# Learning from Intelligent Octopus

Early insights into at-home EV charging behaviour and automation

Centre for Net Zero
Powered by Octopus Energy

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We believe in a people-centred energy system and are committed to building a future energy landscape that works harder for people and the planet. Working at the intersection of tech, energy and climate, our team tackles the biggest and most interesting questions in the energy sector.

We conduct independent research and analysis, build products, collaborate with academics and form commercial partnerships.

We work with world leaders and innovators in technology and academia to co-design the future energy system — and wherever possible, we share our research in transparent and open formats.

If you're interested in future analysis and reports, or if the insights in this report have sparked some more questions, we'd love to hear from you. **Get in touch with us at** info@centrefornetzero.org

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# Terminology

| | |
|---|---|
| **EV** | Electric Vehicle |
| **BEV** | Battery Electric Vehicle |
| **Bump charge** | A specific feature of Intelligent Octopus, where the user is able to press a button in the app which charges the vehicle up to 100%, unless it is disconnected or the user cancels it. |
| **CCC** | Climate Change Committee, an independent, statutory body established under the Climate Change Act 2008 |
| **Charge event** | The “event” starting when the vehicle starts charging, and ending when the vehicle stops charging. The vehicle will only be charging for some of the time that it is plugged in. |
| **LCT** | Low Carbon Technology |
| **Plug event** | The “event” starting when the vehicle is plugged into the chargepoint, and ending when the vehicle is plugged out of the chargepoint. |
| **SoC** | State of Charge [of an electric vehicle] (units in %) |
| **ToU** | Time of Use. A tariff where the price depends on the time, either dynamically (changes every half hour) or static (fixed windows). |

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# Introduction

The energy transition will result in a proliferation of low carbon technologies (LCTs) which will impact household electricity consumption patterns and their energy bills. As our previous work identifies, electric vehicles (EVs) present the largest load from a single LCT type. If all EV charging were to be left unmanaged, there is a risk that higher energy consumption coincides with existing high grid load periods, potentially resulting in unnecessarily high bills for consumers or even challenges with grid stability.

We have already seen that there are mechanisms that can help reduce grid strain by incentivising customers to switch their energy use to periods outside of grid peaks through Time-of-Use (ToU) tariffs. One way in which this change in behaviour could be achieved -with potential benefits for consumers and the grid -is through automation. Customers on the Intelligent Octopus beta tariff are exploring some of this potential right now, offering us valuable insights into how the future might look.

In this piece, we analyse customers on the Intelligent Octopus beta tariff. First, we explain how this tariff is different from other Octopus Energy tariffs. Then, we explore patterns of user and charging behaviours of those on Intelligent Octopus. Finally, we comment on the key findings relevant for a future energy system, how consumers interact with automation and technology as well as key research areas for the future.

# Context

Transport is the largest emitting sector in the UK, accounting for almost a quarter of the carbon emissions in 2020.[1] Passenger cars are the largest source of emissions in the transport sector.[2]

Currently there are more than 380,000 EVs,[3] with the market share of BEVs sold in February 2022 double that of the same month in the previous year.[4] By 2030, more than 10 million cars and vans are expected to be fully electrified in the UK.[5,6]

There are three different types of charging:

- Unmanaged charging: when plugged in, the vehicle starts charging at the highest capacity available.
- Managed charging or smart charging: the vehicle only charges reacting to price or carbon signals, avoiding peak expensive electricity prices or times when electricity on the grid is most carbon intensive.
- Vehicle-to-X charging: the battery of the electric vehicle can be seen as a bidirectional energy asset. The vehicle is able to charge when electricity is cheap and demand is low, but also discharge electricity back to the grid when demand is high, potentially receiving a payment for doing so.

According to the CCC's Sixth Carbon Budget, EVs are expected to increase electricity demand today by between 20% and 30% by 2050.[7] This represents an electricity ramp-up from 65 to 100 TWh added to today's demand[8], with unmanaged charging potentially adding to demand at grid peak. Grid reinforcement costs to accommodate the extra demand for unmanaged electrification of heat and transport could be as high as £40 billion.[9]

The grid procures services to help rebalance supply and demand in the grid using large scale assets. With system balancing costs increasing,[10] there are opportunities to view these distributed domestic assets as a "large scale asset" in and of itself.

The value of such embedded flexibility in a net zero system is estimated to be as high as £16.7 billion per annum by 2050.[11] The benefits are twofold: firstly those who participate will get paid to do so, and secondly if these services result in reduced system running costs then this reduction is spread over all bills, supporting a fair and just net zero transition.

As more consumers purchase and use electric low carbon technologies, the greater the value of this resource. It also raises important questions to consider from a product, policy and regulation perspective.

In order to best understand the potential for how EVs can provide flexibility benefits to the grid, we must first understand what they are doing today.

**1.** '2020 UK Greenhouse Gas Emissions', GOV.UK. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1051407/2020-final-emissions-statistics-one-page-summary.pdf (accessed Mar. 24, 2022) | **2.** '2020 UK Greenhouse Gas Emissions, Final Figures', GOV.UK. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1051408/2020-final-greenhouse-gas-emissions-statistical-release.pdf (accessed Mar. 24, 2022) | **3.** 'Electric Car Count' New Automotive. https://newautomotive.org/ecc (accessed Mar. 24, 2022) | **4.** 'The popularity of petrol is waning', New Automotive. https://newautomotive.org/blog/electric-car-count-february-2022 (accessed Mar. 24, 2022) | **5.** 'Transitioning to zero emission cars and vans: 2035 delivery plan', GOV.UK. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005301/transitioning-to-zero-emission-cars-vans-2035-delivery-plan.pdf (accessed Mar. 24, 2022) | **6.** 'Future Energy Scenarios 2021' National Grid ESO. https://www.nationalgrideso.com/document/199871/download (accessed Mar. 24, 2022): Consumer Transformation and Leading the Way BEVs and vans | **7.** 'The Sixth Carbon Budget: the UK's path to Net Zero', Committee on Climate Change. https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf (accessed Mar. 24, 2022) | **8.** Dukes 2021 Chapter 5 Electricity', GOV.UK. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1006701/DUKES_2021_Chapter_5_Electricity.pdf (accessed Mar. 24, 2022) | **9.** 'Accelerated Electrification and the GB Electricity System', Committee on Climate Change. https://www.theccc.org.uk/publication/accelerated-electrification-and-the-gb-electricity-system/ (accessed Mar. 24, 2022) | **10.** 'Open letter on trends in balancing costs in 2021', Ofgem (accessed May 18 2022) | **11.** 'Flexibility in Great Britain', Carbon Trust. https://www.carbontrust.com/resources/flexibility-in-great-britain (accessed Mar. 24, 2022)

# Previous studies

Understanding the habits and charging patterns of EV owners is crucial to understand the impact on the electricity system. As the electric vehicle industry has grown in recent years, several pilot trial projects have been conducted which provide key insights into behaviour patterns, as well as how different signals can modify these behaviours. Some of the trials most relevant to this report are listed below:

- ***Charge up then charge out? Drivers' perceptions and experiences of electric vehicles in the UK:*** drivers in the UK Ultra Low Carbon Vehicle trial were interviewed before using an EV and after driving it for three months. The results showed that these drivers became increasingly relaxed about the frequency and when to charge their vehicles over time, even preferring this option over refuelling. The study showed participants were more aware of $CO_2$ emissions and the impacts of unmanaged charging after the trial.

- ***Analysis of electric vehicle driver recharging demand profiles and subsequent impacts on the carbon content of electric vehicle trips*** outlines the results of the Switch EV trial, lasting two successive 6 month periods. One of the main outputs of the study suggests that if left unmanaged, EV charging from private users will increase energy demand most in the evening, between 5 and 8pm. They conclude that smart charging should be used to shift part of that demand to later periods after 11pm.

- ***How Electric Vehicles and the Grid Work Together: Lessons Learned from One of the Largest Electric Vehicle Trials in the World:*** My Electric Avenue deployed more than 200 Nissan LEAFs to customers in the UK to study the driving and charging habits of a geographically and socioeconomically diverse population. They found a highly erratic charging pattern shown by EV owners during roughly the first seven days of use. Additionally, the majority of EV owners (70%) charged their vehicle only once per day, most commonly after 6pm (after work), with no significant difference between weekdays and weekends, and they do so when their battery is between 25% and 75% charged.

- ***Crowdflex Phase 1:*** UK customers with different types of low carbon technologies, or none, were notified to turn up and turn down their demand in response to a request from National Grid. It also explores the effect of how tariffs shift consumption away from periods of high demand in the grid. The project found that EVs can very easily shift their demand to other periods when there are price signals to incentivise that change. Customers on fixed time-of-use tariffs reduced the consumption in these periods by 17%, whereas customers with variable pricing throughout the day further reduced their consumption by 23%. Customers with EVs were able to turn up and turn down by a greater amount of energy in the specified window compared to those without an EV.

