ELECTRIC NATION

YOUR ELECTRIC VEHICLE
YOUR SMART CHARGE

POWERED UP

CHARGING EVs WITHOUT STRESSING THE ELECTRICITY NETWORK

ABOUT ELECTRIC NATION

When launched, Electric Nation was the world's largest home smart charging trial with nearly 700 Electric Vehicle (EV) owners taking part in the 18-month trial. Between them, our trial participants provided data for more than 2 million hours of car charging. Importantly they also gave us first-hand feedback on what it is like living with an EV in the real world and how they found the smart charging experience.

The results from Electric Nation have global significance and allow electricity distribution network planners to replace high level axioms with statistically robust facts. The lessons from this project will greatly assist local electricity networks in accommodating home EV charging whilst ensuring that drivers always have the ability to charge when they need to.

Electric Nation provides evidence that a combination of well-designed EV tariffs (offered by an energy supplier) coupled with flexible smart charging has the ability to provide the lowest-cost solution for customers whilst ensuring a high level of customer satisfaction. In short, it delivers a low-hassle customer experience at an acceptable cost.

Further, for network businesses like WPD it means that we have confidence in market–based solutions for moving demand away from peak hours, which in turn reduces the cost of upgrading our network for low carbon technologies such as EVs.

This project has set a new standard for understanding consumer attitudes toward smart charging. The project was delivered by a dedicated team drawn from WPD and our project partners EA Technology, Drive Electric, TRL and Lucy Gridkey. But in addition to recognising the hard work of the project team, I must also acknowledge the amazing support and enthusiasm (and sometimes patience) of our 673 drivers. Without them there would be no project conclusions.

WPD's electricity networks in the Midlands, South West England and South Wales will not be a barrier to the rapid decarbonisation of the transport sector through vehicle electrification. We look forward to continuing our engagement with stakeholders and delivering innovative solutions to facilitate our nation's net zero aspirations.

Roger Hey
Western Power Distribution
DSO Systems & Projects Manager

TRIAL COLLABORATORS

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Electricity distribution network operator

ea technology

Technical expert and analysis and trial manager

DriveElectric

Participant liaison and smart charge point installation and maintenance coordinator

Lucy Electric

Developing an EV load detection algorithm

TRL

Project management

IMPACT
FROM INSIGHT TO INFLUENCE

Customer Research specialist

CrowdCharge

Demand management system provider

GreenFlux
Smart charging

Demand management system provider


MAP
VOICE
MENU
STATUS
SEEK
TRACK
OPEN/TILT
13:07
POWER

TECHNOLOGY, LANGUAGE AND APPROACH

THE WORLD OF EVs IS RAPIDLY EVOLVING AND SOME OF THE WORDS USED TO DESCRIBE VEHICLE CHARGING AND ELECTRICITY NETWORKS MAY BE UNFAMILIAR. TO HELP THE READER OF THIS DOCUMENT, WE'VE ADOPTED THE FOLLOWING DEFINITIONS:

The Electric Nation project was concerned with private cars powered either entirely by electricity ("battery electric vehicles" or BEVs), or those with a conventional engine combined with a battery that can be recharged by plugging in ("plug-in hybrid electric vehicles" or PHEVs). All these cars can be plugged in to a chargepoint to fill up their battery and so are referred to collectively as "plug-in electric vehicles" or PEVs.

The units of electrical energy that go into the battery are measured in "kilowatt-hours" or kWh. This is the same unit that appears on your electricity bill. Each unit usually costs less than 20p.

Finally, a word on charging speeds. Although rapid chargers can top up a PEV battery very quickly, home charging is a somewhat slower affair. The chargepoints used in Electric Nation had a rating of 32 amps (32A). This means they can charge at up to 7 kilowatts (7kW). In other words, they can put seven units of energy into the battery every hour. BEVs usually have 32A chargers onboard, so they can charge at this maximum speed. Most PHEVs have a 16A charger, so they charge at half this speed.

For the local, low-voltage electricity network that supplies our homes, these are quite significant loads – especially if everyone plugs in at the same time. Most domestic electrical appliances take less than 13A – and those that use more aren't usually used for long. PEV charging is different, drawing 16A or 32A for many hours from the time the car is plugged in. "Smart charging" is a way of dynamically managing the charging speed so that stresses on the local network are reduced, while still ensuring everyone gets the charge they need.

Electric Nation sought to find out two things: what will be the effect of PEV uptake on low-voltage electricity networks and can smart charging help mitigate these effects?

Paul Barnfather
EA Technology
Head of Electric Vehicle Infrastructure

THE CHALLENGE

EVs MAY BE NOTHING NEW, BUT FEW PEOPLE PREDICTED THE RAPID DEVELOPMENTS OF THE PAST DECADE. THEY HAVE BEEN DRIVEN PARTLY BY THE EMERGENCE OF MORE AFFORDABLE, VIABLE BATTERY TECHNOLOGY, AND PARTLY BY A SENSE OF ENVIRONMENTAL URGENCY.

While the UK's decision-makers debate HS2 and local public transport commitments, the electrification of transport continues apace and electric cars are an increasingly attractive option for many commuters and business owners. The figures back this assertion up: only 1,039 cars were eligible for the plug-in car grant in 2011; by 2018, that number had risen to 157,181.

ATTENTION TURNS TO THE ELECTRICITY NETWORK

As PEV take-up accelerates, many commentators have started to ask legitimate questions about the UK's electricity infrastructure, particularly low-voltage (LV) networks. Can it cope with this new demand? This was the central question that the Electric Nation trials were designed to answer.

The question is often framed as a capacity issue – do we have enough power stations, wind turbines, solar capacity etc. to charge all these vehicles? The power generation industry is in no doubt that the answer is "yes".

The real question is how that demand is spread out throughout the day. Figure 1 shows how PEV users currently answer that question, by illustrating the demand on a typical 11kV feeder over a typical winter's day. The pink line shows existing demand without PEVs. The blue line shows demand with PEVs factored in. Commuters are returning home from work, turning on their lights, cookers, TVs and heating – and charging up their cars. For a few hours in the evening, demand exceeds capacity in this example.

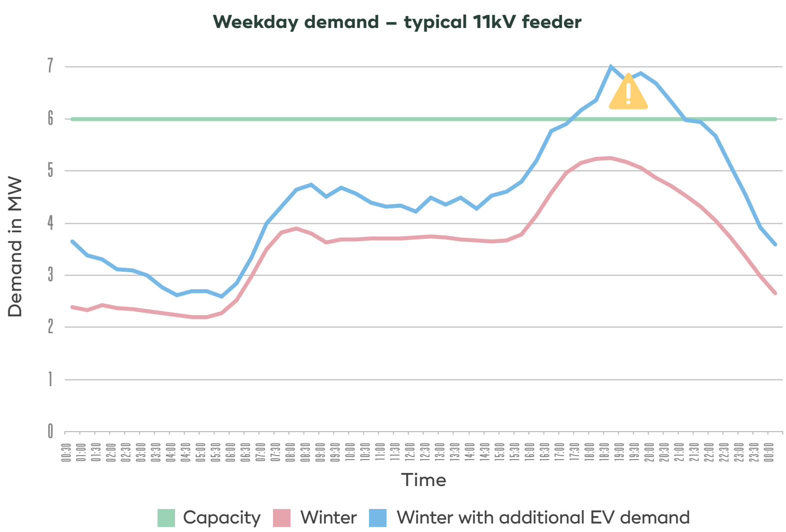
But look more closely at the graph and you'll see that even with PEVs, demand doesn't come close to capacity outside the evening peak. It becomes clear that the fear of PEVs overwhelming the system are unfounded - provided charging can be spread out across the day and night.

ELECTRIC NATION: THE BACKGROUND

Western Power Distribution (WPD) is the Distribution Network Operator (DNO) responsible for 7.9 million customers from Isles of Scilly to the Lincolnshire coast, covering South Wales, Bristol, Birmingham, Nottingham and Milton Keynes.

WPD used its Network Innovation Allowance to fund Electric Nation, the aim of which was to analyse real-world PEV use through a series of schemes and studies. Only through observing real activity and getting honest feedback from PEV users can we arrive at workable solutions to the demand issue.

