CrowdFlex – Phase 1 Report

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nationalgridESO

Executive summary

Background and motivation

The road to decarbonisation will undoubtedly result in more low carbon technologies in the home, including electric vehicle (EV) chargers, heat pumps, storage heating, home batteries and more. The rollout of these technologies will fundamentally reshape domestic electricity demand but also unlock a nascent source of flexibility. Flexibility can empower customers to reduce their household electricity bills, by moving demand to times where electricity is cheaper. By supporting the power system, the system benefits of flexibility can be shared with customers via the system charges in their electricity bills.

Currently there is significant uncertainty regarding the technical availability of flexibility from the domestic sector, and how this flexibility can be incentivised effectively. Key power system stakeholders including the System Operator (SO) and Distribution Network Operators (DNO), will need increased certainty and confidence in the amount of flexibility, the reliability of delivery, and the mechanisms and incentives with which to unlock it.

CrowdFlex Phase 1 is the first phase of a study into how domestic households can provide flexibility to influence energy demand and reduce stress on the electricity system. CrowdFlex aims to:

- Quantify the electricity flexibility potential from UK households,
- Identify the key parameters that influence the flexibility a household may provide, such as technology and tariff structure,
- Understand the cost of incentivising flexibility and which flexible services will be most relevant to the mass market,
- Guide market development of domestic flexibility-related services and provide a knowledge base for greater adoption into system operations.

Leveraging Octopus Energy and Ohme's large customer datasets and analysis products, CrowdFlex provides unique and robust insights on how domestic consumption can respond to price incentives and the technologies providing flexibility. To investigate this, CrowdFlex Phase 1 analysed four distinctive historical consumption datasets, arising from two types of interventions:

- **Enduring:** these assessed the change in demand resulting from a move from a flat to a dynamic energy price or time-of-use (ToU) tariff. Octopus' Go[1] (Static ToU) and Agile[2] (Dynamic ToU) tariffs were assessed.
- **One-off:** these assessed the change in demand from single events of limited duration. The events rewarded a change in customer demand over a specified 2-hour duration. "Big Turn Up" and "Big Turn Down" events were run at different times, with customers notified of the request and opting in ahead of time.

Due to the significant size of Octopus Energy and Ohme's customer datasets, CrowdFlex is the largest project of its kind investigating domestic demand shifting and flexibility. Altogether, the four interventions included over 25,000 customers, who were analysed from 2020 onwards, broken down in Table 1.

Trial	**Number of customers analysed**	
	Go	**Agile**
Tariff switch	18,000	2,378
	Number of customers participated	
Big Turn Up	19,206	
Big Turn Down	396	

Table 1: The number of customers analysed in the four distinctive interventions studied during CrowdFlex Phase 1.

[1] Go is a Static ToU tariff that offers a cheaper priced electricity (5p/kWh) between 00:30 and 04:30 each day.
[2] Agile is a Dynamic ToU tariff that tracks the UK Wholesale market to determine half-hourly energy prices, updated daily.

Results

Enduring interventions of customers **switching from a flat to a ToU tariff** proved to be capable of significantly reducing households' demand during the evening peak, and sustaining that reduction over many months. Analysis of the 20,000 Octopus customers demonstrated that households that switched from a flat to a Dynamic (Agile) or Static (Go) ToU tariff reduced the proportion of daily demand consumed during the evening peak (evening 4-7pm) by an average of 15% and 17% respectively:

- The response was greatest for EV owning customers switching to a Dynamic ToU (Agile) tariff. They demonstrated an average reduction of -0.2kW over the 3-hour evening peak. This equates to a 23% reduction in the proportion of a household's daily demand consumed during the evening peak. Similarly, the Static ToU (Go) tariff demonstrated a -0.2kW or a 19% reduction during the same 3-hour period.
- Non-EV customers, who have a lower initial peak demand than EV customers, demonstrated a lower response when switching to a Dynamic ToU (Agile) tariff. On average they reduced their demand for by -0.1kW over the 3-hour evening peak. A 12% reduction in the proportion of a household's daily demand consumed during the evening peak.
- The move of demand out of the peak evening period is robust and endured at least over the length of the trial data available (6 months).

As with the tariff switching trial, in the one-off **Big Turn Up** trial, a significant distinction was observed in the response between EV owning households and non-EV owning households. The intervention was much more effective in EV households (+5.8kW on average over the 2-hour period) compared to non-EV households. Nevertheless, non-EV households still demonstrated a significant demand turn up (+1.5kW). This increase in demand is equivalent to 617% of the magnitude of average power demand expected during a households evening peak for EV owning households (compared to 131% of the equivalent baseline in non-EV owning households).

In contrast, the results from **Big Turn Down** were similar between EV and non-EV owning households. Averaged over the two-hour window of the trial, the Big Turn Down produced an average change in demand of -0.6kW in EV owning households and -0.5kW in non-EV owning households. In percentage terms, these represent a very significant reduction in demand compared to the average evening peak power demand; -59% in demand over the period for EV households and -41% for non-EV households.

The response results of the CrowdFlex trials are summarized in Table 2.

Intervention type	**Trial**	**Average response per household: kW (% change relative to evening peak)** [3]..	
		Non-EV household	**EV household**
Enduring	Flat → Agile tariff switch	-0.1 (-7%)	-0.2 (-18%)
	Flat → Go tariff switch	0.0 (0%)	-0.2 (-17%)
One-off	Big Turn Down	-0.5 (-41%)	-0.6 (-59%)
	Big Turn Up	1.5 (131%)	5.8 (617%)

Table 2: The average response per household for each of the four interventions analysed in CrowdFlex Phase 1.

Insights

CrowdFlex Phase 1 has shown that ToU tariffs and other price incentives can engage customers to materially change their domestic energy consumption profiles. If utilised in the right way, these can be useful tools with which to provide domestic flexibility. CrowdFlex Phase 1 allows the following insights to be drawn out to inform how these devices can be utilised effectively to provide flexibility.

[3] Please note, the percentage change relative to the evening peak provides context on the magnitude of response. It is not equivalent to the percentage reduction in demand consumed during the evening peak as a proportion of daily demand, quoted in the reporting of tariff switching. For a full description, see section 6.

Tariff switching and Big Turn Down materially reduced peak demand. When switching to the Agile Tariff, non-EV and EV owning households demonstrated a notable (12-23%) reduction in the proportion of energy consumed during the evening peak. In addition, Big Turn Down resulted in a ca. 50% reduction of peak demand.

EV owning households provided much greater flexibility than non-EV households in response to **Big Turn Up** events. This reflects the significant technical capability of EV charging to turn up, which EV owning households can utilise to provide response in the Big Turn Up. A very high level of participation was observed for Big Turn Up in EV owning households (63%), indicating the willingness of customers to provide EV assets for flexible charging. Non-EV households have a smaller technical capability to respond to the Big Turn Up; but they showed a turn down capability equivalent to EV households.

Tariff switching is effective in moving EV charging demand out of peak times. The reduction in the proportion of daily demand consumed during the evening peak was far higher for EV owning households than non-EV owning households. However, before the switch, EV households had higher evening peak period demands, compared to non-EV households, suggestive of a "passive" charging profile. The 24-hour consumption profiles of EV owning households following the switch to a ToU tariff indicates they changed to either a timed or smart charging profile following the switch, shifting EV charging demand out of the evening peak. In order to exploit the full benefits of tariff switching, EV owners need to be incentivized to keep their vehicles plugged in for long durations.

For demand turn down, the similarity in response across EV and non-EV households indicates that **underlying demand (including appliances and white goods) is responsible for the majority of the reduction observed**.

Nearly all of Octopus' customers are dual fuel (with gas for heating). The small **number of electric-heating customers (15%) were not sufficient** to provide reliable conclusions on the impact of tariff switching and Turn Up/Down on heating.

CrowdFlex Phase 1 has demonstrated that there are a variety of tools available to power system stakeholders to encourage a large response in domestic demand. Having established this, **future work should involve practical trials to prove reliability, repeatability, and the cost of domestic flexibility**. This is to tune the findings from CrowdFlex Phase 1 to produce a roadmap to ensure domestic flexibility meets the needs of the SO and the DNOs.

Estimating contribution to 2030 GB domestic flexibility

In order to understand the total flexibility a household can provide, both by increasing its consumption, "demand turn up", or decreasing its consumption, "demand turn down", we have estimated how the responses to each intervention may be combined. The flexibility response results from CrowdFlex Phase 1 can be extrapolated to estimate the technical potential of the domestic flexibility that households may be able to provide the system across Great Britain (GB) in 2030. Note that these extrapolations should be interpreted as technical potentials and are not projections or forecasts.

Two scenarios, a High and a Low, have been considered when making projections. These account for uncertainty in EV uptake and participation rates. The EV uptake is the expected percentage of GB passenger cars that will be battery electric vehicles (BEV) in 2030. The participation rate is the number of households expected to deliver a significant flexible response (up or down), as a percentage of the total number of GB households. The High scenario draws on the FES Consumer Transformation scenario for EV uptake (38%) as well as the high participation rates of households providing flexibility in the CrowdFlex analysis (up to 63%[4]). Meanwhile, the Low scenario assumes the FES Steady Progression scenario for EV uptake (14%) and conservative estimates on participation rates in flexibility (up to 10%[5]). For full details of the calculations and the assumptions taken, please see section 6.

Extrapolating to GB in 2030, CrowdFlex Phase 1 implies that domestic flexibility provided by households could reduce the GB system peak demand by up to 10% (6.8GW) in the High scenario. In the High scenario, the results of CrowdFlex Phase 1 suggest that GB households could provide up to 37GW of demand turn up flexibility; this equates to 53% of the magnitude GB system peak. We note however that these GW estimates vary significantly depending on the scenario and primarily the level of household participation. These results are summarised in Table 3.

[4] The observed participation rate for customers on a smart tariff in the Big Turn Up.

[5] Low Scenario conservative assumption for household participation in demand turn up.

	Demand turn down		Demand turn up	
	Low	High	Low	High
Total GB 2030 household flexibility implied by CrowdFlex Ph. 1 (GW)	-0.4	-6.8	3.8	37.0
% of GB 2030 system peak[6]	-1%	-10%	6%	53%

Table 3: Estimates of the technical potential for domestic resources to contribute to flexibility in GB 2030. Figures are based on the technologies and responses from CrowdFlex 1. The flexibility in GW has been compared as a percentage of GB 2030 system peak for reference.

The projections for the total domestic flexibility in GB in 2030 calculated in the analysis of CrowdFlex Phase 1 differ from the current FES projections for domestic flexibility. The figures are very different because:

- CrowdFlex is a measurement of the technical potential of domestic flexibility based on historical customer behaviour, rather than an internally consistent “scenario of the future”.
- CrowdFlex derives its results from Octopus customers who represent a more engaged consumer type compared to the GB average, as explained further in the text.

It is worth noting, home energy use could change substantially with new LCT uptake and the shift of transport costs from petrol stations to the home energy bill. This may drive large changes in customer behaviour and lead to more engagement, whether directly or through forms of automation. Therefore, CrowdFlex Phase 1 offers extremely useful insight into the potential of domestic flexibility. It could act as a useful foundation to design a bespoke flexibility trial to confirm both the technical potential and the projected participation in flexibility services.

[6] High scenario GB system peak = 69GW - FES Consumer Transformation scenario – 2030. Low scenario GB system peak = 69GW - FES Steady Progression scenario – 2030.

Contents

1. Introduction

Background and motivation

The road to decarbonisation will inevitably result in more electric low carbon technologies (LCT) in the home, including electric vehicle (EV) chargers, heat pumps, storage heaters, home batteries and more. The rollout of these technologies will fundamentally reshape domestic electricity demand. Understanding how residential demand profiles will change following the introduction of these technologies, is paramount to both the network and system operators.

The electrification of domestic demand presents an opportunity both to households and to power system stakeholders. Flexibility is the ability, within the electricity system, to adjust supply or demand to respond to the needs of the network and consumers. Flexibility in the form of demand side response (DSR) is an important resource that can help manage peak electricity demands and reduce the need for additional electricity generation capacity[7]. By consuming electricity in a more flexible manner, households can shift demands to times when electricity is cheaper. By supporting the power system, the benefits of flexibility could flow through to households via the network and operating costs that typically comprise over 1/3rd of domestic electricity bills.

Demand side flexibility can be split into two categories:

- Demand turn up – increasing demand, for example to match high generation from variable renewable energy technologies
- Demand turn down – decreasing demand to reduce generator or network capacity requirements.

Understanding how households can reliably provide domestic flexibility and participate in flexibility services will become increasingly important for the SO and DNOs. Currently there is significant uncertainty regarding the technical availability of flexibility from the domestic sector, and how this flexibility can be effectively incentivized.

CrowdFlex Phase 1 is the first phase of a study into how households can provide flexibility to reprofile energy demands in a way that supports the electricity system, but without inconveniencing customers. CrowdFlex aims to:

- Quantify the electricity flexibility potential from UK households,
- Identify the key parameters that influence the flexibility a household may provide, such as technology and tariff structure,
- Understand the cost of incentivising flexibility and which flexible services will be most relevant to the mass market,
- Guide market development of domestic flexibility-related services and provide a knowledge base for greater adoption into system operations.

This exploration into domestic behaviour will give insights into the potential depth of domestic flexibility provision. This will assist the System Operator and other power system stakeholders in developing a much more granular understanding of how domestic customers can be encouraged to provide flexibility.

Structure of CrowdFlex

CrowdFlex Phase 1 uses historical data on households' electricity loads to investigate their response to economic incentives and information remedies designed to elicit flexible electricity consumption. It aims to identify the technical potential of domestic flexibility and what parameters and incentives are necessary to encourage households to participate effectively.