These trials have been focused on consumer behaviour, but focus less on the potential for flexibility e.g by scheduling charging sessions away from peak times. Managed charging, and the impacts on the consumer and grid, has yet to be explored in detail.

Exploring the behaviours of customers using these systems in the "real-world" will help us understand how to manage EV charging in a way that conforms to consumer needs whilst providing grid benefits.

# What is Intelligent Octopus?

Intelligent Octopus is a beta tariff offered to EV owners with a compatible vehicle and chargepoint (CP). Tesla was the first supported manufacturer and makes up the majority of EVs in the dataset used for this analysis. Jaguar and Land Rover were recently added. More EVs and CPs will be supported soon.

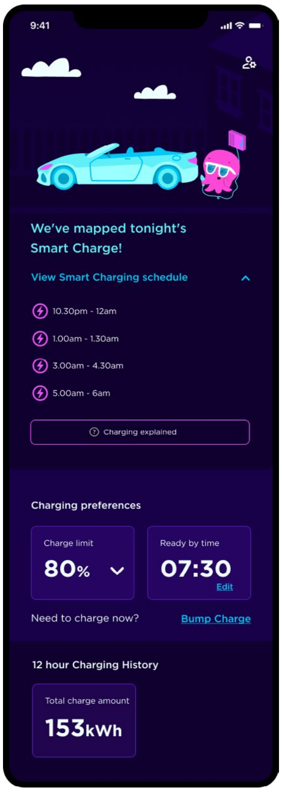
Intelligent Octopus offers consumers 6 hours of cheap electricity, 1-2 hours more than other Octopus EV specific tariffs Octopus Go/Go Faster.

With Intelligent Octopus, the user specifies a target charge percentage and a deadline, for example 80% target state of charge by 6:30am. The charging itself is managed using Octopus Krakenflex algorithms on the owner's behalf, which optimise against wholesale prices to charge when prices are cheapest. This often coincides with lower carbon intensity.[12]

This contrasts with static ToU tariffs such as Octopus Go or Go Faster where the EV owner is incentivised to start charging their vehicle when the tariff is cheaper (during their fixed window). EV owners can use a timer to start and stop charging, but setup is manual and could involve a different app.

## Sign up experience

Intelligent Octopus is a beta tariff, so customers are early adopters. To sign up for Intelligent Octopus, customers need a compatible EV and chargepoint and to complete a test charge. Customers can then set their preferred target charge and deadline in the Octopus app. They can change their preferences at any time.




| Tariff Name | Tariff Type | Cheap overnight charging | Window of cheap charging | Price during charging window | Smart Meter Data | Vehicle and chargepoint data |
|---|---|---|---|---|---|---|
| Fixed | Fixed | ❌ | None | Varies on tariff | Depends | ❌ |
| Octopus Agile[13] | Dynamic ToU | Varies daily | Varies daily | Varies half hourly | ✅ | ❌ |
| Octopus Go[14] | Static ToU | ✅ | 4 hour window 00:30-04:30 | 7.5p/kWh | ✅ | ❌ |
| Octopus Go Faster[15] | Static ToU, customisable | ✅ | User chooses 4 / 5 hour window starting between 21:30-01:30 | 4 hour window: 7.5p/kWh<br>5 hour window: 8.5p/kWh | ✅ | ❌ |
| Intelligent Octopus | Static ToU for consumer, automated against dynamic ToU prices | ✅ | 6 hour window 23:30-05:30 | 7.5p/kWh | ✅ | ✅ |

*Table 1: Showing the differences between different Octopus tariffs for EV owners*

**12.** 'How the market decides where Great Britain gets its electricity from', Drax. https://www.drax.com/power-generation/market-decides-great-britain-gets-electricity/#:~:text=What%20is%20the%20merit%20order,are%20brought%20onto%20the%20system. (accessed Mar. 24, 2022) | **13.** 'What is Agile Octopus and how do I join?'Octopus Energy. https://octopus.energy/help-and-faqs/categories/tariffs/agile-tariff/ (accessed May. 16, 2022) | **14.** 'What is Octopus Go and how do I join?'Octopus Energy. https://octopus.energy/help-and-faqs/categories/tariffs/go-tariff/ (accessed May. 16, 2022) | **15.** 'Octopus Go and Go Faster' Energy Stats. https://www.energy-stats.uk/octopus-go-tariff/ (accessed May. 16, 2022)

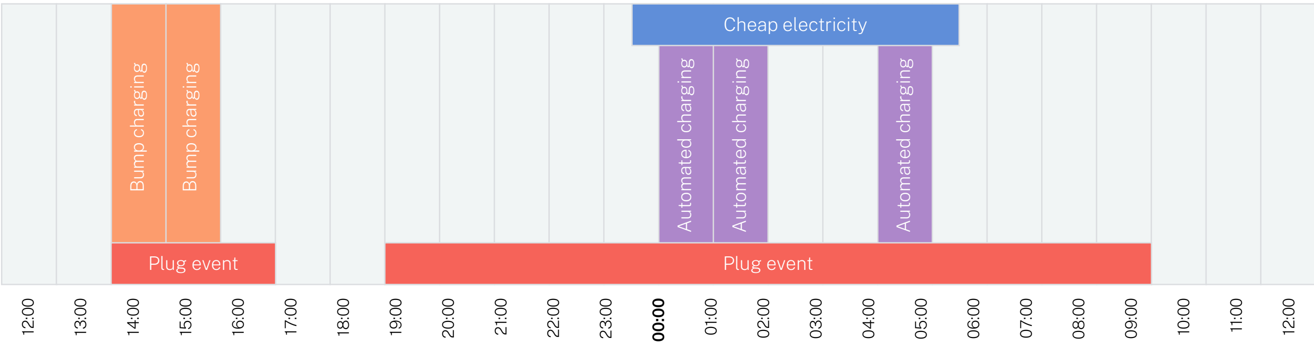



*Figure 1: An example highlighting the key information which can be extracted from Intelligent Octopus. This customer plugs in twice, once during the day and once overnight. During the day they bump charge and overnight the automation charges the EV when electricity is cheap to meet their preferences*

# Automation process

Much like the charging of a mobile phone, with EV charging the user's main concern is that their EV is reliably charged to a sufficient level by a certain time. So, the logistics of the automation are not important for the user experience, but provide context for this analysis.

When customers plug in after 4pm (the time at which day-ahead wholesale prices are released) an overnight charging schedule is created, optimising for price and ensuring that the consumer preferences are met.

The Krakenflex algorithm calculates how long it would take to charge the vehicle to the target "State of Charge" (SoC), which depends on the SoC at the time the vehicle is plugged in. Most EV batteries charge more slowly at higher states of charge to protect the battery health, so the Krakenflex algorithm accounts for this time.[16]

Once a user plugs in, the charging duration is calculated and the algorithm creates a charging schedule choosing the cheapest half hour periods so that the target SoC can be reached before the user's 'ready by' time and schedules charging in these periods.

The user can choose to override the automated schedule using the "bump charge" function on the app at any time. This is priced according to the rate at the time of the bump charge. A bump charge, once started, continues until the battery is fully charged, the vehicle is unplugged, or charging is stopped in the app.

# The data

We have analysed data from over 2500 Intelligent Octopus customers, dating from October 2021 to present day, with the analysis in this report covering data up to May 2022. Almost all customers plug in their EVs at least once per week. 200 EVs plugged in daily in October 2021. By May 2022 this had grown to over 1200 daily connections.

Intelligent Octopus collects data from the chargepoint, as well as the smart meter, so we know how much energy was specifically used for EV charging, as well as other helpful information about the charging session. This allows us to understand both user behaviour and EV charging patterns.

From the data we can see the following:

- Plug in and plug out times which mark the beginning and end of what we refer to in our analysis as a plug event;
- Charging preferences;
- The SoC of the battery at various points, including plug in and plug out;
- The overnight blocks when the EV is charged; and
- Whether and when customers choose to bump charge.

Figure 1 shows an example timeline of events. The sample shows two plug events, the first from 2 pm to 5 pm and the second from 7 pm to 9 am the next day, with plug duration of 3 hours and 14 hours, respectively.

The first plug event contains one bump charge event (as defined in Section Automation process) for two hours. The second plug event contains the charge event that is scheduled and executed by Intelligent Octopus. The scheduled charge duration is three hours. Each "block" of charging is a charge event so the three hour period of chargingis considered to be two separate charge events.