FIGURE 1



THE OPPORTUNITY

AS LONG AS A COMMUTER HAS A FULLY-CHARGED CAR IN THE MORNING, DOES IT REALLY MATTER WHETHER IT WAS FULLY CHARGED BY 23:00 OR 04:00? BUT WE CAN'T EXPECT DRIVERS TO PHONE THEIR NEIGHBOUR TO AGREE ON A CHARGE TIME – ESPECIALLY WHEN THERE ARE 10,000 DRIVERS IN A TOWN. THIS IS WHERE SMART TECHNOLOGY COMES IN.

By using smart chargers, PEV charging is automatically controlled in response to demand. Depending on what demand there is, an individual car's charger could be set to full, half, trickle or off. It's likely that PEVs would be de-prioritised during those winter evening peaks, and charging would pick up as users start to go to sleep. This also has the benefit of moving charging to times when energy is usually cheaper, potentially lowering customer bills.

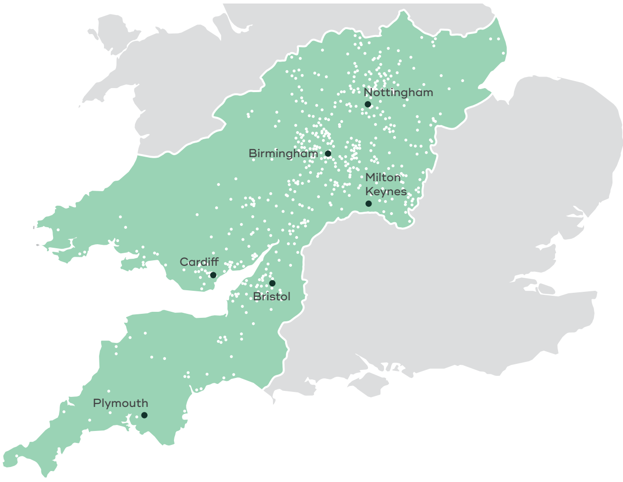
The information fed back from the smart charging network is vital for DNOs to build up a picture of day-to-day use and enable strategic network infrastructure planning. DNOs will be the first to know when demand is growing, and can invest accordingly in improving their networks.

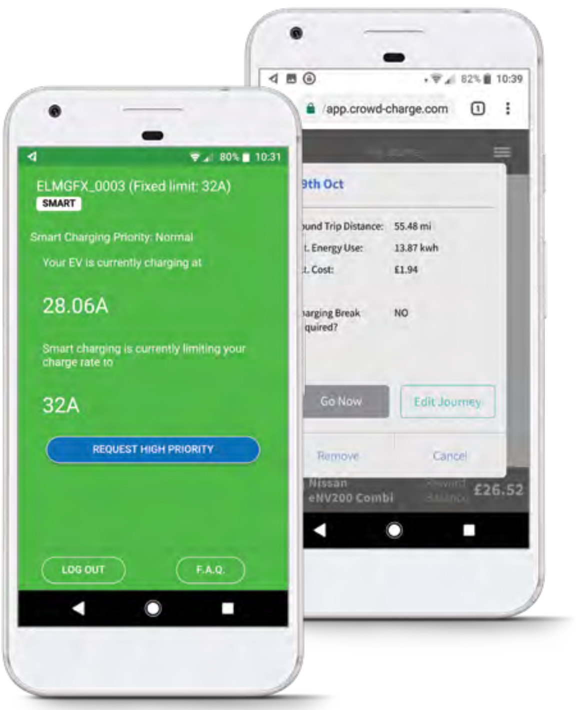
THE ELECTRIC NATION SMART CHARGING TRIAL

AFTER AN EXTENSIVE AWARENESS-BUILDING AND RECRUITMENT CAMPAIGN, AND WITH THE CHARGER SUPPLIERS IN PLACE, ELECTRIC NATION'S SMART CHARGING TRIAL RAN FROM JANUARY 2017 TO DECEMBER 2018. THE 673 PEV DRIVERS RECRUITED FROM THE WPD REGION (SEE FIGURE 2) ENTHUSIASTICALLY PARTICIPATED, WITH VAST AMOUNTS OF DATA RECORDED OF REAL-WORLD PEV OPERATION. THIS SECTION COVERS HOW RECRUITMENT TOOK PLACE AND THE NATURE OF THE TRIALS.

FIGURE 2

Trial participant spread throughout WPD's licence areas





PROJECT PROMOTION AND RECRUITMENT

To achieve a rigorous set of trial results, 500–700 participants were required. With PEVs accounting for just 1.5% of vehicle sales in 2017, and the trial being restricted to the Western Power Distribution region, a strong promotion, recruitment and retention operation was required. The trial employed two companies for this: EA Technology and DriveElectric.

EA Technology

With 50 years of electricity innovation (including prototype electric cars back in the 1970s), EA Technology is a world leader in power network management, monitoring, efficiency and safety. For Electric Nation they developed and oversaw the communication strategy, created its website, produced recruitment-focused videos and literature, and managed the all-important Twitter account.

DriveElectric

What started out as a traditional vehicle leasing company in 1994 was revolutionised in 2008 when they funded the UK's first Tesla Roadster. From then on, the company has been committed to getting more PEVs on Britain's roads. For Electric Nation, they managed all the customer-facing activities such as test-drives and events, and dealt with all enquiries, application forms and recruitment. They then managed the charge-point installation and maintenance.


Raising awareness

The publicity push was a great success, and the team met its recruitment goals. The campaign included the following activities:

- Project leaflets distributed in car showrooms
- Targeted posting on PEV-focused websites and forums
- Test drives arranged
- Connections made in WPD-covered cities with Go Ultra Low schemes to attend events and publicise the project
- The project highlighted to DriveElectric's leasing customers
- Project launched at LCV2016, the UK's premier low carbon vehicle event
- Robert Llewellyn interviewed Electric Nation team members and put the interviews on the Fully Charged Show YouTube channel, with 100,000 highly relevant subscribers and many more viewers
- Press releases were fed to media outlets detailing milestones and raising awareness among PEV owners and buyers
- The website was regularly updated with news items for maximum search engine visibility

Retention of participants was an important part of the trial. Regular and ongoing feedback showed how they felt about smart charging: finding a happy medium between supply and demand is key to making a success of PEVs.

SMART CHARGERS AND SOFTWARE

The smart chargers for the trial were supplied by Alfen and eVolt, two of the biggest names in smart charging technology, with GreenFlux and CrowdCharge supplying the back-office systems that controlled power delivery and took instructions from drivers. The trial participants were distributed roughly half and half between the two back-office suppliers.

The chargers fed information back to GreenFlux and CrowdCharge, such as whether a car was plugged in and, if so, whether it was charging. Over the course of the trial, two million hours' worth of charging activity data were captured.

GreenFlux and CrowdCharge could also send instructions to the chargers, telling individual chargers to switch off or reduce the charging rate, as would be the case in a genuine smart charging network. This was key to the trial, as it simulated expected demand management. Thorough testing of the algorithms was carried out before the systems were delivered to participants.

THE TRIALS

The trial was split into three sub-trials to mimic different potential future scenarios. Before the trials began drivers had some time where they could "charge at will" without management.

Trial 1: Blind

To simulate a future where great demands are put on electricity substations by PEV charging, the trial organisers would limit charging to vehicles when demand was high during the early evening. An example of this was shown previously in Figure 1, where demand is greater than the network's capacity for a few hours in the evening. For that reason, participants who habitually charged up outside of the peak hours rarely, if ever, had their charging limited. Similarly, owners of 3.6kW vehicles would have been limited less often than those with 7kW vehicles. However, as Trial 1 was blind, many users didn't know if or when their vehicle was having its charge limited.

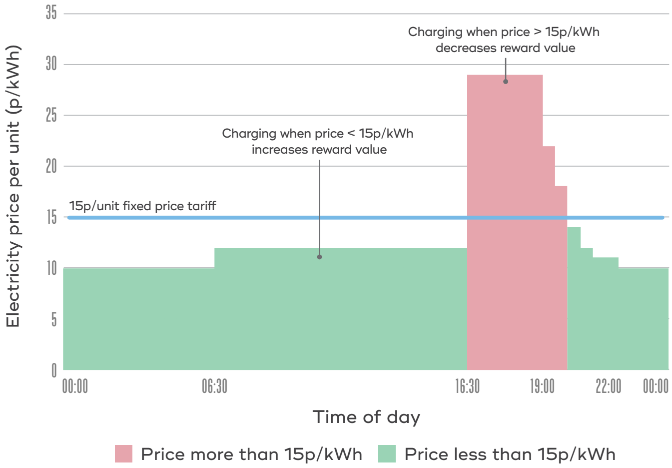
Trial 2: Interactive

Trial 2 introduced interaction and customer demand into the equation, as participants were given phone apps that would allow them to have some control over their charging. The systems used differed slightly between the smart charging providers.