National Grid ESO and Scottish and Southern Electricity Networks (SSEN) partnered with customer-centric companies, Octopus Energy and Ohme to perform the analysis on their historical datasets on household consumption, tariff data and EV charging. Leveraging Octopus and Ohme's large customer datasets and analysis products, CrowdFlex provides unique and robust insights on how domestic consumption can respond to price incentives and the technologies providing flexibility.

[7] National Grid ESO, FES 2021 – Flexibility, 2021.

CrowdFlex is the largest project of its kind investigating demand shifting and flexibility. Over the four interventions investigated, over 25,000 customers were analysed from 2020 onwards, broken down in Table 10.

Trial	Number of customers analysed	
Big Turn Up	19,206	
Big Turn Down	429	
	Go	**Agile**
Tariff switch	18,000	2,378

Table 4: Summary of the number of customers analysed in the four distinctive interventions studied during CrowdFlex Phase 1.

To investigate the technical potential, information remedies, and financial incentives associated with domestic flexibility, CrowdFlex Phase 1 analysed four distinct historical datasets of domestic electricity consumption across the above populations of homes. These analyses can be grouped into two types of interventions applied to households:

- **Enduring:** these assessed the change in demand resulting from a move from a flat to a dynamic energy price / time-of-use (ToU) tariff. Octopus' Go (Static ToU) and Agile (Dynamic ToU) tariffs were assessed.
- **One-off:** these assessed the change in demand from single events of limited duration. The events rewarded a change in customer demand over a specified 2-hour duration. "Big Turn Up" and "Big Turn Down" events were run at different times, with customers notified of the request and opting in ahead of time.

In addition to the analysis of these four intervention experiments, CrowdFlex Phase 1 conducted deep dives into data on customer response to Dynamic ToU tariffs and EV charging behaviour. The deep dive into Dynamic ToU tariffs drew on Octopus' historical data on its Agile tariff customers. Specifically, it investigates how Agile tariff customers participate in negative price events, and the customers' sensitivity to electricity prices at different times in the day and year, disaggregated by EV and non-EV customers. The second deep dive investigates EV charging behaviour based on a panel of c.3,500 EVs from Ohme's EV domestic charge point data. This deep dive discusses how EV driver habits related to plugging in or out, charging times, battery state-of-charge (SoC), and electricity tariffs can influence flexibility potential.

The outcome of CrowdFlex Phase 1 is a deeper understanding of and confidence in the technical potential of domestic flexibility. It provides insights into the incentives required to improve the willingness of customers to provide flexibility. The result of this analysis and insight is a robust set of recommendations for how future work can increase the SO and DNOs' confidence in the ability of domestic customers to provide flexibility and the incentives and technologies that can be utilised to increase participation in flexibility services.

2. Sustained flexibility from smart tariffs

Background & method

Smart ToU tariffs encourage customers to shift consumption out of periods where demand is likely high and the system is stressed, such as the evening peak. They incentivise customers through offering higher electricity prices at these times and lower electricity prices at times with low demand. In this way, customers switching from flat to smart tariffs can be a useful source of demand turn down flexibility in the evening peak period, as well as turn up of demand at other times.

This section investigates Octopus' dataset of customers who switched from a flat to a smart tariff in 2020. Octopus offered their customers two types of smart tariff, Agile and Go. Agile is a Dynamic ToU tariff that tracks the UK Wholesale market to determine half-hourly energy prices, updated daily[8]. Go is a Static ToU tariff that offers cheaper-priced electricity (5p/kWh) between 00:30 and 04:30 each day[9].

Customers' half-hourly data was analysed for 4 weeks before switching to determine their baseline energy consumption. It was further analysed for 24 weeks after switching to measure the response and to what extent it endures. A baseline was constructed for each household by calculating the percentage of daily consumption that occurred in evening peak periods (4-7pm), this was averaged across each day of the 4 weeks before a tariff switch for all customers switching tariff. This process was then repeated for the 6 months following the switch to determine the change in demand within the evening peak period as a result of the tariff switch.

Pre tariff-switch, if EVs predominantly charge during the evening peak, following the "passive charging" profile established by many trial projects, then they can act as a source of turn down flexibility in these times. Because of this, it is expected that EV owning households will be capable of providing more demand turn down flexibility during the evening peak than non-EV owning households. To explore this further, the analysis of tariff switching has been disaggregated into Octopus customers whose only household LCT is owning an EV and customers who have no LCT. For the purpose of this analysis, households that own only an EV will be referred to as EV owning households and households that own no LCT will be referred to as non-EV owning households.

Beginning with a large dataset of approximately 20,000 customers, CrowdFlex identified the change of behaviour demonstrated by customers after 2 months of switching. CrowdFlex then further analysed the ~5,500 customers that had a complete dataset for the 6 months following their switch to ensure any change in behaviour was sustained. Both analyses were disaggregated to analyse the households who own an EV only and households that do not own any LCT. The results presented in this report draws upon the data of ~1,700 customers with 7 complete months of data who could be identified as owning an EV only or no LCT[10]. The full breakdown of the customers is in Table 5 below.

Analysis	Number of customers analysed	
	Go	Agile
Original – 2 months after switch	18,000	2,378
6 months after switch	3,282	2,176
EV only – 6 months after switch	843	250
No LCT – 6 months after switch	79	544

Table 5: A table of the attrition of the number of customers analysed in the tariff switching intervention.

Response to Tariff Switching in EV owning households

EV owning customers switching from a flat tariff to an Agile or Go tariff demonstrated similar peak shifting behaviour following a tariff change. Both Agile and Go customers reduced the proportion of energy consumed in the evening peak considerably, by 23% and 19% respectively. This equates to an absolute reduction of 0.54

[8] Octopus Energy, Introducing Agile Octopus, https://octopus.energy/agile/.
[9] Octopus Energy, Introducing Octopus Go, https://octopus.energy/go/.
[10] The remaining ~3,800 customers with 7 months of data either had multiple LCT or did not specify what LCT they owned.

kWh and 0.38 kWh respectively over the 3-hour evening peak. What was particularly stark was the immediacy of the reduction in customers' peak consumption following the switch. Figure 1 and Figure 2 show the immediate drop in the percentage of daily energy that these customers consume in the peak period, following the tariff switch to Agile or Go respectively. This reduction in peak consumption is maintained for at least 6 months following the switch, which was the limit of the data available. Therefore, the switching of EV owning households onto ToU tariffs, both Dynamic (Agile) and Static (Go) can be characterised as a provider of enduring demand turn down flexibility over the evening peak.

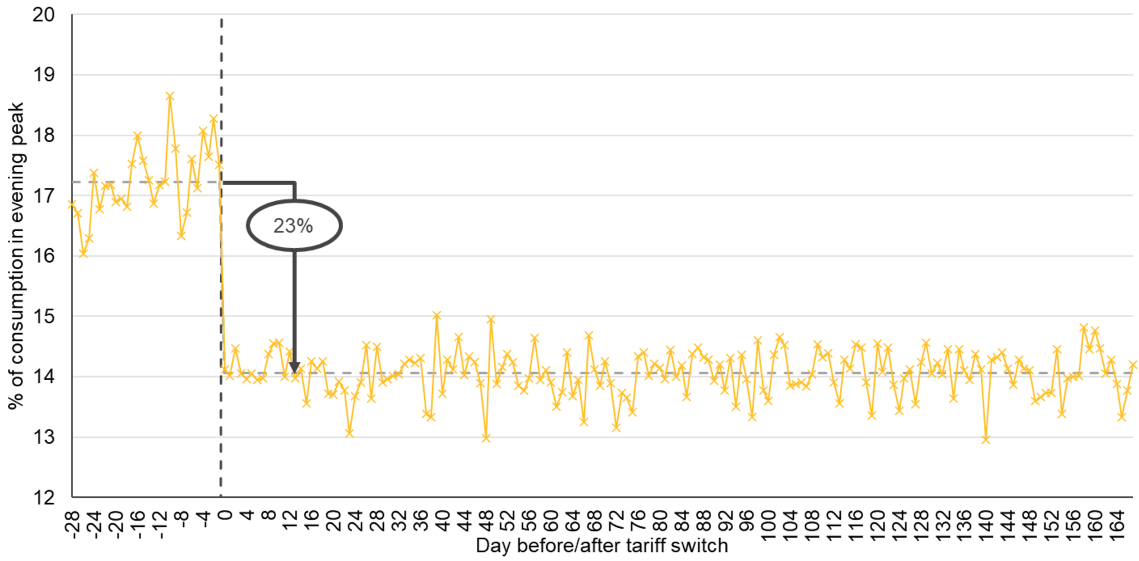

Figure 1: The average reduction of the percentage of daily energy demand of an EV owning household consumed during the evening peak. Data shows period before and after switching from a flat to an Agile tariff. The horizontal dashed lines represent the average consumption fraction, over the periods measured before and after the switch.

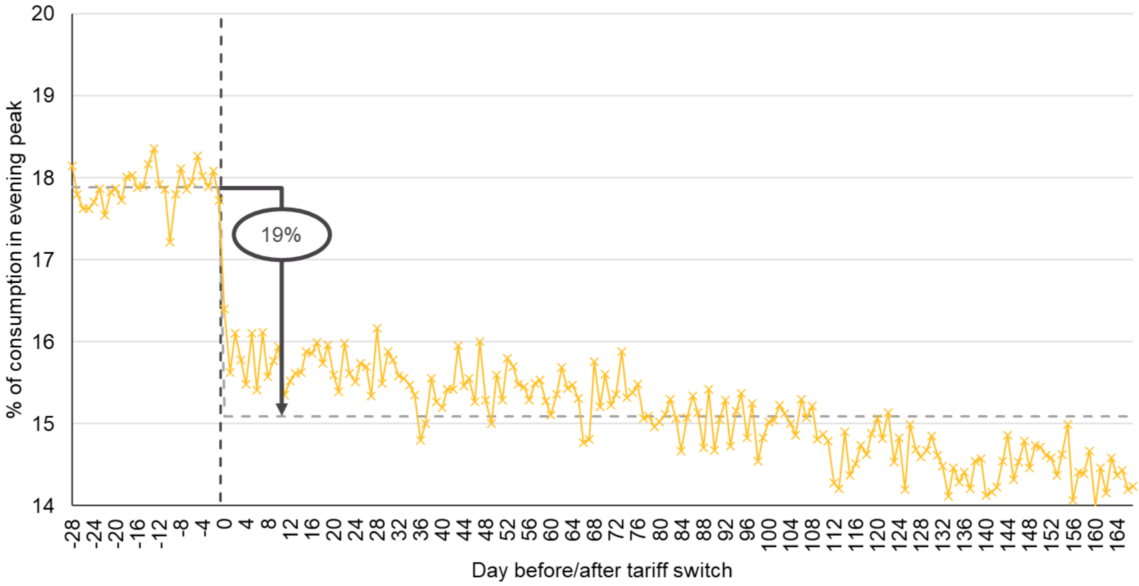

Figure 2: The average reduction of the percentage of daily energy demand of an EV owning household consumed during the evening peak. Data shows period before and after switching from a flat to a Go tariff. The horizontal dashed lines represent the average consumption fraction over the periods measured before and after the switch.

It is important to note that before switching to a ToU tariff, electricity consumption in the evening peak of EV owning households was 20% greater than that for non-EV owning households (3.0 kWh vs. 2.4 kWh over the 3-hour evening peak). This behaviour is indicative of a passive EV charging profile, although the source of the demand cannot be directly attributed from Octopus' dataset, only inferred. Nevertheless, as evident in Figure 3, which illustrates the average 24-hour consumption profiles for EV owning households, in the month before and the 6 months after switching from a flat tariff to an Agile tariff, upon switching onto a ToU tariff, much of the evening peak demand is shifted into the night/early morning. This could be explained by a switch from passive to timed or smart automated charging behaviour. Of the EV-owning customers switching from a flat to an Agile tariff, approximately 24% of customers use smart automated charging, and 44% use timed charging. For those switching to the Go tariff, the percentage using smart automated charging was 18%, while the proportion using timed charging was to 68%. The remaining customers continued with passive charging behaviour. So, while EV households are capable of reducing a significant proportion of their evening peak consumption when switching from a flat to a ToU tariff, it appears that much of this reduction is achieved by removing the additional energy demand created by EVs themselves when charging in “passive” mode. An important outcome is that these incentives are effective in moving EV charging demand out of the evening peak period and into other times.

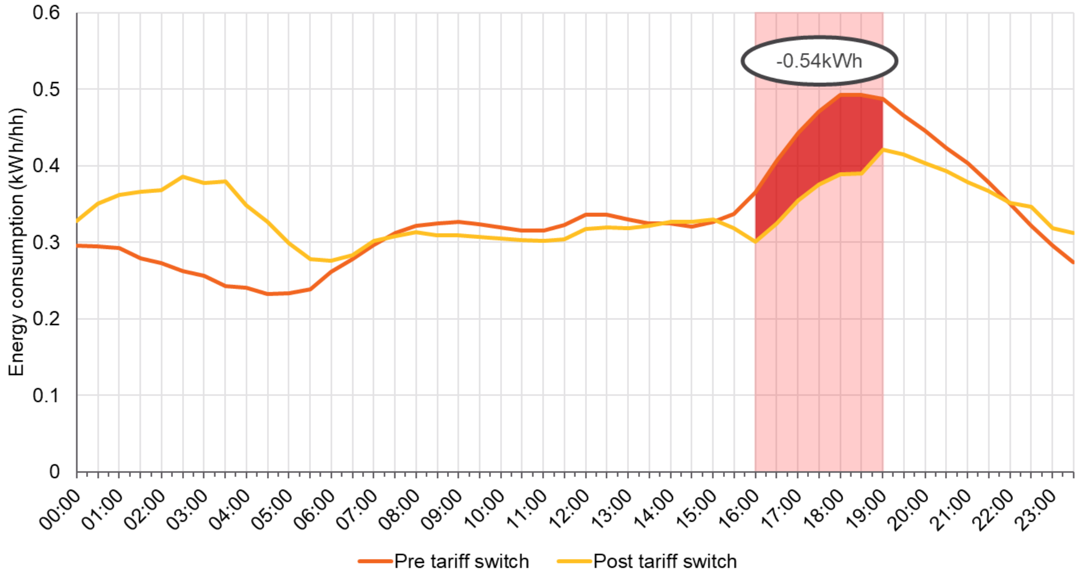

Figure 3: The 24-hour consumption profile for EV owning households, averaged over the month before and the 6 months after switching from a flat tariff to an Agile tariff. The region highlighted in red is the evening peak period.

