Report on Electric Vehicle Charging Trial

Prepared for Wellington Electricity
By Jake Roos Consulting and Concept Consulting

Final version - July 2018

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Acknowledgements

This trial was commissioned and funded by Wellington Electricity Lines Limited (we*), but it was a collaborative effort involving many people and organisations, each of whom have a common interest in seeing the large-scale adoption of electric vehicles (EVs) in New Zealand succeed.

We* employed Jake Roos Consulting Limited (JRCL) to provide overall project co-ordination. JRCL has written Section 1 of this report.
We* also employed Concept Consulting to analyse the electricity usage data. They have written Section 2 of the report. The executive summary and preamble have been written collaboratively. We*, JRCL and Concept working together were the project team for the trial.

The project team would like to acknowledge everyone that contributed, first and foremost the EV owners that took part, without whose help it would not have been possible; the electricity retailers who provided data: Contact Energy, Meridian Energy, Mercury Energy, Trustpower, Flick Electric, Ecotricity, Electric Kiwi, Nova, Powershop, Paua to the People and especially Genesis Energy, who also provided the control group data; the Electricity Networks Association who allowed us to adapt some of their reference material; and those that helped promote the trial including Charge.Net.NZ, EV Talk magazine, car dealerships EV Central and Gazley Motors, retailers Paua to the People and Ecotricity, Flip the Fleet and Greater Wellington Regional Council. Many thanks and we hope that you find the results of the trial interesting and useful.

0.2 Executive Summary

0.2.1 Purpose

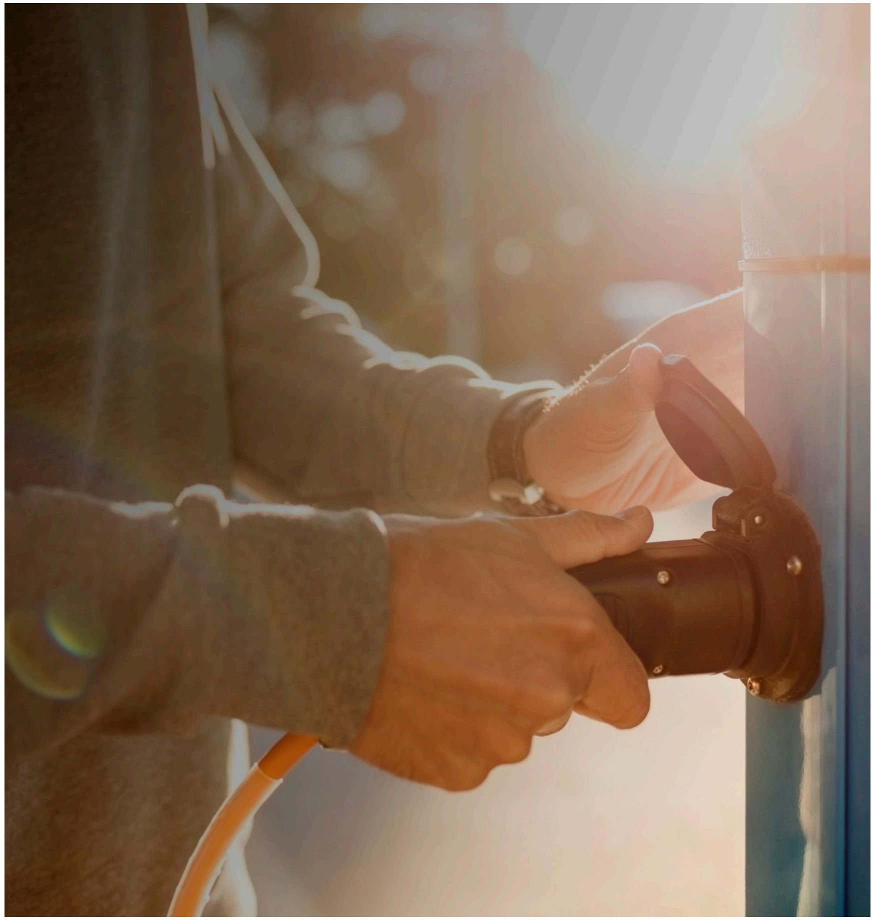
There are predicted to be in excess of 64,000 electric vehicles (EVs) on the road in New Zealand by 2021, approximately 2% of the total vehicle fleet. EVs present a new challenge for electricity network operators: how to manage and plan for the demand for EV charging, the majority of which is be expected to be done by private EV owners at home. There is concern that if not planned and managed carefully, this extra demand might require costly network upgrades. Pricing-based and technology-based approaches that influence the rate and timing of EV charging will help to minimize any network impact.

The objective of the EV Charging Trial was to better understand the scale of this challenge by using half-hourly metering data to measure the size and timing of electricity demand of both a group of EV-owning households (useful data was obtained for 77 of these in total), and a control group of non-EV owning households (860 in total).

The trial also undertook a questionnaire survey to try and examine the reasons, motivations and habits of the EV-owners that gave rise to their electricity demand profiles. It included questions about their attitudes towards new approaches for managing EV charging demand, including pricing and other information-based incentives.

As part of this, differences in electricity charging approaches between EV owners that are receiving EV-Nite (and other time-of-use pricing plans), and those that were not, were also examined.

Specifically these insights were intended to help we* update its EV-Nite tariff.



64,000

EVs on the road in NZ by 2021

35%

Average residental electricty demand increase from EV chraging

0.2.2
What we found

It was found that EV charging will materially increase average residential electricity demand: By approximately 2,500 kWh per annum – roughly 35% of the average residential demand.

In the absence of an electricity price signal or other information-based intervention, a significant proportion appears to occur when trial participants get home from work – coinciding with electricity system evening peak. However, despite chargers typically having capacities of 2.5 to 4 kW, there appears to be material diversity (variety) in the start of and duration of such charging, meaning the after-diversity kW impact is likely to be of the order of 0.5 to 0.8 kW.

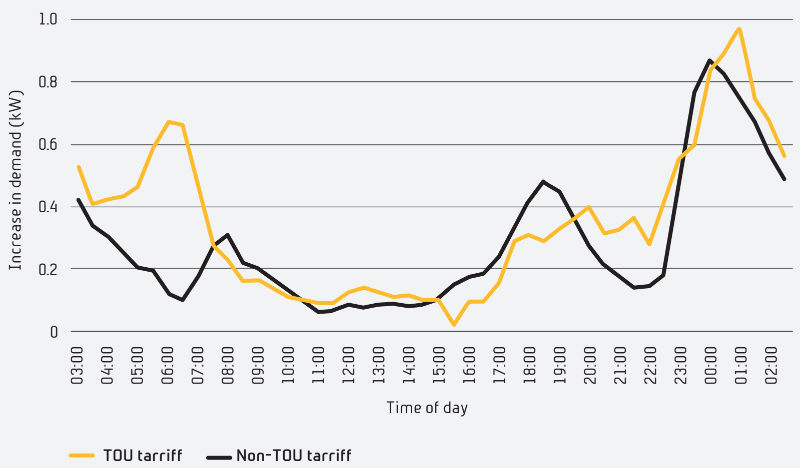
However, in the sample of EV customers examined, a greater proportion appears to charge much later – i.e. midnight and beyond. This is even when customers have no electricity tariff incentive to do so. Given the small, and potentially 'unusual' nature of the sample group (i.e. technology early-adopters), and the fact that information about charging approaches was provided to this sample, it is not possible to infer whether this would be typical of charging behaviour when EVs are adopted more widely.

Analysis of participants' response to the questionnaire found that while 78% of participants said they adopted the behaviour of charging after 9pm immediately within a month of getting their EV, 10% did so after switching retailer (from which it can be inferred it was at that point they then had a cheaper night rate for electricity) and 7% did during the trial period, suggesting they were responding to the information and practical guidance on off-peak charging that was provided to them. Of the participants that didn't charge after 9pm, the most common reason cited was convenience and practical barriers, rather than the absence of a price signal.

A material increase in demand in the morning peak (although half that of the evening demand increase) was observed in demand profiles. This is understood to be associated with 'pre-conditioning' of EVs in the winter – i.e. in the half-hour or so before the car is to be driven, warming up the battery and cabin while the car is plugged-in in order to increase the vehicle range.

Notwithstanding that many of the EV consumers in this study charged their vehicles overnight even without an electricity tariff incentive (potentially due to the information that was provided them as part of the study), a far greater proportion of EV consumers who were exposed to a time-of-use (TOU) tariff signal charged their vehicles outside of the evening and morning peaks. This effect was greatest for those exposed to the we* EV-Nite tariff, but was also significant for those exposed to spot wholesale prices (e.g. Flick customers). This difference is illustrated in Figure 1.0 below.