- CrowdCharge users told the app how much charge their vehicle currently had, and how much they needed the next day. The system would then ensure that sufficient power was delivered to top up the battery to meet the users' needs.
- Those using the GreenFlux app could see if their charge session was being managed and requested 'high priority' to opt out of management for that charging session.

FIGURE 3

Electric Nation EV Charging 'Tariff'



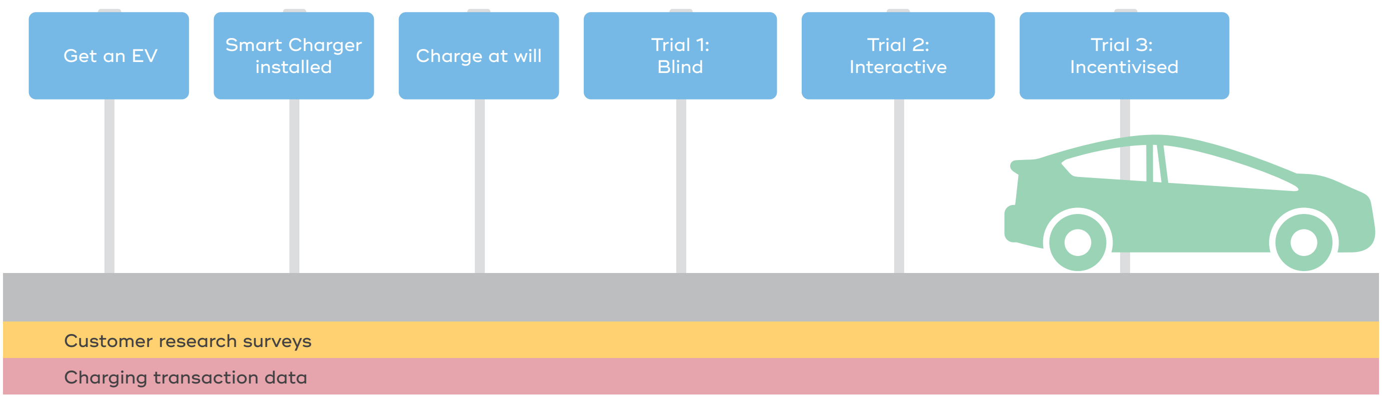
For both groups, a limited charge was available to share between participants, although the total power available was slightly more generous than in Trial 1.

Trial 3: Incentivised

In Trial 3, the options available in Trial 2 were modified to include a "Time of Use Tariff" (ToU) so users could earn shopping vouchers if they opted to charge outside of peak hours, reflecting the fact that energy is cheaper off-peak. Figure 3 shows when the high and low tariff periods applied. Again, the systems differed slightly between the two Smart Charging providers.

- CrowdCharge used the same journey plan as in Trial 2, but the system would try to use the cheapest energy possible. So:
  - If a user got home from work and told the app that they needed to drive 50 miles later that evening, the cheaper tariff would be ignored and charging would be prioritised over cost.

Typical Participant Trial Journey



   - If they didn't need the car until the following morning, the charger would wait until the cheaper tariff kicked in.
   - If no instructions were given, the vehicle would charge up regardless of tariff.
- Under GreenFlux, drivers used the app to decide if they wanted to prioritise time or cost, and the charger would charge straight away or only charge when off-peak, respectively. A user's preference would remain the same every day unless changed. However, as in Trial 2, users could opt to be prioritised, so their car would be given priority if demand management was active. The app also gave users information on charge sessions and the impact their choices had made on their rewards.

THE VEHICLES

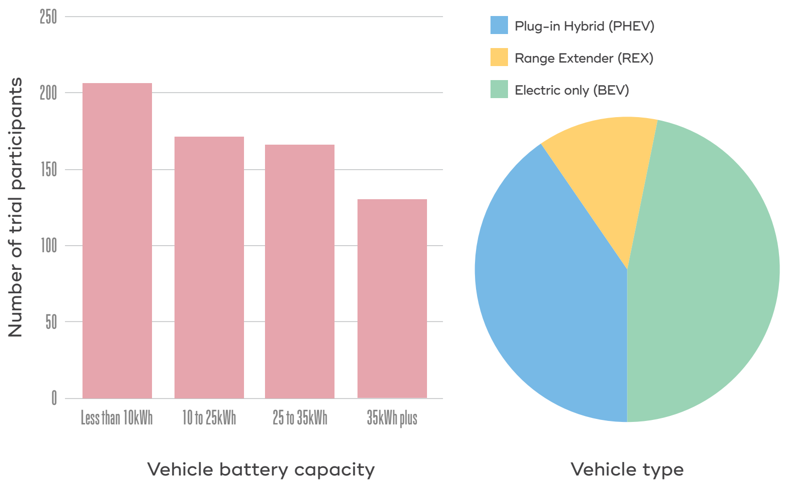
Forty-five different PEVs were used, from 18 manufacturers. The commonest brands were BMW, Tesla, Nissan, VW, Mitsubishi and Mercedes-Benz. Vehicles fell into three categories (see Figure 4 for a ratio breakdown):

- **Battery electric vehicles (BEV)** – a purely electric vehicle that is powered by a battery and an electric motor, with no internal combustion engine.
- **Plug-in hybrid (PHEV)** – a combustion-engined vehicle with a battery-powered electric motor, each of which can power the wheels independently or together. The battery can be charged by plugging in, and the vehicle itself can charge the battery when in use. (PHEVs are distinct from "self-charging hybrids", which are entirely powered by petrol, and therefore have no place in this trial.)
- **Range extended (REX)** – a plug-in electric motor powers the wheels, but there is also a small combustion engine that acts solely as a generator to charge the battery if required.

All vehicles were owned or leased by the participants or their employers. The trial did not supply vehicles.

FIGURE 4

Vehicles in the Electric Nation Trial



THE FINDINGS

THE PURPOSE OF ELECTRIC NATION WAS TO ANSWER SEVERAL KEY QUESTIONS RELATING TO PLUG-IN ELECTRIC VEHICLES FOR DRIVERS WHO HAVE ACCESS TO A HOME CHARGER.

At present, this group is overwhelmingly represented by drivers who live in a home with a driveway and/or a garage with mains electricity connected. Further studies will be required to assess the needs of people without a private parking space, for example those living in flats or terraced homes. The key questions addressed by this study are:

- When do people charge electric cars?
- How often do they charge them?
- Where do they charge them?
- How much energy do electric cars consume?
- What are the charging habits of EV owners?
- Is there flexibility in EV owners' charging behaviour?
- Are people happy to have their charging managed?
- Can incentives influence charging habits?

This section presents the answers to these questions.

WHAT WE MEASURED

Our trial created a transaction record each time a vehicle was plugged in. Each transaction record had three pieces of data:

- What time the vehicle was plugged in
- What time it was unplugged
- How much energy was transferred to the car

It is worth noting that the plug-in time is not necessarily the time charging started. If a driver set the timer in their car to take advantage of an off-peak rate in their energy tariff, but plugged in during peak-price hours, charging would not start immediately.

All times stated are in local time (Greenwich Mean Time or British Summer Time), as that determines normal behaviour (particularly working hours).

WHEN ARE DRIVERS PLUGGING IN AND CHARGING?

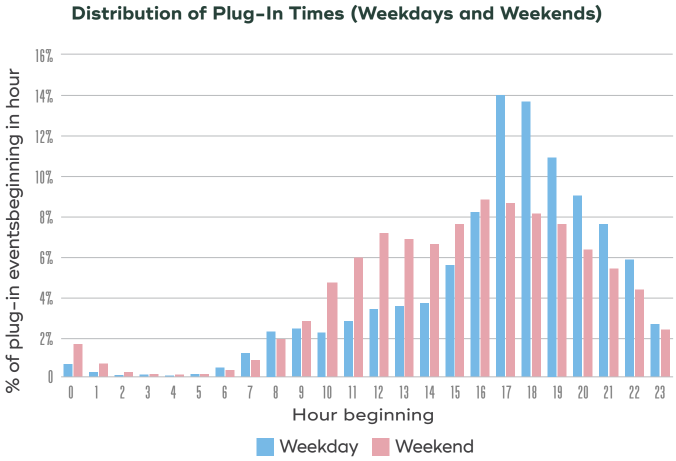
Weekday and weekend plug-ins
A total of 98,656 weekday and 35,541 weekend charging events were recorded, and these are shown in Figure 5 overleaf. As expected, the distribution is flatter at weekends, mirroring waking hours rather than commuting times. Around 28% of all weekday plug-in events occurred between 17:00 and 18:59.