Response to Tariff switching in non-EV owning households

Non-EV owning households do not have the large source of flexibility associated with passive-to-smart charging patterns. Nevertheless, when structured in the right way, the dataset of 623 non-EV owning Octopus customers switching from a flat to a ToU tariff suggests that ToU tariffs are capable of incentivising non-EV owning households to shift demand out of the evening peak, providing demand turn down flexibility.

The 544 households that switched from a flat to an Agile Octopus tariff demonstrated a clear 12% reduction in the ratio of daily demand consumed in the evening peak. This is a 0.23 kWh reduction over the 3-hour evening peak. As with EV owning households, this reduction occurred immediately after the tariff switch and was sustained for at least 6 months after the tariff switch. This immediate fall in consumption during the evening peak is illustrated in Figure 4. This implies that an Agile tariff is capable of effectively incentivising both EV and non-EV owning customers to reduce their demand during the evening peak by reducing underlying consumption from household appliances, such as white goods, lights, electrical cooking equipment and electric heating.

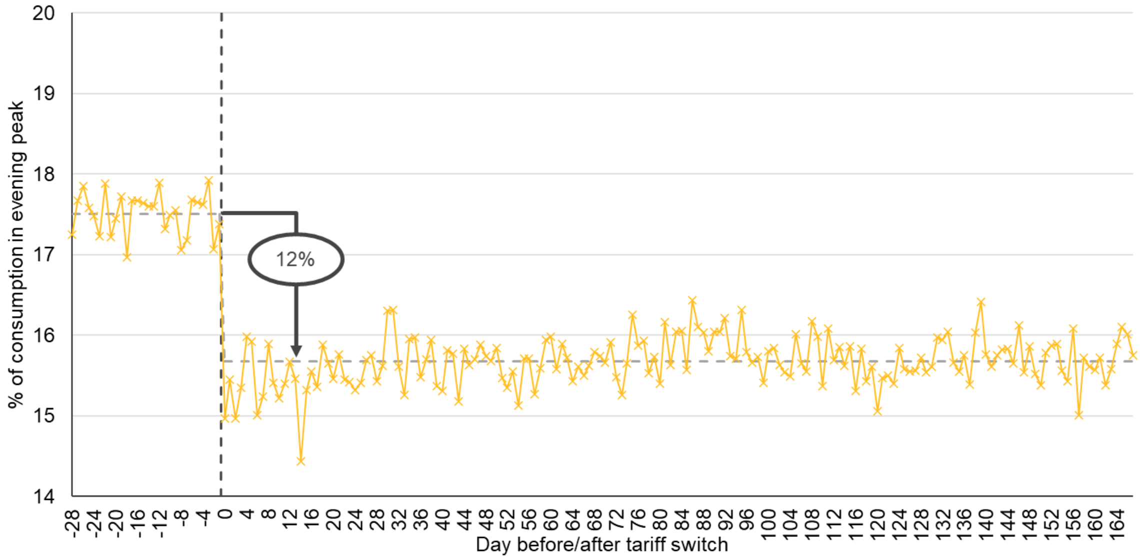

Figure 4: The average reduction of the percentage of daily energy demand of a non-EV owning household consumed during the evening peak. Data is shown before and after switching from a flat to an Agile tariff. The horizontal dashed lines represent the average consumption fraction, over the periods measured before and after the switch.

Such a behavioural change was **not** observed from the 79 non-EV owning households analysed that switched from a flat tariff to an Octopus Go tariff, displayed in Figure 5. This is perhaps not surprising, as the Go tariff was designed to be attractive to EV owning customers. While a re-profiling of daily consumption out of the peak period is evident from the figure, the change is gradual and may be a result of other factors that changed over the six-month period – it cannot be ascribed to the Go tariff.

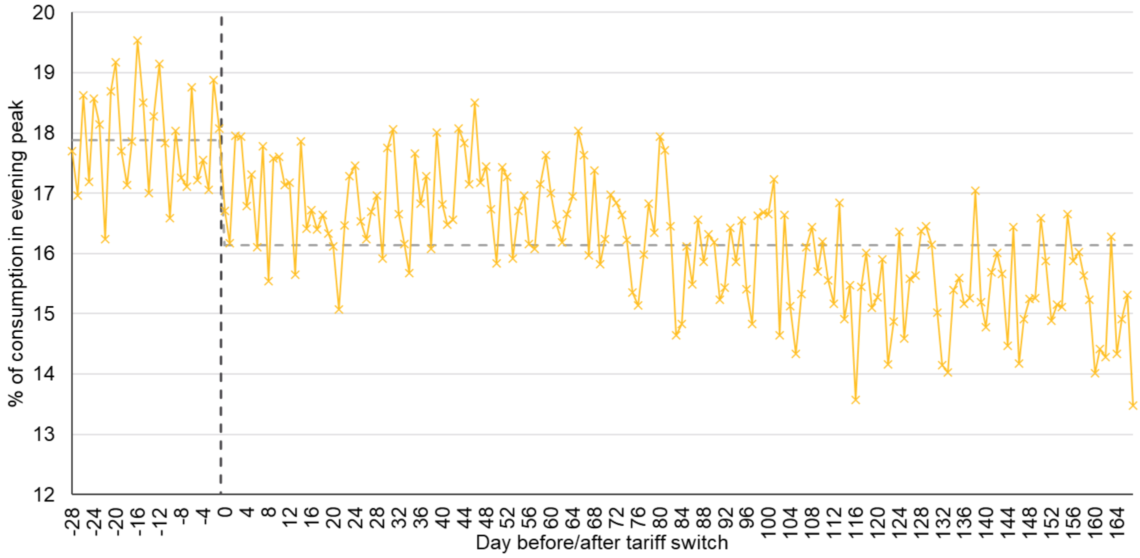

Figure 5: The average reduction of the percentage of daily energy demand of a non-EV owning household consumed during the evening peak. Data is shown before and after switching from a flat to a Go tariff. The horizontal dashed lines represent the average consumption fraction, over the periods measured before and after the switch.

There is no large shift in evening peak demand directly following a tariff switch. We note there is a large amount of noise and variation in the evening peak demand throughout the post-switch period. One possible cause of this noise is the small sample size compared to the other datasets.

This outcome suggests that tariffs must be structured correctly to provide non-EV owning customers with the incentive to reduce their peak demand. The results of CrowdFlex Phase 1 suggest an effective tariff would have features closer to a DToU (Agile) tariff, or should utilise a SToU specifically designed to reduce evening peak consumption. The Octopus Go tariff was designed to shift the demand of EV charging out of the evening peak and into the overnight/early morning period. The Go tariff was **not** designed to encourage the shifting the demand of white goods from non-EV owners out of the evening peak.

Analysis

Switching customers from flat to ToU tariffs can provide a valuable source of demand turn down by encouraging households to reduce their consumption during the evening peak, shifting demand to other times of the day. EV owning customers were able to significantly reduce the percentage of their daily demand they consumed during the evening peak after switching to either Agile or Go tariffs. The change in the demand profile of EV owning households before and after the tariff switch, illustrated in Figure 3, implies that much of the reduction in peak demand is achieved by shifting EV charging demand out of the evening peak and into the overnight/early morning period. This is indicative of a shift from a “passive” to a “managed” charging schedule. A number of previous studies, such as CVEI[11], Shift[12], and Electric Nation[13], have all demonstrated that customers have a high willingness to make such a change and be flexible about their charging behaviour.

Non-EV owning households were also capable of producing a significant reduction in consumption during peak times, however the results of CrowdFlex Phase 1 suggest that this is dependent on the structure of the ToU tariff that customers switch to. Non-EV owning customers switching to an Agile tariff demonstrated a reduction consistent with that observed for EV owning households, while customers switching to the Go tariff did not. It is recommended that future work in this area focuses on confirming how tariff offerings to non-EV owning customers should be structured in order to provide sustained demand turn down during the evening peak period. Other studies into flexibility including Shift[12], Electric Nation[13], and Low Carbon London[14], corroborate this result. They showed mechanisms such as a Dynamic ToU tariff are successful in encouraging behavioural change that benefits the different participants in the energy system. These studies also investigated other mechanisms to control energy pricing such as peak and capacity pricing and found them similarly as effective as Dynamic ToU tariffs. Future work should draw on these findings when investigating pricing structures that ensure a sustainable demand turn down during the evening peak period.

[11] CVEI – Consumers, Vehicles and Energy Integration project commissioned by the Energy Technologies Institute.
[12] Shift commissioned by UKPN.
[13] Electric Nation commissioned by Western Power Distribution.
[14] Low Carbon London, UKPN.

3. Flexibility from one-off interventions

Background & method

Separately from sustained response due to tariff switching, it is important to understand how to influence demand closer to real time and over a shorter, more specific time period. Such one-off interventions act as experiments to quantify the technical potential of the demand turn up and turn down flexibility households can provide.

Two distinct historical intervention experiments were analysed in CrowdFlex Phase 1. The Big Turn Up occurred on 24 May 2020. It invited households, via email, to opt-in to increase their demand as much as possible over a defined period. Customers were invited to opt-in[15] to two independent Big Turn Up periods, one between 05:00-07:00, for which customers were charged at a rate of 5p/kWh, and one between 14:00-16:00, for which customers were charged at a rate of 2p/kWh. Customers were given 3 days advanced notice to opt-in to participate in one of the two Big Turn Up event windows. 19,199 customers participated in the Big Turn Up event, the selection of which is defined in Table 6.

Stage of Big Turn Up	Number of customers	
	Smart	Non-smart
Emailed (asked to participate)	2,470	97,528
Opted-in	1,890	32,867
Participated	1,546	17,653

Table 6: Number of customers who were asked to participate, opted-in, and participated in the Big Turn Up event.

The Big Turn Down, which occurred on 5 November 2020, invited households, via email, to opt-in[15] and reduce their demand as much as possible in the 2-hour period between 16:30-18:30. Customers were incentivised with an offer of a credit for free electricity if they reduced their consumption compared to a predefined baseline. Due to an administrative issue, customers were given <24 hours to opt-in to the Big Turn Down, less than the Big Turn Up. 396 customers participated in the Big Turn Down event, the selection of which is defined in Table 7 below.

Stage of Big Turn Down	Number of customers	
	Smart	Non-smart
Emailed (asked to participate)	771	18,694
Opted-in	102	1,212
Participated	33	363

Table 7: Number of customers who were asked to participate, opted-in, and participated in the Big Turn Down event.

For the Big Turn Up/Down, the baseline is defined as the power demand maintained across the 2-hour period, averaged over the 4 same days of the 4 weeks prior to the experiment. Each customer's consumption is then measured over the 2-hour period of the event. The difference between the average consumption over the duration of the Big Turn Up/Down and the baseline is the household's response to the Big Turn Up/Down event.

After opting-in, it must be determined whether customers participated in the Big Turn Up/Down event or not. Because there is an equal probability that a household will increase or decrease its demand on a given day compared to the same day the previous week, a threshold must be set. If the change is above the threshold, it is determined to be significant and in response to the experiment. The threshold is set by assessing all half hourly deviations relative to their four week baselines. This gives a distribution of deviations over a customer's

[15] Customers opted in by responding to the email from Octopus, confirming they wished to participate in the event. Customers who were emailed but did not respond to confirm they wanted to opt-in, could not participate.

entire consumption history. If the Big Turn Up/Down deviation was outside the median absolute deviation level for a given customer then they are considered to have participated.

The advantage of this choice in baseline and participation criteria is that by selecting the same day of the week in the previous four weeks prior to the Big Turn Up/Down events, the baseline avoids variation of demand across the week, which can fluctuate day-to-day dependent on the patterns of demand in each household. However, the disadvantage of this method is it means that the baseline is constructed from an average of only four data points for each half hour period. The limitation of this is somewhat mitigated by averaging the response to each event over all of the households participating. However, the limited historic data sample still limits the accuracy of the responses observed for each experiment – an issue inherent in any baselining process.

As is shown in Table 6 and Table 7, the results of the Big Turn Up/Down are disaggregated by customers on smart tariffs (i.e. Octopus Agile or Go tariffs) and customers on non-smart, flat tariffs. This is because there is a large disparity between the consumption profiles of participating customers on smart tariffs vs. those on non-smart tariffs. The differences between these groups can be explained by the presence of an EV, which may be on a timed or smart EV charging profile. Therefore, when interpreting the results, households with a smart tariff may be interpreted as EV owning households and households with a non-smart, flat tariff may be interpreted as non-EV owning households.