**16.** E. D. Kostopoulos, G. C. Spyropoulos, and J. K. Kaldellis, 'Real-world study for the optimal charging of electric vehicles', Energy Reports, vol. 6, pp. 418–426, Nov. 2020, doi: 10.1016/j.egyr.2019.12.008.

# Analysis

The charging patterns and plug-in/out behaviours of Intelligent Octopus customers can help us to understand where and how EV customers can be flexible with their demand and therefore offer valuable insight into the potential benefits afforded by these behaviours for ensuring grid stability and reducing potential infrastructure investment costs aligned with energy transition.

However, it is also worth noting that Intelligent Octopus customers are early adopters, so their behaviour might not be representative of the population.

## User preferences

**Most customers prefer their EV charged to 80% by 7 am**

Based on the customers' preferences, the top 3 most common end SoC preferences are 80%, 90% and 100%, which represent 25%, 24% and 23% of preferences, respectively.

Between 15-20% of customers prefer that their vehicle is ready by 7 am or 8 am. Figure 2 shows that the most common preference is 80% target SoC by 7 am, closely followed by 80% target SoC by 8 am.

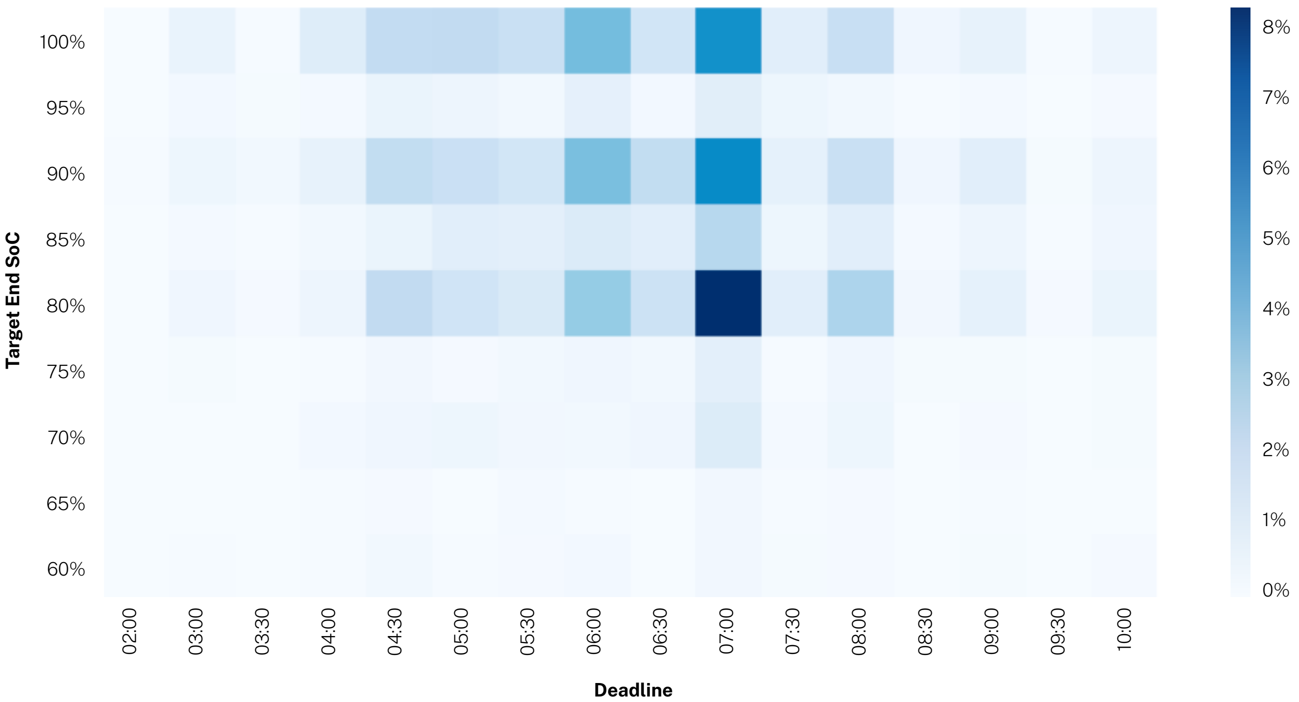



*Figure 2: A heatmap showing user preferences: the end state of charge and the deadline the vehicle should be "ready by". Most customers choose high multiples of 10, with 80% most common followed by 100% and 90%. 7am is the most popular deadline, over twice as popular as the next-closest at 6am. The most common combination is 80% by 7am.*

Our data shows that users do not change their preferences frequently; 24% of customers have never changed their preference and another 20% have only changed their preferences once or twice. Since our sample reflects engaged early adopters, we would expect these customers to change their preferences more frequently - perhaps as a result of greater enthusiasm, interest or intrigue - than the average late-stage adopters.

There are a few customers who frequently change their preferences (more than once per week). From inspecting the data, it is difficult to say why these customers are doing so and there does not appear to be regular, consistent weekend/ weekday switching of preferences among the customers who do switch regularly.

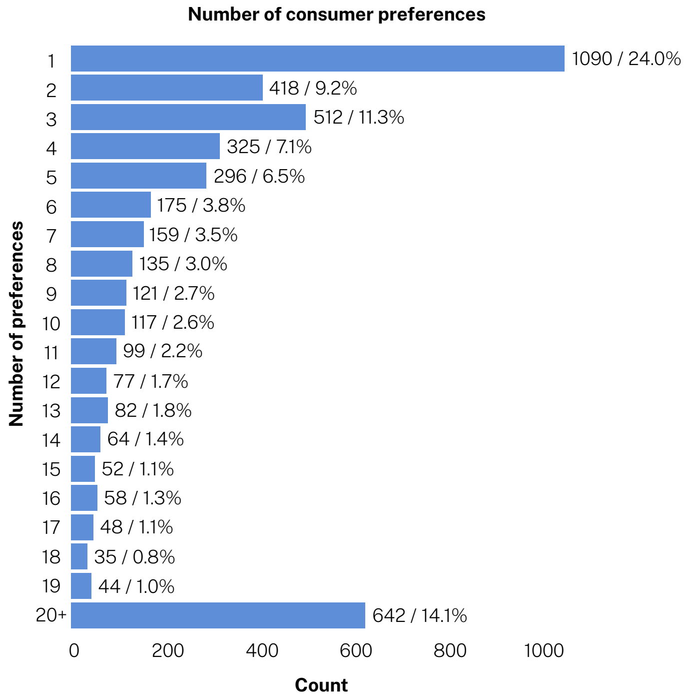



*Figure 3: A graph showing the number of times customers have changed their SoC and/or 'ready by' preferences. 24% have never changed their preferences.*

# Plug-in behaviour

### Most EVs are plugged in daily

Table 2 shows that most customers plug in their EV every day. However, it is not uncommon to plug in every two or three days.

| Time since last plug in | Percentage |
|---|---|
| Less than 12 hours | 26.3% |
| Approximately 1 day | 43.5% |
| Approximately 2 days | 16.4% |
| More than 2 days | 13.8% |

*Table 2: A table showing the number of days between subsequent plug-ins - most users wait a day before plugging in again.*

### Most customers plug in between 5-7 pm and plug out between 7-9 am on weekdays

Figure 4 shows Intelligent Octopus customers show a clear propensity toward plugging in EVs in the evening on both weekdays and weekends. Users tend to plug in later on weekdays compared to weekends; the most common plug-in time is around 6 pm Monday-Friday and around 5 pm on weekends.

Users typically plug out their vehicles in the morning. During the weekdays, this tends to be between 7 and 8 am, whereas on weekends plug out is later and more spread out between 9 and 11 am.

There is a relative increase in plug-ins and plug-outs for short periods in the middle of the day on weekends compared to weekdays.