When measuring participants' habitual charging times, the results from Trial 3 (incentivised) are not taken into account, as they are influenced by the trial, and not people's usual routines. Trials 1 and 2, however, did not attempt to influence drivers, so the figures represent normal use.

Weekday Charging
Figure 6 shows the average percentage of participants who were charging their vehicles over a 24-hour period on a weekday. There is a clear pattern of use picking up from around 15:00 and peaking between 19:00 and 21:00, before gradually dropping off to a minimum at around 06:00. This clearly represents drivers returning home from work and plugging in in preparation for the following day's commute, then unplugging as they set off for work.

As a percentage of participants, the lowest percentage of drivers charging up at a given time was 0% in early morning, and the highest percentage experienced was 25% at 19:00, but the general peak was usually in the 15–20% range, for about 3 hours from 19:00 to 22:00.

FIGURE 5



DIFFERENCES BETWEEN PLUG-IN TIME AND CHARGING TIME

While the time the car was plugged in was detected in each transaction, this does not necessarily coincide with the time the charger was delivering power. PEV owners can set a timer on their vehicles, so charging might start later. This would usually be done to take advantage of cheaper night-time electricity, and is more convenient than staying up until midnight to plug in.

FIGURE 6

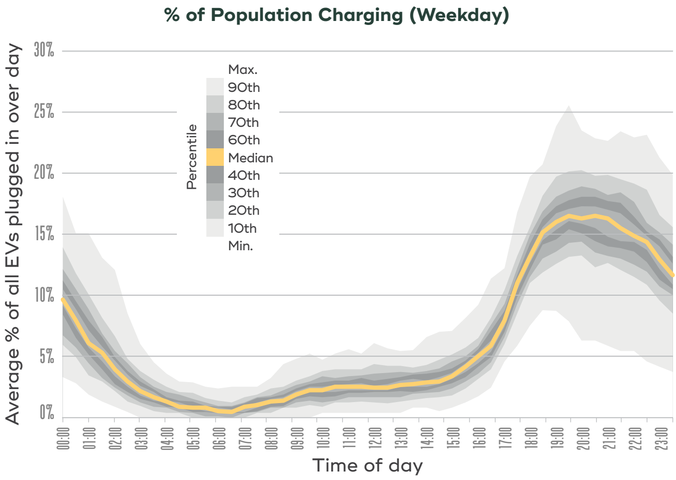
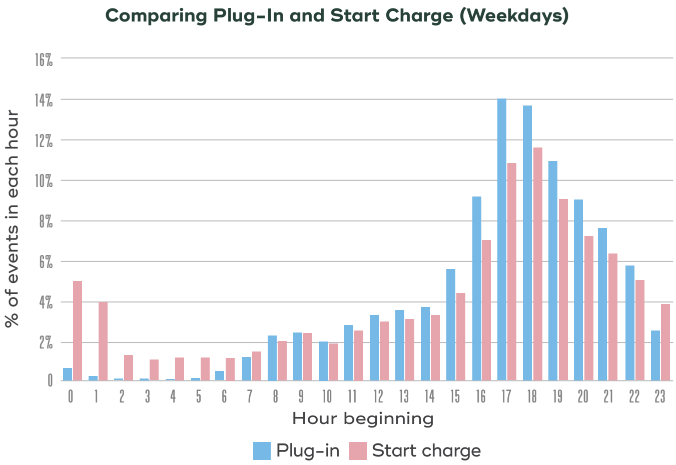


Figure 7 compares the difference between weekday plug-in times and when charging began. It shows that although 14% of plug-in events happen between 17:00 and 18:00, only 11% of charging events start in this hour. There is a noticeable jump in vehicles being charged in the midnight hour, despite less than 1% of plug-in events taking place then. This can only be accounted for by the use of timers.

It is worth noting that most electricity customers do not have a separate night-time tariff, so there is no incentive for them to wait until after midnight to charge. Also, some drivers have no choice when it comes to charging times – drivers' needs do not always follow the 9 to 5 pattern.

FIGURE 7



The trial found that when people plugged in during the day, they tended not to use a timer, as there would be no financial benefit; also, if the vehicle was required later that same day, delayed charging was not an option. Timer use picks up for those who plug in between late afternoon and early morning, as those people are more likely not to need their vehicles until the next day.

Timers are used in 20% of charging events in the week, and 17% of events at the weekend.

HOW OFTEN DO PEOPLE CHARGE THEIR EVs?

Despite what might be assumed, the majority of owners of PEVs usually do not charge their vehicles at home every day. So knowing how often they do charge is a critical factor in calculating demand and the need to manage and incentivise consumption over the 24-hour period. Factors that influence how often drivers charge at home include:

- Average daily mileage
- Battery size
- Whether the driver also charges elsewhere

The trial discovered that the average number of charges was between three and four a week. Only 14% of users charged their vehicles at least once a day, and 72% of those were PHEV drivers.

FIGURE 8

Charging Frequency for Different Vehicle Types

Category		Median Charging Frequency (Charge Sessions per Day)
All Participants		0.52
PEV Type	PHEV	0.76
	REX	0.45
	BEV	0.39
Battery Capacity	Less than 10kWh	0.73
	10 to 25kWh	0.63
	25 ro 35kWh	0.39
	35kWh +	0.31

Figure 8 shows how this breaks down by type of PEV and battery capacity. It might not seem surprising that the vehicles with the larger battery capacities were charged less frequently, but remember that this chart measures number of plug-in events rather than energy delivered, and as we'll see later, drivers' charging frequency preferences don't necessarily follow mileage or battery capacity. Plug-in hybrids were charged more often than range-extended vehicles, with battery-only vehicles needing recharging the least often.

If all users charged up every day, it would put a very different complexion on the figures from the previous section because capacity would be reached more often.

Note: Frequency was calculated in whole calendar months of activity; partial months' data were disregarded. Various thresholds were put in place to account for missing data, and these were factored into the figures. Anyone leaving the trial part-way through had only their whole months' data considered. Chargers installed but not used (e.g. if the driver was awaiting vehicle delivery) only began having their data used from the start of the first month of activity. Only users with at least six months' valid data contributed to the findings.

CHARGING AT HOME AND AWAY

To maintain the integrity of the trial, and to ensure realistic energy consumption was being measured, it was important to discover charging habits that were not being captured electronically from participants' home chargers. People who also charged their PEVs at work or during shopping trips would clearly lead to underestimation of the total energy use for PEVs in the trial, and therefore of total UK demand when scaled up.

The only way this information could be recorded was through regular questionnaires. We asked drivers to tell us how often they charged up at eight possible locations away from home, on a scale from "more than once a day" to "less than once a fortnight". Participants were categorised according to whether they regularly (more than once a fortnight) charged at work, regularly charged somewhere else (e.g. a shopping centre, or a service station) or charged at home only.

We then performed a statistical analysis comparing how often participants charged at home with which charging infrastructure they used. This was based on 327 participants where full data was available. The results are shown below.

MOST FREQUENT CHARGING LOCATION

87% of participants said that "home" was their most frequently used charging location, with the remaining 13% charging elsewhere more often.

Participants who said that their most frequently used charging location was away from home were more likely to have the lowest charging frequencies at their home charger (0–1.6 times per week). The drivers who said that their most frequently used charging location was at home were more likely to have a higher charging frequency at their home charger – more than 5.7 times a week.

USE OF OTHER CHARGERS

Of the 327 eligible participants:

- 68% charged only at home
- 19% regularly (more than once a fortnight) charged at work
- 16% regularly charged elsewhere (e.g. a shopping centre or motorway service station)

Those who charged up at work were much more likely to charge at home relatively infrequently (fewer than 1.6 times a week). Those who regularly charged "elsewhere" (i.e. not at home or work) were also more likely to charge infrequently at home. This group were more likely to occupy the second quartile for charging frequency at home (1.6–3.4 charges per week).