Big Turn Down

The Big Turn Down invited customers to reduce their demand as much as possible over a 2-hour period in early November 2020. The event took place during a winter weekday evening peak during a period where night-time temperatures in parts of GB approached zero degrees Celsius, although this was not the coldest period in that winter. The data was selected in response to a predicted period where the Grid was expected to be overloaded due to a reduction in renewable generation, coupled with an increase in domestic consumption resulting from COVID restrictions. Of the ~19,500 customers that were invited by email to participate, 396 participated in the event. Due to an administrative issue, customers were only given <24 hours' notice to opt-in to the event before it occurred. This limited notice (compared with Big Turn Up) cannot be determined to be the cause of the low participation rate in the event (compared to Big Turn Up), although it is noteworthy[16]. The full details of the event and the demand turn down response achieved by the households participating is summarised in Table 8 below.

	Smart	Non-smart
Date	5 November 2020	
Window	2 hours, 16:30-18:30	
Incentive	Credit for free electricity for participating	
Notification period	<24 hours, via email	
Number of customers participated	33	363
Participation rate	4%	2%
Average reduction in consumption per participating household (kWh)	1.1	0.9
Response per participating household (kW)	0.6	0.5

Table 8: A table summarising the parameters and results of the Big Turn Down event.

[16] Another factor that may have limited the participation numbers is the threshold. If the measured response is comparable to the baseline median absolute deviation, the threshold will exclude more of the population, than would be excluded when the response is very large compared to the baseline deviation.

Big Turn Down response: smart tariff

Households on an Octopus ToU (smart) tariff, i.e. either Octopus Agile or Go, that participated in the Big Turn Down event, were able to reduce their consumption by 1.1 kWh over the 2-hour period. This represents a considerable 64% demand turn down compared to the baseline consumption in the same period.

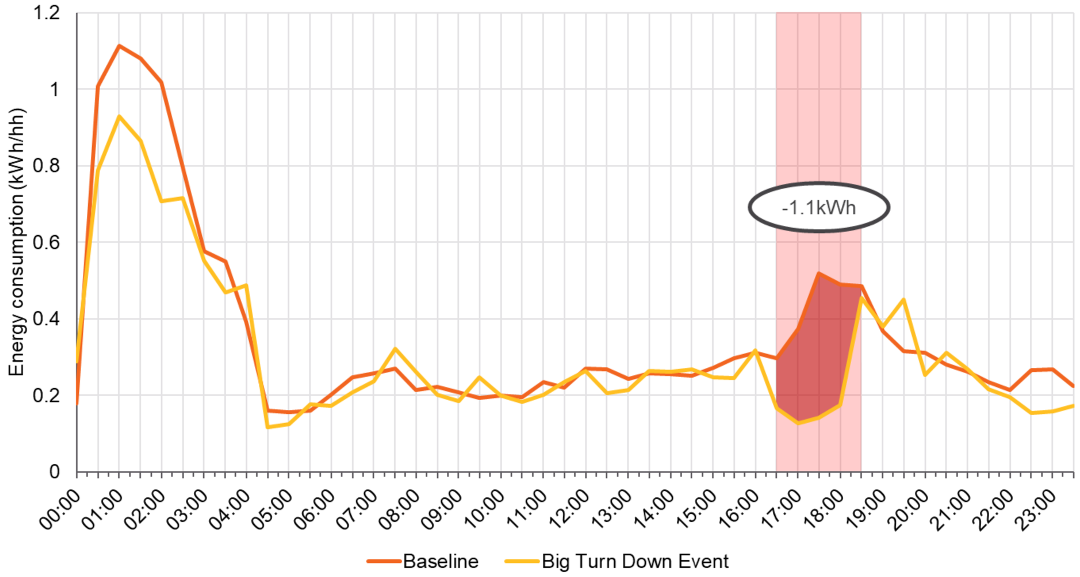

Figure 6: A graph showing the average 24-hour consumption profile for households on smart tariffs, participating in the Big Turn Down, compared to the average 24-hour baseline consumption profile for the same households. The region highlighted in red is the Big Turn Down event.

Figure 6 shows the 24-hour energy consumption profile of an average participating household with a smart tariff in the baseline and on the day of the Big Turn Down. Immediately following the Big Turn Down event, the consumption of the average household participating in the event returned to be in line with the baseline consumption.

Big Turn Down response: non-smart tariff

Households on a flat tariff participating in the Big Turn Down event were able to produce a similar average response to the Big Turn Down as households on smart tariffs. The participating households on a flat tariff were able to provide reduction of 0.9 kWh of consumption over the 2-hour Big Turn Down event. This amounts to 60% reduction in their demand compared to the baseline consumption in the same 2-hour period. Figure 7 shows the 24-hour energy consumption profile of an average participating household with a non-smart tariff in the baseline and on the day of the Big Turn Down.

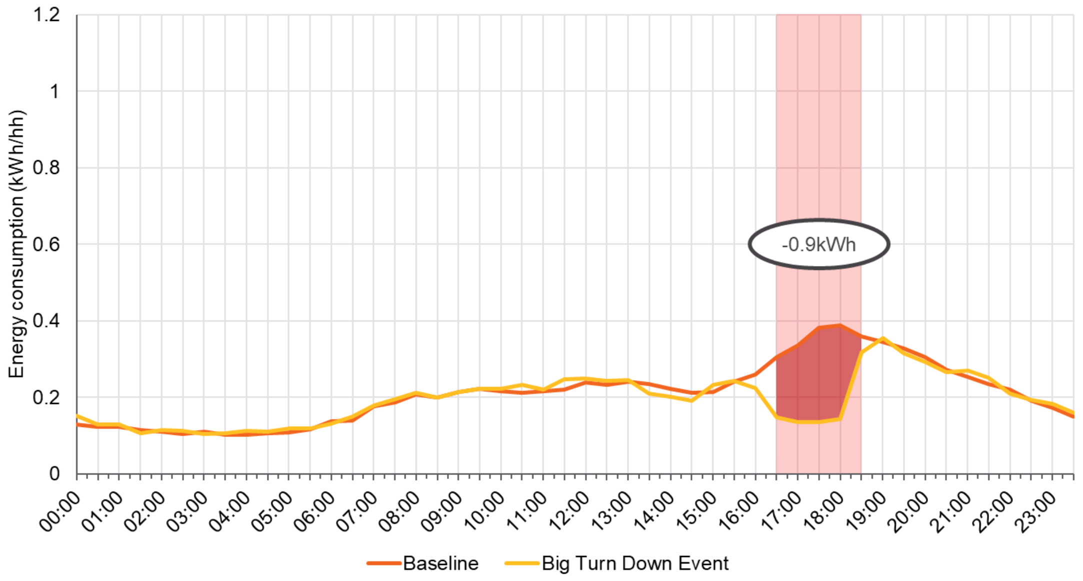

Figure 7: The average 24-hour consumption profile for households on non-smart tariffs, participating in the Big Turn Down, compared to the average 24-hour baseline consumption profile for the same households. The region highlighted in red is the Big Turn Down event.

The comparable magnitude of the reduction in consumption observed for smart (EV owning) and flat (non-EV owning) tariff customers during the 2-hour Big Turn Down events implies that EVs are not responsible for the majority of demand turn down. Furthermore, similar to the smart tariff households, the average non-smart tariff household's consumption returned to be in line with the baseline consumption in the half hour period following the Big Turn Down event. This contrasts with the results of the Big Turn Up event, discussed in the next subsection, which demonstrated a vastly different result between EV and non-EV owning households.

It is expected that the majority of EV owning customers on a smart tariff will already have shifted their demand out of the evening peak period as default (i.e. in the baseline) in order to benefit from the smart tariff. This is evident when examining the 24-hour demand profiles illustrated in Figure 6. While there is a clear reduction in demand in the overnight/early morning period in the Big Turn Down compared to the baseline, both profiles are indicative of either timed or smart (automated) EV charging. Therefore, EV charging is not likely to contribute to the baseline demand for smart customers during the Big Turn Down period. It suggests that the vast majority of demand turn down is provided by household appliances such as white goods, lighting and electric cooking and heating. As consumption is essentially unchanged outside of the turndown period, this suggests that energy demand has been moved out of the test day, and displaced to another day.

Big Turn Up

The Big Turn Up invited customers to increase their demand as much as possible over one of two independent 2-hour periods on the same day over during the Late May Bank Holiday, 2020. The event date and times were selected in response to a predicted period where the Grid was expected to have to turn down renewable generation due to surplus supply. Of the ~100,000 customers that were invited by email to participate, ~19,000 participated in the event. The full details of the Big Turn Up events and the demand turn up response achieved by the households participating is summarised in Table 10 below.

	Smart	Non-smart
Date	24 May 2020	
Window	2 hours, i) 05:00-07:00 or ii) 14:00-16:00	
Incentive	Energy priced at i) 5p/kWh or ii) 2p/kWh	
Notification period	3 days, via email	
Number of customers participated	1,546	17,653
Participation rate	63%	19%
Average reduction in consumption per participating household (kWh)	11.6	2.9
Response per participating household (kW)	5.8	1.5

Table 9: Summary of the parameters and results of the Big Turn Down event.

Big Turn Up response: smart tariff

Households who are on an Octopus ToU (smart) tariff, i.e. either Octopus Agile or Go tariffs, that participated in the Big Turn Up event were able to increase their consumption by 11.6 kWh on average over the 2-hour period. This 5.8 kW average demand turn up power response, represents an increase in demand of approximately 15 times the baseline power demand maintained in that period. It is extremely likely that the magnitude of this response was driven by the use of 7 kW EV chargers from households participating in the Big Turn Up event.

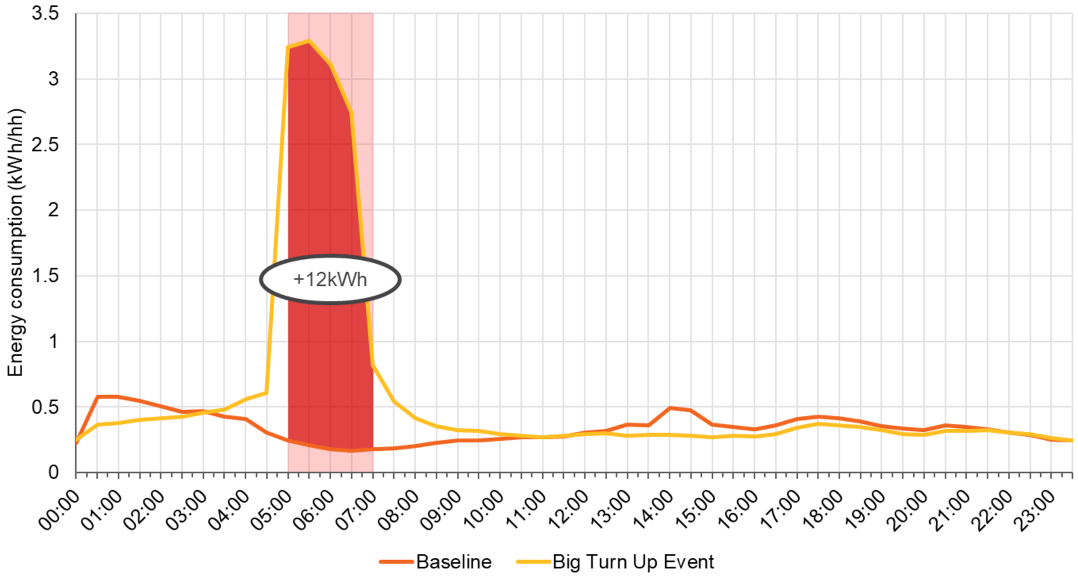

Figure 8: The average 24-hour consumption profile for households with smart tariffs, participating in the Big Turn Up, compared to the average 24-hour baseline consumption profile for the same households. The region highlighted in red is the Big Turn Up event.

The independent results for the two different Big Turn Up events, both conducted on the same day were very similar in magnitude for smart tariff households. Illustrated in Figure 8, participating smart tariff households in the 05:00-07:00 period were able to increase their demand by 11.6 kWh during the Big Turn Up. Meanwhile, participants in the 14:00-16:00 period were able to increase their demand by 10.0 kWh over the course of the period.

It is notable that in both Big Turn Up periods there is a small decrease in demand during the overnight/early morning periods, suggesting a small reduction in EV charging during that period. It was also recorded that daily energy demand on the day of the turn up experiments, increased between 60%-72% compared to the baseline. Hence demand turn up for EV households primarily moved charging demand into the test day (presumably from other days) rather than simply redistributing charging demand within the test day. This raises concerns on the sequential repeatability of demand turn up events of this magnitude. The baseline profile suggests that there is some diversity in EV overnight charging, that is to say, EV owners do not charge their EV every night. However, during the Big Turn Up event, there is strong evidence of concentrated EV charging. Assuming the 12kWh increase in demand per household during the Big Turn Up can be allocated entirely to EV charging, this equates to enough energy to add approximately 60km of range to a medium sized EV[17]. Given the average mileage for a private consumer is approximately 30km per day[18], this level of response observed during the Big Turn Up event might only be repeatable every other day at the most[19].

Big Turn Up response: non-smart tariff

Households on a non-smart, or flat, tariff participating in the Big Turn Up event were not able to produce a demand turn up as great as EV-owning customers on a smart tariff, nevertheless, they were still able to respond with a substantial increase in demand over the 2-hour period, averaging 2.9 kWh per household. Without access to EV charging to increase demand, non-EV owning households are thought to have provided the demand turn up by utilising household electrical appliances such as white goods, lighting, and electrical cooking and heating. Hence the observed response is significantly smaller than that of smart EV owning households. Nevertheless, non-smart households are still able to provide a response approximately 5 times greater than the baseline power demand maintained in that period.