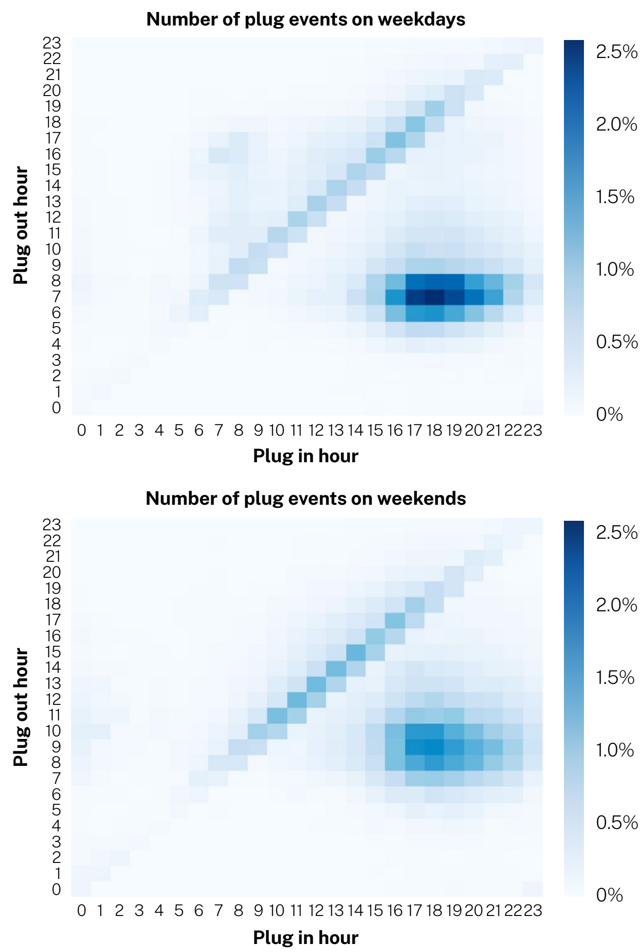



*Figure 4: Each heatmap shows the hour in which the vehicle plugs in vs the hour they plug out. Events lasting less than 10 minutes are excluded. The diagonal line reflects short duration charging sessions, for example bump charge events. The graphs show weekday behaviours (top) and weekend behaviours (bottom).*

### EVs are plugged in overnight for 10-15 hours but some plug in during the day for shorter periods

Figure 4 suggests that most people plug in their vehicles when they come home from work and plug out ahead of their morning commute. Figure 5 supports this hypothesis: customers who plug in their EVs in the evening typically leave them plugged in for 15 hours on both weekdays and weekends (slightly longer on weekends), corresponding to overnight charging.

Figure 5 also shows some differences in plug-in behaviour by customers who charge during the day. On weekdays, those who plug in between 7 and 9 am tend to do so for 3 to 5 hours. On weekends, those who plug in from 6 am to midday, do so for less than 2 hours.

The longer plug duration and later plug-out time on weekends means that the windows for charging EVs might not be the same every day. Figure 6 shows that customers who plug in on a Friday or a Saturday, leave their EVs plugged in for longer. This can be used to spread the load required to charge over longer periods to increase demand flexibility.

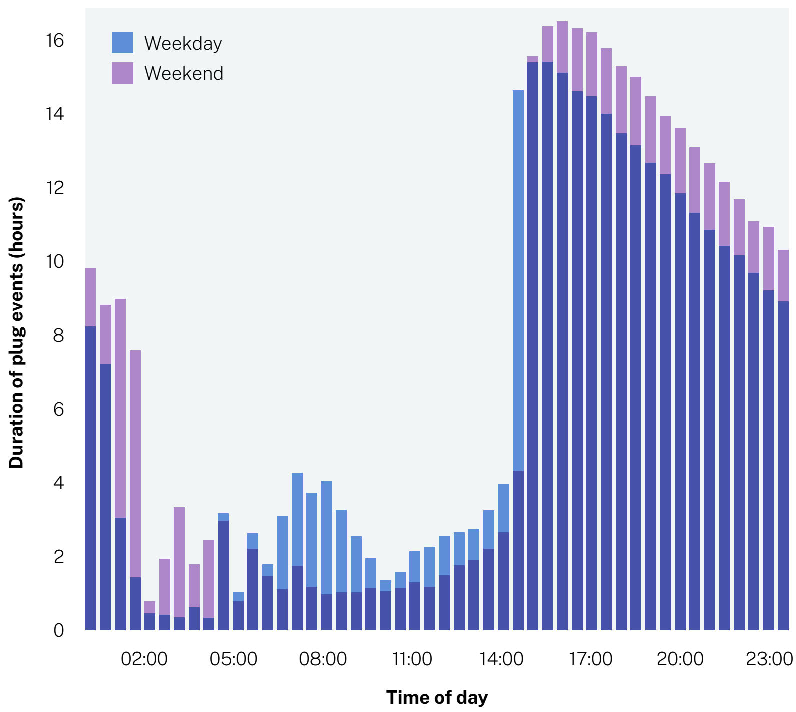



*Figure 5: A graph showing the median duration of plug events, in hours, on weekends and weekdays by the time of day that the plug event started. Vehicles plugging in during the evening are plugged in for longer on weekends compared to weekdays. If plugged in during the day, they tend to plug in for shorter time periods on weekends compared to weekdays.*

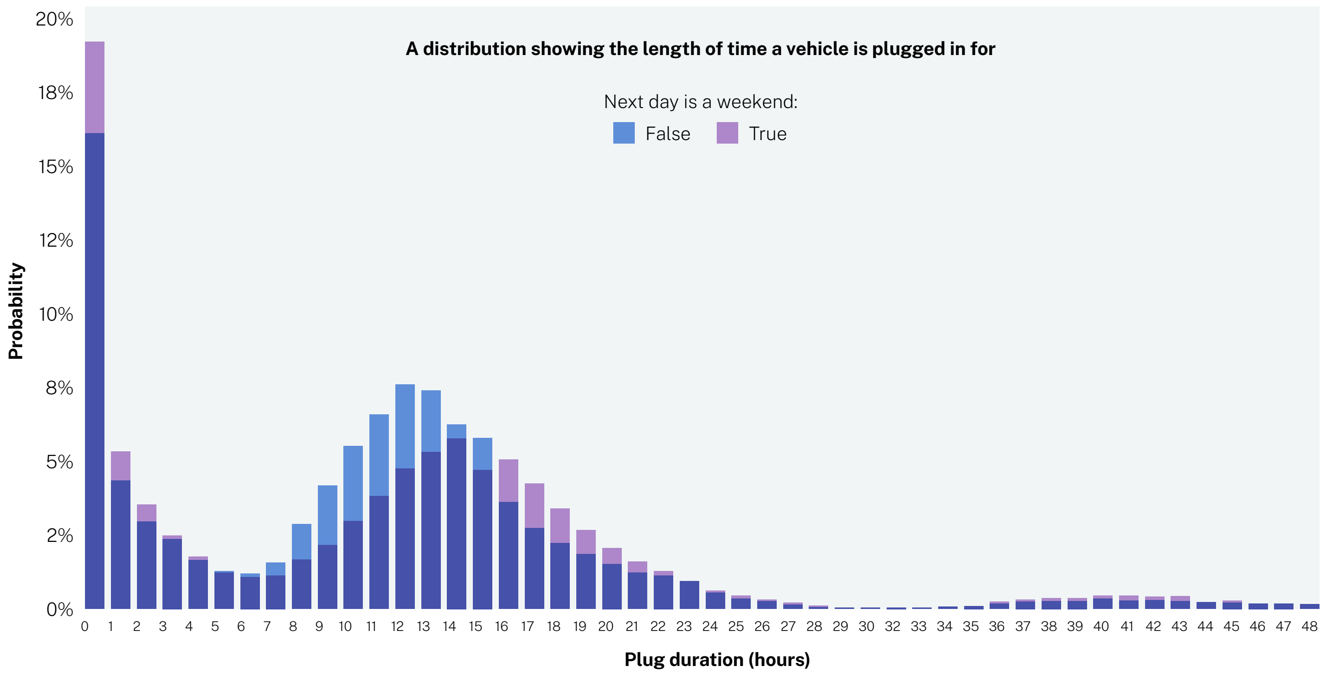



*Figure 6: The length of time a vehicle is plugged in for, split out by day type. EVs are plugged in for longer on Friday and Saturdays, when the next day is a weekend, compared to other days.*

### Most EVs plug in with over 50% state of charge

Intelligent Octopus also collects data on the state of charge (SoC) when the EV is plugged in or out or when charging begins and ends. The SoC at plug-in is shown in Figure 7 and can range from 15% to 80%.

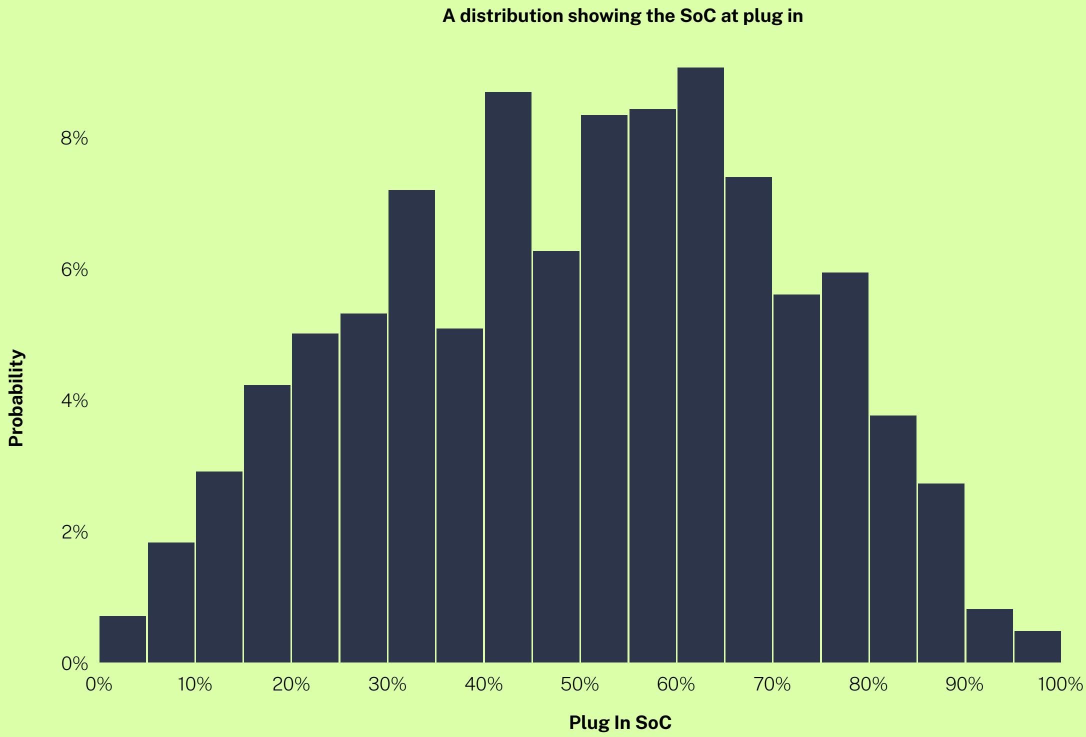



*Figure 7: The distribution of state of charge at plug in, with a median plug in state of charge of 52%.*

The median plug in SoC is 52%. Figure 7 shows it is most common to plug in at 50-65%, but the data also shows high plug-in rates with a SoC between 40-45%. Less than 10% of events are plugged in with less than 20% state of charge.

Customers who are plugging in on high SoC, and therefore aren't using much charge between the times that they plug in, may be able to reduce their preferences which will reduce overall grid load from EVs.

The fact that users plug in on states of charge above 50% and charge despite not using much power between plug events is likely to reflect habitual charging patterns (Table 2) but could also be a product of so-called 'range anxiety'-future research would need to be conducted to understand this. In 3% of cases, EVs are plugged in on less than 10% state of charge.

# Charging Behaviour

On Intelligent Octopus, EVs are not typically charging the whole time they are plugged in, and crucially, the automation of the tariff ensures they are not charging during traditional grid peak hours, i.e. between 5 and 8 pm. The Octopus Go, Go Faster and Intelligent Octopus tariffs incentivise customers to move charging away from these hours by offering lower prices outside of these time periods.

The majority of the current Intelligent Octopus sample is Tesla EV owners with battery capacities around 72.5kWh. Other popular EVs, such as the Nissan Leaf, Volkswagen ID.3, Kia e-Niro or short range Teslas may have battery capacity around 60 kWh. Regardless, the home chargepoint power is still likely to be 7kW. For context, it is worth noting that the smaller vehicles require less time to charge and so the sample used in this analysis will be biased towards longer charging durations.

### Half of all plug events spent up to three hours charging

Charging on Intelligent Octopus happens in half hour blocks. The algorithm chooses the slots in which to charge based on wholesale energy prices, and thus these blocks might be staggered rather than one contiguous charging block.

The median charging duration is 2.5 hours, with 40 minutes being the lower quartile and 4 hours 40 minutes being the upper quartile. The median time spent idle (the total time plugged in minus the time spent charging) is 7.5 hours, with a quarter of all events being idle for over 13 hours.

### In 85% of overnight plug events, we could move the charging to complementary times and still meet customer preferences

We noted in previous sections that the typical time between an evening plug in and the subsequent plug out was 15 hours, and that significantly less time is spent on charging.

In fact, for half of all overnight plug events, only a quarter of the plug duration was spent charging and 85% of all overnight plug events spent half of the plug time charging, as seen in Figure 8.

This suggests EVs can provide the grid a significant amount of flexibility to shift the electricity load while still meeting user preferences, provided the right signals and incentives are in place to do so. If properly incentivised, the user could participate in shifting their load to reduce strain on the grid while having negligible-to-no impact on the driver.

**A graph showing the distribution of the proportion of time overnight plug events spent charging**

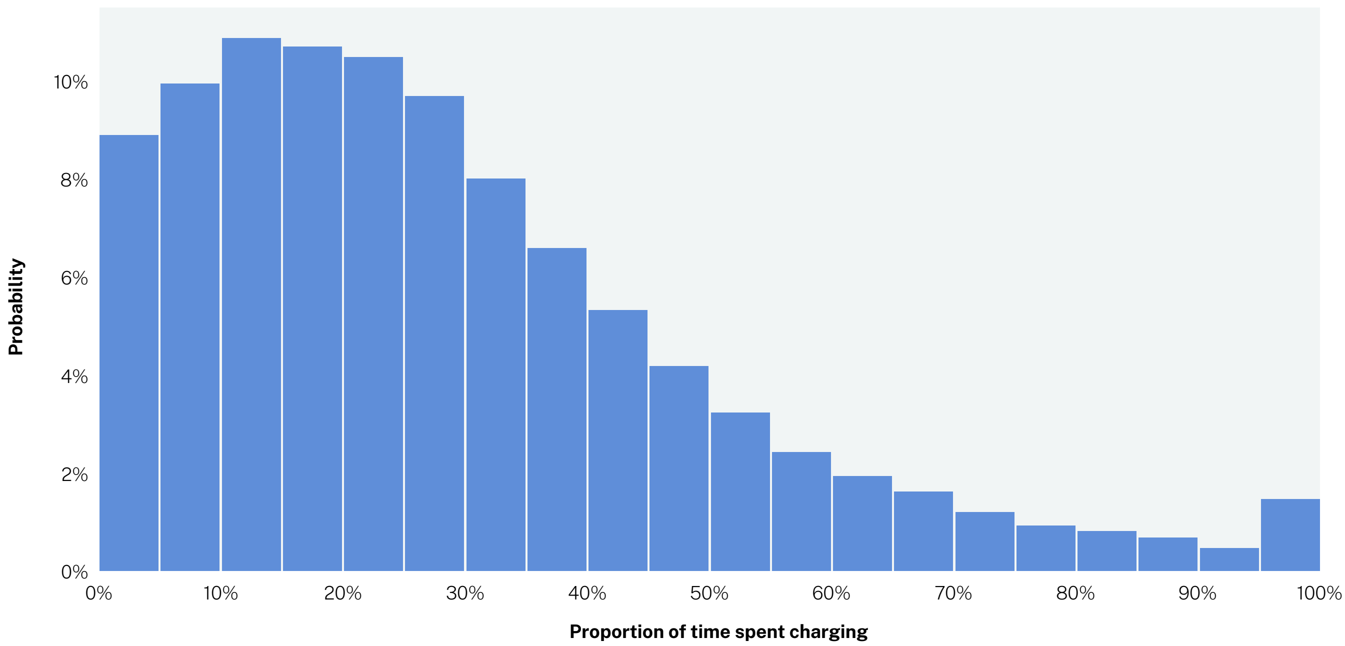



*Figure 8: a cumulative distribution chart showing the proportion of time spent charging. 20% of overnight charge events spend less than 15% of their time charging. About 2% of charge events spend their entire time charging -this is due to low plug in states of charge and low chargepoint powers (customers with 7kW chargers rarely spend the full duration charging).*

## On average customers top-up their EV charge overnight by 30%

By “customers top-up their EV charge by 30%”, we mean that (for example) a vehicle starting on 50% SoC would be topped-up to 80% SoC. Given that EVs on Intelligent Octopus are not continuously charging while plugged in, the amount by which the SoC differs at the beginning and end of a plug event can inform us on the amount of EV flexibility.

Our data shows that for half of all overnight plug events, customers top-up their EV by 30% or less, whereas in 90% of overnight plug events, they top-up their EV by 65% or less. The average battery capacity in our dataset is 72.5kWh, which means for an average overnight charging session there is just under 22kWh of energy per plug event that can be shifted to different times, and still meet consumer preferences.