THIS TRIAL TOOK PLACE OVER 2017 AND 2018, AND IT WAS INTERESTING TO OBSERVE HOW SOME RESPONDENTS' ANSWERS CHANGED OVER THAT TIME: A REFLECTION OF THE GROWTH OF THE SECTOR AND THE WIDER AVAILABILITY OF CHARGE POINTS.

WHAT MILEAGE DID DRIVERS CLOCK UP?

Weekly mileage was divided into four ranges, and the proportion of participants in each range was:

- 0–75 miles a week: 14%
- 75–200 miles a week: 44%
- 200–350 miles a week: 29%
- 350+ miles a week: 13%

Statistically (and perhaps unsurprisingly), the fewer miles a driver typically covered in a week, the more likely they were to charge relatively infrequently.

The conclusions to be drawn from charging frequency and mileage statistics are clouded by the manner in which people charge. For example, some drivers like to keep their vehicles as close to fully charged as possible, so might still plug in even if their battery is on 90%. Others will wait until the battery is at 20% before putting their vehicle on to charge. The capacity of the battery is also important in this calculation.

The time of year can play a part, too. As we will discuss in more detail later, EVs get more mileage from their batteries in summer months. Analysis from the trial backs this up, showing that charging frequency is higher in winter months, peaking in February 2018. The lowest frequency was in August 2018, which was a particularly warm and dry summer (it was also holiday season, when vehicles might not have been charged at home for weeks at a time).

HOW MUCH ENERGY DO EVs TAKE WHEN THEY ARE CHARGED?

The amount of energy that has to be delivered to vehicles is just as important as the time of day when vehicles charge from a power capacity point of view. Electric Nation gathered a good deal of data on energy use, including linking this with information on battery sizes, time of year and a range of other factors.

Battery size matters
Just as petrol cars' fuel tanks come in all sizes, so EVs have a variety of battery sizes. Along with the weight and performance characteristics of the vehicle, the battery capacity is a key determinant of range, and also influences the frequency of charging and how much energy is delivered each charge.

For the purposes of the trial, we divided batteries into four size groups:

- Less than 10kWh
- 10–25kWh
- 25–35kWh
- More than 35kWh

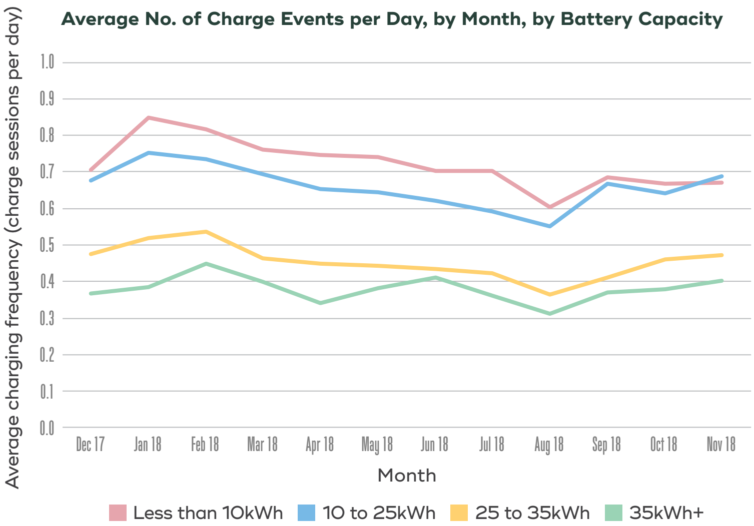
How much charge is needed?
When charging up the largest batteries (35kWh+), they tended to start at between 50% and 84% charged. For the smallest batteries (less than 10kWh), they tended to start between 17% and 48% charged.

The two middle groups showed similar behaviour to each other, starting between 30% and 70%.

These measurements tally with what would be expected. The smaller the battery, the lower the vehicle range, and so the more likely it is that it is fully discharged at the start of each charging event.

SEASONAL CHARGING HABITS

FIGURE 9



Winter has a triple effect on EVs:

- Heating is in use
- Cold batteries are less efficient
- Drivers are more likely to use demisters and headlights

Summer weather does sometimes compel drivers to turn on the air conditioning, but in the UK that is more likely to be for just a few days of the year, and uses much less energy than heating in winter. Summertime also has the holiday factor. Drivers are often either not driving their EVs, or are charging them up elsewhere (this study gathered at-home data only).

It therefore comes as no surprise that over the 12 months of a year, charging frequency follows a pattern that is consistent across all battery capacity groups, as Figure 9 illustrates.

However, smaller batteries need to be charged more often throughout the year than higher-capacity ones. In the depths of winter, the less than 10kWh group needed to be charged almost daily, compared to 0.45 times a day for the 35kWh+ group. In the height of summer, the small battery group could get by on 0.6 charges per day, compared to 0.31 charges per day for the larger battery group.

FLEXIBILITY: PLUGGED IN BUT NOT CHARGING

We know that if a car is plugged in, it is not being driven, so there's an opportunity to charge it. We also know that a plugged-in car is not necessarily charging – it could be that it's on a timer or awaiting a cheaper tariff, or its battery could already be full. The time when the car is plugged in, but not charging, is 'spare time'. This 'spare time' can be used for slower charging, or charging at a different time.

We call the difference between the plugged-in hours and required charging hours "flexibility".

High flexibility is when a vehicle is plugged in for much longer than the time over which it is drawing electricity from the charger. Low flexibility is when it's charging up for most of the time it's plugged in. The lower the flexibility, the more likely it is to be inconvenient if the car is charged at a slower rate. The formula for flexibility is:

$$\left(1 - \frac{\text{CHARGE DURATION}}{\text{PLUG-IN DURATION}}\right) \times 100\%$$

By this definition, a car that's charging all the time it is plugged in would have a flexibility of zero, or 0%. A car that's plugged in for eight hours but is only charging for two hours would have a flexibility of 0.75 (1 – [2/8]), or 75%.

Flexibility findings
Figure 10 shows how flexibility varies depending what time the car is plugged in, for weekdays. The grey area shows the variability in each hour.

Drivers who plug their cars in during or at the end of the working day are generally quite flexible. Cars that were plugged in around 18:00 usually only charged for 20% of the time they were plugged in. Helpfully, this coincides with the evening "peak period", when demand for charging PEVs is at its highest.

Managed charging will only be necessary at times of day when the network is very heavily loaded – during the evening peak. We can see from Figure 10 that drivers who plug in at this time have plenty of flexibility.

Analysis of charge and plug-in durations tells us that high flexibility is quite normal. Of all weekday charging events:

+ 75% have flexibility of more than 44%
+ 50% have flexibility of more than 76%
+ 25% have flexibility of more than 87%

Flexibility and battery size
Battery size is an important factor in flexibility. It is also influenced by mileage required, charging power, time available to charge, state of charge at plug-in and the type of EV used.

We can use two examples to illustrate how these factors influence flexibility. Both assume plug-in at 17:00 and unplugging at 07:00 the next morning (14 hours' available time), and both charge to 100%.

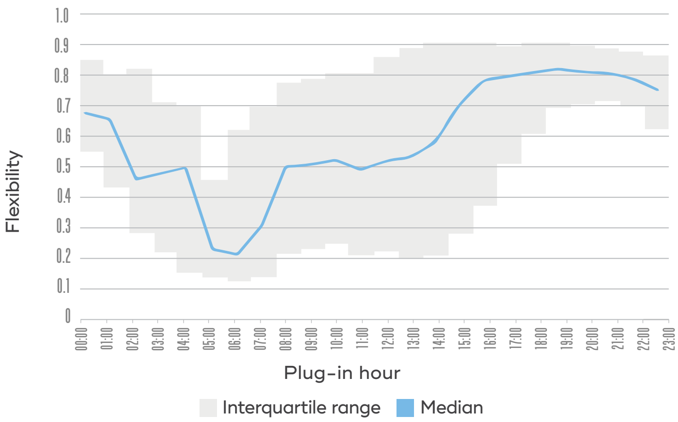
+ **Driver 1:** A PHEV, rated 16A (3.5kW), has a 12kWh battery that is empty. The battery takes 3.5 hours to charge. Flexibility = **75%**
+ **Driver 2:** A BEV rated at 32A (7kW), has a 70kWh battery that is 40% charged. The battery takes 6 hours to charge until it is full. Flexibility = **57**%

These scenarios illustrate the complexity of measuring flexibility and the way that it varies with every charging event. In the scenario above, Driver 2's flexibility would match Driver 1's 75% if Driver 2's car was at 65% charge on plug-in, rather than 40%. From our analysis, vehicles with smaller batteries tend to have greater levels of flexibility. However even the vehicles with the largest batteries tended to offer at least 60% flexibility half of the time.