Figure 1.0
EV demand for TOU and non-TOU customers



This customer response to tariffs is potentially a double-edged sword:

- In the short-term it has a beneficial effect in terms of moving EV demand outside of the electricity system peak.
- In the long-term, as the number of EVs purchased by customers increases, it may create a new peak coinciding with the start of the off-peak period. In particular, if all vehicles start charging at the start of the off-peak period all the significant diversity benefits that have been observed with EV charging would be lost, leading to the new peak being significantly greater than the current network peak. This additional peak demand could be of the order of 4kW per EV – on top of the approximately 1.5 kW per customer after-diversity demand at 9pm on a cold winter's evening. This is considerably greater than the current peak demand of approximately 2.25 kW per customer during current peak periods.

  That said, the sample group with the EV-Nite tariff did not show a sharp increase at 21:00 (the start of the EV-Nite period) but a few hours later. It is not clear why this would be the case.

In terms of the diversity effect, the analysis shows that while the anytime peak demand of individual customers increases significantly with an EV (by approximately 4 kW for the sample), the after-diversity peak increase for the sample is significantly less (approximately 0.5 kW to 0.8 kW).

This beneficial diversity effect is significant, even for relatively small groups of customers – i.e. of the order of 5 or so. As such, unless TOU signals create incentives for a new sharp, step-change peak at the start of the off-peak period, EV uptake may not cause widespread capacity exceedance on the low voltage (LV) networks (which typically have 50 ICPs).

Generally trial participants were comfortable with suggested approaches to managing the impact of EVs on the grid (which included demand-based electricity pricing, a centralised service to control the timing of their EV's charging, and vehicle to grid technology), although the level of financial benefit to them from agreeing to use these was important for most people.

Section 1.0

Analysis of participant-provided data

Prepared by Jake Roos Consulting Limited

About Jake Roos Consulting Limited

Jake Roos Consulting Limited (JRCL) is a provider of expert advice and assistance in the fields of sustainable energy and climate change mitigation, from policy development through to project delivery. Areas of expertise include energy markets, energy management, renewable energy, electric vehicles, Greenhouse gas emissions accounting (ISO-14064) and innovative community engagement. For more information see www.jakeroosconsulting.co.nz

1.1 Background

The objective of the trial was to better understand the peak electricity demand of households of both EV-owners and a control group of non-EV owners, to inform changes to Wellington Electricity's EV-Nite tariff*.

Differences in peak electricity demand between EV owners that were receiving EV-Nite (or some other pricing option whereby participants get a cheaper rate for electricity at night) and those that are not were also examined.

The trial also had the objective of gaining a greater understanding of the reasons, motivations and habits of the EV-owners that gave rise to their electricity demand profiles, and their attitudes towards new approaches for managing EV charging demand.

The call for participants to sign up was promoted via Facebook groups, pages and advertisements, through some electricity retailers, the 'EV Talk' news website, radio, the 'Flip the Fleet' initiative and two car dealerships.

Half hourly resolution (HHR) electricity data for the 24-month period through to 6 October 2017 for the participant's homes was sought from their electricity retailers (twelve different companies in total). Complete HHR datasets were successfully assembled from the data supplied for 77 of the participants, and this was used for the analysis.

For the control group, 24 months of anonymised HHR electricity consumption data for a random selection of 6,000 domestic electricity connections (ICPs) in the Wellington Electricity supply catchment was obtained from an electricity retailer.

we replaced EV-Nite with EVB, a new time of use tariff for EV owners, from 1 July 2018.

Participants were given information about the importance of off-peak charging, practical advice on how to charge off-peak and practical advice on the use of timers for charging if they did not already use one. They were also surveyed on their views on electricity pricing and other demand management approaches for EVs, and information about their EVs and charging habits was also collected.

92 **eligible participants were recruited. The inclusion criteria were that participants must:**

- Live within Wellington Electricity supply catchment
- Own or lease at least one EV that they charge at home
- Have an advanced (HHR) data)

1.2

Participants' EVs and driving habits

Of the 92[1] participants, 85 had one EV, 6 had two EVs and one participant owned three EVs. 32% of participating households owned no internal combustion engine vehicles.

The breakdown of EV types owned or leased by participants are shown in Table 1.0.

Table 1.0

Vehicle make and model owned or leased by trial participants

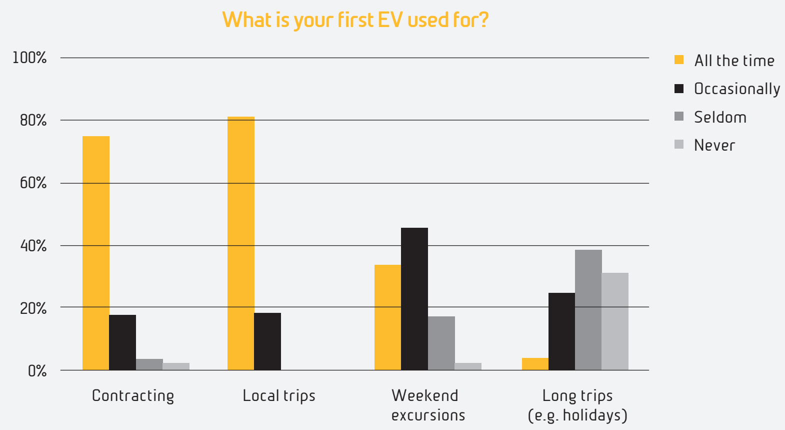
Make and model	No.
Nissan Leaf	72
Mitsubishi Outlander PHEV	11
Nissan E-NV200 Electric Van	4
Hyundai Ioniq	3
Audi A3 Sportback E-Tron	2
Other	6
Total	98

1. 92 eligible people registered from the trial. Usable electricity consumption data was obtained for 77 of these.

The main uses of the participant's first EV were for local trips and commuting, as shown in Figure 2.0.

Figure 2.0

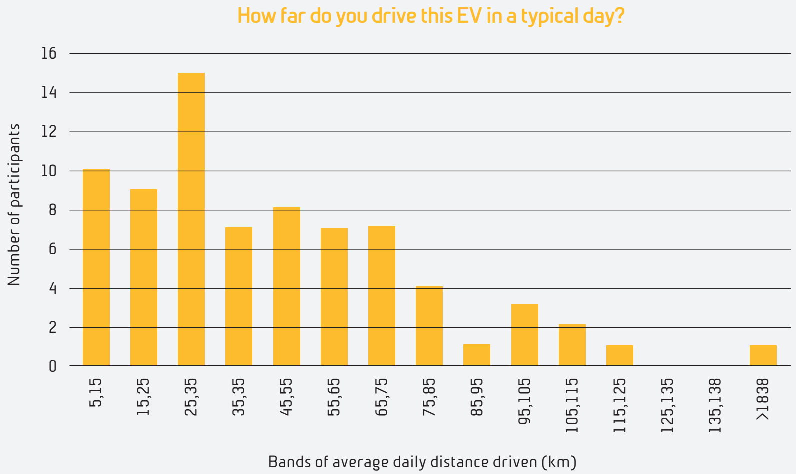
Frequency of uses of their first EV reported by participants



49% of participants drive their EV an average of 40km/day or less on a typical day. The distribution of the estimated average daily distance driven in the first EV is shown in Figure 3.0.

Figure 3.0

Daily distance driven in their first EV reported by participants



41% of participants have owned their EV for 6 months or less.

1.2.1
Are the EV Charging Trial participants 'early adopters'?

The term 'early adopter' originates from Everett M. Rogers' Diffusion of Innovations (1962). 'Innovators' and 'early adopters' in the technology adoption bell-curve represent the first 15% of people who adopt a technology, in this case EVs.

Early adopters, according to the formal definition, tend to give feedback on a product to its supplier that allow them to refine the product or the associated systems of service and support. They often have to pay more for a product, and have to deal with bugs associated with early versions of the product, sometimes referred to as the 'early adopter tax'.

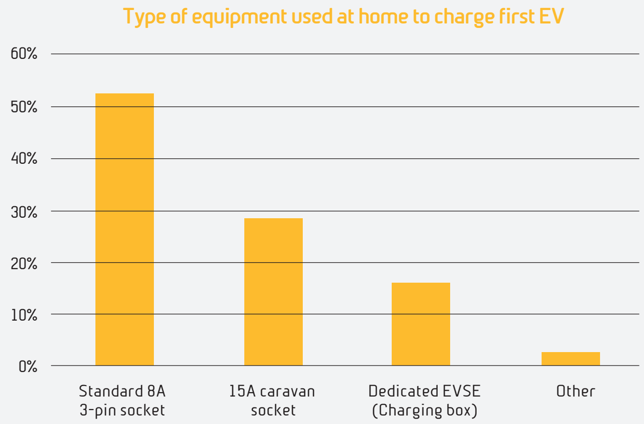
As EVs make up much less than 1% of the light vehicle fleet in New Zealand, all of the participants in the trial could be considered early adopters, especially as this trial itself is a means of gathering feedback on a 'associated system of support' (home EV charging and its pricing) that they have volunteered for. However, given the price of EVs, particularly the Nissan Leaf, has reduced significantly and they are mature products that are not prone to faults (The Nissan Leaf was rated NZ's most reliable car in a survey conducted by Consumer NZ[2]), many of recent purchasers do not completely fit the definition.