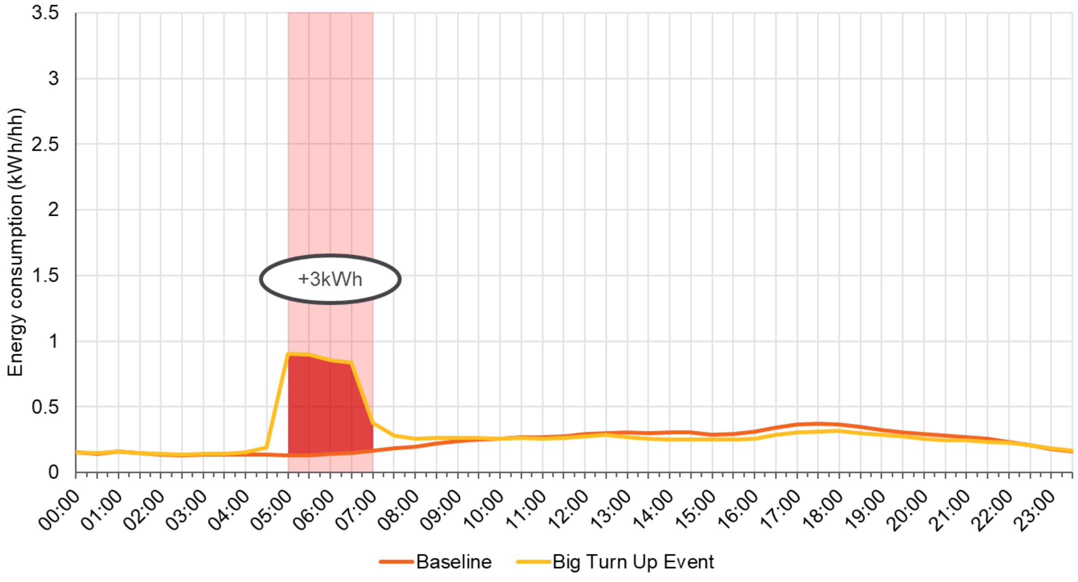

Figure 9: The average 24-hour consumption profile for households with non-smart tariffs, participating in the Big Turn Up, compared to the average 24-hour baseline consumption profile for the same households. The region highlighted in red is the Big Turn Up event.

The increase in consumption observed during the later Big Turn Up event, 14:00-16:00, of 3.0 kWh is very similar in magnitude to that observed in the early Big Turn Up event, 05:00-07:00, illustrated in Figure 9, of 2.9 kWh. The response observed in the later event is approximately 2.5 times of that maintained in the baseline during the same period.

As with households on smart tariffs, households participating in the Big Turn Up who are on non-smart tariffs increased their total energy consumption during the day of the Big Turn Up. For the 05:00-07:00 Big Turn Up event, participants increased their daily consumption by 24% compared to the baseline. For participants in the

[17] Assuming BEV energy consumption of ~0.2kWh/km, Element Energy, Electric Car Consumer (ECCo) model.
[18] Assuming annual mileage of ~11,00km for private cars, DfT, Vehicle mileage and occupancy, 2021.
[19] Assuming mileage remains constant.

14:00-16:00 Big Turn Up event, this was 26% over 24-hours. Other than in the immediate hours following both events, the consumption of a participating customer was in line with the baseline consumption, suggesting that additional demand had been drawn in from other days, rather than shifted from another time within the 24-hour period. This may indicate that the response could reduce should the experiment be repeated over consecutive days.

Analysis

Both the Big Turn Up and the Big Turn Down events demonstrated that households are capable of providing large amounts of domestic flexibility through one off interventions. For demand turn up, households on non-smart tariffs were able to provide a promising average response of 1.5 kW. The magnitude of response provided by smart households was much higher, averaging 5.8 kW of demand turn up over the 2-hour period. This strongly implies that EVs are a resource of significant turn up flexibility. For demand turn down, households on smart and non-smart tariffs provided a significant, but similar, response of -0.6 kW and -0.5 kW respectively, indicating that EVs are not critical to the turn down observed. This equates to a 60% and 64% reduction respectively when compared to their respective baselines during the same period.

Both Turn Up and Turn Down events did not just result in a redistribution of demand within the day of the event; they both showed a significant change in daily energy demand, compared to the baseline. This indicates that customers were able to either “draw in” or “push out” energy demands from and to other days. For example, this would be achieved by moving infrequent charging to the event day, or by delaying the use of washer/dryers to a later day. This would imply that repeating the turn up and turn down calls over consecutive days, could result in a lower response. Note that this contrasts with trials which tested customer persistence in providing domestic flexibility. This includes CLNR[20], which completed 14 events, and Low Carbon London[21], which completed 13 events. Low Carbon London reported that no significant trends were identified between event persistence (i.e. the number of consecutive days the tests occurred) and the outcome as measured either by peak demand reduction or mean demand reduction. As the reliability of such a service needs to be understood by stakeholders– even if it is to be used infrequently – further work is needed on the extent to which consecutive calls for turn up or turn down may be needed by power system stakeholders.

The very different participation rates recorded from the two events is notable. Big Turn Up had participation rates of 63% (smart) and 19% (non-smart households). Meanwhile, the Big Turn Down event had participation rates of 4% and 2% for the same groups. Low levels of engagement were also seen in a similar study as part of CLNR[20]. All other things being equal, this might imply a relative customer enthusiasm for Turn Up compared to Turn Down. However, it is notable that customers had less notice for Big Turn Down compared to Big Turn Up, and no doubt this had an adverse impact on participation rates. Also, the threshold has a greater impact in filtering down the population who participated, when the response is closer to the baseline variation, as was the case for turndown. The difference in participation rates between the two events does highlight the complexity of consumer engagement, showing that price incentives are not the only lever in engagement, and that the method and timing of information is also important, and warrants further exploration.

An aspect that was not fully explored in the Big Turn Up and Down events was the potential impact automation could have on flexibility. The price signals and notifications for the Big Turn Up and Down events were sent to customers via email notification and were not inputted to Octopus’ tariff APIs. Customers had to manually set any planned response for each event rather than allowing an autonomous daily optimiser to respond for them. Optimisation has the potential to increase participation rates, and the magnitude of response that could be achieved, potentially at a lower cost. This is substantiated by the Shift[22] and Electric Nation[23] studies, which determined that automation can be successful in achieving the desired level of flexibility at lower cost compared to incentivizing customers. These conclusions are further supported by the outcomes of the Core4Grid[24] and FRED[25] projects. Therefore, future work should investigate how automation in the household can improve on the response provided during one-off interventions.

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[20] CLNR – Customer-Led Networks Revolution commissioned by Northern Powergrid and partners.
[21] Low Carbon London, UKPN.
[22] Shift commissioned by UKPN.
[23] Electric Nation commissioned by Western Power Distribution.
[24] Core4Grid commissioned by UKPN.
[25] FRED – Flexibility Responsive Energy Delivery commissioned by Catapult Energy Systems.

4. Deep dive into Dynamic ToU tariffs

The Agile tariff is Octopus Energy's Dynamic ToU tariff. It tracks the UK Wholesale market to determine half-hourly energy prices, updated daily. Currently capped at 35p/kWh, domestic customers can pay anything from 0p/kWh to 35p/kWh and can even be paid to consume energy in "price plunge" periods where the Agile tariff has negative pricing (i.e. the cost of energy is <0p/kWh). The tariff incentivises customers to reduce their consumption when wholesale price is high or increase their consumption when the price is low.

Building on the customer response to tariffs shown in the previous chapters, this chapter is a deep dive on two aspects of dynamic tariffs and response:

- Response in periods where there is a large surplus of excess generation through the use of negative pricing. These events are known as price plunges.
- How sensitivity to pricing varies by technology, through the day, and seasonally.

The price plunge events and price sensitivity analysis will draw on historic data from Octopus' Agile tariff customers from 2020.

Price plunge

A price plunge is a period during which the price signal drops below 0p/kWh, i.e. customers are paid to consume energy. Customers are notified of a price plunge event by a "nudge", sent out as a text message a day ahead between 16:00-20:00. An autonomous daily optimiser integrated with Octopus' Agile API is notified of the price plunge via the API. In 2020, 49 price plunges occurred where unit rates dropped below zero.

Octopus has analysed the data of 1,200 Agile tariff customers to gain an insight into how households react to price plunge events, both the magnitude of their increase in consumption and the percentage of Agile tariff customers that participate in price plunge events. Similar to the Big Turn Up/Down, the baseline for determining the increase in consumption during a price plunge is defined as the power maintained across the period of the price plunge event, averaged over the 4 same days of the 4 weeks prior to the experiment. Each customer's consumption is then measured over the period of the event. The difference between the consumption during the price plunge event and the baseline is the household's response to the event. A household is deemed to have participated in a price plunge event if its increase in consumption is greater than a threshold. The threshold is set by assessing all half hourly deviations relative to their four week baselines. This gives a distribution of deviations over a customer's entire consumption history. If the deviation during the Price Plunge was outside the median absolute deviation level for a given customer, then they are considered to have participated.

Octopus' analysis determined that on average, customers participated in 31% of events. The average increase in consumption per price plunge event was 0.38kWh/hh. This equates to an average power demand turn up of 0.76kW, a 170% increase on the baseline power demand. An example of the demand turn up during a price plunge event is illustrated in Figure 10. It demonstrates how the demand of a customer on an Agile tariff greatly increases as the unit rate of energy becomes negative and then returns to the previous level of demand as the price of electricity returns to being positive. This is compared to the demand profile of a non-smart (flat) tariff customers in the same period to demonstrate that they do not exhibit a similar behaviour, without the incentive of a dynamic tariff or price plunge.

Figure 10: The demand profile of an average Agile tariff customer during a price plunge event. This is compared to the behaviour of a non-smart tariff customer in the same period. The price of energy is shown for reference.

A crucial insight from the perspective of maximising flexibility is that Octopus' analysis of each price plunge event has found that there is a correlation between the negative pricing of energy and the participation rate in a price plunge event. As the price of electricity becomes more negative (i.e. as consumers are paid more to consume energy), there is an increase in the participation rate in the price plunge event. As implied in Figure 11, it is expected that, on average, as the price of energy falls from 0p/kWh to -5p/kWh, the participation rate in the price plunge event will increase from approximately 30% to 45%.

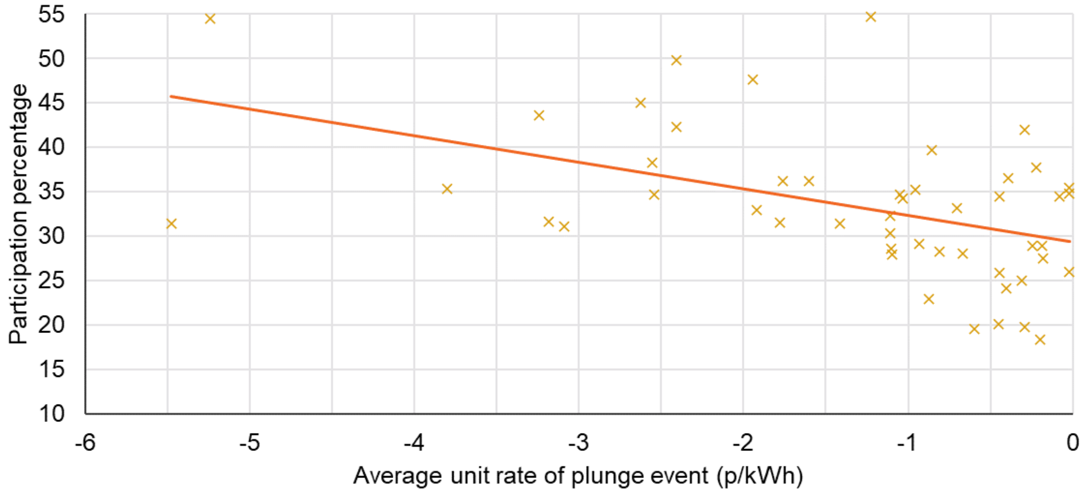


Figure 11: The linear relationship between the average unit rate of a price plunge event and the participation rate, based on the 2020 data of Agile tariff customers.

While the analysis of the price plunge events suggests that the amount of demand turn up flexibility that households can provide can be controlled by the unit price of electricity, it should be noted that there is a wide spread of data (R^2 of the dataset plotted in Figure 11 is 0.22). This indicates that several other factors influence the participation rate in price plunge events other than the unit rate of electricity, such as the time and the day of the week of the price plunge. In fact, both outlying price plunge events that achieved ~55% participation began at between 09:30-10:00 on weekend mornings, suggesting there is an increased participation when customers are likely to be at home and available during the price plunge event. Nevertheless, the data indicates a causality between the price set for a plunge event and the participation rate for demand turn up. In this way, the total magnitude of demand turn up flexibility provided can be controlled by influencing the percentage of customers providing it through negative pricing.

Price sensitivity

It has already been shown that Octopus Agile tariff customers are capable of responding to price incentives. This subsection will explore how this response is sensitive to the technology used to provide response, and to the times of day and year.

For the purposes of this study, price sensitivity is a measurement of how customers consume energy in response to the electricity prices on Octopus' Agile tariff. When the half hourly consumption of customers is plotted against the unit rate of electricity, Octopus found there was a linear relationship between the two factors. Therefore, the price sensitivity is formally defined as the gradient of the linear relationship between the half hourly consumption of energy (kWh/hh) and the unit rate of electricity (p/kWh).