Is peak demand management inconvenient?
In conclusion, managing drivers' charging is unlikely to cause much inconvenience to the majority of drivers, especially when the ability to override management is considered (and assuming most drivers would opt for cheaper energy given the choice). This deduction was put to the test later on in the trial.

FIGURE 10

Flexibility – Median Value and Interquartile Range – Weekdays



"NORMALLY THERE'S A FAIRLY LONG WINDOW OVERNIGHT OR AT LEAST WHEN PEOPLE AREN'T WORKING OR AREN'T TRAVELLING. THERE COULD BE A SEVERAL HOUR WINDOW WHEN THEY CAN GET THE CHARGE THAT THEY NEED. AND FLEXING THE CHARGING TIME WITHIN THAT WINDOW I THINK IS A SENSIBLE WAY, A SMART WAY OF COPING WITH DEMAND."

Electric Nation participant

WHAT IS THE EFFECT OF SMART CHARGING?

At present, the small numbers of EVs on Britain's roads means there is never a need to manage demand. The trial's aim was to reach findings assuming demand was scaled up so that EV take-up was much more widespread, as per medium-term predictions.

The area of most concern regarding demand overload is not necessarily power generation to supply EVs; it is the capacity of substations serving localities. Electric Nation simulated this part of the power infrastructure by dividing the chargers into groups and managing supply when those group members collectively reached the group's demand thresholds. This happened when the demand for groups of chargers would have been greater than the available network capacity.

CrowdCharge and GreenFlux
In Trial 1 (blind), CrowdCharge and GreenFlux used slightly differing systems.

CrowdCharge started managing when it was no longer possible to allocate 7kW to all the chargers that were plugged in and demanding energy.

As GreenFlux knew which vehicles were 3.6kW and which were 7kW, it only started managing when those specific power demands could not be met. If some 3.6kW vehicles were charging this meant that a larger number of chargers could be active before management was needed.

A series of capacity profiles were implemented to account for seasonal changes and the number of vehicles in the group.

Winter demand and management
Figure 11 (CrowdCharge) shows 24-hour weekday demand during the winter (5 January to 11 March) for chargers managed by CrowdCharge, while Figure 12 (GreenFlux) shows the same period for chargers managed by GreenFlux. For reasons described earlier, winter is the season of maximum energy demand for EVs, so the daily peaks in winter are the most significant to measure from a capacity and management point of view.

The amount of demand for electricity to charge EVs during the evening peak led to demand management becoming active:

- In the **CrowdCharge** group, **8%** of Trial 1 charging events were subject to demand management, with **75%** of participants experiencing management at some point. Those with vehicles rated at 16A (3.6kW) were less likely to be managed than the 32A (7kW) vehicle drivers, as the current allocated by CrowdCharge rarely fell below 16A.
- In the **GreenFlux** group, **17%** of Trial 1 charging events were subject to demand management, with **81%** of participants experiencing management at some point.

FIGURE 11

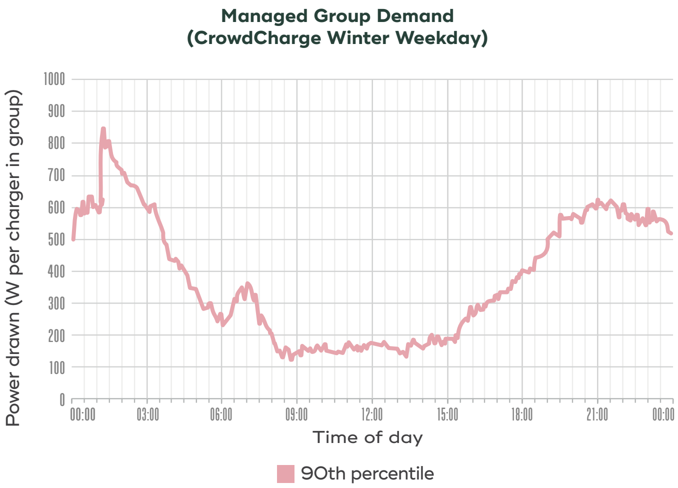
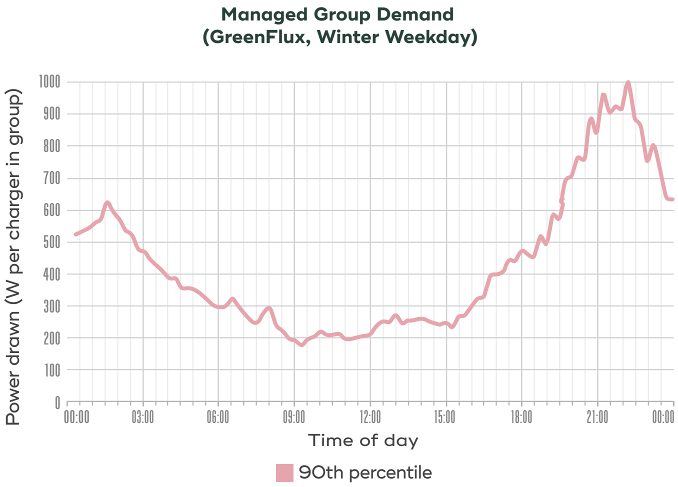


FIGURE 12



For **CrowdCharge**, weekday management happened every weekday during winter, but only during the evening peak (specifically 16:23–22:25). Within that time range, it was rare that management was triggered after 21:30. At the weekend, any management occurred between 16:00 and 20:59, and was always less restrictive than typical weekday management. However, during some weekends there was no need for management at all.

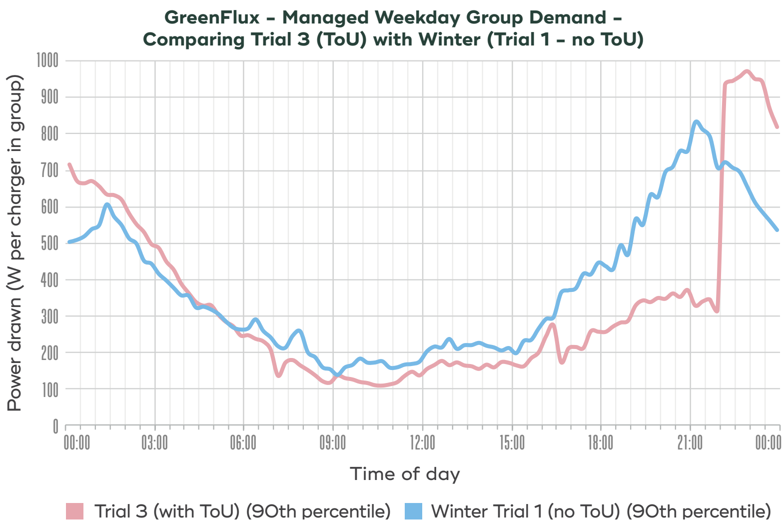
> “IT MAKES A LOT OF SENSE. IF IT’S BENEFITING THE GRID AND CERTAIN SUPPLIERS, THEN IT MAKES SENSE TO HAVE THAT IN PLACE.”
>
> *Electric Nation participant*

With **GreenFlux**, winter management happened on 40% of weekdays, always between 17:00 and 21:15, and 30% of weekend days, always between 16:30 and 19:00.

DO TIME OF USE TARIFFS AND SMART CHARGING INFLUENCE CHARGING HABITS?

One of the aims of Electric Nation was to discover the effect different energy tariffs would have on drivers’ charging habits, particularly when this was supported by smart charging. This was chiefly to minimise stress on substations during the peak hours shortly after the evening rush hour, particularly in winter.

FIGURE 13



As we covered on page 10, in the GreenFlux cohort, Trial 3 allowed drivers to choose between charging at all times of day, or only at times when the price was low. The idea was that people were incentivised to choose a charging time outside peak demand, but still had the option to charge straight away if they needed their vehicles sooner than the following morning.