2. https://www.consumer.org.nz/articles/car-reliability

1.4
Participants' charging equipment and habits

The breakdown of home EV charging equipment used by participants is given in Figure 4.0. Over half are using a standard 8A household plug.

Figure 4.0
Equipment used by participants to charge their first EV at home



26% of participants are on an electricity tariff incorporating EV-Nite, and including these, 63% are on a home electricity supply option that is cheaper between 9pm and 7am.

Of those not on such a tariff, their reasons are given in Table 2.0.

Table 2.0
Reasons given for not being on a cheaper night tariff

Reason	No. of respondents
Not worth effort/cheaper to stay with current retailer	5
Going to switch/presently are switching	5
Loyal to current supplier	3
Unaware anyone offered this	2
Unsure of the benefits/need to learn more	2
Other	2

Also, some participants with Mitsubishi Outlander plug-in hybrid EVs (PHEVs) noted their vehicles required relatively little charging, so switching from their existing deals would not be financially beneficial.

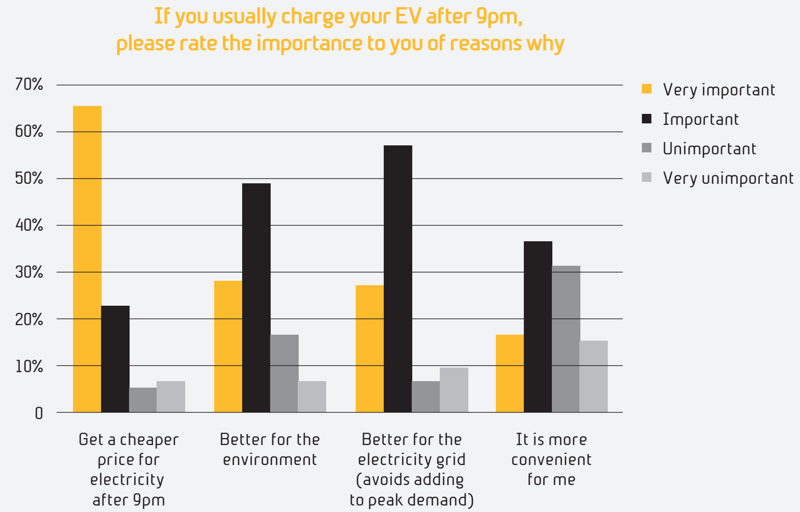
31% of participants claimed they always charged their EV after 9pm, and a further 49% said they usually did this. Analysis of electricity consumption data found that 50% of participants had their peak electrical demand between 9pm and 7am, highly suggestive of EV charging between these times. It is possible other participants were also charging then, but their early evening peak was still their highest, because of other non-EV related demand at their home. Interestingly, a significant proportion of participants' claimed timing of their EV's charging did not match with their load profiles.

Two thirds of participants said they always or usually used an automatic timer of some kind to control when home charging starts.

Participants that did charge their EV after 9pm were asked to rate the importance of different reasons. 'Getting a cheaper price after 9pm' was rated as 'very important' by 66% of participants. 'Better for electricity grid' and 'Better for the environment' were rated as 'important' by 57% and 49% of participants respectively. See Figure 5.0.

Figure 5.0

Importance given by participants to different reasons for charging their EV after 9pm



Of the participants who always or usually charged after 9pm, 78% said they started this immediately or within a month of getting their EV, 10% when they switched electricity suppliers, 7% during the EV Charging Trial (but more than a month after getting their EV) and 5% at some other time.

Of the participants that did not charge their EV after 9pm, the main reason given why in Table 3.0.

Table 3.0

Main reason participants don't charge their EV after 9pm

Reason	No. of respondents
It is inconvenient/there are practical barriers	12
Makes no difference to me (no cost saving)	4
Have home solar PV so prefer daytime charging	2
I was not aware it made a difference	1
I haven't got around to it yet, but I intend to do this	0

Practical barriers included participants needing to use the EV later in the evening (and therefore needing to give the car a boost charge during the 5 – 9pm peak period) and understanding how to programme their charger, given their vehicle console's language is Japanese.

1.5
Participant attitudes towards peak demand management approaches

1.5.1
Demand-based or time-of-use electricity pricing

89% of participants responded yes to the following question:

"If your current electricity supplier offered a cheaper electricity price at certain times of the day, but more expensive at other times of the day (so it may cost you more or less overall depending on when you timed certain activities like EV charging) would you consider switching to it?"

Electricity pricing options for EV owners that are presently available generally have no downside price-wise. The responses to this question shows that the participant group has considerable appetite for more sophisticated pricing arrangements where load would have to be carefully managed to minimise costs.

1.5.2
Centralised control service

Centralised control services for EV charging and other load was explained this way to participants:

"Rather than relying on electricity users to make their own arrangements to control the timing of EV charging and other flexible load to manage peak demand, your electricity supplier or distribution company could potentially do this for you. Furthermore, if data is collected on the typical size and duration of loads (for example, the amount of time it usually takes your EV to charge) electricity use could be co-ordinated across a neighbourhood to avoid large peaks in demand. It is likely there would be an additional financial advantage to electricity users who agreed to this approach, and a means for them to override the control from time to time if it was necessary."

When asked 'how comfortable would you be with this arrangement', 70% said they would be 'comfortable' or 'very comfortable'. 18% said they would be 'uncomfortable' or 'very uncomfortable'.

Figure 6.0

How comfortable participants are with the idea of letting their EV charging be controlled by a centralised service

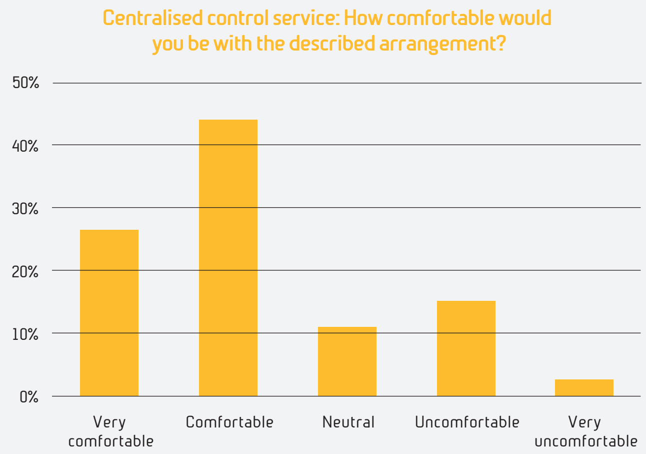
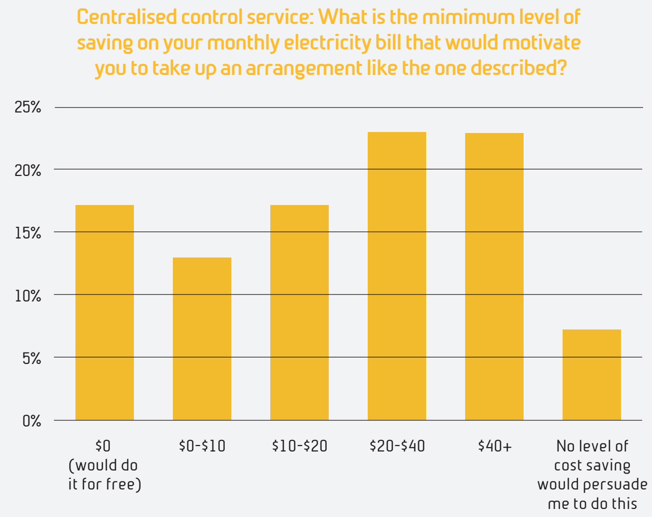


Figure 7.0

Level of saving participants would expect for letting their EV charging be controlled by a centralised service



93% of the people that said they would be uncomfortable or very uncomfortable gave 'I want full control of all electricity use at my home at all times' as the reason. The level of financial advantage participants would expect to enter into such an arrangement is given in Figure 7.0.

1.5.3 Vehicle to grid

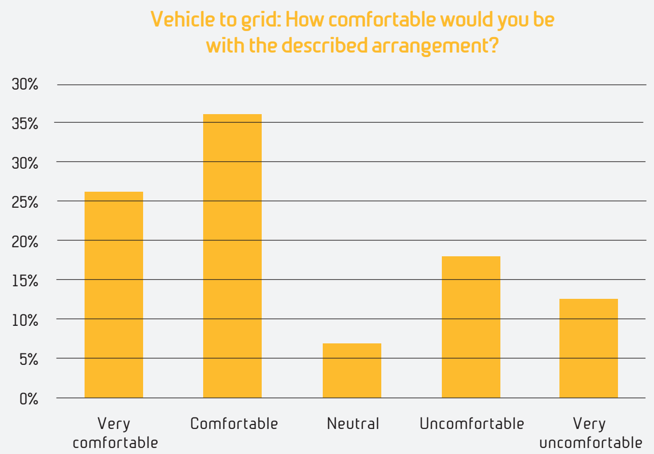
Vehicle to grid technology was explained this way to participants:

"Electric vehicles could potentially be set up to feed power back into the grid at critical times to help manage peak demand. Owners of these vehicles would get a payment or reward of some kind for allowing this, as it would mean the vehicle could not be used at these times and would take longer to recharge. The owner would have the choice of overriding the set-up if they needed to, but their payment would be less as a result."

When asked 'how comfortable would you be with this arrangement', 63% said they would be 'comfortable' or 'very comfortable'. 31% said they would be 'uncomfortable' or 'very uncomfortable'. See Figure 8.0.

Figure 8.0

How comfortable participants are with the idea of letting their EV be used to feed electricity into the electricity distribution network at key times (Vehicle to Grid)

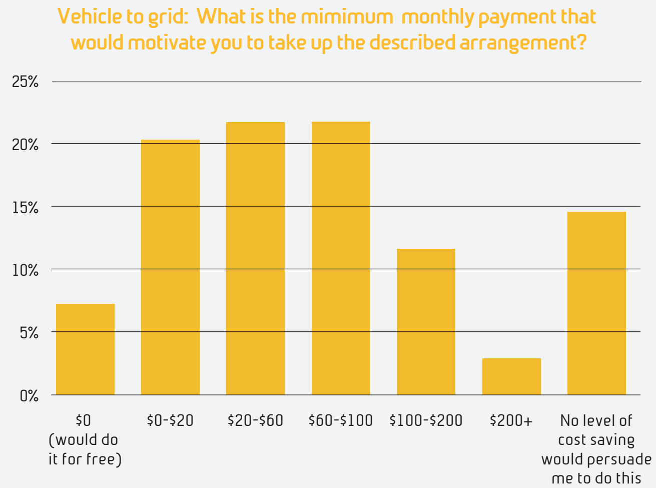


Of those that said they would be uncomfortable or very uncomfortable, 52% ranked 'it would be inconvenient' as their top reason, while 39% ranked 'it might shorten the battery life of my EV' as their top reason.

The level of financial advantage participants would expect to enter into such an arrangement is given in Figure 9.0 below.

Figure 9.0

Level of saving participants would expect for letting their EV be used for Vehicle to Grid



Discussion

The participants in the trial are somewhat exceptional in that they are part of what is currently an exclusive group, there being around 5,500 registered EVs in New Zealand at the time the trial was conducted. It could be expected that they are more conscious of environmental issues given their interest in EVs and thereby may be more conscientious about charging later at night, to minimise the greenhouse gas emissions associated with charging. (It should be noted that Flick Electric, who supplied 20 of the participants in the trial provides real-time information on the emissions intensity of grid-supplied electricity, which would give this group especially clear signals regarding this). Therefore the finding that most participants already charge outside the traditional evening peak would not necessarily apply to the population at large once EVs are more widely adopted.

However, the fact a small but significant proportion of participants who did not already charge after 9pm started doing so in response to advice and practical guidance would suggest public education is a tool that could be employed for influencing charging behaviours, alongside price and technology based measures.

Interest/comfort amongst the participant group for pricing incorporating demand charges, centralised control of charge timing and vehicle to grid technology were all high, with some people willing to use these for no financial reward. It suggests the electricity sector have a willing group in current EV owners to work with to further develop such systems and products.

It should be noted that over half of participants charge their EV with a standard 8A domestic wall socket. WorksafeNZ guidance discourages the use of this plug format for EV charging leads. It could be expected that as these leads become less common, the average peak power demand for EV charging will increase slightly compared to what has been measured in this trial, given the other charging formats have higher current ratings.

5,500

Registered EVs in NZ at the time of the trial

Prepared by Concept Consulting

Concept Consulting Group Ltd (Concept) specialises in providing analysis and advice on energy-related issues. Since its formation in 1999, the firm's personnel have advised clients in New Zealand, Australia, the wider Asia-Pacific region and Europe. Clients have included energy users, regulators, energy suppliers, governments, and international agencies.

Concept has undertaken a wide range of assignments, providing advice on market design and development issues, forecasting services, technical evaluations, regulatory analysis, and expert evidence.

Further information about Concept can be found at concept.co.nz

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Section 2.0

Analysis of electricity usage data

2.1
Methodology

2.1.1
Purposes and approach

This study is focussed on answering two broad questions:

1. **How and when customers charge their EVs**
   - In particular, what time of day do they start charging, for how long, and how much power do they use.
2. **How this might change in response to price signals.**
   - In particular, do customers on Time of Use (TOU) tariffs behave differently to others.

This analysis was based on half-hourly data from 77 EV-owning customers in Wellington Electricity's (we*) network, and the results of a customer survey that included information such as how often they drive their EV, and what retail tariff they use.

Given the relatively limited data set, and the fact that EV charging is separately metered, mathematical techniques have had to be used, including the development of a linear regression model, to enable EV charging patterns to be discerned.

The exercise also had to overcome a number of other data challenges, including considerable effort acquiring and processing the data from the eleven different retailers who provided it.

The electricity consumption data was "half-hourly" – that is, it specifies how much electricity is used in each 30-minute block of each day. This is the length of a trading period for the wholesale market, and is the highest resolution data available.

In addition to data from EV customers, data was received from a large number of customers without an EV. The data from customers without an EV served as a "control group" to help establish the ***difference*** in demand that results from an EV.

A key challenge in this process is that metered data isn't available for electricity used specifically for EV charging, as most EVs are metered as a part of the entire household's demand. Therefore, the electricity used for EV charging has had to be inferred from the total household demand data using mathematical techniques.

The majority of the analysis focussed directly on customers with an EV by comparing them with themselves:

- Electricity data was provided for the previous two years for most customers, and most customers have been using their EV for less time than that.
- This means that demand can be examined before and after the customer starts using an EV.

Although many things might contribute to changes in electricity demand for any single customer, the analysis looks at many different customers, so the individual changes mostly "cancel out". This process also works well because charging an EV is a substantial increase in demand.

2.2
Data validation

Half-hourly data was received from electricity retailers. Each retailer is required to supply data for the previous two years for each customer when requested. In an ideal world, this would be a straightforward process, but various complications meant that a large amount of effort was required to convert the supplied data into a useable form. Key data validation issues and processes included:

- Different data formats from 11 different retailers. Although there appears to be a standard electricity consumption format, many retailers used their own format with different fields and formatting types. The data was standardized into a single format, and combined into one database table.
- When a customer switches retailer, often both the new and old retailer continue to supply data, leading to multiple series for the same customer. Duplicates had to be identified and removed.
- The number and type of meters or registries at an ICP can change over time. To deal with this, demand was aggregated at an ICP level. It might be useful to look at differences between different types of meters or registries, but this was difficult because it was unclear which meter was which type. Ultimately, the main reason for doing the analysis at an ICP level was because the small number of customers meant that splitting the data further into meter type would result in very small sample sizes.
- Some customers had net negative electricity demand at times – presumably due to solar PV at their properties. This means that instead of importing electricity from the local power grid, they were exporting it. For the analysis, any negative values were set to zero. Local generation complicates analysis, and should be properly accounted for when modelling demand. However, since data on generation was not directly available - only the net demand was metered – it is simplest to ignore any electricity exports.
- The demand data was also "eyeballed" to determine if the reported start date for using an EV from the customer questionnaires coincided with a noticeable increase in demand. Generally, this was the case, but where necessary the start date was adjusted to match the observed increase in demand.

2.3
Analysis

The analysis attempts to answer two broad questions:

1. **How and when customers charge their EVs**
   - In particular, what time of day do they start charging, for how long, and how much power do they use.
2. **How this might change in response to price signals.**
   - In particular, do customers on Time of Use (TOU) tariffs behave differently to others.

The first question was addressed by looking at EV users, and comparing their demand before and after they started using their EV.

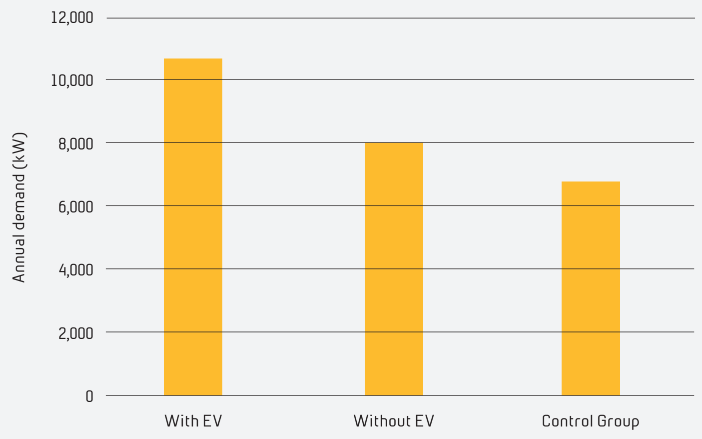
Electricity demand is highly seasonal, and the data set was for the period up to the end of winter. That means that an approach which simply looked at how electricity demand changed when customers got an EV, might incorrectly perceive extra winter demand as EV charging.