Note the price sensitivity should not be confused with the price elasticity of demand. The price elasticity of demand is a function which measures the change in demand as a response to the change in the unit price compared to a baseline. Price sensitivity measures the relationship between the absolute demand of customers and the unit rates of electricity that they are offered. For example, for customers on a flat tariff (i.e. uninfluenced by hourly electricity prices), we would expect a positive correlation between their half hourly consumption of energy and the unit rate on the wholesale market; for them the price sensitivity is a positive value. This is because prices on the wholesale market reflect demand for electricity, and that is strongly influenced by residential demand profiles. In effect, the "baseline" price sensitivity of a typical (flat tariff) domestic customer has a positive value, and it is against this value that the impact of an Agile tariff may be measured. A negative price sensitivity indicates success in turning down demand during high prices or turning up demand during low prices. A positive price sensitivity for customers on the Agile tariff indicates a period where the demand is relatively inflexible and therefore cannot be varied significantly through changing tariff price signals.

Figure 12 displays the price sensitivity of customers on the Agile tariff. On the left are customers with an EV, and customers on the right are those with no LCT (i.e. no EV). The price sensitivity is disaggregated by time of the day and seasonally as there is a large variation between each time period. As in section 2, for brevity these segments will be referred to as EV owning customers and non-EV owning customers. Price sensitivity has been segmented in this way because it was shown above that EV owning customers will be able to react to changing prices more dynamically than non-EV owning customers given the large source of flexibility that is available from their EV battery.

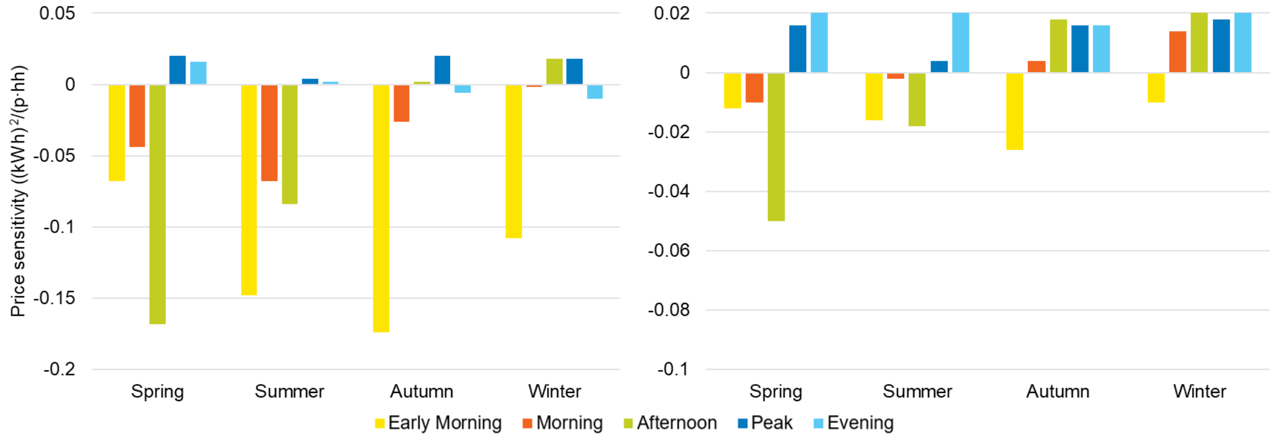


Figure 12: The price sensitivity[26] of customers on an Agile tariff at different times in the day and seasonally. This has been disaggregated into left) customers with an EV and right) customers with no LCT (i.e. no EV). Early morning = 00:00-06:00; morning = 06:00-12:00; afternoon = 12:00-16:00; peak is 16:00-19:00pm; evening is 19:00-00:00.

Figure 12 demonstrates that ownership of an EV significantly increases the capability to react to changing prices. EV owning customers can schedule their EV charging with a timer or using an autonomous daily optimiser to take advantage of the cheapest energy periods on the Agile tariff and avoid the more expensive ones. Without an equivalent source of demand and flexibility like an EV battery, non-EV owning households

[26] While conceptually the price sensitivity can be viewed as how a customer's consumption is affected by the price of electricity offered on the Agile tariff, the $(kWh)^2$ term in the units for price sensitivity tells us that the energy consumed (kWh) does not have a strictly linear relationship with the total cost of electricity for a consumer (p).

cannot take advantage of the variations in prices during this period and hence cannot provide much variation of their demand to provide flexibility.

Its notable however that during the evening peak, EV households do not demonstrate the ability to react dynamically to energy prices and demonstrate a positive price sensitivity. As shown in section 2, customers on a dynamic tariff have already switched EV charging demand out of the evening period. So, what is seen in the EV household cohort is inelastic consumption in the evening period due to the remaining loads in the households. In smart households, EV demand is not “inelastic” in the evening periods – charging is simply not available at these times.

Both household cohorts show that evening demand is not price sensitive. This indicates that the background demand, from white goods etc, is significantly harder to shift, compared to a demand such as EV charging.

The final observation from these graphs is that there is a seasonality to the price sensitivity. Across EV and non EV demands, price sensitivity is highest in the summer period and lowest in the winter period. This may indicate that all domestic demands will be more difficult to incentivise in the winter period. Note that the Low Carbon London project identified that flexibility from Heat Pumps increased as the winter months approached (as might be expected as the load factor on the heating system increased). So, when including all LCTs, it may be that the reduction in price sensitivity seen in CrowdFlex, may be offset by an increase in the capability to be price sensitive, when owning a Heat Pump. As the winter period coincides with the system peak demand, further investigation of this trend will be important to power system stakeholders requiring confidence in the flexibility available from the domestic sector, at peak times.

5. Deep dive into EV charging

It is clear from sections 2 and 3 that EVs play a vital role in influencing the magnitude of flexibility that households can provide. They do this by both shifting EV charging demand out of the evening peak, through switching from a flat to a ToU tariff (section 2), and providing demand turn off in one-off interventions, such as the Big Turn Up (section 3). Drawing on Ohme's large dataset of domestic EV charge points, this section will explore domestic EV charging in detail. It will gather insights into the times of the day that EVs are available to provide flexibility and how the magnitude and availability of flexibility changes depending on battery size and tariff structure.

An EV battery can be an unprecedented source of flexibility for the domestic sector. However, an EV battery can only serve as this source of flexibility when it is both plugged in and is not fully or near being fully charged[27]. Of course, on the way to being fully charged, the EV may have provided flexibility services.

This section explores three key aspects of charging behaviour:

- Plugged in and idle (plugged-in, but not charging) time of EVs.
- The impact that energy tariffs have on charging behaviour.
- The impact of EV battery size on charging patterns.

Plugged-in and idle time

The plugged-in and idle time features of EV charging behaviour are crucial aspects to consider when determining the ability for an EV to participate in domestic flexibility. EVs spend the majority of the time that they are plugged-in, in an idle state (i.e. not charging). So long as the EV is not fully charged, or near its charge limit, it can be an significant source of domestic flexibility.

Figure 13 shows the distribution of the duration EVs spend charging, idle and the sum of these two states, plugged in. The mean duration for each of the states is indicated with a cross. The ratio of the mean plugged-in time (14.5 hours) to the charging time (4.0 hours) is a measure of how much flexibility is available to move the demand across time to provide flexibility.

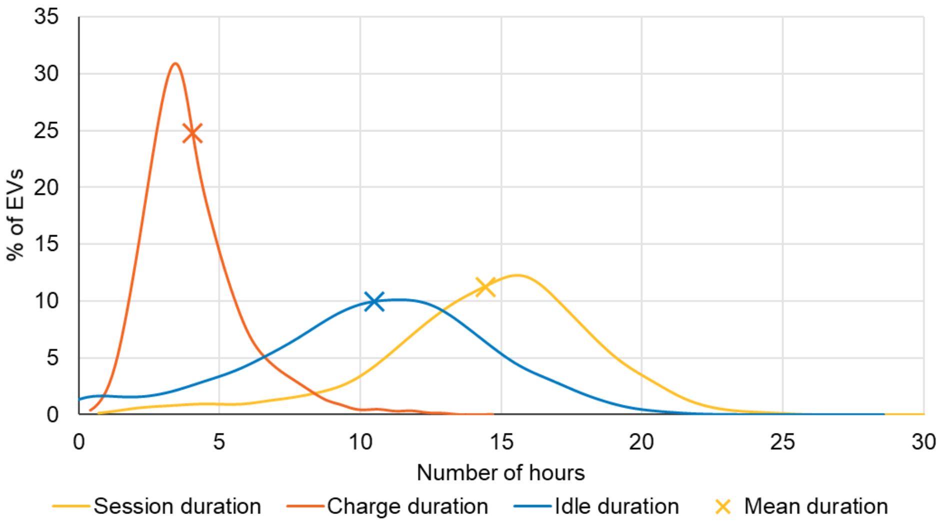


Figure 13: The distribution of hours spent charging, idle, and plugged in. The mean duration for each of the states is indicated with a cross.

Having established that EVs have plenty of opportunity to provide flexibility during a charging session due to the large idle time, it is important to determine at which times EVs are plugged in to charge. This is to ascertain the period in which EVs are likely connected to their charge point and hence capable of being called upon to provide flexibility, rather than out on a trip or left unplugged. EV behaviour is habitual, as EV owners go about

[27] As EVs approach their maximum charge (i.e. state of charge (SoC) is ≳90%), the power that a charger is able to draw is greatly reduced to protect battery health.

their daily routine, therefore by assessing the average plug-in time, the availability of EVs to provide flexibility can be assessed.

Based on Ohme's data, the mean time to plug-in an EV is approximately 16:00. This supports the inference made in earlier chapters, that unmanaged charging tends to overlap with the peak evening demand period – unmanaged charging tends to begin when the vehicle arrives back at the home and is plugged in. Clearly, smart charging incentives are needed to avoid EV charging adding to the evening peak demand, and the effectiveness of smart tariffs to do this has been clearly demonstrated in CrowdFlex. To maximise the flexibility EVs can provide, smart charging incentives may need to be coupled with incentives which encourage customers to plug in regularly and remain plugged in.

Impact of tariff structure on charging profile

Section 2 has already described how switching from a flat to a smart or ToU tariff can considerably reduce the consumption of households during the evening peak. For EV owning households, a large portion of that reduction is shifting EV demand out of the evening peak and into the overnight/early morning period. When the average EV charging demand profiles on each tariff are isolated, as in Figure 14, this becomes clear. For flat tariff customers, charging demand rises through the day and evening period. In contrast, the charging profile for the ToU tariff customers is lower in the evening period. The SToU did not explicitly discourage charging during the evening peak (rather it incentivised charging in the midnight – 4am period). The DToU tariff was alone in discouraging charging during the evening peak and as a result it generated the lowest average EV charging demand at those times.

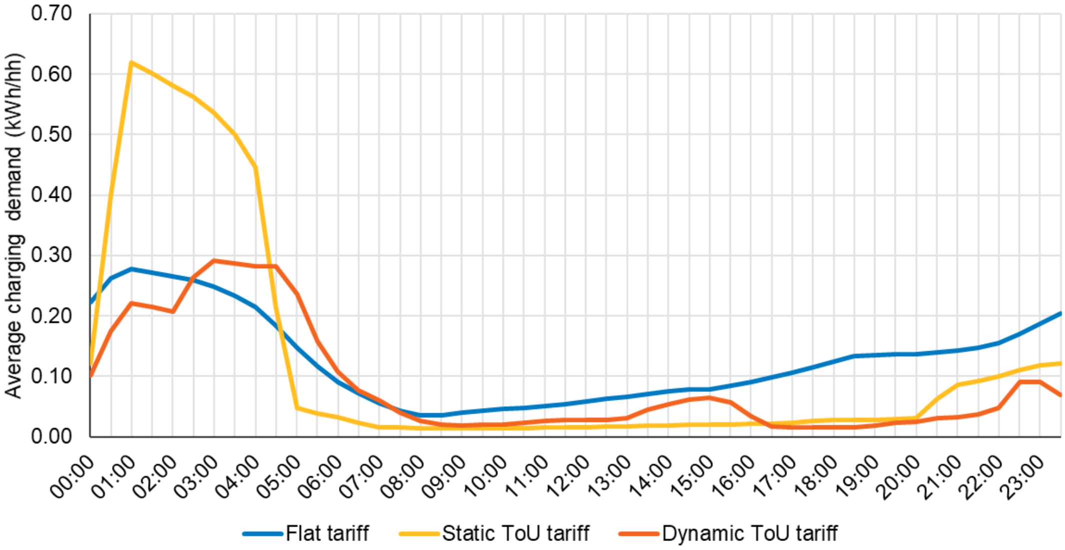


Figure 14: The average EV charging demand profiles of customers on flat, static ToU and dynamic ToU tariffs.

The graphs indicate that caution is required to ensure that widespread adoption of a Static ToU should not result in a new peak in demand; whereas the Dynamic ToU is more flexible in identifying peaks in demand (through wholesale prices) and discouraging consumption at these periods.

EV battery size

The size of an EV battery impacts charging behaviour in that EV owners with a larger battery do not need to charge as often, as they are less concerned by range anxiety. In addition, given their longer range and greater capability, owners are more likely to use their EV for long distance journeys, which increases average energy demand.

Illustrated in Figure 15, the average charging demand of an EV with a "large" or "huge" battery (i.e. >50kWh) is greater in magnitude than smaller batteries at all points after the evening peak (19:00), throughout the night and the early morning where the vast majority of charging occurs. In fact, at its peak demand, the average power demand from EVs with “large” batteries is 20% greater than for EVs with “medium” batteries and 120% greater than for EVs with “small” batteries.

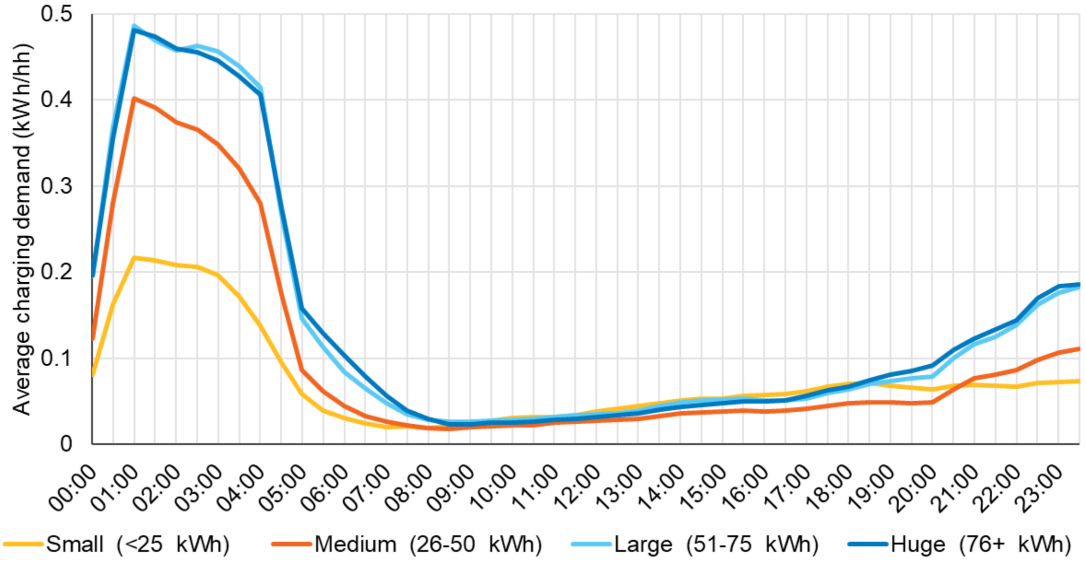


Figure 15: A graph showing average EV charging demand profiles for batteries varying in energy capacity in kWh.

While larger capacity EVs may imply greater capability to provide flexibility, this may be offset by less frequent charging of such EVs. This becomes clear following Ohme’s analysis on range anxiety. It found that on average EV owners prefer to keep their battery SoC greater than 30%, with some EV owners rarely dropping below 50%. For EVs with larger batteries, this would imply less frequent charging is required to mitigate range anxiety. This is a concern that should be explored further in future work to understand the impact that increasing battery capacities in EVs will have on their ability to provide flexibility.

Note that batteries of smaller sizes (<25kWh) are generally plug-in hybrid vehicles (PHEVs) and therefore have a lower peak charging demand. This is because PHEVs typically have 16-amp on-board chargers. Therefore, PHEVs offer much lower flexibility potential compared to BEV. Hence when extrapolating to determine the domestic flexibility potential across GB, only BEV uptake is taken forward.

6. Summary of CrowdFlex results

Summary of trials

Each trial measured the average response provided by a participating household to the intervention, whether that be a tariff switch or a Big Turn Up or Down signal. The average response for each intervention is summarised in Table 10. The response is defined as the change in demand, over the period specified for each trial, relative to the baseline specified for each trial. The baseline for each intervention is described in detail in their respective method subsections of sections 2 and 3. For tariff switching, the baseline was the power maintained across the peak 4-7pm period, averaged over the 4 weeks prior to the switch. For the Big Turn Up/Down, the baseline was the power maintained across the 2-hour period, averaged over the 4 same days of the 4 weeks prior to the experiment. To provide context on the magnitude of the response for each intervention, the response has also been displayed as a percentage of the diversified peak power demand of a participating household in kW (~1.1kW for a household on a flat tariff, ~0.9kW for a household on a smart tariff) for comparison. The percentage change is defined as the average power over the period of the intervention, divided by a reference power consumption, which is the power maintained across the 4-7pm period, averaged over the month prior to the experiment[28].

Intervention type	Trial	Average response per household: kW (% change relative to evening peak)	
		Non-EV household	EV household
Enduring	Flat → Agile tariff switch	-0.1 (-7%)	-0.2 (-18%)
	Flat → Go tariff switch	0.0 (0%)	-0.2 (-17%)
One-off	Big Turn Down	-0.5 (-41%)	-0.6 (-59%)
	Big Turn Up	1.5 (131%)	5.8 (617%)

Table 10: A table containing the average response per household for each of the four interventions analysed in CrowdFlex Phase 1.

Big Turn Up and Down data are disaggregated into smart and non-smart tariffs in the experiments. This is assumed to be a proxy for EV and no-EV owning households respectively as customers participating with a smart tariff were overwhelmingly EV owners and vice versa.

Estimate of the technical potential of household flexibility

The responses to the various interventions can be combined to predict the flexibility a household can provide in kW, by either increasing its consumption, “demand turn up”, or decreasing its consumption “demand turn down”. The technical potential of both the total demand turn up and demand turn down flexibility that a household can provide is calculated by summing the responses to the various interventions. Two key assumptions have been made to understand which interventions must be combined to determine the technical potential of the two types of flexibility for EV and non-EV owning households looking out towards 2030:

1. Customers are encouraged to switch to smart, Dynamic ToU tariffs, reflecting Octopus’ Agile tariff, whether they are EV owners or not.
2. The majority of EV owners in 2030 do not currently own an EV, so are currently on a flat tariff rather than a ToU tariff.

Therefore, demand turn down flexibility is the sum of an enduring intervention, (switching from a flat tariff to an Agile tariff), plus the reduction in consumption during the Big Turn Down event. The potential flexibility for demand turn up is assumed to be that observed during the Big Turn Up event as the purpose of tariff switching

[28] Please note, the percentage change relative to the evening peak is not equivalent to the percentage reduction in demand consumed during the evening peak as a proportion of daily demand quoted in the results of section 2. The percentage change relative to the peak demand is simply provides context on the magnitude of demand.

is to reduce peak demand and therefore is not relevant for turn up. The resultant technical potential of flexibility is summarised in Table 11 below:

Event	Technical potential of flexibility per household, kW	
	Non-EV household	EV household
Demand turn down	-0.5	-0.8
Demand turn up	1.5	5.8

Table 11: The average technical potential of flexibility provided by a participating household.

Extrapolation to 2030 – total technical potential of 2030 GB flexibility

CrowdFlex aims to assess the impact of the domestic flexibility on the entire power system in Great Britain (GB). To estimate this, the technical potentials of demand turn up and demand turn down per household, detailed in Table 11, are extrapolated to estimate the total technical potential of GB domestic flexibility that households are able to provide the system in 2030 based on the results of CrowdFlex Phase 1. This enables us to assess the value in providing domestic flexibility across the entire GB energy system.

Illustrated in Table 12, two scenarios, a High and a Low, have been considered when projecting the technical potential of domestic flexibility to 2030. This is to account for two factors that the total GB domestic flexibility is very sensitive to, uncertainty in participation rates and EV uptake.

The participation rate is the number of households expected to participate in demand turn up or down flexibility as a percentage of the total number of GB households. Participation rates are derived from the Big Turn Up and Down experiments. For demand turn up, the High scenario captures the observed participation in the Big Turn Up, while the Low scenario participation is a conservative lower assumption on the participation rate for demand turn up. For demand turn down, the Low scenario captures the Big Turn Down observed participation rates, while the high scenario is a conservative upper limit assumption of participation based on the observed participation in the Big Turn Up event[29].

A further key assumption that the total GB flexibility is sensitive to, specifically EV uptake, originates from National Grid ESO FES scenarios. The EV uptake is the expected percentage of GB passenger cars that will be battery electric vehicles (BEV) in 2030. The system peak is the maximum expected total power demand on the GB system throughout the year in 2030. This figure is also extracted from National Grid ESO FES scenarios to contextualise the magnitude of the total technical potential of 2030 GB domestic flexibility. The High scenario draws on the FES Consumer Transformation scenario for EV uptake (38%) and system peak (69GW). Meanwhile, the Low scenario assumes the FES Steady Progression scenario for EV uptake (14%) and system peak (68GW).

The number of households in GB is based on the 2020 ONS data, which indicates there were 27.8 million households in 2020. This is a 5.6% increase on the number of 2010 households. In this report we make a transparent assumption that there will be a similar increase out to 2030, giving a projected 29.3 million households. This assumption is supported by the fact that a similar increase in the number of households was observed between 1990-2000 and 2000-2010.

[29] The participation rate for EV customers in the High scenario of the Big Turn Down is assumed to be the same as for the Big Turn Up (63%). The participation for non-EV customers is based on scaling the high scenario Big Turn Down assumption (63%) by the measured ratio of the participation rates for non-EV customers to EV customers (~25%).

	Demand turn down				Demand turn up			
	No-EV		EV		No-EV		EV	
	Low	High	Low	High	Low	High	Low	High
Households in segment (m)	26.0	20.7	3.3	8.7	26.0	20.7	3.3	8.7
Participation	2%	25%	4%	63%	5%	18%	10%	63%
Technical potential of flexibility per household (kW)	-0.5	-0.5	-0.8	-0.8	1.5	1.5	5.8	5.8
Total technical potential of GB 2030 flexibility (GW)	**-0.3**	**-2.7**	**-0.1**	**-4.1**	**1.9**	**5.3**	**1.9**	**31.7**
% of GB 2030 system peak	**0%**	**-4%**	**0%**	**-6%**	**3%**	**8%**	**3%**	**46%**

Table 12: Calculation of the total technical potential of GB 2030 flexibility for each household segment (EV and non-EV) implied by results CrowdFlex Phase 1 for High and Low flexibility scenarios.

The flexibility calculated in each scenario provided by EV owning and non-EV owning households are combined for demand turn up and demand turn down to produce the total technical potential of GB 2030 household flexibility implied by CrowdFlex Phase 1. Summarised in Table 13, the result is that CrowdFlex Phase 1 implies that domestic flexibility provided by households could reduce the 2030 GB system peak demand by up to 10% (6.8GW). A much greater level of demand turn up flexibility could be available based on the results of CrowdFlex Phase 1. In the High scenario, the results of CrowdFlex Phase 1 suggest that GB households could provide up to 37GW of demand turn up flexibility, this equates to 53% of the magnitude GB system peak.

	Demand turn down		Demand turn up	
	Low	High	Low	High
Total technical potential of GB 2030 household flexibility implied by CrowdFlex Ph. 1 (GW)	-0.4	-6.8	3.8	37.0
% of GB 2030 system peak	-1%	-10%	6%	53%

Table 13: Estimates of the technical potential for domestic resources to contribute to flexibility in GB 2030. Figures are based on the technologies and responses from CrowdFlex Phase 1. The flexibility in GW has been compared as a percentage of GB 2030 system peak for reference.

CrowdFlex Phase 1 results segment consumers by EV ownership because the results indicate that this, of all factors analysed in the study, has the greatest impact on the domestic flexibility a household can provide. Care is required when extrapolating or projecting the wider technical potential of flexibility based on CrowdFlex, because Octopus' customer base is not likely to accurately reflect the GB average or range of consumers. For example, National Grid ESO has developed a more sophisticated approach to the segmentation of customers[30] than that taken in CrowdFlex. It splits the GB population into six segments to identify which customers could be supported and inspired through different engagement strategies to make environmentally-friendly lifestyle changes. We may expect that Octopus' customers are more likely to be represented by National Grid ESO's engaged customer (early mover) segments compared to their less engaged (later mover) segments[31]. Nevertheless, as CrowdFlex reports a range of outcomes (based on observed participation rates), it is appropriate for scaling up the technical potential of CrowdFlex interventions to GB levels.

[30] National Grid ESO, Empowering Climate Action report: Inspiring and supporting consumer participation in the energy transition, 2021.
[31] Priority engagement segments: "Climate Worriers", "Price Sensitive" and "Actively Engaged" make up 56% of the GB population. Less engaged segments: "Busy convenience-seekers", "Pragmatic Sceptics" and "Disengaged Cynics" make up 44% of the population.

Despite this, the figures for the total domestic flexibility projected for GB in 2030 by the analysis of CrowdFlex Phase 1 differ from the current FES projections for domestic flexibility. Two key factors can explain this difference:

- CrowdFlex is a measurement of the technical potential of domestic flexibility – extrapolations based on CrowdFlex are not intended to be an internally consistent “scenario of the future”.
- CrowdFlex derives its results from Octopus customers who represent a more engaged consumer type compared to the GB average, as explained above.

It is worth noting, home energy use could change substantially with new LCT uptake and the shift of transport costs from petrol stations to the home energy bill. This may drive large changes in customer behaviour and lead to more engagement, whether directly or through forms of automation. Therefore, future work should place an emphasis on both confirming the technical potential and the projected participation for National Grid ESO’s detailed segments. This is necessary to gain a comprehensive understanding on the value domestic flexibility can play in reducing stress on the electricity system.

7. Conclusions and recommendations for future work

Primary insights from CrowdFlex Phase 1

CrowdFlex has been successful in proving that there is a significant flexibility resource in the domestic sector. Providing more robust insights than a trial, CrowdFlex has identified real-world customer flexibility response to information and price incentives. It has shown that, when incentives are attractive and communicated effectively, a high proportion of customers are able to make significant adjustments to their electricity demand. In doing so their actions can reduce their electricity bills and support the power system. CrowdFlex has provided valuable insights into the parameters of domestic flexibility, across technical potential and consumer behaviour, that can be used to design efficient and effective mechanisms to encourage the desired response.

CrowdFlex draws from Octopus' active customer base, responding to information provided by Octopus. As such, CrowdFlex provides a high level of confidence in the relevance and more widespread repeatability of the outcomes measured, beyond what could be expected from trial conditions, or from surveys of intended behaviour or stated preference. Also, the high number of participants gives confidence in the statistical significance of the outputs of the project.