More than 60% of users went for lowest price for at least one charging event – delaying when charging began in exchange for cheaper energy. 53% chose this option most of the time. That meant that during the simulated evening peak, there was a much more gradual rise in energy demand, to the point where demand management of charge points became unnecessary throughout the whole of Trial 3 (which took place in winter).

> “THE FEW TIMES I HAD TO USE THE HIGH PRIORITY, BUT I WAS PREPARED FOR THAT TO EFFECTIVELY COST ME AS OPPOSED TO THE REWARDS BECAUSE I WANTED THE FUNCTIONALITY. I WANTED THE CAR CHARGED. SO, I WAS QUITE HAPPY WITH THAT REWARD MECHANISM.”
>
> *Electric Nation participant*

A delayed surge

One result of cost optimising was that there was a sudden surge in demand at 22:00 as can be seen in Figure 13. Virtually all the participants who had delayed charging until after peak tariff switched on at the same time. Indeed, the surge was much more sudden than a normal end-of-rush-hour demand rise, which happens over several hours as drivers gradually arrive home. Furthermore, the surge maxed out higher than at any point during the previous trials.

The 22:00 surge did not reach the overall limits for a substation, as the usual evening peak was over, with people winding down for the night. Because only vehicle chargers were being monitored for the trial, this spike is from vehicle charging only, not overall electricity consumption.

Sudden step changes like the one shown at 22:00 can *potentially* cause issues for the electricity system. This is a useful observation rather than a problem, however. There are technical solutions such as randomising switch-on times which could be deployed to make any rise in demand less sudden. It does illustrate how smart charging is a crucial element in any tariff-based system, as without smart charging this management would not be possible.

> "IF I'M SAVING TWENTY POUNDS OVER TWO-THOUSAND, BASED ON THE FACT IT DOESN'T REALLY DAMAGE MY LIFESTYLE, I'D BE HAPPY TO DO IT AT THAT LEVEL."
>
> *Electric Nation participant*

During weekends, the same simulated tariffs applied, and the phenomenon continued to occur at 22:00. As the night progressed, demand settled into a pattern similar to that seen in the non-tariff winter trials. The total amount of energy delivered on weekend days was less than during the working week, although demand for charging was generally slightly higher during the day. Both findings follow expectations, as commuters are at home and can charge at any time during the day. Sunday's demand was higher than Saturday's, but lower than a typical weekday's.

> "I GET HOME SEVEN, EIGHT O'CLOCK IN THE EVENING, PLUG MY CAR IN, I DON'T REALLY MIND WHEN MY CAR GETS CHARGED UP. I DON'T NEED IT INVARIABLY UNTIL SEVEN O'CLOCK THE NEXT MORNING."
>
> *Electric Nation participant*

Did the incentive work?

Drivers in Trial 3 were incentivised to change their charging behaviour with a 'reward value' system. All participants began the trial with a reward value of £10. Each unit of electricity their charger used during the peak period would decrease their reward balance by 13p. Each unit their charger used overnight would increase the balance by 5p. At the end of the trial participants received a shopping voucher equal to their reward value. On average, participants received £21 from the nine-week trial. The largest reward was £80.

The incentive, combined with smart charging and the app, had a significant impact on drivers' behaviour. The app certainly helped the switch by making it a simple choice between high and low cost (here simulated by the vouchers). Before tariffs were introduced in Trial 3, there wasn't the option to choose a lower cost, unless participants were already on a time of use tariff (such as Economy 7).

It is therefore reasonable to assume that the majority of PEV drivers do respond to such incentives. They had two other options – to ignore the incentive altogether or prioritise time – but actively accepted it. Remember also that some participants who chose to prioritise time might not have had a choice as they might have needed their vehicles during the night.

Use of the app

The use of an app certainly seemed to have an effect on nudging users into economising, thus (theoretically) reducing stress on the local power network. During Trial 3, 76% of all participants began a lower proportion of their charging events during the weekday evening peak (when prices were highest). Amongst app users this proportion rose to 89%.

Once the choice was made on the app, that choice would be applied to all charging sessions at home with no further action required. Unless the driver had a need to switch back to charging in the peak (e.g. needing the car in the night or being dissatisfied with their morning charge), most people probably just got used to the setting and effectively forgot about it. Analysis of the charging preferences drivers used over the course of the trial showed that drivers tended to switch once (e.g. to the "minimise cost" option) and then remain on this setting. Only a small minority of drivers switched between preferences multiple times.

> "I THINK A GOOD INCENTIVE TOO IS THAT THERE WAS A MIX OF PENALTY ASSOCIATED WITH DEMANDING INSTANT CHARGE AT PEAK RATE, AND AN INCENTIVE JUST LEAVING IT ON TO BE MANAGED ON OFF-PEAK ELECTRICITY."
>
> *Electric Nation participant*

CrowdCharge Trial 3 System

The CrowdCharge algorithm for Trial 3 was updated to use journey plans alongside the tariff to move charging to cheap periods where the journey plans indicated this was possible. An example would be, avoiding the evening peak when vehicles plugged in at 18:00 if the next planned journey was the following morning.

However, interaction between participants and the journey planner was low, so charging often occurred during peak hours, meaning the system made very little difference to the peak demand.

CUSTOMER FEEDBACK

While we have the figures for how drivers acted both with and without ToU tariffs, the only way to find out how they felt about it is to ask them. At the end of the trial we asked participants to assess:

- their (and their families') attitude towards PEVs
- their attitude towards charging their vehicles at home and elsewhere
- their experience of participating in the project
- how acceptable they found each of the three trials
- whether the trial was likely to inspire long-term behavioural change

Here are some of the key findings from the customer research we carried out after the end of the trial. On owning PEVs in general:

- Asked what would fuel their next vehicle, only 5% said pure petrol or diesel; 63% said BEV, 23% PHEV and 4% REX (total PEV: 90%).
- 86% of BEV drivers and 50% of PHEV drivers intend to stick with the same type, but only 18% of REX owners intend to do a straight swap – 71% of them intend to move to a pure electric vehicle.

Drivers who said they intended to return to petrol or diesel were not more dissatisfied with their charging arrangements during the trial than other participants. They were more likely to have got their PEV through a company scheme, be more motivated by costs than environmental benefits, and were less confident about making long journeys in their PEV. The last point may be indicative of issues with charging infrastructure away from home, which were often raised by participants in the surveys. This is an issue that society, car manufacturers and policymakers at local, national and international level will need to address. (see "Next Steps" on page 28)

When asked specifically about the systems used in Trials 1 (blind), 2 (interactive) and 3 (incentivised), the following feedback was received.

- Overall satisfaction remained at over 80% over all three trials.
- Asked which trial they preferred, the most common answer from the CrowdCharge group was "no preference" (38%), followed by Trial 1 (31%). Only 4% preferred Trial 2.
- When the GreenFlux participants were asked which trial they preferred, Trial 3 had 51% support, followed by Trial 2 (22%), "no preference" (17%) and Trial 1 (9%).

ARE CUSTOMERS READY FOR ToU TARIFFS AND SMART CHARGING?

Whether customers are influenced by ToU incentives and whether they are happy to be influenced are subtly different matters. Customer acceptance makes it a viable strategy; reluctance or hostility would necessitate a re-think. From our surveys we found:

- 88% of GreenFlux participants who had used the app found the charging preferences and reward structure easy to understand
- 86% of the GreenFlux group were either 'very likely' or 'slightly likely' to use a similar app in the future
- 62% of GreenFlux participants thought that having an app was useful
- 81% of GreenFlux participants believed that the tariff structure and charging profiles would encourage many, or most, PEV owners to charge their cars outside of peak times
- 76% of GreenFlux participants said they would sign up to a ToU scheme like Trial 3 if it was available
- 76% of GreenFlux participants said they would recommend the ToU tariff system to a friend
- 28% of participants changed electricity tariff since they got their EV. Of those, just under two thirds went to a specific PEV tariff or Economy 7
- Of the 70% who did not change tariff, 59% have considered doing so

The overwhelmingly positive response to the ToU tariff scheme shows that it is a viable method of limiting peak evening demand, and that having control via a phone app is popular.

Had customers experienced uncharged vehicles in the morning, satisfaction would no doubt have been very different. Thanks to our understanding of how demand for energy is shared between the different types of vehicles, and how flexibility can be used to supply this power efficiently, conveniently and without stressing substations, the system offers a win-win-win situation for power companies, drivers and the environment.