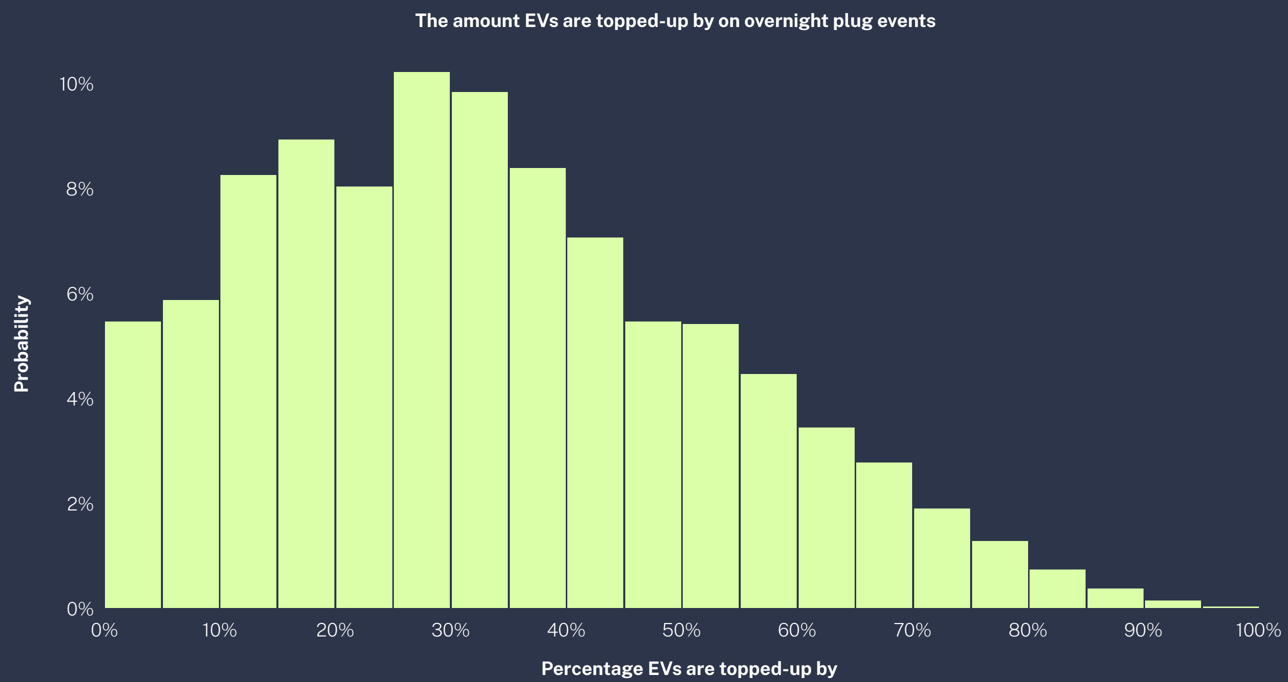



*Figure 9: The amount (%) EVs are topped-up by for overnight plug events. Most commonly it is between 30-35%, and is usually less than 45%.*

The amount a vehicle is topped-up by depends on the state of charge it plugs in at. Figure 10 shows that the greater the plug in state of charge, the less a vehicle charges by, but also that vehicles plugging in on lower states of charge have greater uncertainty on the amount that they charge by.

Our data shows that most of the time, customers top-up to their self-selected preferences, rather than plugging out prematurely. If a customer plugs in on a lower SoC then they charge their vehicle more. For example, assuming the user has a preferred target SoC of 80%, if the vehicle is at 10% SoC at plug in, then the SoC at plug out is typically higher by 70%, compared to if it were 30% at plug in, then the increase in SoC is approximately 50%.

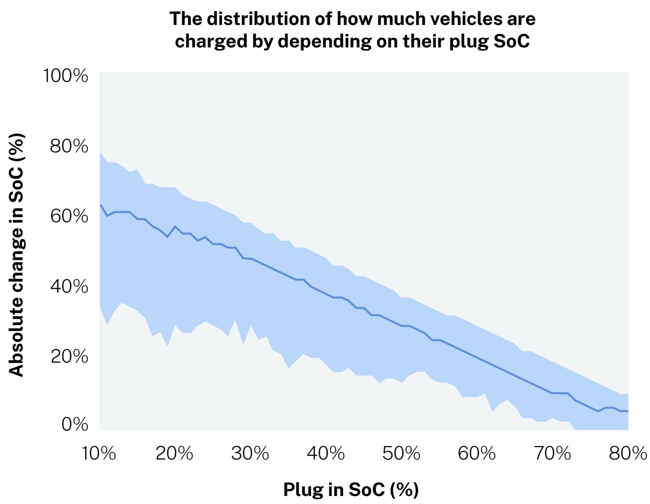



*Figure 10: Graph showing how much EVs are charged based on the SoC at plug in. The line indicates the median amount, with the band representing the 25th and 75th percentiles.*

# Overriding automation

Customers on Intelligent Octopus can override the automated charging schedule to manually boost the charge of their vehicle at any time using a bump charge (see Section Automation process). About 20% of bump charge events are ended by the user before the vehicle reaches 100%, while in 80% of cases users allow the boost to continue until their EV is fully charged.

While bump charging is an Intelligent Octopus specific feature, it is important to analyse how consumers interact with this feature to understand how frequently customers choose to charge outside of the automated schedule. By understanding this, we can create more people-centred charging experiences enabled by better designed automation and technology.

### 58% of customers have never used the bump charge feature

While some customers use the bump charging feature frequently, 58% have never used it. This could be due to high user friction or low customer awareness of this feature (see Section Sign up Experience for more details). However, it may suggest that the majority of customers typically trust the automation, or have found no reason to charge the vehicle beyond their preferences or at times different to the automated schedule.

Customers who used the bump charge feature tended to do so in their first week on the Intelligent Octopus Tariff (Figure 11), specifically in the first couple of days, after successfully completing their test charge. This may be because they were testing the feature themselves or were not sure if the automated charging would work. In subsequent weeks, bump charges are less frequent, perhaps indicating that customers know they can trust the automated charging, or are happy with their target SoC and 'ready by' time.

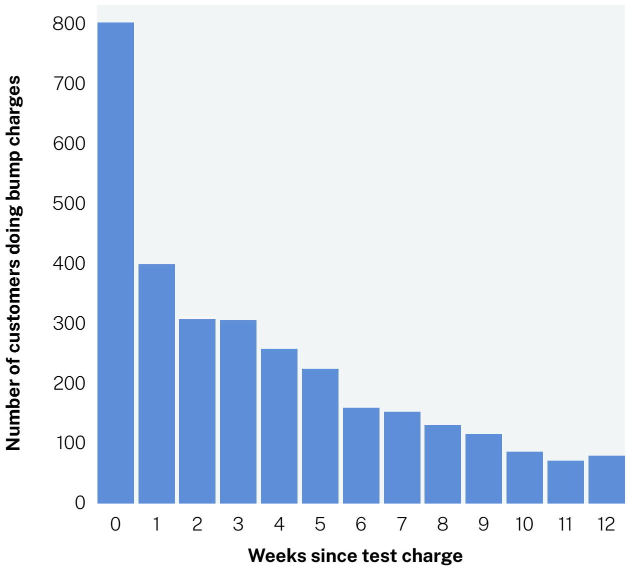



*Figure 11: a chart showing the number of customers using the bump charge features after successfully completing their test charge.*

### Bump charging is more common between 7 and 9 am on weekdays and between 8am and 12 pm on weekends

Users predominantly choose to bump charge their EVs during the day and rarely overnight. On weekdays, customers most frequently bump charge their vehicles between 7-9 am and around 10 pm, with the former likely due to customers choosing to charge beyond their pre-set preferences just before heading off to work. On weekends, there are more bump charges starting between 8 am and 12 pm. This may also explain the shorter plug durations that were observed during the day on weekends (Figure 5).

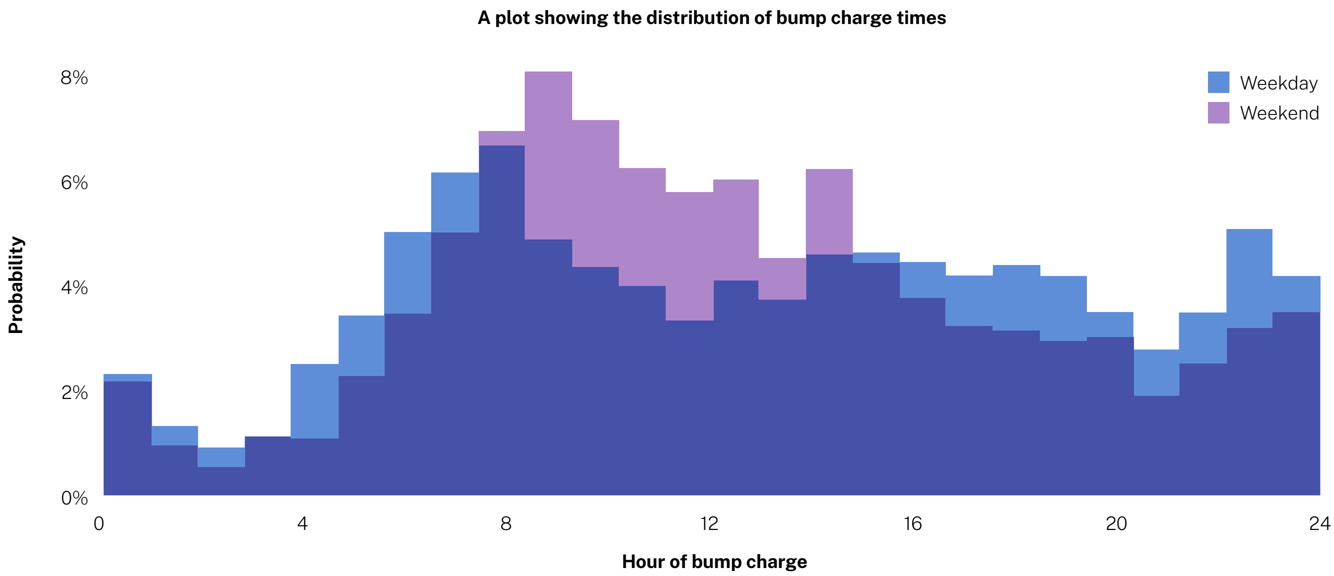



*Figure 12: A plot showing the distribution of bump charge start times on weekends (purple) and weekdays (blue). The probability is over all bump charge events, not all "plug in" sessions.*

# Comparisons to other smart tariffs

As explored in our previous research (released as a blog post), grid peak is between 5-8pm. During this time the amount of demand on the electricity grid is typically higher than any other time of the day. Unmanaged EV charging would add to this peak.

Delaying charging to periods of low consumer demand can also be advantageous from a carbon emissions perspective. High electricity demand can coincide with high utilisation of gas as supply is ramped up to meet demand. This results in high electricity prices, since fossil fuels are more expensive to generate compared to renewables[17], and higher carbon emissions, as seen in Figure 13.

Incentivising consumers to shift their energy to overnight periods would help consumers save money and carbon. This can be done through fixed Time-of-Use (ToU) tariffs such as Octopus Go/Go Faster which offer cheaper charging in a fixed time window. While these fixed windows are a good "rule of thumb" for the present system, they lack the agility to reflect changes in price and carbon intensity of the grid throughout a given day.

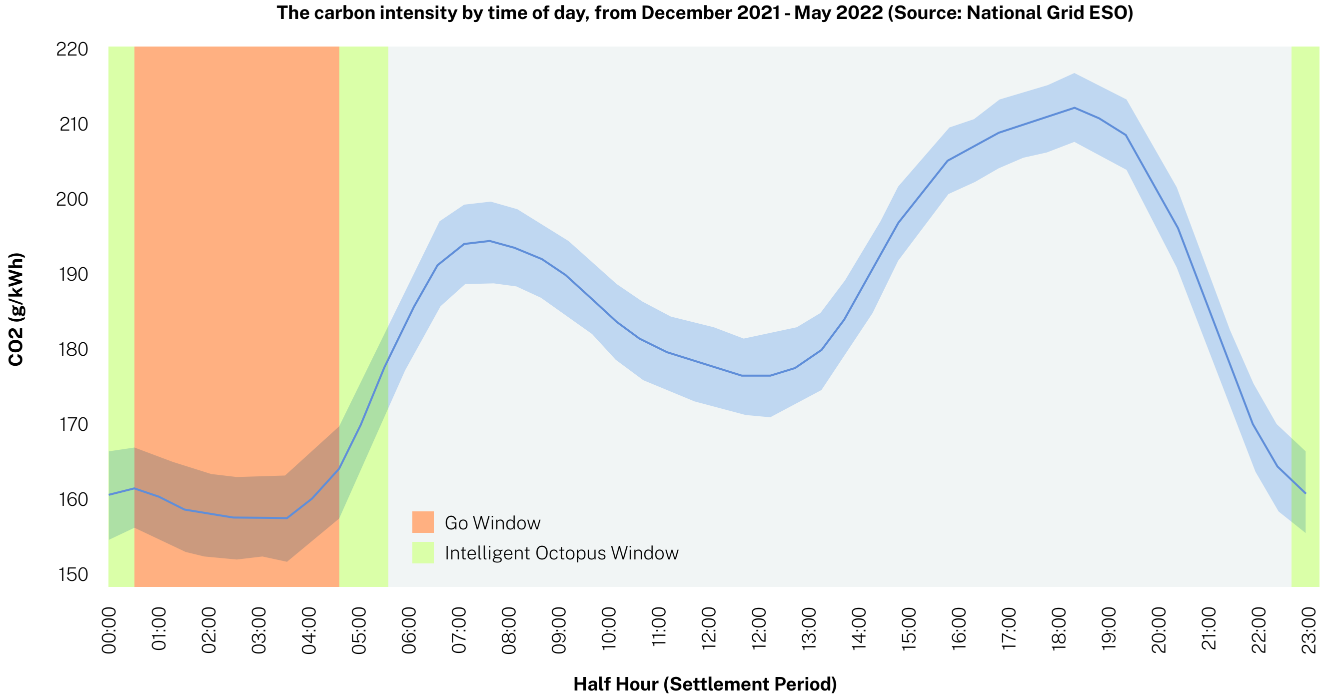



*Figure 13: Grid CO2 emissions are over 30% higher during the evening peak compared to early morning. Charging overnight reduces CO2 emissions by 25% on average. Source: National Grid ESO[18] The green band shows the Intelligent Octopus window. The orange band shows the Octopus Go window. Both windows incentivise customers to use lower carbon electricity.*

**17.** IRENA (2021), Renewable Power Generation Costs in 2020, International Renewable Energy Agency | **18.** 'National Carbon Intensity Forecast', National Grid ESO. https://data.nationalgrideso.com/carbon-intensity1/national-carbon-intensity-forecast (accessed May. 16, 2022)

Using intelligent algorithms, such as the one used by Intelligent Octopus, EVs can be charged at scale without adding strain on the grid or increasing the carbon intensity of the grid. Solutions such as this can shift load to periods of low cost (an incentive for the customer) and periods of low demand (a bonus for the grid) on a day-by-day basis while meeting user preferences. The periods that Intelligent Octopus charges in is shown in Figure 14. Automating this makes it easier for more consumers to use electricity flexibly without needing to change their behaviour.

Using the plug in times, plug out times, and charge duration of Intelligent Octopus customers, it is possible to analyse how similar charging behaviour would have looked in an 'unmanaged' scenario.

If charging started immediately after plug in, which is frequently during grid peak (shown in Figure 4), it would coincide with high levels of carbon emissions from the grid.

We estimate, using the above simulation methodology, that the 2500 customers on Intelligent Octopus have already reduced almost 250 tCO2 in just over 6 months by automatically charging at low cost (and low carbon) times compared to unmanaged charging. This is equivalent to the CO2 that internal combustion engine vehicles (ICEs) produce in almost 55,000 days. That means for each month a customer is on Intelligent Octopus, simply by charging their vehicle overnight, they are reducing their CO2 by the same amount as 3.6 days of typical ICE usage.[19]