The sustained turndown of consumption in the peak evening periods, observed over the length of the data available and in response to Dynamic Time of Use Tariffs, is very encouraging. Non-EV households demonstrated an immediate 12% decrease in the proportion of their daily demand consumed during the peak evening period. It shows that customers have adjusted consumption patterns to avoid peak periods and have maintained those new patterns of daily consumption. The sustained change in behaviour is very encouraging, as the reliability and repeatability of domestic flexibility response is a vital feature for the System Operator and for the Distribution Network Operators.

The one-off Big Turn Up and Big Turn Down interventions resulted in an even greater response, while also showing that demand turn up and down response is not symmetrical. Approximately 76% of Smart Tariff customers responded positively to taking part in Big Turn Up, but the equivalent figure for Big Turn Down was just 13%. This may indicate that customers respond positively to longer notice periods (which the Big Turn Up provided); or that demand turn down is less attractive to customers.

The demand turn up and down experiments provided clear insights into how technology can impact the level of response provided. CrowdFlex showed that the ownership of an EV can significantly increase the turn up flexibility provided by a household (during Big Turn Up, EV households showed a 617% increase in demand relative to evening peak, compared to 131% for non-EV households). In the context of domestic flexibility, EVs are an unprecedented asset in terms of the storage available (kWh), peak power (kW) and flexibility potential (daily charge requires only a fraction of the plugged-in time). Such technical features give rise to a large turn-up potential, and the response seen in CrowdFlex is in line with this.

In a broader context of increasing electrification, turning down demand will also be a vital tool for stakeholders. Big Turn Down resulted in significant reduction in demand (64% compared to baseline) across the two-hour period. For demand turn down, the response of EV and non EV households was comparable, implying that loads other than EV are behind the turn down. While the source of demand reduction was not monitored, the level of response from non EV/LCT households is extremely encouraging. The implication is Big Turn Up is able to draw on potential demand (from new LCTs) to increase a household's consumption while Big Turn Down can reduce the underlying of demand of a household.

The overall drop in daily demand for Big Turn Down suggests that customers moved demand to other days. Similarly, the large increase in daily demand elicited through Big Turn Up, indicates that EV charging demand was moved from other days. This may have implications for achieving repeatable and reliable Big Turn Down and Big Turn Up of this magnitude, particularly if called for over consecutive days.

A primary concern for distribution network operators and the system operator is to ensure the system can respond to the growth in domestic demand from low carbon technologies such as EVs and heat pumps. An important outcome of CrowdFlex is that the measures explored here can move the additional “passive” EV charging load away from the evening peak. These incentives should be considered alongside traditional solutions such as network reinforcement or procuring additional generation capacity. Care will be required to ensure they do not incentivise a new demand peak at other times, or that other impacts such as changing the daily duty cycle of transformers, does not generate new challenges. CrowdFlex measures such as Dynamic ToU tariffs and demand turn down, focussed on moving demand out of the evening peak. This is appropriate because this aligns with the peak load on the distribution system, and with the peak in generation capacity. However, the needs of the DNO and the SO may not always be perfectly aligned temporally. Flexibility measures will need to be robust in meeting the needs of all those assuring reliability of the power system.

Repeatability and reliability are vital features of response to stakeholders. While CrowdFlex Phase 1 set out to mine insights from existing datasets of consumer response, further work will be needed to examine response at/near to the system peak demand, where demand may be less elastic. Also, the existing dataset focussed on EV/no-LCT owning customers; future work would need to augment this with electric heating customers to determine the response available from that cohort.

CrowdFlex has highlighted the importance - and the technical challenge - of determining a proper baseline of demand, from which the level of flexibility is assessed. For example, the project showed that smart tariffs applied to EV charging can be effective in moving the evening charge out of the peak period, i.e. the starting point is of a passive charging profile that adds demand in the peak evening period. So, the significant EV flexibility potential should be seen as the ability to turn down to avoid problems passive charging created in the evening period, as well as the capability to significantly ramp-up charging demand when called.

Furthermore, CrowdFlex showed that determination of the “correct” baseline, is challenging. There is a tension between the desire to generate a more recent (and therefore more relevant) historical baseline, but also to ensure there is sufficient customer specific data to make this estimate statistically reliable. This tension may be more acute in sectors where demand can vary more rapidly from week to week, for example electric heating demand following a sudden drop in temperature. Without the development of novel methods for determination of baseline consumption, an EV customer may be rewarded for providing flexibility by virtue of going on holiday, or a heat pump customer rewarded for providing flexibility, simply because the weather becomes warmer.

This also speaks to a broader, strategic issue, which is the move away from a rigid, deterministic view of flexibility, and towards a statistical basis for estimating the level of resource available. Baseline consumption and response are properties of individual households, yet only when aggregated across many households can residential response provide the features of reliability and repeatability that system stakeholders require to valorise this nascent asset. A statistical underpinning for domestic response will need to be reflected in the modelling of the resource. It will also need to be reflected in the construction of the incentives and market mechanisms used by power system stakeholders to elicit domestic response to support the power system.

Finally, it was identified from the CrowdFlex datasets that the vast majority of Octopus’ customers are dual fuel (with gas for heating). The small number of customers with electric heating (15%) were not sufficient to provide reliable conclusions on the impact that electric heating can have on providing domestic flexibility. This is true of the majority of studies that investigate domestic flexibility in a broad context. Both the Low Carbon London[32] and the CLNR[33] studies found that data on heat pumps is very limited and where data is available the impact of flexibility measures can be inconclusive. The rapid growth of the EV market indicates they will provide a more readily available and reliable source of residential flexibility in the near term. The very significant system impact of widespread electrification of heat does mean flexible residential heating will need further exploration.

Recommendations for future work

CrowdFlex has shown that dynamic time of use tariffs and one-off interventions such as information remedies and financial incentives can change domestic electricity consumption profiles, which, if scaled up across GB, would represent a flexibility resource potential of significant national importance.

A strength of CrowdFlex is that it could draw from a very large dataset of real customer behaviour, rather than trial data. However, that inevitably placed limitations on the design of the trials and what dimensions they could

[32] Low Carbon London, UKPN.
[33] CLNR – Customer-Led Networks Revolution commissioned by Northern Powergrid and partners.

explore. It was always envisaged that it would provide a strong foundation upon which to undertake further work which is required to prove the reliability of domestic response.

The recommendations aim to build confidence for the System Operator and Distribution Network Operators that these aggregated resources can reliably provide the required flexibility, when called upon. This is addressed via four key topics:

- To reflect the **statistical nature of the domestic flexibility resource** through development of appropriate baselining, modelling methods, consumer trial design, and market mechanisms that can elicit flexibility.
- To prove the **technical potential**, mainly of demand turn down for all technologies, including EVs, but also underlying demand and electric heating, particularly at or near system peak.
- To understand and **encourage consumer response** in the most effective and efficient way.
- To determine **the impact of automation** on the volume and reliability of response generated.

1. **Reflect the statistical nature of the domestic flexibility resource** – CrowdFlex was a substantial data analysis exercise, showing that the move from a deterministic model of flexibility assets, to a statistical one, has many challenges, including:
    - The development of consumption baselining techniques that are accurate and precise i.e. that retain high statistical confidence while ensuring the baseline is up to date.
    - The development of large-scale consumer trial designs that provide sufficient statistical confidence in the outcomes of the trial.
    - The variation in response from different National Grid ESO segments from the Empowering Climate Action report[34]. How does the technical potential and level of engagement in flexibility services vary between segments? How do these segments vary between DNO regions and how does this impact the level of flexibility that can be expected in each geographic region?
    - Explore how the non-deterministic nature of the domestic flexibility resource impacts on key power system stakeholders, including the System Operator and Distribution Network Operators. This includes the reliance on the resource at critical times, and how this should be reflected in the development of appropriate market mechanisms. This should improve understanding of how the ESO and DNOs coordinate to achieve the desired domestic flexibility response.

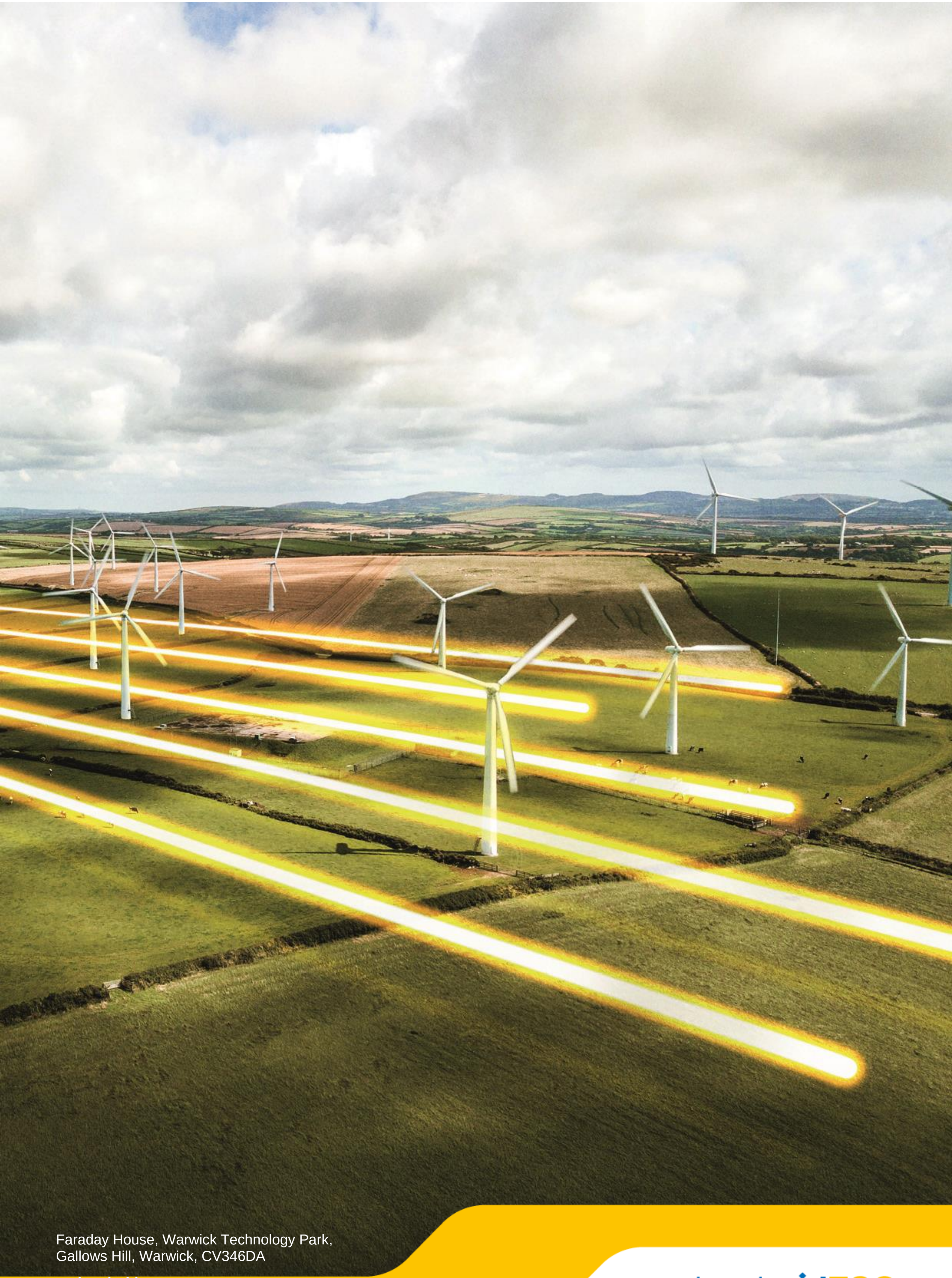
2. **Prove technical potential of key demand sectors** – Big Turn Down showed that underlying demand during the evening peak could be reduced by approximately half.
    - What component of underlying demand contributes to this; are these loads moved in/out of nearby days to provide the response observed?
    - How does the availability of the resource change with time of day, and with season, in particular near system peak?
    - Electric heating will be a more significant component of domestic demand. How much flexibility can this resource provide? How much flexibility is available during extended cold weather periods, in particular at/near system peak? How is this affected by the availability of thermal storage.

3. **Encouraging response at least cost** – The Big Turn Up/Down interventions showed significant technical potential, but they were one-off events.
    - Noting that engagement varied significantly between smart/non-smart customers, what is the most effective way to maximise engagement with Turn Up/Down requests?

[34] National Grid ESO, Empowering Climate Action report: Inspiring and supporting consumer participation in the energy transition, 2021.

- How does response from varying notice periods align with ESO service requirements (such as Dynamic Containment/STOR)?
- Do non-EV customers respond differently to Turn Up and Turn Down requests, even if they are expressed to the customer in a similar way?
- How does the value of the incentive influence the level of flexibility provided? i.e. What is the price elasticity?
- To what extent would flexibility continue to be provided following repeated Turn Up/Down requests?
- How can EV owners be incentivized to plug their vehicles in regularly and for long durations to unlock their maximum potential flexibility?

4. **Impact of automation** – CrowdFlex showed that automation of EV charging is important for delivering useful load shifting on dynamic tariffs; but customers still intervened manually to respond to one-off events:
   - To what extent could automation of underlying demand increase the technical potential of flexibility, without impacting customer satisfaction?
   - To what extent could automated response to Big Turn Up/Down interventions improve engagement and reduce cost of flexibility?
   - How can automation combine with alternative incentives (such as availability payments) to improve reliability of flexibility service delivery?
   - To what extent can staggering charging deliver diversity of response over geographic areas (such as primary/secondary substation level)?



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