CONCLUSIONS

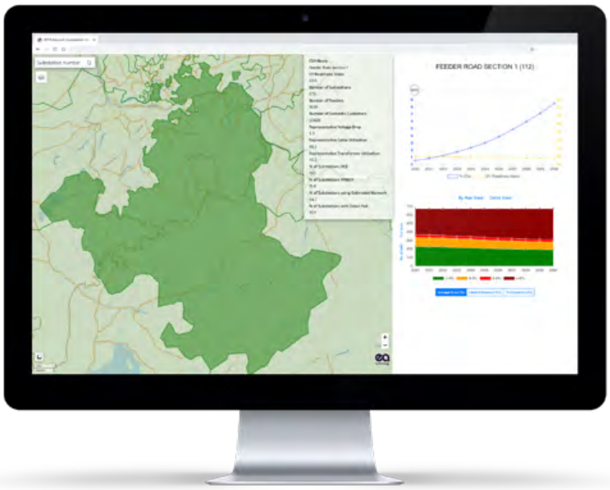
TO ANSWER THE CENTRAL QUESTIONS OF WHETHER THE UK NEEDS TO UPGRADE ITS ELECTRICITY DISTRIBUTION NETWORKS FOR CAR CHARGING (AND TO WHAT EXTENT SMART APPLICATIONS CAN TAKE THE STRAIN) THE FINDINGS OF THE ELECTRIC NATION TRIALS WERE THEN MODELLED AGAINST WPD'S NETWORK OF 7.9 MILLION CUSTOMERS.

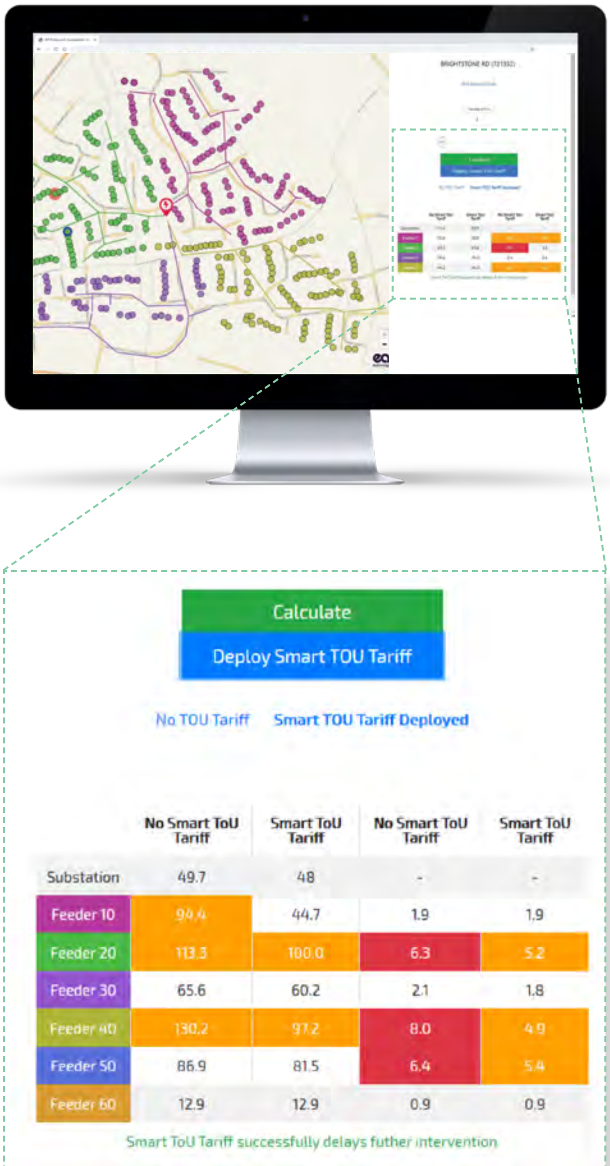
To do this EA Technology developed the Network Assessment Tool software (or "NAT"), which maps:

+ Low Voltage (LV) substations and their associated networks (underground cables and overhead lines making up feeders)
+ Customer meter points mapped to LV substations and networks
+ Known EV charge point installations

It then assesses the network conditions that will arise for given PEV uptake scenarios in the future, calculating feeder loading and voltage drop using the same approach as WPD's existing network modelling tools. From this, it is possible to determine an "EV Readiness Index" for every network, providing WPD with the information it needs to plan network upgrades.

Finally, based on the behaviours observed from the Electric Nation smart charging trials, WPD can use the NAT to evaluate the effect of smart charging deployment on each network – and avoid disruptive or unnecessary network upgrades as far as possible.





	No Smart ToU Tariff	Smart ToU Tariff	No Smart ToU Tariff	Smart ToU Tariff
Substation	49.7	48	-	-
Feeder 10	94.4	44.7	1.9	1.9
Feeder 20	113.3	100.0	6.3	5.2
Feeder 30	65.6	60.2	2.1	1.8
Feeder 40	130.2	97.2	8.0	4.9
Feeder 50	86.9	81.5	6.4	5.4
Feeder 60	12.9	12.9	0.9	0.9

KEY POINTS TO TAKE AWAY

Electric Nation trial data shows:

- There is flexibility in charging – but without an incentive the demand in the evening peak requires management
- Demand management is technically feasible, and is acceptable to the majority of trial participants
- Time of Use incentives appear to be highly effective at moving demand away from the evening peak – particularly when supported by smart charging (with an app), which makes it simple for the user
- Smart charging can support the introduction and management of ToU-based EV tariffs
- Smart charging provides a way to manage any negative consequences of mass uptake of ToU incentives
- Data from smart chargers provides a strong evidence base to help DNOs make efficient investments

NEXT STEPS

WE ARE ON THE CUSP OF A BIG CHANGE: NATIONAL GRID SCENARIOS NOW FORECAST MILLIONS OF EVs BY 2030, IN THE RUN-UP TO NET ZERO BY 2050.

Our network will need to grow and adapt to accommodate a steep uptake in low carbon technologies such as EVs and heat pumps, whilst keeping costs to the end customer as low as possible.

As an electricity system operator our approach is to ensure that a suitable network exists for all charging requirements in all situations. This has many factors as charging requirements vary dependent on the type of vehicle and the owner's access to either their own or public charging infrastructure. Only 60% of car users have access to an off-street parking location which is likely to be suitable for charging and because of Electric Nation, we now have a much better picture of this type of charging.

We predict that the majority of our larger local transformers will currently be able to accommodate one 35kWh charge every five days for each of the customers connected to it. This provides a charged range of around 150 miles in many EVs and it is likely that this will support a large proportion of home charging. On networks where this is not sufficient which require upgrading, we may deploy our charge system called LV Connect and Manage, which is trialled in Electric Nation. The project has demonstrated that the majority of customers are open to accepting charge management, and it generally doesn't interfere with journey plans. We view the LV Connect and Manage system only as a short term solution, and once deployed it would trigger reinforcement of the network.

Flexibility will provide a key role in delivering EV charging in the future, this is likely to provide solutions for many customer types; from domestic users to fleet users who return their vehicles to a depot overnight. Domestic users will be able to take advantage of time of use tariffs that we expect electricity suppliers to offer in conjunction with smart meters. With their vehicles at home when not in use, they will be able to use managed charging to charge their vehicle at times when price signals show it to be beneficial for the wider electricity network, as demonstrated in Electric Nation.

We have written an Electric Vehicle Strategy in response to predicted EV growth: the data from Electric Nation has informed our approach and the decisions made within the document. The growth of EVs will impact on DNOs such as WPD in a range of ways, including proposals to install three-phase cables in every new home, working with local authorities to provide enough power to install large numbers of charge points in car parks, and working with companies who are looking to set up high power EV charging hubs. As such, Electric Nation is not the end, but it's the beginning of future innovation projects.

Paul Jewell
WPD Policy Manager


MODEL S

ENQUIRIES

FOR FURTHER ENQUIRIES ABOUT THE ELECTRIC NATION PROJECT, PLEASE CONTACT THE FOLLOWING PROJECT LEADERS.

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COLLABORATION PARTNERS

Electric Nation is the customer-facing brand of CarConnect, a Western Power Distribution (WPD) and Network Innovation Allowance funded project. WPD's collaboration partners in the project are EA Technology, DriveElectric, Lucy Electric GridKey and TRL.

ea technology DriveElectric Lucy Electric TRL

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales