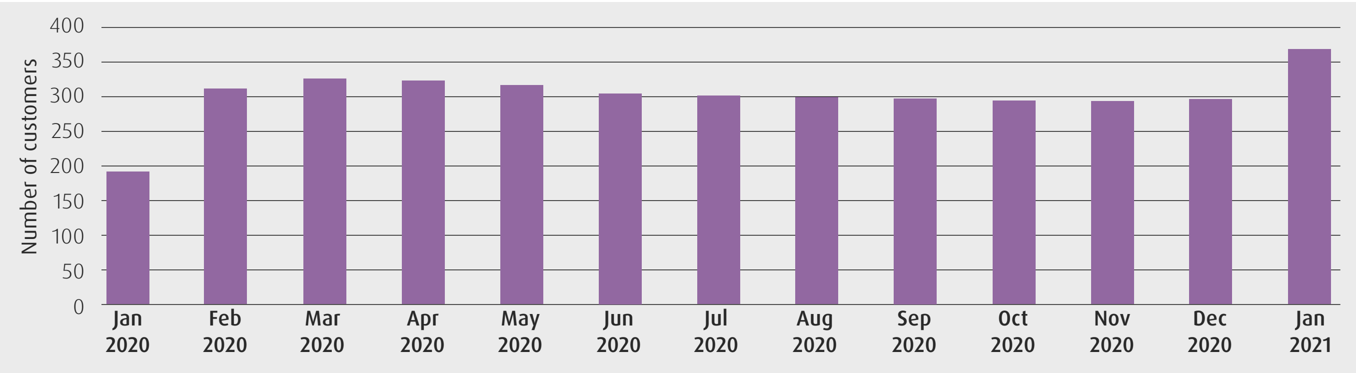
Figure 12
Overview of data from Octopus Energy trial

Tariff type	HHS
Automated charging	Combined
Charging session data collected	No
HH household meter data collected	Yes

3.4.5. Overview of recruitment and trial customers

Over the course of the study, 1,182 customers adopted the Go Faster tariff and were included in the trial at any one time. Figure 13 shows how the number of customers on the trial evolved over the period, reflecting the fact that customers joined and left the Go Faster tariff as the trial progressed.

Figure 13
Average number of Go Faster trial participants over time



Octopus Energy undertook a survey with their customers, receiving 194 responses. The majority of those surveyed (70%) were two driver households and 39% had solar PV installed at their home. The most common EVs were the Nissan Leaf and the Tesla Model 3 both representing 23% of those surveyed and at least 95% had a full EV (as opposed to a plug-in hybrid) with only 5% selecting 'other' when describing their EV (which could have been full EVs too).

Using electricity when it is cheapest was by far the most important reason for smart charging (69%), with 25% citing using electricity when it is cleanest to minimise the carbon intensity of running an EV and only 5% referring to using electricity when the local electricity network has capacity to minimise reinforcement works. Most charging appears to be undertaken at home, with 20% stating they only charge at home and 38% stating that they only charge away from home 1-2 times a month.

Based on the survey response, Figure 14 provides an overview of the customers involved in the trial.

Figure 14
Customer characteristics from Octopus Energy trial *(based on survey respondents)*

Vehicle type	94% BEV 0% PHEV 6% unknown
Average EV battery capacity	54 kWh
Charging point rating	Various

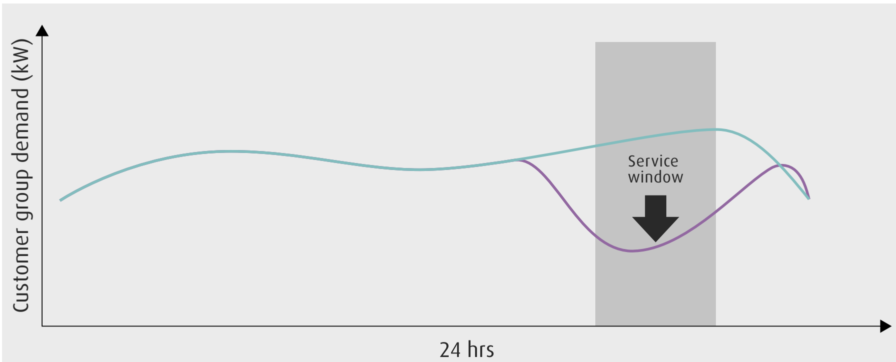
3.5. LV Flexibility Procurement trial (ev.energy)

3.5.1. Product overview

As the transition to DSO progresses, more networks have been incorporating flexibility procurement into their operations. The LV flexibility product developed for Shift was developed in line with existing approaches for HV and EHV flexibility.

In this product design, 'service windows' were defined at times of the day that correspond to real network constraints, and within these windows the product requests that a service provider limit the aggregate load of their EVs to a pre-defined level as illustrated in Figure 15.

Figure 15
Illustrative flexibility procurement product



Key
Unmanaged EV charging
Managed EV charging

3.5.2. Product design

The value of the service per kW of turn-down response is defined by the avoided cost of reinforcing the network. Typically, this is set by calculating the cost of capital saving generated by deferring reinforcement for a defined number of years, and then dividing this by the number of kW required per year to defer the need for reinforcement.

The value of the service is therefore highly location-dependent and driven by a number of factors specific to each substation and constraint, such as the expected costs of reinforcement for a given site and the number of hours per year the service is required for.

In the market, values are revealed through tenders, which establish the price at which a service provider can offer the service. If this offered price is less than the value of the service at that location, then this is an economic option for customers. If the offered price is higher, then reinforcement is the right option for customers.

The product design for this trial requested a 'guaranteed load limit' from the service provider in the service windows – i.e. the maximum demand level that a group of EVs can exhibit – with the service provider incentivised to manage customer load into other time periods.

The amount of load reduction provided was measured against a baseline determined by a 'default load factor', which is a diversity-adjusted level of charging per EV. This attempts to account for the fact that it is unlikely that all EVs in the service providers' portfolio will be charging at the time of the service window, and that we would likely be over-rewarding the service provider if we assumed all EVs were plugged in and charging ahead of the window.

3.5.3. Customer proposition

ev.energy tested a range of propositions, including rewards for every 20 charging sessions and offers powered by partner energy suppliers. ev.energy offered a range of incentives to customers to sign up to the trial and were looking to incentivise customers around type of use rather than time of use (e.g. plug in more often for longer periods) to increase the amount of flexibility available.

The control approach was third party managed where customers who signed up to the smart agreement allowed ev.energy to manage their charging, although an override option was available to the customer. ev.energy then automated the load of their customers within the service window and optimised their usage against other market services, cost and carbon intensity of electricity.

The choice of incentives available to customers on the trial received great feedback and these incentives correlated to higher levels of smart charging.

By having a rewards scheme ev.energy were able to get flat rate users to engage in smart charging as they now have an incentive to charge this way. Since introducing the choice of smart charging rewards in April 2020, most customers opted for financial incentives over green credentials, the most popular were Amazon vouchers (80%), coffee vouchers (12%) and carbon credits (8%).

3.5.4. Charging control and optimisation

Figure 16 provides an overview of the optimisation data used by ev.energy in their capacity based DUoS pricing trial:

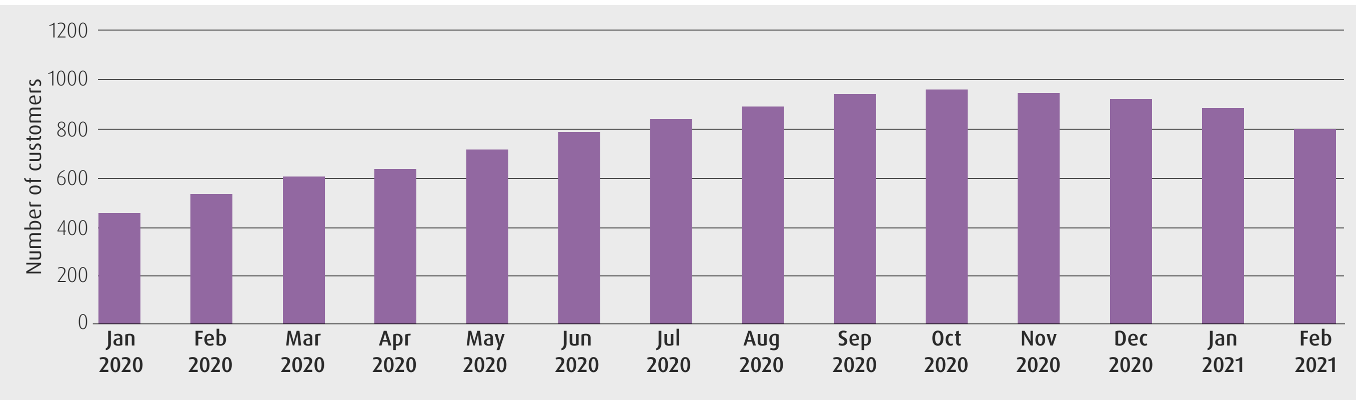
Figure 16
Overview of data from ev.energy trial

Automated optimised charging	All customers
Optimisation	Half hourly
Charging session data collected	Yes
HH household meter data collected	No

3.5.5. Overview of recruitment and trial customers

ev.energy targeted 3,264 customers as part of the trial, these customers were targeted through an initial email campaign, with continuous recruitment via the smart charging rewards page in the app. Over the course of the trial, 1,026 customers participated and are included in the trial data. Figure 17 shows how the numbers of active customers varied over the course of the trial.

Figure 17
Number of ev.energy participants over time



As the customer proposition for ev.energy was based on the number of smart charging sessions, the customer rewards were sufficient to accommodate a greater number of customers. This was in part due to the decreased number of charging sessions due to the COVID-19 lockdown measures and changes in customer behaviour. The number of customers and point at which they joined the trial has been considered in the analysis.

Figure 18 provides an overview of the customers involved in the trial, taken from a mid-trial snapshot.

Figure 18
Customer characteristics from ev.energy trial

Tariff type	41% ToU 11% on a dynamic tariff 48% on a flat rate tariff
Vehicle type	92% BEV 8% PHEV
Average EV battery capacity	ww 55 kWh
Charging point rating	7.2 kW

Trial Results and Observations

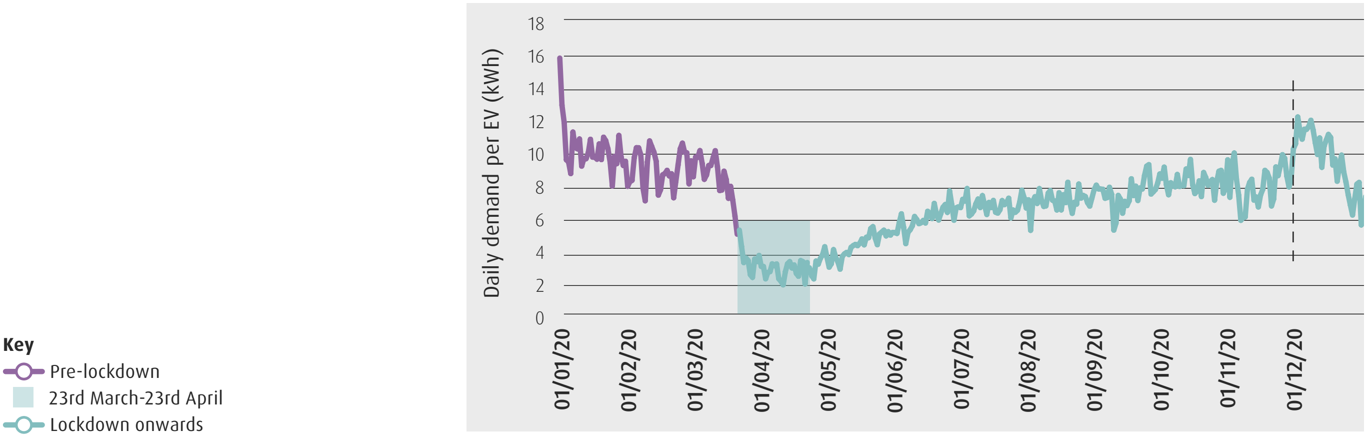
4

4. Trial results and observations

4.1. Note on the impact of Covid-19

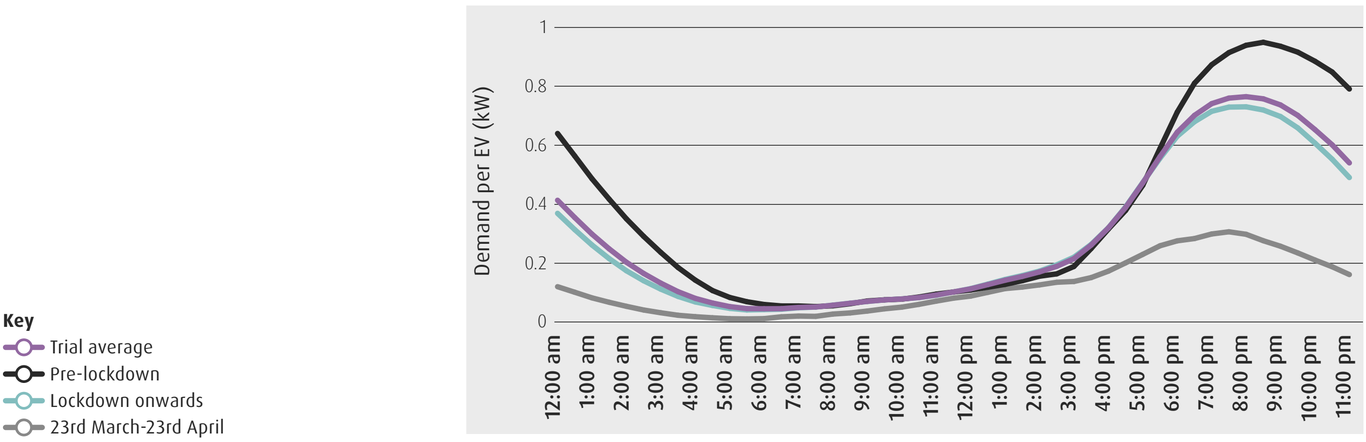
The UK lockdown measures were announced on the 23rd March 2020. This had a significant impact on the average electricity consumption across customers involved in the Shift trials. Figure 19 shows the daily average EV demand changed over the course of 2020. There is a rapid drop in demand initially, with a fairly steady trend back to the pre-lockdown demand levels by the end of that year.

Figure 19
Daily EV demand pre- and post-lockdown *(based on Kaluza and ev.energy trials)*



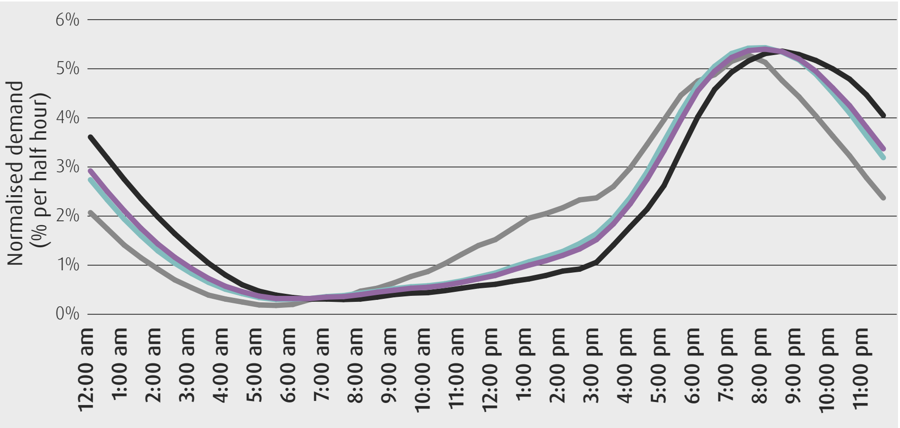
This drop in demand is reflected in the average EV charging profile, as seen in Figure 20. Pre-lockdown refers to data collected up to the UK lockdown announcement on the 23rd March 2020, and lockdown onwards refers to data collected following this announcement until the end of the trial period. The first month of UK lockdown saw significantly lower demand per EV, and hence it has been displayed separately.

Figure 20
Effect of Covid-19 Lockdown on EV charging profiles *(Kaluza and ev.energy trials)*



However, on a normalised basis[9] the profile shapes look broadly consistent, as shown in Figure 21. During the first month of lockdown, there are some differences in that the demand during the day is relatively higher during lockdown, with a corresponding reduction in late evening and overnight demand. This is consistent with a reduction in commuting and a more uniform distribution of charging events across the day.

Figure 21
Effect of Covid-19 Lockdown on normalised EV charging profiles *(Kaluza and ev.energy trials)*



Key
- Trial average
- Pre-lockdown
- Lockdown onwards
- 23rd March-23rd April

It is unclear how working patterns will change in the future, and what the long-term impact will be of Covid-19 on commuting and travel behaviour more generally. The dramatic impact of Covid-19 on demand highlights the need to stress test assumptions about consumer behaviour when considering their impact on the network. There is likely to be significant uncertainty, particularly when it comes to long-term network planning.

For the purpose of this report, we show normalised profile, focusing on the shape rather than the absolute demand. Because on a normalised basis the profiles are broadly consistent before and after lockdown. Unless otherwise specified, we show results that represent an average across the whole trial period. In order to convert these back into absolute profiles, it is appropriate to scale the normalised profile by the daily demand (for an EV charger or household, as appropriate).

[9] Normalised profiles retain the shape of the absolute profile, but are scaled such that the area under each profile is the same (and equal to 1)

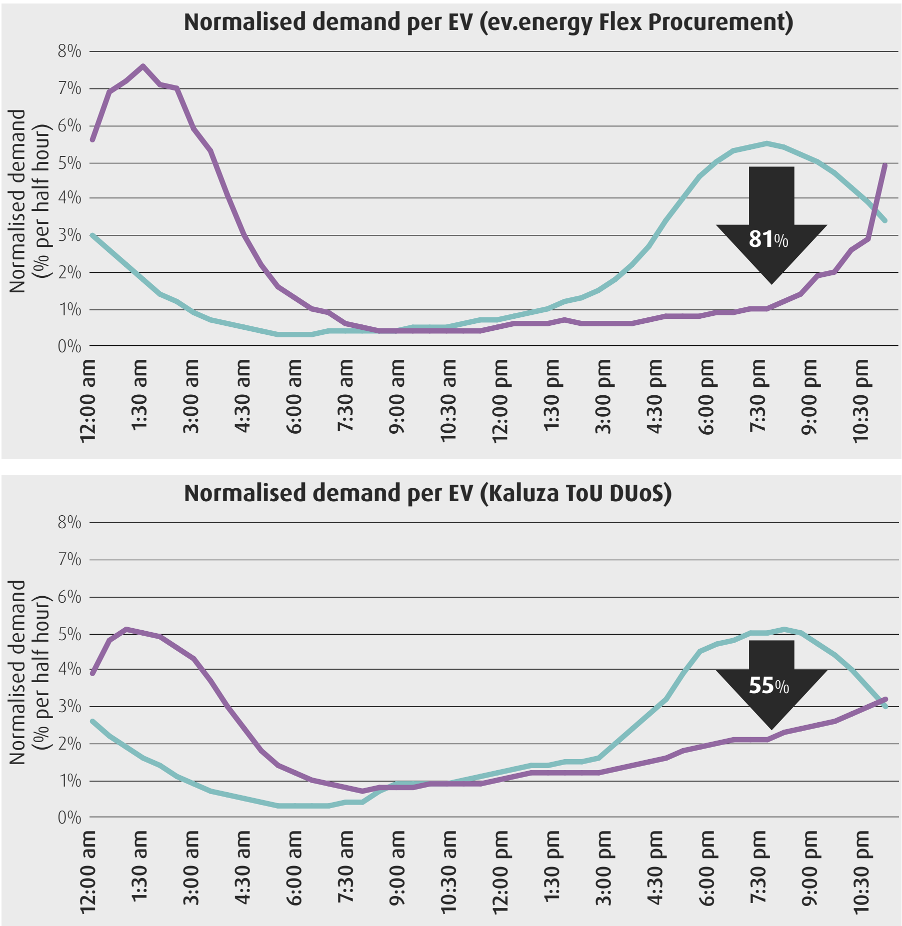
4.2. Observed peak shift

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, Flex Procurement and Capacity-based charging) reduced the EV demand at peak times. The demand reduction at peak time is determined by comparing the peak EV demand between the unmanaged baseline and smart profiles between 6-9pm. Analysis herein has been split into EV charging peak shift and household peak shift, due to the differences between the ev.energy and Kaluza trial designs and that of Octopus.

4.2.1. EV charging peak shift

Figure 22
Average EV Charger profiles – ev.energy Flex procurement trials and Kaluza ToU DUoS



Key
Unmanaged EV charging
Managed EV charging

In both trials the unmanaged profile peak occurred at 8pm. Figure 22 shows the ev.energy Flex Procurement trial elicited an 81% reduction whereas the Kaluza ToU DUoS trial resulted in a 55% reduction. The ev.energy Flex Procurement trial shows a secondary peak which is higher than the evening peak observed during unmanaged charging (at the level of the EV charger). Whilst the Kaluza ToU DUoS trial does show an overnight peak, it does not exceed the unmanaged evening peak. This appears to be because there is a lower level of load shifting away from the evening peak.

To understand the cause behind this, further analysis was done on the trial data. It is unlikely that the lower response seen in the Kaluza ToU DUoS trial is because of an inherent difference in the market mechanism between ToU DUoS and Flex Procurement. It is more likely that the specifics of the trial implementation led to the lower response. In particular, three potential causes can be highlighted:

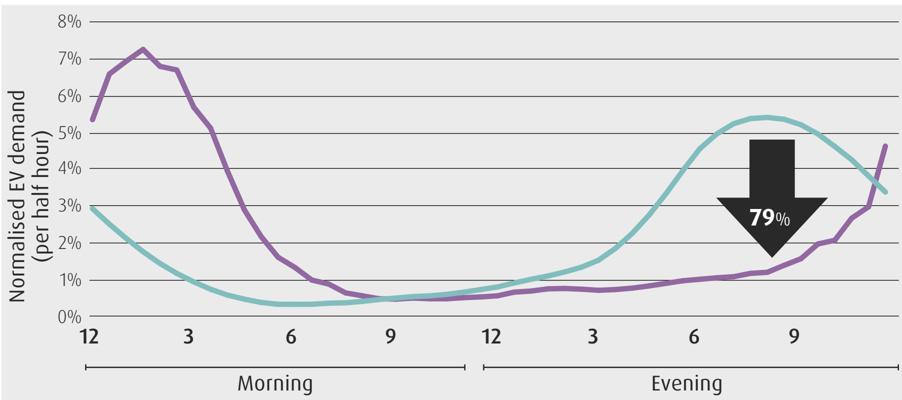
1. **Impact of the customer proposition:** Kaluza's ToU DUoS trial saw more 'boosting', which may be a result of the trial design, which saw no ongoing customer incentives. Since customers were more likely to override the managed charging option, this would explain why the evening peak reduction was limited. This is further explored in Section 4.3.
2. **Impact of technology and optimisation:** The Kaluza ToU DUoS trial algorithm did not have access to each EV's state of charge, which meant that it had to be conservative and assume the maximum charge time necessary to meet the customer's stated 'ready by' time. This meant commencing charging in some cases during the evening peak.
3. **Impact of trial design:** The Kaluza ToU DUoS trial involved two groups and the observed results differ between the two. The red band group (Group 1) exhibited an evening peak reduction of 56%, compared to 54% for the shoulder pricing group (Group 2). However, given the sample size, this difference could be explained by the variability of charging behaviour, so it does not appear that the pricing regime had a significant impact on the outcome.

There is reason to expect that a real-world implementation of this approach could shift more of the evening demand, depending on customer proposition, implemented technology and specific design of the market mechanism. We would expect to see:

- **Customer proposition:** Incentives becoming targeted to discourage boosting, thereby encouraging higher levels of managed charging
- **Technology and data:** More refined charging algorithms and better sharing of data between the charge point and the vehicle (in particular, sharing information relating to the vehicle's state of charge)
- **Market mechanisms:** More refined market design (whether price-based or procurement-based) that elicit a stronger and more reliable turn-down response.

If we combine the data from the customers on the Kaluza ToU DUoS and ev.energy Flex Procurement trials, the average diversified peak EV charging demand seen at 8pm was reduced by 79%[10], as seen in Figure 23.

Figure 23
Average EV Charger profiles from Kaluza and ev.energy trials *(all customers across the full trial period)*



Key
Unmanaged EV charging
Managed EV charging

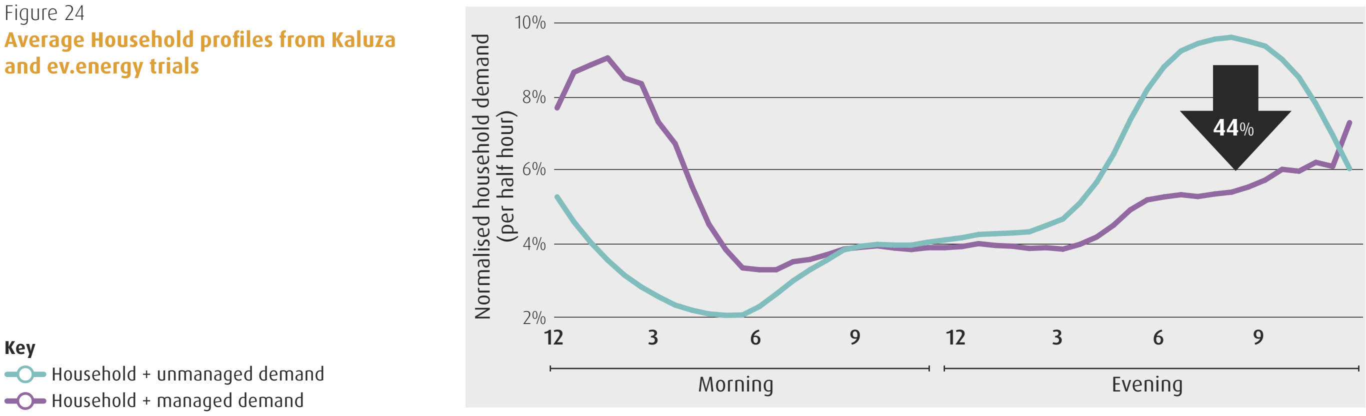
Note that this profile is more heavily weighted towards the ev.energy Flex Procurement result, since the number of customers on that trial was larger than on the Kaluza ToU DUoS trial.

[10] Because of the trial design, the Octopus customer demand was only measured at the household level rather than the EV charge point level

4.2.2. Household peak shift

At an overall household level, if we assume the underlying (non-EV) customer demand aligns to Profile Class 1[11], the effect of the smart charging as trialed via Flex Procurement and ToU DUoS would be to reduce the 8pm peak demand (as compared to the unmanaged charging peak) by 44%, as seen in Figure 24. This reduction is lower than that seen at the EV charger level because – for the purpose of this analysis – we assume that the underlying PC1 household demand is not shifted.

Figure 24
Average Household profiles from Kaluza and ev.energy trials



4.3. 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.

As Figure 25 shows, on average boosting occurred fairly consistently across the day. Therefore, as a proportion of overall charging events it is more likely to occur during the day (where plug-in events are less common). Over the trial period, boosting as a proportion of overall charging sessions was fairly flat, although it drops towards the end of the trial period. Whilst the reason for this is not certain, it is speculated that this could correlate to a return to routine following Covid-19 lockdowns, or a reflection of consumer understanding and confidence in the charging schedule reducing the need to boost.

[11] 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

Figure 25

Boosting behaviour over duration of the day and the trial *(Kaluza and ev.energy trial)*

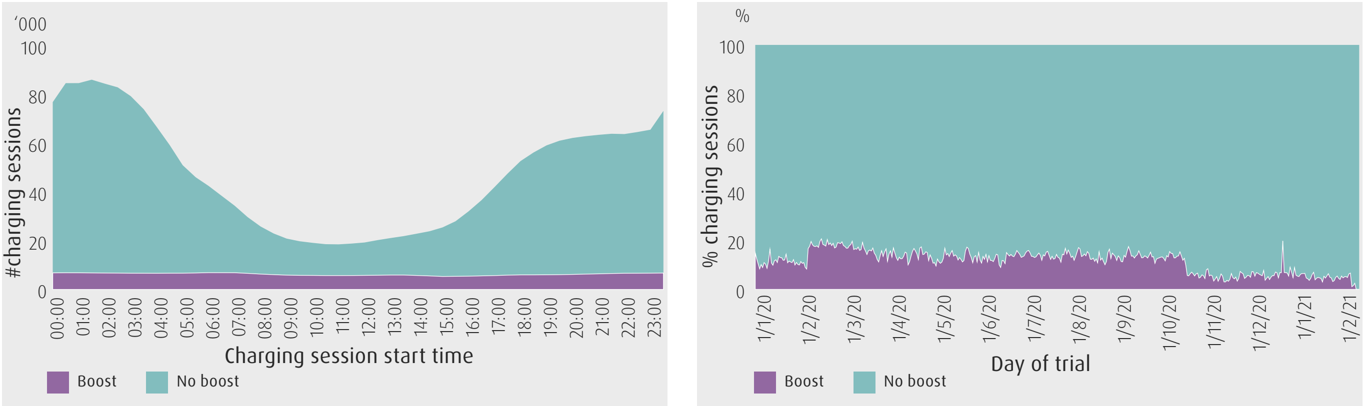


Figure 26 shows that boosted sessions were typically shorter, which is to be expected for two reasons. First, it is because a managed charging session is able to include periods where charging is paused, which extends the overall session duration. The second reason is that boosting is more prevalent for PHEV, which have smaller batteries and hence shorter charge times.

This is supported in Figure 27 and Figure 28, which show the same plots of charging over time split by battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV).

Figure 26

Distribution of charging sessions and device usage by the duration of charge *(Kaluza and ev.energy trial)*

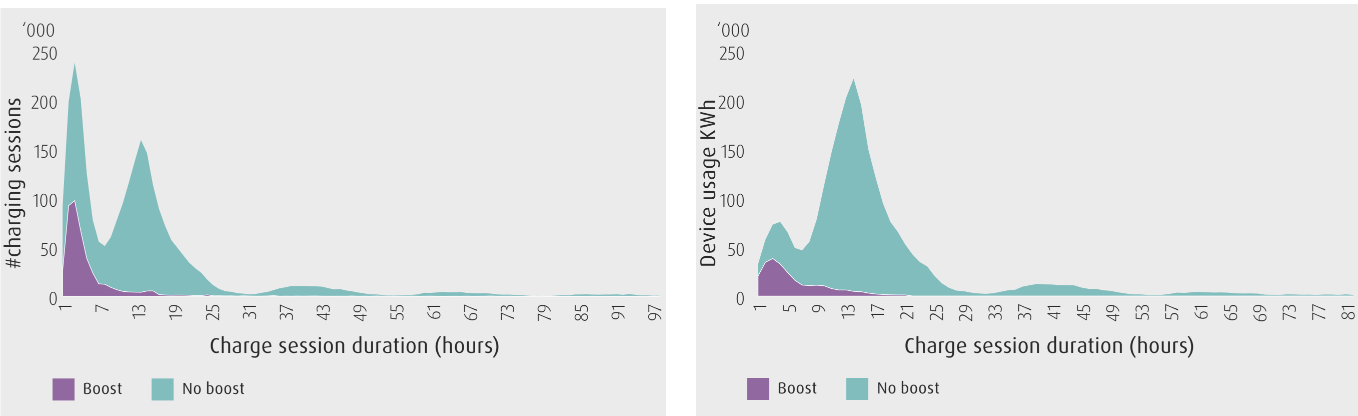


Figure 27

Boosting behaviour over time *(Kaluza and ev.energy trial)* **– BEV only**

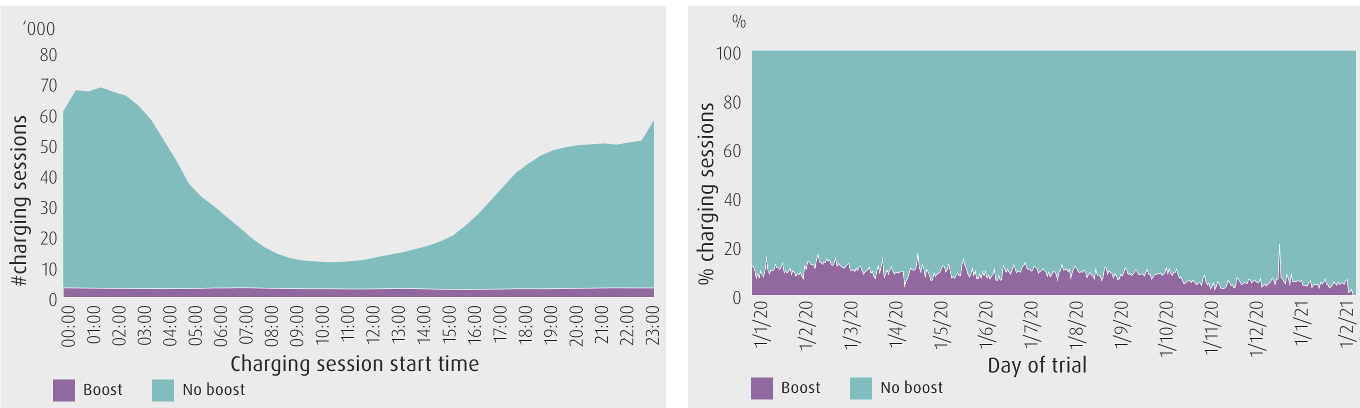
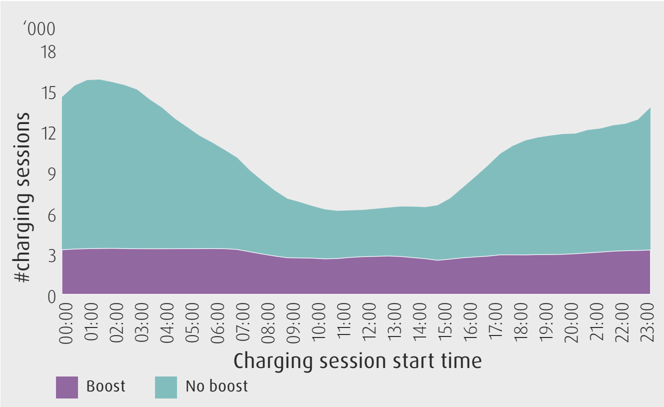


Figure 28
Boosting behaviour over time *(Kaluza and ev.energy trial)* **– PHEV only**



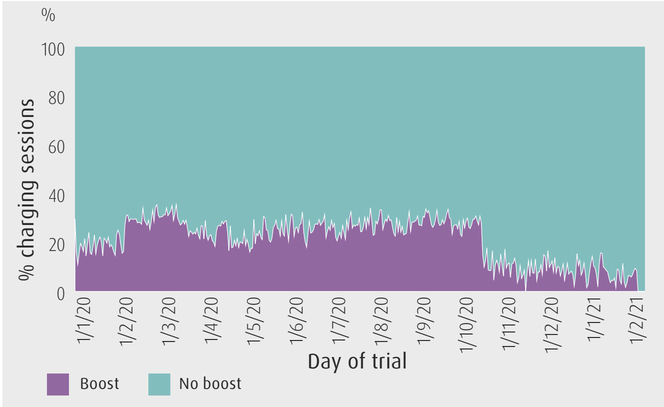
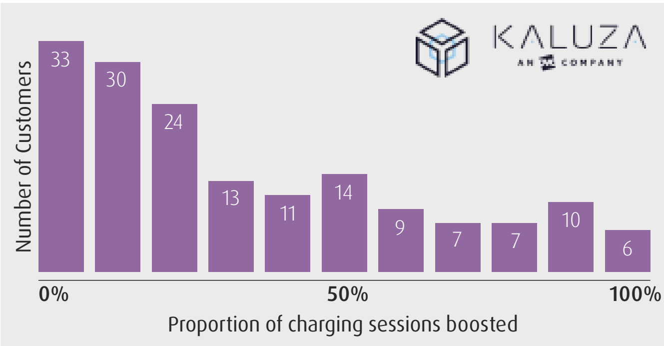
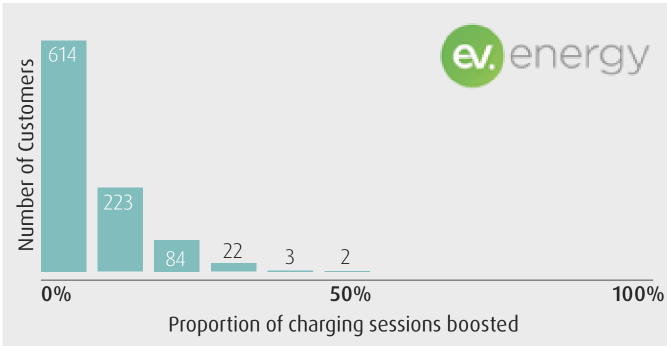


Figure 29 shows how boosting behaviour varied across trial customers. For the ev.energy trial, the majority of customers boosted less than 10% of their charging sessions. There were no examples of customers boosting more than half of their charging sessions. By contrast, the Kaluza trial included customers who boosted more often, although the largest single grouping still boosted infrequently.

Figure 29
Boosting behaviour in the Kaluza and ev.energy trials

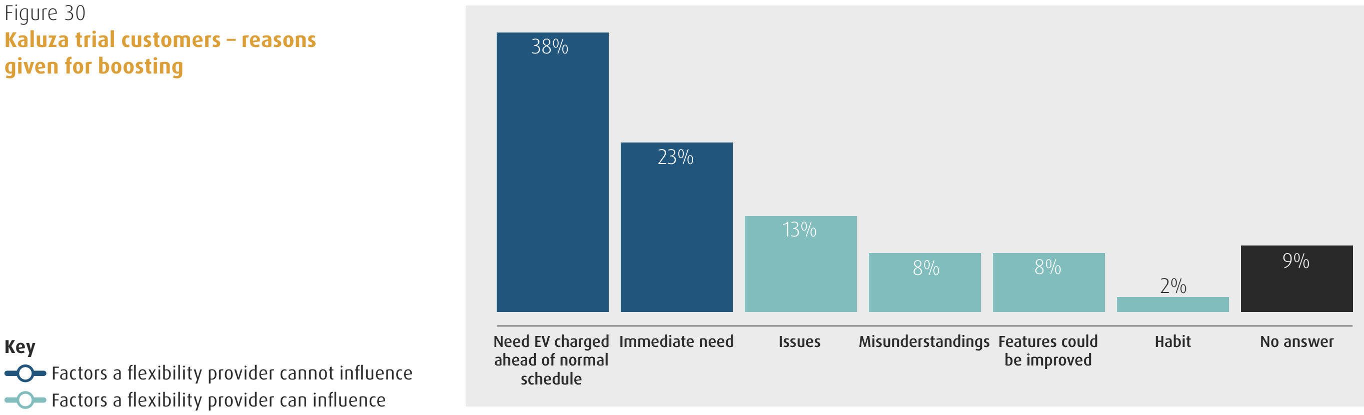




The rewards for smart charging in the ev.energy trial gave these customers a financial incentive not to override smart charging sessions and the majority of customers rarely or never used the boost function. Boosting behaviour was more prevalent on the Kaluza trial, and a small proportion of customers 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 not to override or even 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.

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 (see Figure 30).

Figure 30
Kaluza trial customers – reasons given for boosting



4.4. Contribution to peak demand and the effect of peak shifting

The trial mechanisms 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 had been hypothesised that secondary peaks could become an issue under smart charging arrangements, with smart charging serving to reduce the natural diversity of charging behaviour.

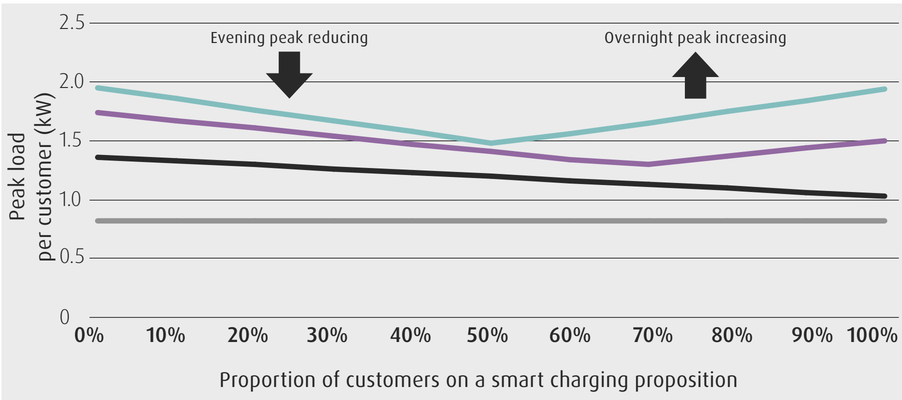
In both the Kaluza ToU DUoS and ev.energy Flex Procurement trials, the EV charger peak demand shifted to the overnight period. In the Kaluza trial, the magnitude of this peak was the same as the original evening peak. However, for the ev.energy trial, the peak was higher than the baseline evening peak, 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 customer 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 31 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.

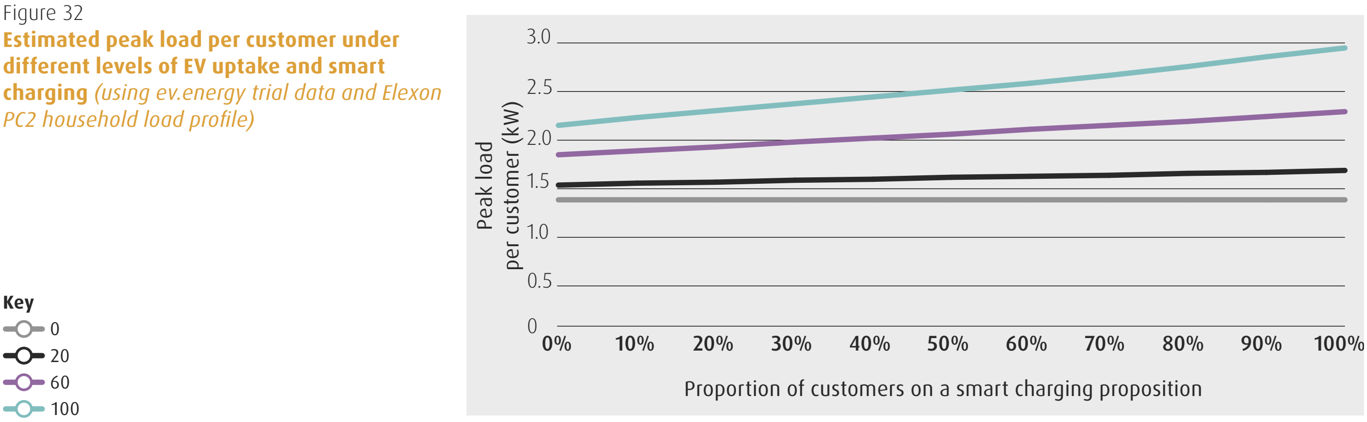
Figure 31
Estimated peak load per customer under different levels of EV uptake and smart charging *(using ev.energy trial data and Elexon PC1 household load profile)*



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

However, if the same analysis is done but overlaying smart charging on a Profile Class 2 domestic household (so-called 'Economy 7') we see in Figure 32 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.

Figure 32
Estimated peak load per customer under different levels of EV uptake and smart charging *(using ev.energy trial data and Elexon PC2 household load profile)*



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.

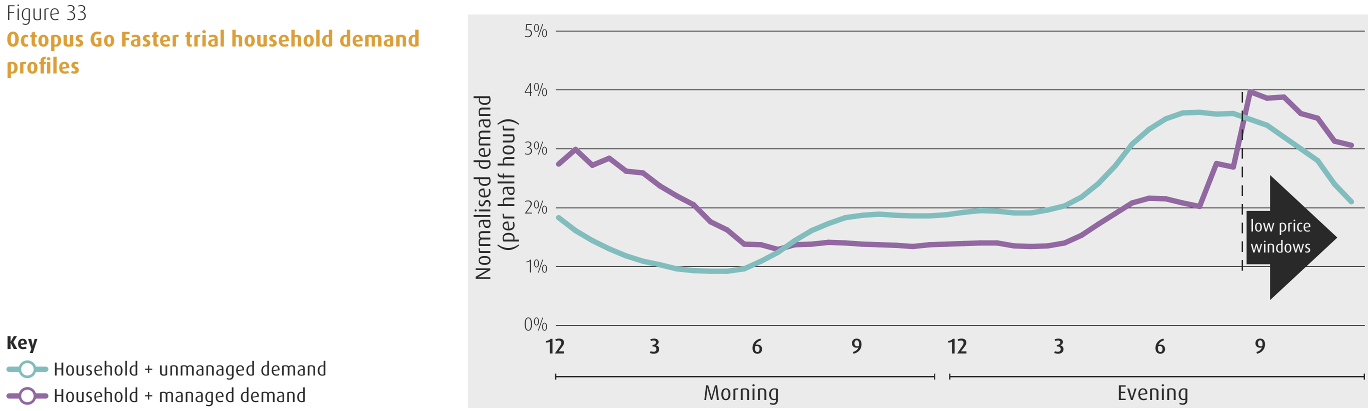
4.5. Preventing the overnight peak

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 ToU DUoS trial nor Flex Procurement explicitly attempted to avoid the formation of a secondary overnight peak.

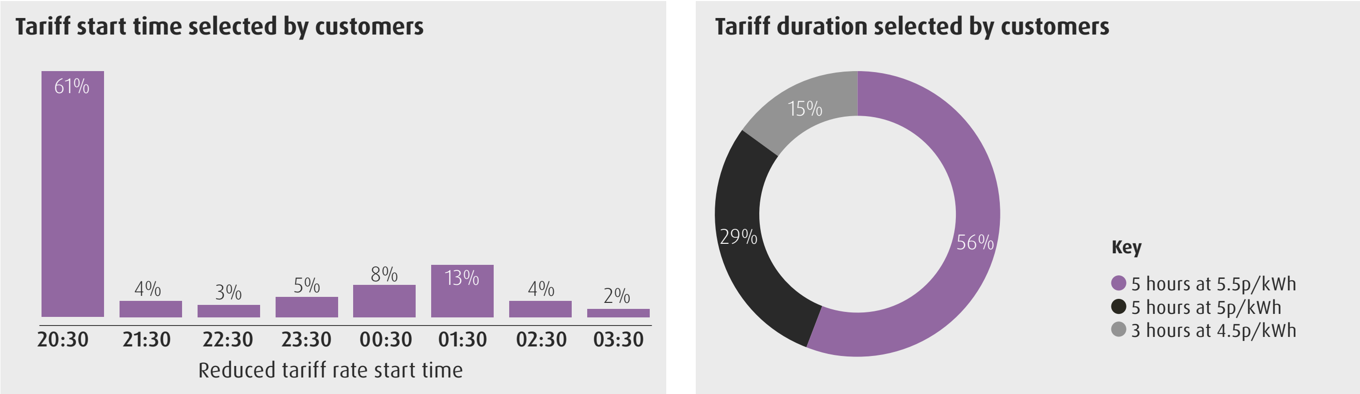
Capacity-based charging, which was trialled by Octopus Energy, is intended not only to reduce the contribution to the evening peak, but to smooth the shifted demand across the overnight period. In the trial design, this was to be done by offering different 'low price' windows to different customers so 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, as seen in Figure 33.

Figure 33
Octopus Go Faster trial household demand profiles



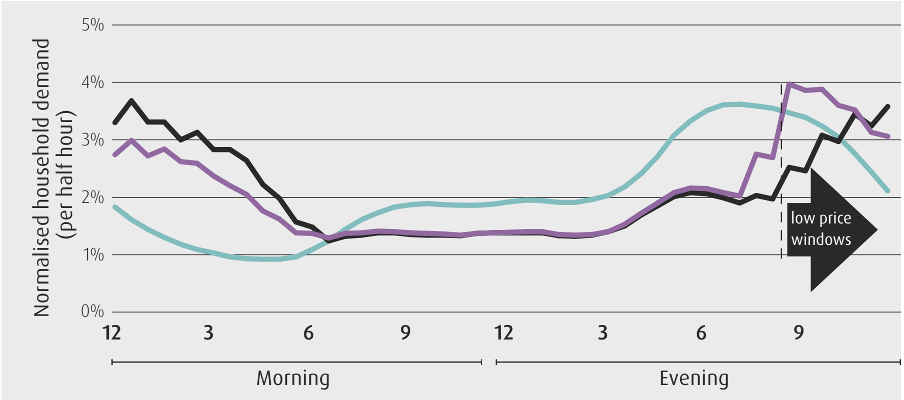
This peak occurred at 8.30pm, which corresponded to the first of these 'low price' windows. Some of the Octopus Go Faster customers were therefore incentivised to begin charging, and using their other domestic appliances, from 8.30pm, which they did either manually or using their own devices' smart capabilities. Furthermore, this 8.30pm cohort represented a significant majority of the customers on the Octopus Energy trial, as can be seen in Figure 34.

Figure 34
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. Figure 35 shows 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 optimising the proportion of customers on each tariff.

Figure 35
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, with all start times of a specific duration offering the same reduced rate. 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, would require further investigation.

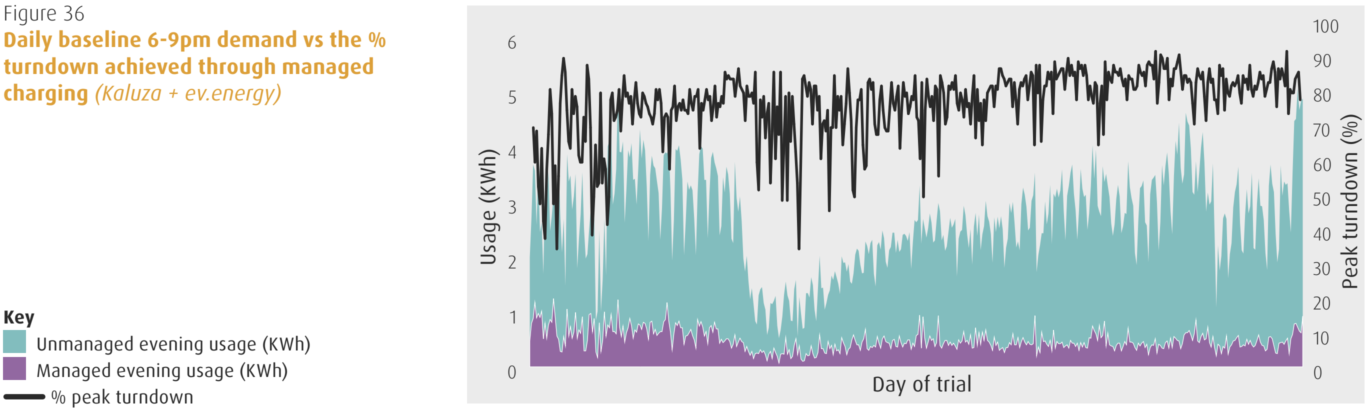
4.6. Reliability of response

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.

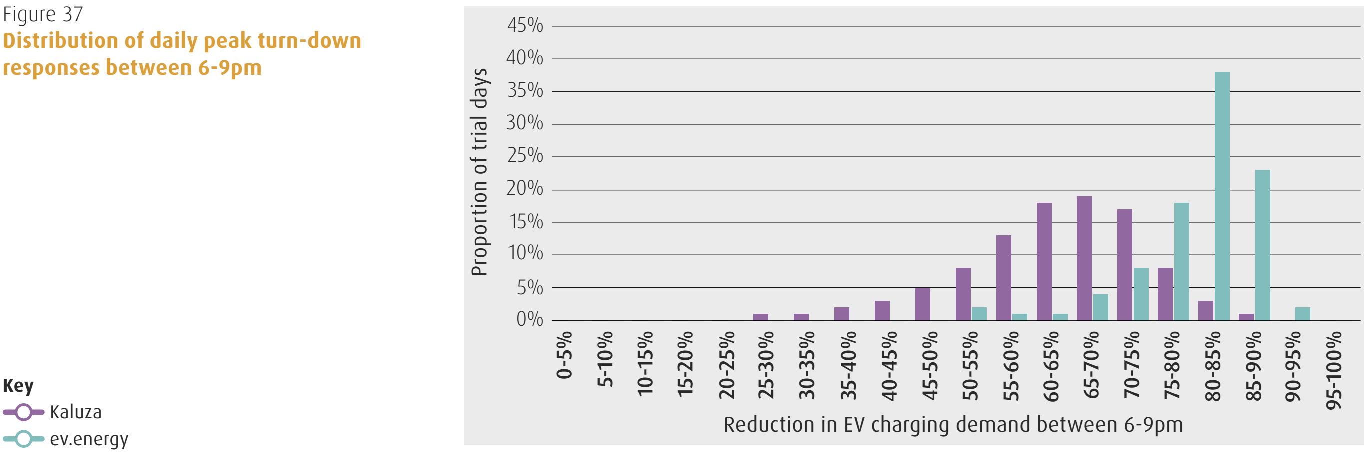
Analysis of the Kaluza and ev.energy trial data shows that there is a fairly consistent peak turn-down percentage over time, although there are some days where the turn-down is relatively small, as seen in Figure 36.

Figure 36
Daily baseline 6-9pm demand vs the % turndown achieved through managed charging *(Kaluza + ev.energy)*



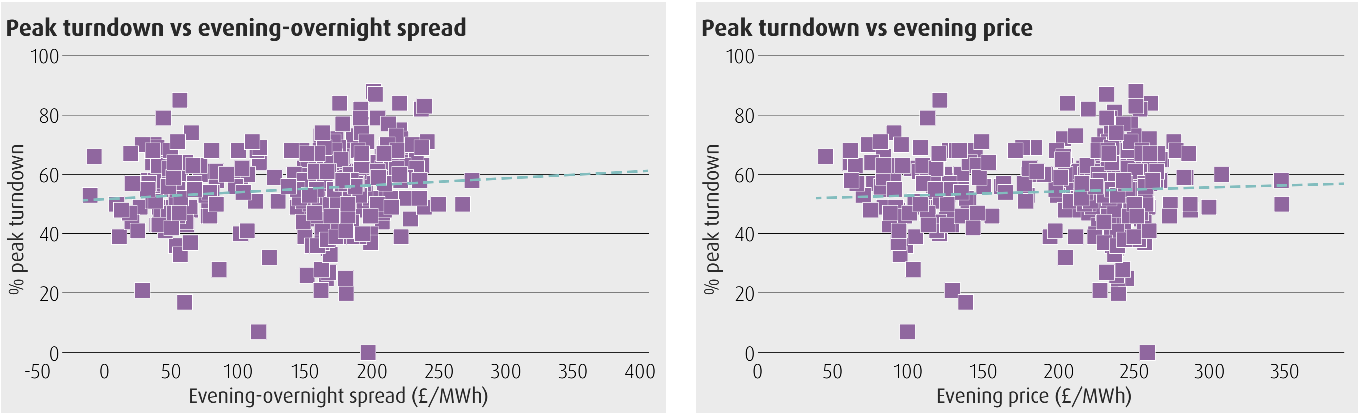
The median peak reduction for ev.energy was 82%, but was 65% for Kaluza (see Figure 37). The Kaluza trial observed a wider distribution of percentage peak turndown. This is likely to be a result of the particulars of the Kaluza customer proposition design (not disincentivising boosting, and not measuring state-of-charge) rather than an inherent difference between the use of ToU DUoS compared with Flex Procurement. Whilst some level of turn-down response can probably be assured through managed charging, there may be days where this mechanism delivers less response than expected. We need to work closely with suppliers to ensure that any schemes are implemented in a way that achieves robust and reliable results.

Figure 37
Distribution of daily peak turn-down responses between 6-9pm



It could be hypothesised that the magnitude of the price of energy during the evening peak, and/or the size of the price difference between the evening and overnight, could affect the turn-down effect seen. The Kaluza algorithm considered not only the ToU DUoS signal, but also the TNUoS signal and the wholesale price signal. These prices have been combined in Figure 38 to understand whether these prices, or the spread in price between the evening and overnight period, explains the differences in the response observed.

Figure 38
Price vs response: the effect of evening price and evening-overnight spread on % turndown



Whilst the absolute price does show a small positive trend (i.e. higher price lead to more turn-down) the effect is small, and well within the noise of the data. There is slightly more evidence that the price spread affects the turn-down response, but again the effect is small.

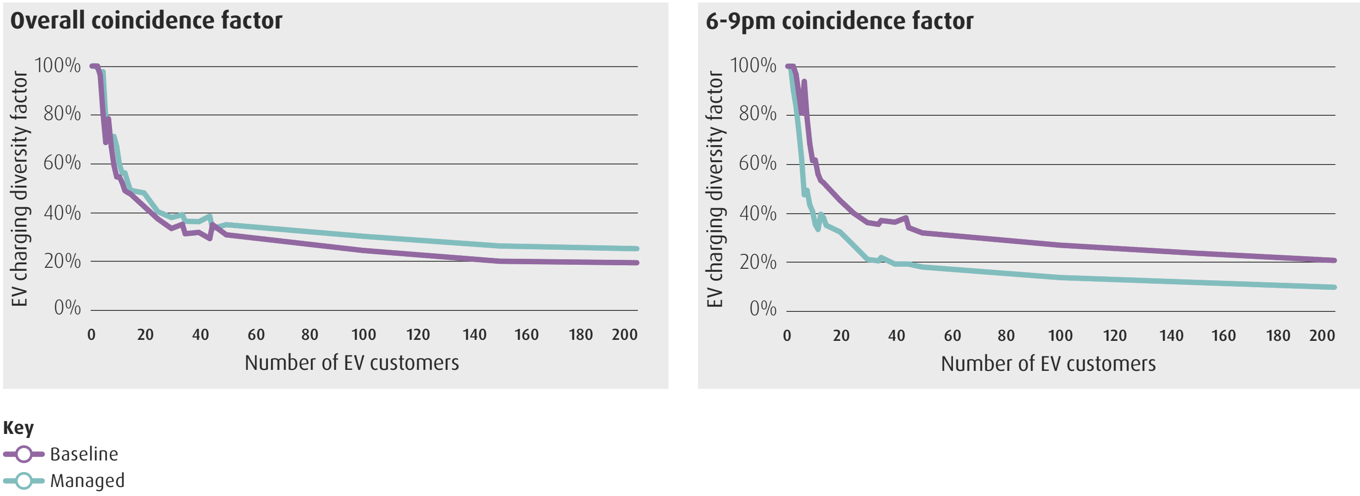
Whilst wholesale prices remain relatively benign, this means that the ToU DUoS signal as tested could be sufficient to elicit the desired response. However, in future, wholesale prices are expected to become more volatile, including periods of negative prices. In this case, the wholesale price could be the determining factor in future smart charging optimisation algorithms, in which case ToU DUoS tariffs may need to evolve.

4.7. Accounting for 'coincident' charging

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 which would exacerbate constraints. As more EVs are connected, the expected average peak demand per EV tends to fall, as represented by the 'coincidence factor' shown in Figure 39.[12]

Figure 39
EV Charging Coincidence Factors across the day and focused on the evening peak



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 via smart tariffs, 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.

12 '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.

5

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.

5.1 Potential implementation roadmap

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.

5.2 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 customer propositions are becoming increasingly popular, and suppliers have the potential to 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 procure services on the LV network and the first DNO in the UK to procure flexibility from an EV service provider. The value of these procured services continues to rapidly grow, demonstrated by the 248MW of flexibility procured from EV batteries in the March 2021 tender round.

As part of this activity, we also developed a robust and adaptable approach to defining an EV charging baseline against which the smart charging response can be measured. This baseline takes account of the numbers of EVs in an area (and hence their Coincidence Factor – see Section 4.7) and how demand evolves over time as smart charging becomes more prevalent.

5.2.1 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.

One advantage of a ToU DUoS signal as an approach to deliver smart charging is that it is similar to current charging methodologies. Suppliers are already exposed to DUoS charges, to cover the cost of using distribution networks to supply end customers, however these are applied at a licence area level.

ToU DUoS charges could be deployed at a more granular level to reflect local network needs. 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.

5.2.2 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 Flex 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 bring factored into UKPN's 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' as would be seen with locationally granular ToU DUoS, which could result in price disparity between areas and 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;
- **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.

5.2.3 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[13] 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.

13 https://innovation.ukpowernetworks.co.uk/projects/envision/

5.3 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, increasing volatility in wholesale prices (mediated by their supplier or aggregator) could influence future smart charging profiles;
- **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) 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.

5.4 Longer-term potential mechanisms

5.4.1 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 affect 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.

5.5 Capacity-based DUoS charging

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

A capacity-based DUoS charging approach can shift demand away from the evening network peak and smoothen it across the entire 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 to 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.

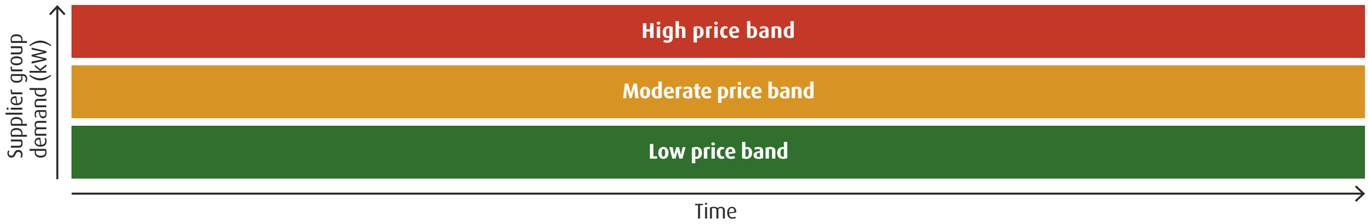
There are conceptual advantages associated with having suppliers 'book' capacity. When applied at a granular level, this approach would signal when additional capacity was required, giving a strong signal to the DNO of when to create additional capacity.

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, as illustrated in Figure 40. 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 associate 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.

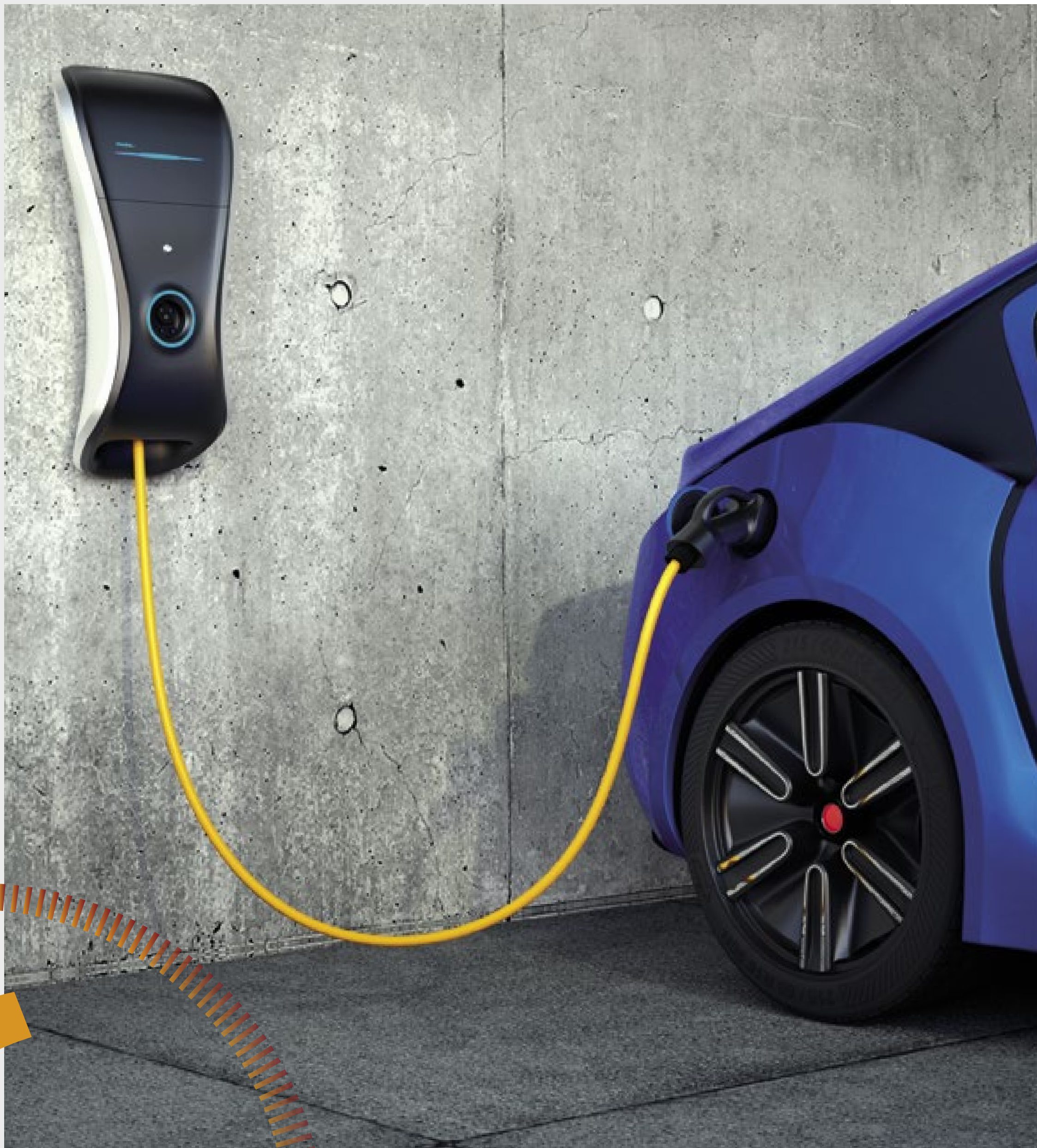
Figure 40
Illustration of network charging based on capacity bands



Whilst 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



6

6.1 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.

6.2 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 19% 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

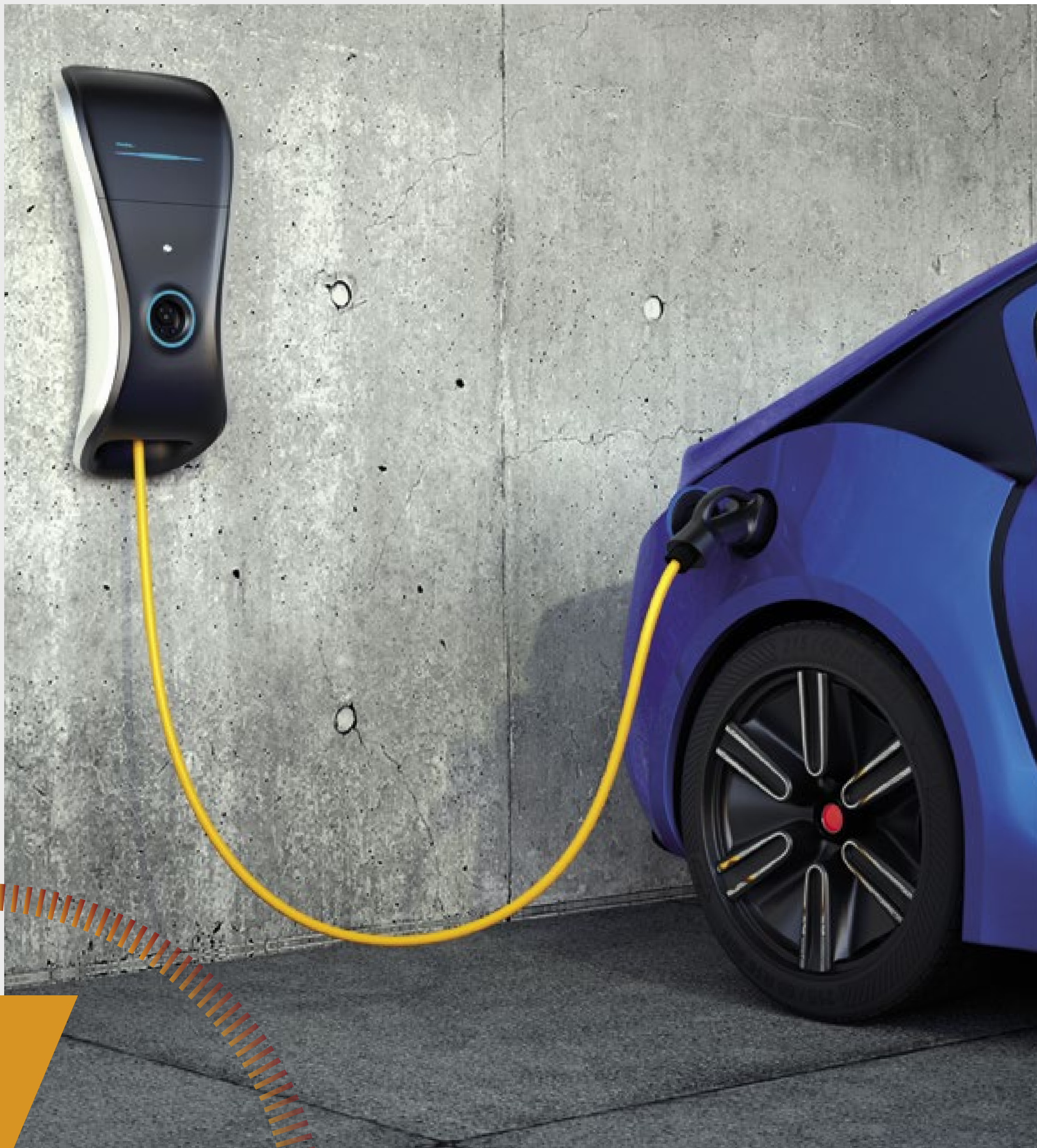
6.3 Next Steps

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.

Appendix



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Octopus Energy analysis of penalty prices and optimal capacity booking

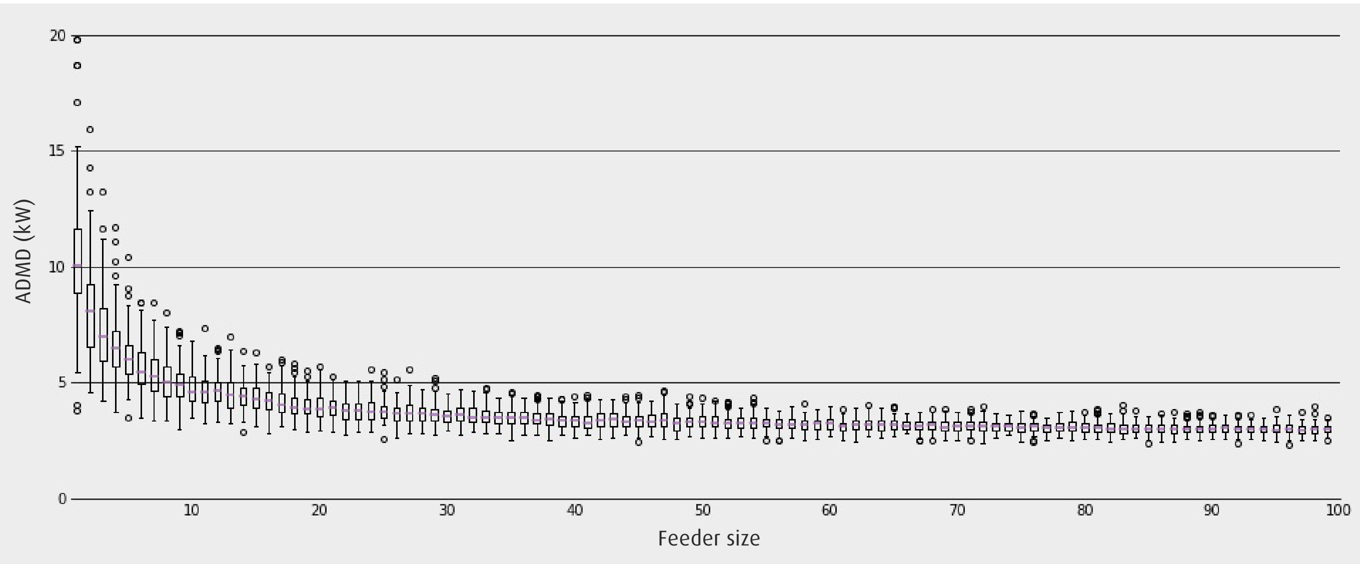
Under the capacity-based approach, suppliers 'book' capacity (kW) for their customers ahead of time. For each unit of capacity that a supplier books, they incur a fee – the 'Capacity Price', expressed in terms of £/kW. If that customer group exceeds the booked capacity, the supplier incurs an additional penalty fee for every unit of energy (in kWh) above that level (the 'Penalty Price').

Under this arrangement, suppliers are incentivised to book an amount of capacity that minimises the expected overall cost. If the penalty price is very high, a supplier is incentivised to book a large volume of capacity in order to keep the volume of consumption above that level to a minimum. Conversely, if the penalty price is very low, a supplier will book very little capacity since the cost of exceeding the booked level is small.

As well as the Capacity Price and the Penalty Price, the supplier needs to take into account the expected profile of their customer group. As discussed in Section 4.7, this is a function both of the average customer profile and the number of customers. A group of customers will have an average peak demand that is lower than the peak demand of each individual customer. This is because of the diversity of consumption behaviours between customers, and the fact that is unlikely that all customers will reach their peak demand at the same time.

Octopus Energy has calculated the After Diversity Maximum Demand (ADMD) for a subset of its trial customers. The results are summarised in Figure 41. If Octopus Energy were booking capacity for a small number of customers on a feeder, they would need to book a relatively large amount of capacity per customer since the diversity (or 'Coincidence Factor') between those customers would be low. However, when booking capacity on a larger feeder, the diversity between those customers would reduce the ADMD, meaning that less capacity per customer would need to be booked.

Figure 41
Household ADMD as a function of feeder size



Octopus Energy carried out a statistical analysis to understand, for different feeder sizes (and hence different points along the ADMD curve), and different Penalty Price levels, what the overall cost associated with booking different amounts of capacity would be. Their methodology was as follows:

1. For each feeder size, take a sample of customers that represents that feeder size
2. Calculate the average profile for that feeder
3. Find the maximum booking capacity (assumed to be equal to the ADMD) for the average profile
4. Calculate DUoS cost for varying penalty prices and booking capacities
5. Repeat 100 times and calculate statistics

For each of the 100 iterations, this process resulted in costs for different combinations of feeder size, penalty price and proportions of ADMD booked. The average cost and standard deviation can be represented in a tabular format, as shown in Figure 42. This illustrates that as the Penalty Price increases, the optimal booked capacity (shown here as a percentage of the Maximum Booking Capacity) increases.

Figure 42
Illustrative summary costs for a range of penalty prices and booked capacity (feeder size = 5)

	Repeats	Feeder Size	Capacity Price (£/kW)	Penalty Price (p/kWh)	Maximum Booking Capacity (kW)	Current DUoS Cost (£)	100%	90%	80%	70%	60%	50%	0%
0	100	5	71	2	6.00 +/- 1.16	40.73 +/- 14.46	112.06 +/- 21.63	100.87 +/- 19.46	89.75 +/- 17.30	78.78 +/- 15.16	68.16 +/- 13.07	58.24 +/- 11.12	52.44 +/- 15.92
1	100	5	71	5	6.00 +/- 1.16	40.73 +/- 14.46	112.06 +/- 21.63	100.90 +/- 19.46	89.90 +/- 17.30	79.29 +/- 15.19	69.55 +/- 13.24	61.57 +/- 11.74	131.11 +/- 39.80
2	100	5	71	10	6.00 +/- 1.16	40.73 +/- 14.46	112.06 +/- 21.63	100.96 +/- 19.46	90.16 +/- 17.29	80.15 +/- 15.26	71.87 +/- 13.61	67.10 +/- 13.09	262.22 +/- 79.59
3	100	5	71	20	6.00 +/- 1.16	40.73 +/- 14.46	112.06 +/- 21.63	101.06 +/- 19.46	90.67 +/- 17.30	81.85 +/- 15.44	76.50 +/- 14.58	78.18 +/- 16.63	524.45 +/- 159.19
4	100	5	71	40	6.00 +/- 1.16	40.73 +/- 14.46	112.06 +/- 21.63	101.28 +/- 19.46	91.70 +/- 17.32	85.27 +/- 15.98	85.77 +/- 17.31	100.33 +/- 25.29	1048.90 +/- 318.37

The following charts show how the optimum booking capacity varies as a function of feeder size and penalty price. The following observations can be made:

- For small feeders, the optimal booking capacity varies since the underlying demand of the customers in each sample varies. It could be optimal to book very little in some instances, but it is risky since a high penalty charge could be incurred.
- For very low penalty prices (2p/kWh), for sufficiently large feeders the optimal booking capacity is around 1kW, approximately 1/3rd of the ADMD (see Figure 41).
- As the penalty price increases, the optimal booking capacity increases until, at very high penalty prices (500p/kWh) is very close to the ADMD.

This demonstrates that, under this market mechanism, a supplier is likely to adjust its booking strategy in response both to the number of customers on each feeder (or whatever grouping of customers to which the DNO applies the capacity charge) and relationship between the Penalty Price and the Capacity Price.

Figure 43
Optimal Booking Capacity vs Feeder Size (Penalty Price = 2p/kWh)

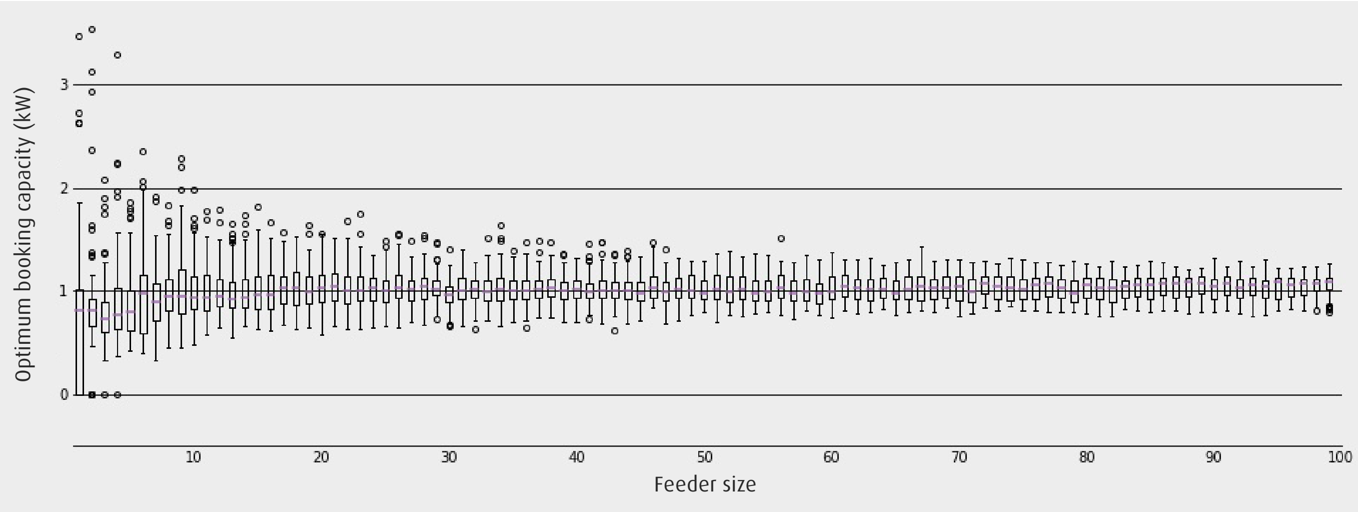


Figure 44
Optimal Booking Capacity vs Feeder Size (Penalty Price = 20p/kWh)

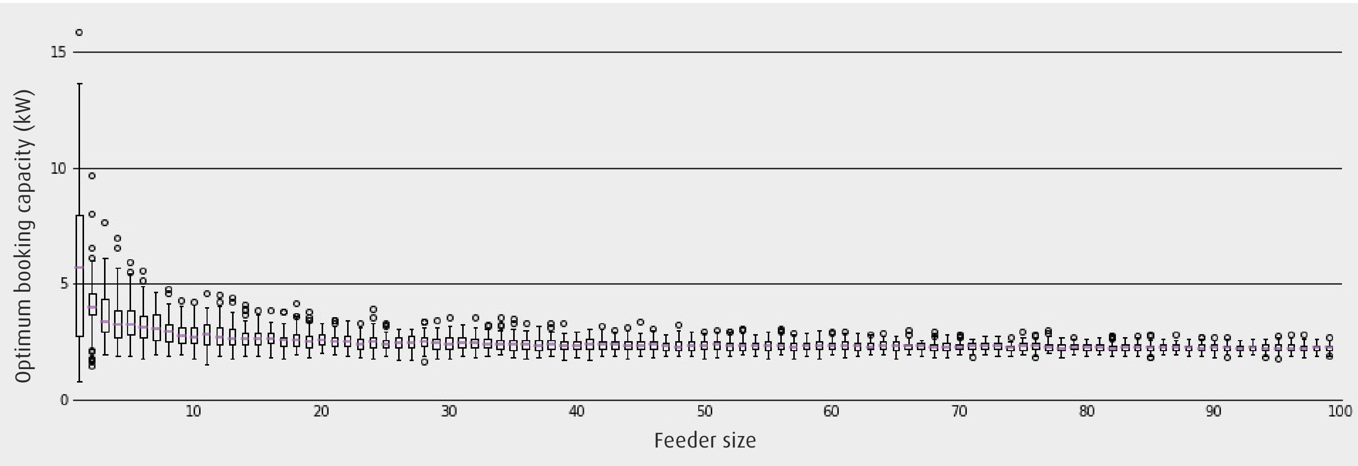


Figure 45
Optimal Booking Capacity vs Feeder Size (Penalty Price = 500p/kWh)