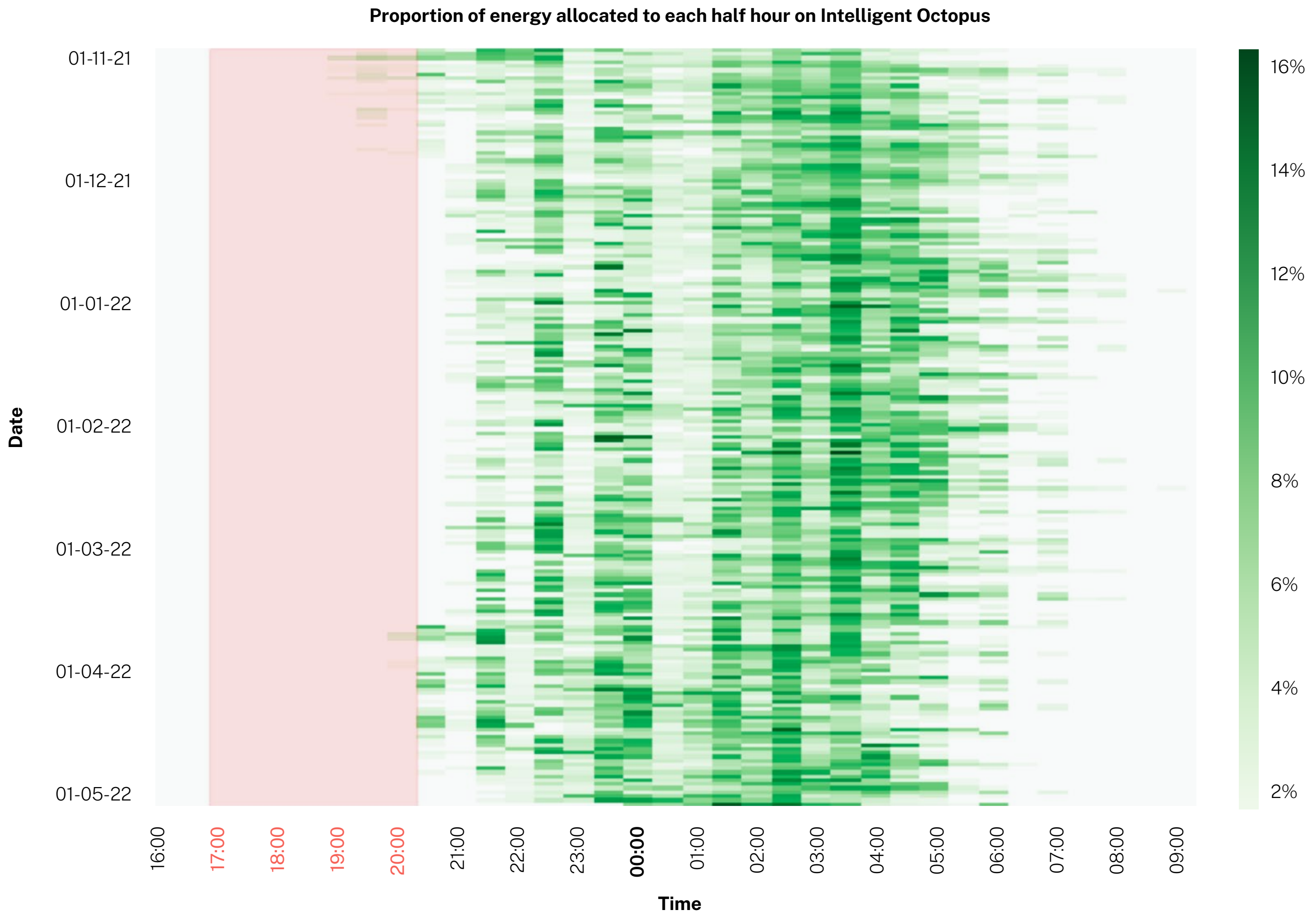



*Figure 14: The percentage of charging that happens in each half hour period for a given day on Intelligent Octopus. Each row sums to 100%. The red band shows the current grid peak, i.e. 5 pm to 8 pm. Intelligent Octopus optimises directly for the lowest price and greenest electrons, which vary depending on the day.*

**19.** Assuming 139.9g/km (Source: 2019 UK Emissions, VEH0206, Department of Transport) travelling 7400 miles/year (Source: 2019 Mileage, VEH0901, Department for Transport)

# Conclusions

Understanding how customers currently use, and could use, technologies that enable us to decarbonise our energy system is crucial as we start to scale up these solutions; through data-driven explorations we can understand the opportunity at a system level from the bottom up and add to the evidence base for how to design a successful grid fit for the future.

## EVs charge for a fraction of the time they are plugged in, unlocking the potential for flexible charging patterns

We saw in Section Charging Behaviour that vehicles spend up to 2-5 hours charging, even with larger-than-average EV batteries. In Section Plug-in Behaviour, we saw that overnight charge events last between 10-15 hours on average, with most vehicles plugging in daily. Our analysis shows that the majority of charge events can be charged at different times, thus unlocking the potential for future flexible charging patterns, either to optimise directly for cost or carbon or to respond to grid needs.

Through automation, we can shift charging to the cheapest, lowest carbon times with minimal user effort: customers plug in as normal, and plug out at their desired preferences, and the automation ensures the lowest cost/carbon.

Intelligent Octopus customers made significant carbon savings compared to if their charging was unmanaged. Thus flexibility and carbon/cost reduction go hand-in-hand.

Figure 4 shows a well defined cluster of behaviour plugging in for the evening peak (4-8pm) and out again early morning (7-9am). On weekends, people tend to plug in at the same time, but plug out later. Figure 6 shows that the length of time a vehicle is plugged in for is longer on a weekend compared to a weekday, but we found that the amount of charge needed did not vary significantly from weekend to weekday. This means that the amount of charging flexibility from EVs could vary throughout the week.

# EV owners are willing to trust automation - especially for overnight charging - enabling them to be more dynamic in response to a variable grid

Intelligent Octopus consumers can manually control their charging through the bump charge feature at any time. Our early findings indicate that customers do not normally choose to override the automated charging. If they do override, we found that it is usually in the first couple of days or weeks of using the product (Figure 11), or to charge beyond their preferences outside of the overnight window (Figure 12). They appear to become more familiar with the setup, and adjust their preferences appropriately.

As EVs and other LCTs become more commonplace, we will need to ensure that the grid is designed to scale at the same pace. There are different ways to do this: from adding more physical infrastructure to using technology and data to optimise the operational needs of the grid.

Static ToU tariffs with different cheap windows mitigate against coincident charging and high load on the grid from EVs, and more importantly move it away from peak times. We have already seen in Section Plug-in behaviour that customers typically plug in during the evening, and so if EV charging is left unmanaged (without tariffs, or automation) we would be adding to an existing grid peak.

While static ToU tariffs offer a good "rule of thumb" to incentivise behaviour change, they are not "dynamic" and thus cannot respond to near real-time grid demands, nor can they take advantage of other periods of high renewable generation. A good distribution of these static ToU tariffs across different windows would be needed to ensure we don't risk creating new "grid peaks" as we scale up.

An automated tariff can enable customers to be more dynamic to grid needs, whilst ensuring consumer preferences are met, resulting in cost and carbon savings.

# EVs plug in regularly, but customers don't change their preferences much, resulting in an opportunity to recommend more personalised, optimised charging schedules.


We also provided some early indications that customers settle on a fixed set of preferences and do not deviate from them often. With EVs plugging in on over 52% SoC on average (Figure 7), not needing to charge by much (Figures 9,10) and often charging up to their preferences (Section Charging Behaviour), there is the potential to recommend more personalised, optimised charging schedules which reduce the overall EV load from the habitual daily plug ins (Table 2).

Future optimisation could include optimising over more than just one day ahead, or potentially skipping a charging session if plugged in on a high enough percentage to meet daily requirements, but below the consumer preferences. More research would need to be done to understand consumer attitudes towards different types of systems.

# Future Research

In the future, we believe charging an EV will be like charging a mobile phone today: so long as the customer wakes up with sufficient EV battery power to carry out the tasks they need until the next charging session, they will have a good experience. With automation in the background, the EV can intelligently charge to reduce strain on the grid, but pass on carbon and cost savings to consumers (both from changing the times at which they charge, and participating in flexibility services).

In this piece, we scratched the surface on Intelligent Octopus, a beta product which automates the charging on behalf of the user. However, there are still key themes where we need to deepen our understanding as a research community as we scale up EVs, and LCTs in general.

### Theme: Understand consumer motivations for changing their energy consumption patterns

We have seen that there are ways in which EV owners can shift their energy consumption such as delaying EV charging to periods of low demand.

However, with LCTs such as EVs, their flexibility is a secondary usage. We must understand the patterns in their primary usage, such as working/trip patterns for EVs, or heating requirements for electric heating, to be able to understand consumer motivations for willingness to change their energy consumption.

We must deepen our understanding of how we can motivate customers to engage in flexibility, or benefit from automation.

### Theme: Potential for domestic consumers to participate in grid flexibility services

EV owners have huge potential to increase demand flexibility. We have seen in this report the potential to shift charging times and still meet consumer preferences, since vehicles only spend a proportion of their time charging. However, we haven't quantified to what level or how we would enable their participation.

In a future analysis we will investigate if customers who use automation are more successful at participating in grid services enabling us to better quantify the overall levels of flexibility EVs could provide.

### Theme: Designing people-centred automation that works at a system level

The transition to net zero can happen in many ways but we believe a people-centred transition is critical to help people feel involved in the transition and ensuring fairness. We believe that automation will be one of the ways the future grid can be greener and more intelligent, but questions remain on how to make the technology work for different types of people with different behavioural patterns, and at a system level.

There might be consumers who are not able to participate in demand flexibility. There may be other consumers who can shift their demand only some of the time. Understanding the ways in which customers can participate, as well as making it easier and rewarding, can reduce balancing costs for the grid which can translate to lower bills for everyone.

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