2.3.1
Simple before/after comparison

The simplest way to deal with this is to look at the increase in demand from the corresponding month in previous years. It was assumed that this difference is due to EV charging, rather than a seasonal effect.

Figure 10.0 shows the estimated annual demand[3] from customers who purchased an EV, both after they acquired their EV (With EV), and before (Without EV). Equivalent data from the customers who don't have an EV (Control group) is shown, which indicates that customers with an EV used more energy than the control group, *even when they didn't have an EV*. This is not surprising, and reflects that the typical household with an EV is different from normal. This may be because EV customers are wealthier than average, or perhaps that they have larger households.

Figure 10.0
Annual demand with and without an EV



3. This is extrapolated from daily demand data, which includes more winter months so may not accurately reflect a full year's worth of demand.

Average demand per customer increased by roughly 33% after acquiring an EV. At approximately 2,500 kWh, and assuming an average EV fuel efficiency of 0.18 kWh/km, this corresponds to an annual distance travelled of 13,900 km. This is consistent with MoT data on the average annual distance travelled by light private vehicles.

2.3.2
Demand duration curve

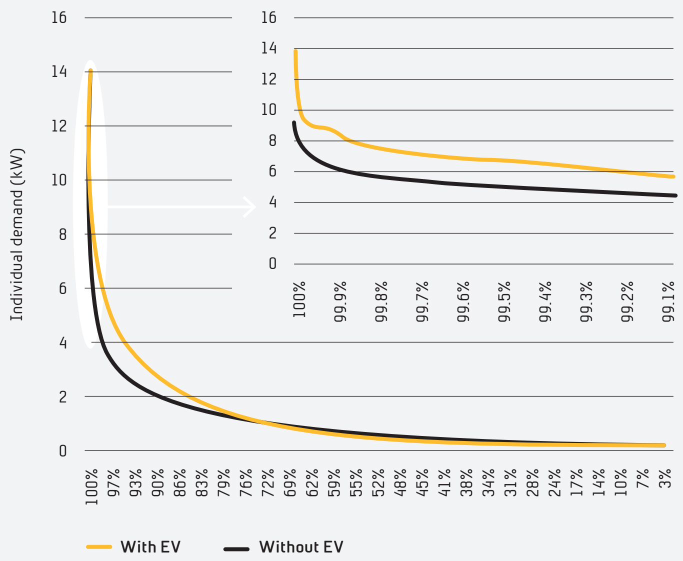
Another way to look at demand is with a "duration curve". Such a curve orders all the individual half-hour demand values from largest to smallest. This is a good way of visualizing the peak demand, minimum demand, and all the percentiles in between.

This was looked at from two perspectives:

- The duration curve of demand for individual customers.
- The duration curve of average per-customer demand for all customers combined. This is also known as the "after-diversity" demand.

Figure 11.0 shows the demand duration curve from individual customers with and without an EV. Each point on the graph represents a single half-hour reading for a single ICP, so the graph is showing both the variability through time, as well as the variability between ICPs. The graph within the main graph shows the top 1% of the curve, as this is of particular interest.

Figure 11.0
Duration curve for individual customer demand



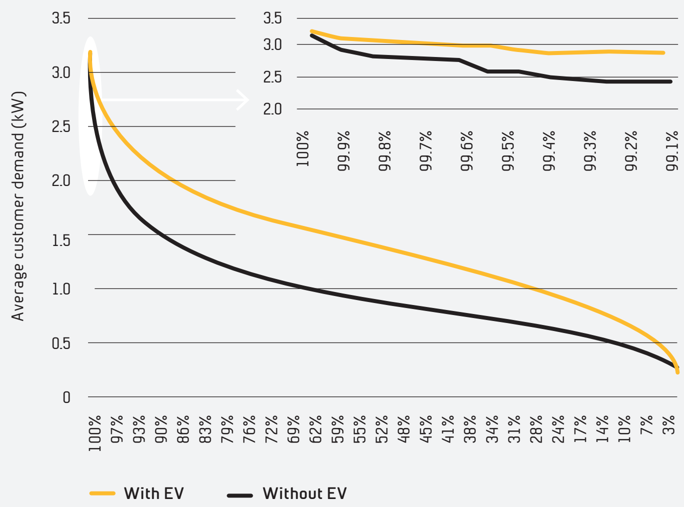
This graph shows the 'peakiness' of residential demand on an individual customer basis. Anytime maximum demand (AMD) by a customer can be more than 10 times the average for all customers.

On this AMD basis, peak demand for individual EV customers increases by about 4kW, or about 45%. Demand is higher for the entire curve, but the increase is proportionally lower the further down the curve. For example, demand in the middle of the curve is about 30% higher, and for the lowest part of the curve the demand is essentially the same[4].

This means that not only is average annual demand higher for EV customers, it is also significantly peakier on an *individual customer* basis.

Figure 12.0 shows the duration curve analysis on an ***after-diversity*** basis. i.e. the average increase across all customers with an EV – but expressed on a per-ICP basis.

Figure 12.0
Duration curve for individual customer demand accounting for diversity[5]



Whereas Figure 11.0 previously showed the increase in individual customer AMD due to EVs is likely to be approximately 4kW, Figure 12.0 shows the increase in ***after-diversity*** maximum demand per ICP due to EVs is likely to be approximately 0.5 kW (at the 99th percentile the point on the x-axis that corresponds to 99%).

This shows that there is significant diversity in the timing of when charging occurs between different customers.

4. Which results in the overall increase of 33% shown earlier.

5. This graph only includes data for September 2016 compared with September 2017. This is because this is month with the most available data.

This diversity in timing means that EVs cause much less increase in after-diversity peak demand compared with individual customer AMD.

This level of diversity benefit shown in the above analysis is understood to be consistent with the general levels of diversity benefit for non-EV demand.

For example, Box 1.0 below shows an extract from Orion's design standard for the capacity required for building new LV networks. This indicates the diversity effects are significant, even for relatively small numbers of consumers.

Box 1.0

Orion design standards for LV networks with small numbers of houses[6]

Diversity factor — Where less than 30 residential are connected to a substation or feeder, the ADMD must be increased by a diversity factor shown in the following table:

No. of houses	Diversity Factor	No. of houses	Diversity Factor
1	4.00	16	1.19
2	2.50	17	1.18
3	2.00	18	1.17
4	1.75	19	1.16
5	1.60	20	1.15
6	1.50	21	1.14
7	1.43	22	1.14
8	1.38	23	1.13
9	1.33	24	1.13
10	1.30	25	1.12
11	1.27	26	1.12
12	1.25	27	1.11
13	1.23	28	1.11
14	1.21	29	1.10
15	1.20	30	1.00

There is insufficient data from this current Wellington Electricity study to meaningfully replicate this Orion analysis of how the diversity effect for customers with EVs changes with the number of consumers.

However, based on the analysis shown in Figure 11.0 and Figure 12.0, and the data shown in Box 1.0, it is considered that an after-diversity basis is appropriate to consider the impacts of EV demand – even at the individual LV network level, given that such networks typically have approximately 50 customers.

2.3.3 Demand increase by trading period

A key consideration is when during the day the increase in demand occurs. Figure 13.0 shows the mean increase in demand, broken down by trading period. Note that the x-axis starts at 3am, and not midnight.

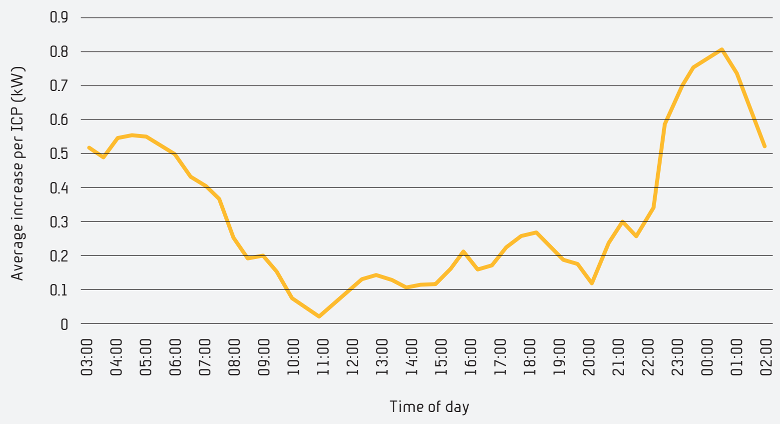
The additional demand increases dramatically at 11pm, and continues to increase until 1am. Then the additional demand decreases through the night. There's also a small increase during the traditional evening peak 6:30pm to 7pm).

This is consistent with most customers starting to charge their EV after 11pm. Demand increases, then drops off as the EVs are fully charged so stop drawing power. There is a small increase during the traditional peak (6:30pm to 7pm), as some customers plug in when they get home, rather than waiting until off-peak periods.

6. ADMD = "After-diversity maximum demand"

Figure 13.0

Simple before/after EV mean change in demand (note non-zero x-axis)



The above analysis has only looked at customers who have a long period with data with an EV, and also without an EV. This was only the case for only 38 out of 77 ICPs – i.e approximately half the available data.

2.3.4
Linear regression model

A more sophisticated method of looking at the before/after EV increase in demand is to create a linear regression model with "has an EV" as one of the input parameters. This model can isolate the effect of the EV, while correcting for other effects, such as seasonality.

Figure 14.0

Linear regression modeled before/after EV increase in demand (note non-zero x-axis)

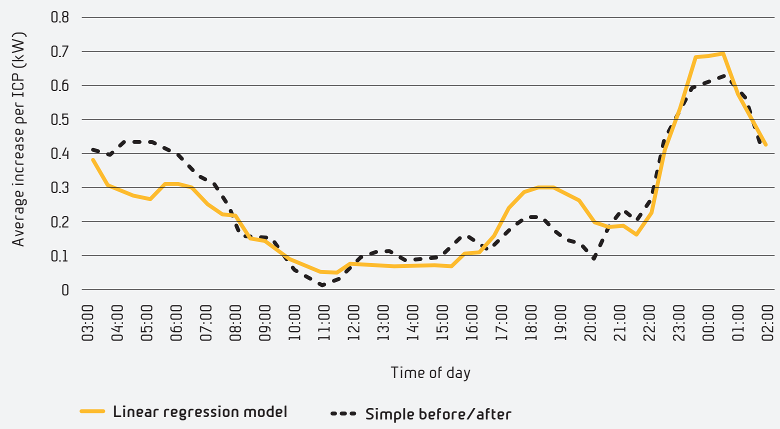


Figure 14.0 shows the results from the linear model (as well as the results from the simple approach.) The two curves are similar. The peak increase in demand occurs about midnight, and then drops off through the night. The increase in demand during the traditional evening peak (6:30pm to 7pm) is more pronounced in the linear model approach.

It also reveals a small peak in the morning between 6am and 7:30am. This is likely to be EVs "pre-conditioning" or "pre-heating" the battery and the cabin while plugged-in prior to being driven[7].

The linear model results are more reliable, as they include all the available data. The simple before/after approach should be considered a "check" on the validity of the linear model results.

7. In cold weather, batteries perform better if they have been pre-heated. Similarly, warming the interior of the vehicle while plugged-in prior to being driven will extend the range of the vehicle. Many EVs have the functionality to perform such 'pre-conditioning' to varying degrees of sophistication.

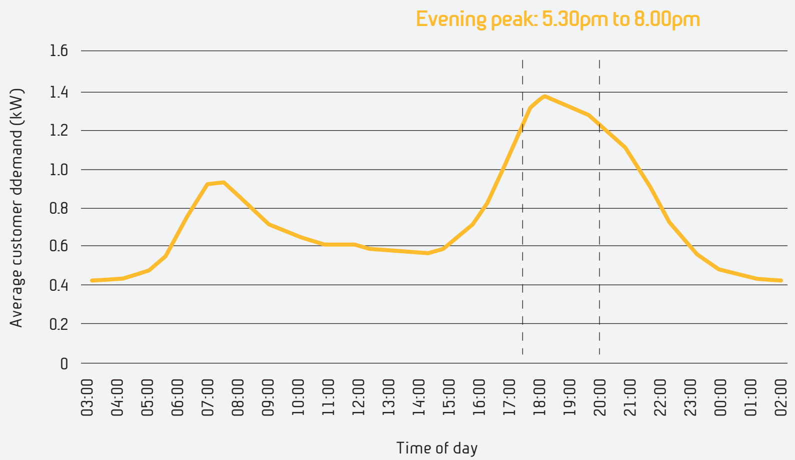
2.3.5

Aggregate EV users demand

Currently, peak electricity demand occurs sometime between 5:30pm and 8pm during winter evenings.

Figure 15.0

Average winter business day ICP demand per customer in control group (note non-zero axis)

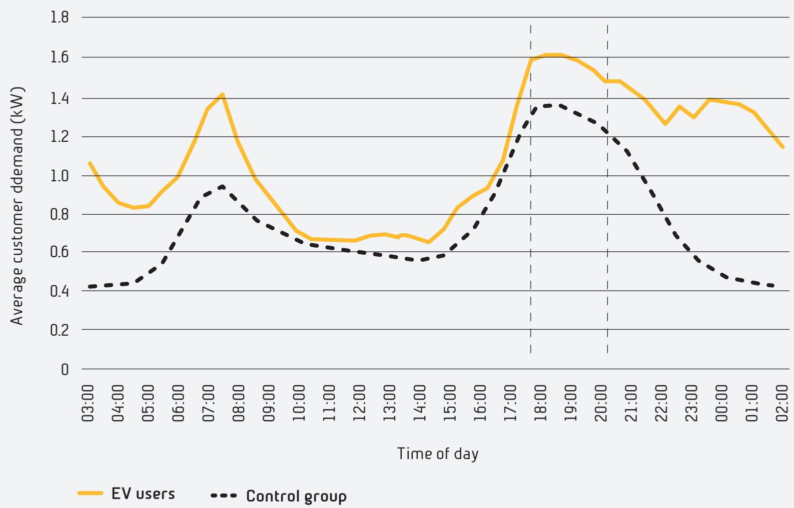


However, EVs are such a large source of demand, that this may change if they are all charged at the same time.

To see if this may be the case, the average per customer demand, a.k.a. "after diversity" demand, was examined for EV customers during business and non-business days. This is a straightforward approach and there is no with/without EV comparison – it just shows average demand for all EV customers, combining their EV demand with their other demand (heating, lighting, etc.)

Figure 16.0

Average winter business day ICP demand per customer for EV customers (note non-zero x-axis)[8]



On business days, there is still the traditional morning and early evening peaks, but there are also noticeable peaks later in the evening and in the early hours of the morning. There is a small increase in demand at 11pm, and a larger increase at midnight[9].

8. Note that a customer with extreme charging behaviour (see section 2.4.4) has been removed from Figure 16.0. This single customer had a noticeable effect on the overall demand, and caused peak demand to occur at 9pm.

9. This is consistent with the charging behaviour shown in Figure 14.0.

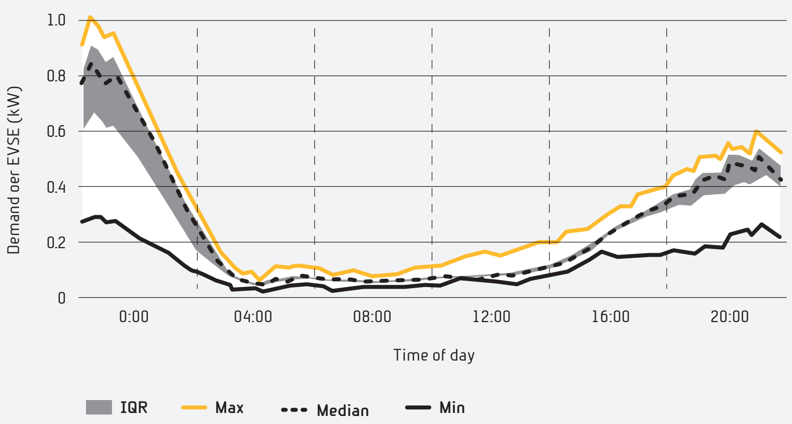
2.3.6

Comparison with international research

Stephen Schey, Don Scoffield and John Smart, *"A First Look at the Impact of Electric Vehicle Charging on the Electric Grid in The EV Project"*[10], looked at EV charging in the United States, and found similarly sized increases in demand. The "demand per EVSE" [11] shown in Figure 17.0 below is the increase in demand at a location from EV charging. This is analogous to the increase in demand per ICP due to EV charging for the Wellington Study as shown in Figure 14.0 (amongst others).

Figure 17.0

Weekday charging for EVs in the United States



The median increase in demand during the evening peak was about 0.3kW (compared to 0.4kW for Wellington). The highest median increase in demand during the day was about 0.8kW (compared to about 0.9kW for Wellington). These results are very similar.

The authors observed that the average demand per charging point is significantly less than the typical charging load for an EV, and commented:

> "On first glance, it may appear that the charging demand magnitude in these figures is too low. After all, a single Nissan LEAF draws about 3.3 kW during steady-state charging, yet the charging demand time-of-day plot never exceeds 1 kW. Note, however, that the percent of EVSE connected to a vehicle never exceeds 60%, - the figure 12 referred to is not here. Thus, the normalized charging demand per EVSE will never exceed 60% of the maximum possible demand for one vehicle. Furthermore, not all vehicles that are connected to EVSE are drawing power. At any given time, a fraction of the vehicles connected have full battery packs and have ceased drawing power from the EVSE. The charging demand plots show the resulting demand of EVSE with vehicles connected and drawing power, normalized with respect to all EVSE in the data set."

This supports our observation that the increase in after diversity peak is significantly lower than the increase in demand for any single ICP.

10. https://energy.gov/sites/prod/files/2014/02/f8/evs26_charging_demand_manuscript.pdf

11. EVSE is short for EV Service Equipment aka a charging point.

2.4
Customer response to Time of Use signals

The other key focus of the analysis was to look at how customers respond to different pricing structures. There were two main pricing options that were analysed – spot price exposure and the EV-Nite distribution charge.

2.4.1
Spot price exposure

The wholesale market settles every half-hour, with a different price for electricity in each period. Traditionally, customers have not directly faced the wholesale price and instead pay an averaged price to their retailer.

More recently, some retailers provide their customers with the option to pay the wholesale price directly, i.e. they are exposed to the spot price.

The charging behaviour of customers exposed to the spot price was compared with those on more traditional pricing structures. To do this, the linear model described in section 2.3.4 was used, and included a "spot price exposed" parameter for each customer with an EV. The model then produced differences in demand for each trading period. The differences were normalised so that the average difference across all trading periods was zero.

Figure 18.0

Change in demand for customers exposed to the spot price (note non-zero x-axis)

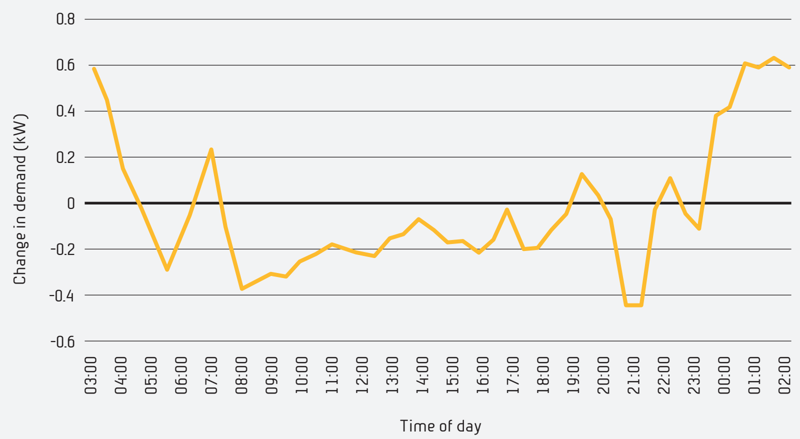


Figure 18.0 shows that customers exposed to the spot price use more demand between midnight and 4amand less demand in other periods. This suggests that those customers exposed to the spot price charge more during off-peak periods. This makes sense, because the spot price is often lower overnight than it is during the day.

2.4.2

EV-Nite customers

Wellington Electricity offers a tariff that is 5c cheaper between 9pm and 7am. Three retailers passed this onto their customers for the period covered in the trial.

Figure 19.0 below shows the change in demand for customers on the EV-Nite tariff.

Figure 19.0

Change in demand for customers exposed to Time of Use prices (note non-zero x-axis)

The change in demand is similar to Figure 18.0, but the effect is larger, and the reduction in demand during the evening peak is more pronounced.

It also indicates a more pronounced step-change increase in demand at the start of the night period. This is one of the potential concerns with a TOU signal.

However, this step-change increase appears to occur at midnight, which was not the start of the EV-Nite period. It is not clear why this would be the case:

- Possibly it is due to customers setting the EVs to 'delay' charging by a period of time, rather than setting them to start charging at a specific time.
- Possibly it indicates the relatively 'unusual' nature of the EV owners – being early-adopters of a technology, and likely to be more engaged with the electricity market. Such consumers' charging behaviour may be more attuned to what is likely to be least cost for the electricity market as a whole (i.e. charging in the middle of the night, rather than starting charging at late evening / early night – i.e. 9pm)

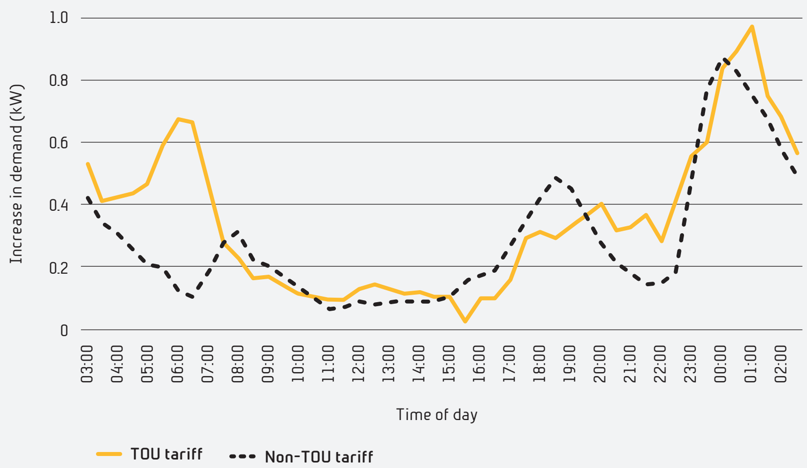
2.4.3

Overall effect of time of use pricing

Figure 20.0 shows the results of the linear model distinguishing between those who have some Time-of-Use price signal (EV-Nite and/or spot price exposure) – referred to as having a "TOU tariff" – and those with no time-based signal "Non-TOU tariff".

Figure 20.0

EV demand for TOU and non-TOU customers



The two types of customers have noticeably different charging behaviour.

- Non-TOU customers have two distinct peaks in the evening, corresponding to two different types of charging approach.
  - — The first coincides with the traditional evening peak, and probably corresponds to customers who plug in their EV as soon as they get home.
  - — The second, even larger peak about midnight, indicates that many more customers delay charging their EV till night time. Participant survey responses detailed in Section 1 indicate the reasons for this both reducing the impact on the environment by utilising night time power, (which has a higher proportion of renewable energy) and the other altruistic aim of reducing peak demand on the electricity network were rated as being important motivations for charging after 9pm by the majority. Only 7% of participants charging after 9pm adopted this behaviour during the trial, indicating the act of providing information on peak demand and practical guidance on timers had a small influence. This would suggest that a higher proportion of customers would likely charge when they get home in the absence of a price signal or guidance on desirable charging behaviour.
- TOU customers also have an increase in demand during the traditional evening peak, although it is smaller. The increase does not decrease through the evening and there is also a peak about midnight from delayed charging.

In the morning, customers on a TOU tariff showed an increase in demand prior to the end of the EV-Nite period (7am). The non-TOU tariff customers also have a morning peak but it is much later. Both such peaks are likely to be due to vehicle pre-conditioning while plugged-in – i.e. warming up the battery and cabin on cold days to improve the range of the vehicle.

2.4.4
Electric Kiwi "Hour of Power"

Electricity Kiwi offers their customers one off-peak "Hour of Power", during which they are not charged for their electricity use. This creates a strong incentive for their customers to shift load into that hour where possible. Data was collected for four Electric Kiwi customers.

The data from one customer indicates the potential power of price incentives to influence consumer behaviour.

Figure 21.0
Electric Kiwi customer demand

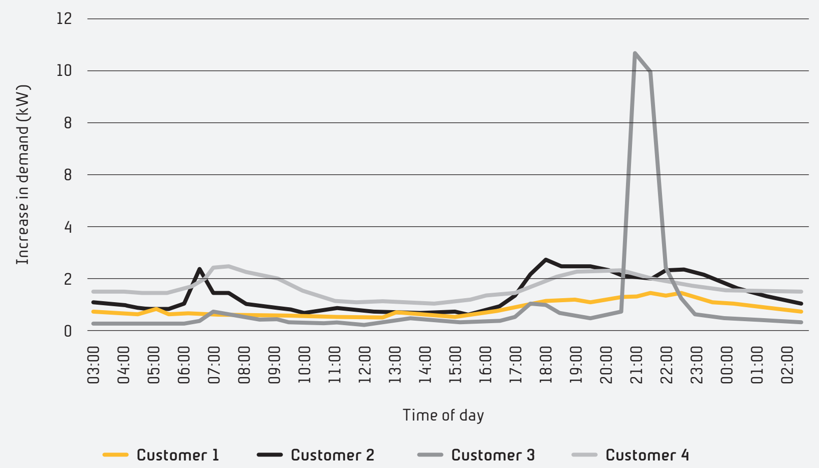


Figure 21.0 shows the average demand through the day. Customer 3 manages to consume 45% of their demand during this hour. Bearing in mind that this is *average* demand, the peak demand for the customer is even higher at 18kW[11]. Such behaviour would put a high load on local networks if it were adopted more widely.

11. Unfortunately, customer 3 is not included in the majority of the analysis. This is because only 9 months of data was available for them, which doesn't include a period before they used an EV.

2.5
Conclusion

EV charging will materially increase average residential demand: By approximately 2,500 kWh per annum – roughly 35% of the average residential demand.

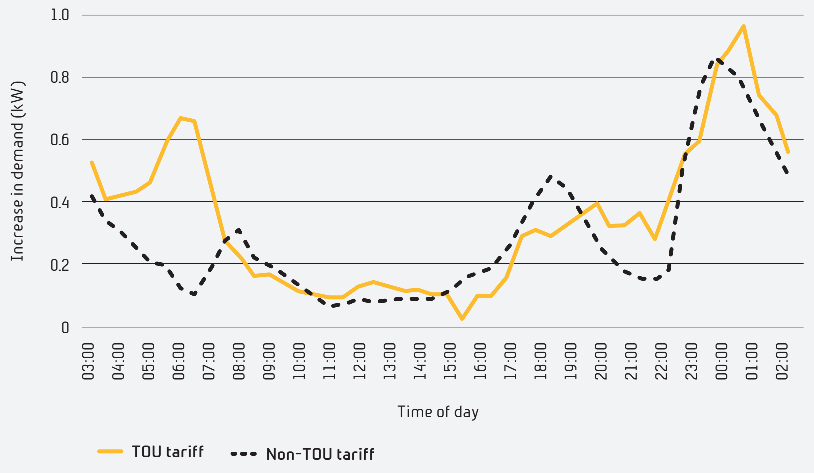
In the absence of an electricity price signal, a significant proportion appears to occur when people get home from work – coinciding with electricity system evening peak. However, despite chargers typically having capacities of 2.5 to 4 kW, there appears to be material diversity in the start of and duration of such charging, meaning the after-diversity kW impact is likely to be of the order of 0.5 to 0.8 kW.

However, in the sample of EV customers examined, a greater proportion appears to occur much later – i.e. midnight and beyond. This is even when customers have no electricity tariff incentive to do so. Given the small, and potentially 'unusual' nature of the sample group (i.e. technology early-adopters), it is not possible to infer whether this would be typical of charging behaviour when EVs are adopted more widely.

There is also a material increase in demand in the morning peak (although half that of the evening demand increase). This is understood to be associated with 'pre-conditioning' of EVs in the winter – i.e. in the half-hour or so before the car is to be driven, warming up the battery and cabin while the car is plugged-in in order to increase the vehicle range.

Notwithstanding that many of the EV consumers in this study charged their vehicles overnight even without an electricity tariff incentive, a far greater proportion of EV consumers who were exposed to a time-of-use tariff signal charged their vehicles outside of the evening (and morning) peaks. This effect was greatest for those exposed to the we* EV-Nite tariff, but was also significant for those exposed to spot wholesale prices (e.g. Flick customers). This difference is illustrated in Figure 22.0.

Figure 22.0
EV demand for TOU and non-TOU customers



This customer response to tariffs is potentially a double-edged sword:

- In the short-term is has a beneficial effect in terms of moving EV demand outside of the electricity system peak.
- In the long-term, as the number of EVs purchased by customers increases, it may create a new peak coinciding with the start of the off-peak period.

Further, if all vehicles start charging at the start of the off-peak period all the significant diversity benefits that have been observed with EV charging would be lost, leading to the new peak being significantly greater than the current network peak. This additional peak demand could be of the order of 4kW per EV – on top of the approximately 1.5 kW per customer after-diversity demand at 9pm on a cold winter's evening. This is considerably greater than the current peak demand of approximately 2.25 kW per customer during current peak periods.

2.5

Conclusion (cont.)

The sample group with the EV-Nite tariff did not show a sharp increase at 9pm (when the EV-Nite period started) but a couple of hours later. It is not clear why this would be the case.

In terms of the diversity effect, the analysis shows that while the anytime peak demand of individual customers increases significantly with an EV (by approximately 4 kW for the sample), the after-diversity peak increase for the sample is significantly less (approximately 0.5 kW to 0.8 kW).

This diversity effect is significant, even for relatively small groups of customers – i.e. of the order of 5 or so. As such, unless TOU signals create incentives for a new sharp, step-change peak at the start of the off-peak period, EV uptake may not cause widespread capacity exceedance on the low voltage networks (which typically have 50 ICPs).

Appendix A

Non average analysis or, a closer look at individuals

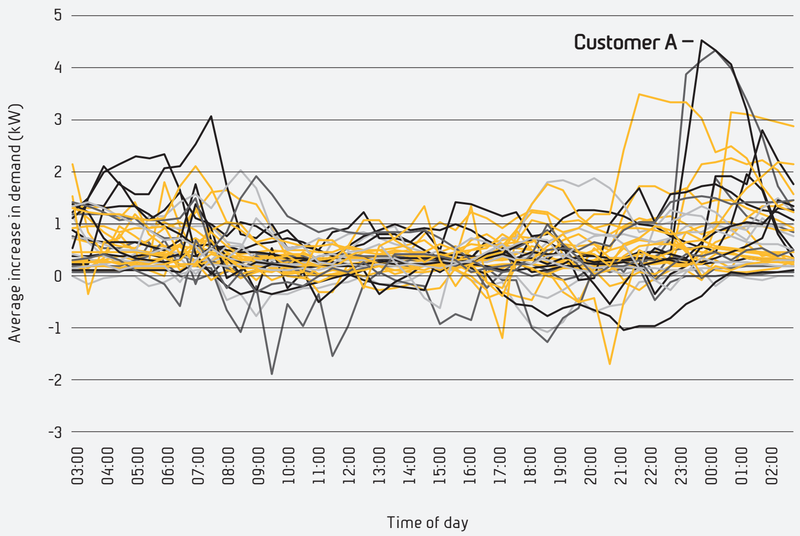
The analysis in the main report has principally focussed on the average increase in demand due to EV charging[12].

This appendix examines the impact of EV charging on individual customers.

Figure 13.0 previously showed the average change in demand across 38 customers whereas Figure 23.0 below shows the average[13] change in demand for the individual customers that made up that graph.

Figure 23.0

Increase in demand for multiple customers (note, non-zero x-axis)



Clearly there is a lot of difference between customers. Some customers stand out, and have increases of 4kW or more, which is many times the average increase. Bear in mind that this is still the average increase for those particular customers, and the actual value may be much higher on any single day.

1.1 Customer A

Customer A from Figure 23.0 has a very large increase in demand during off-peak hours. It appears that they charge their EV starting at 11pm, and are normally finished by 2am. Figure 23.0 shows their average increase in demand, but this obscures the details of their behaviour.

Figure 24.0 shows the maximum daily demand from the customer over the previous two years. Maximum daily demand was between 1 and 3kW before they acquired an EV in early 2016. After that, most of the time maximum daily demand was above 6kW consistent with the change in the individual customer load-duration curve shown in Figure 11.0 previously. However, occasionally, presumably when they did not charge their EV, maximum demand was much lower, similar to the earlier period.

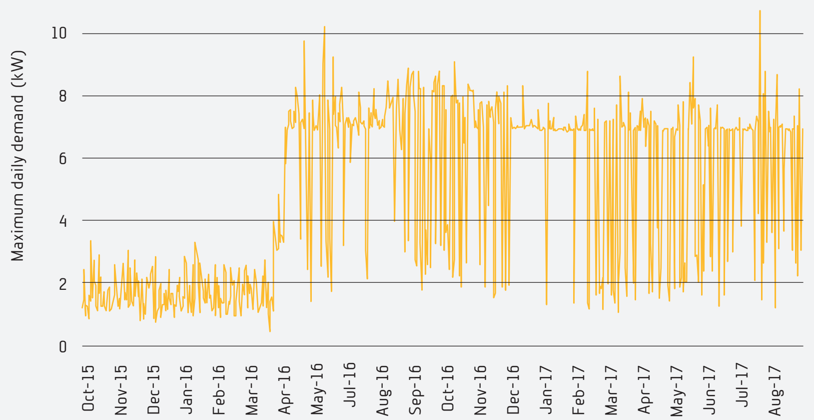
It's easy to see how averaging these two situations can lead to the 4-5kW average increase shown in Figure 23.0 However, this average includes those days when the customer didn't charge the EV.

12.The linear model analysis is also a form of averaging.

13. There is still some averaging going on here. This is the average increase for a particular customer in that trading period across a number of different days. Figure 13.0 went a step further and averaged each customer's average increase in demand.

Figure 24.0

Maximum daily demand for a customer



For looking at the wider network, an analysis that considers averages is appropriate. However, an alternative approach that doesn't just use averages, might be useful for looking at the local level.

1.2
Percentile analysis

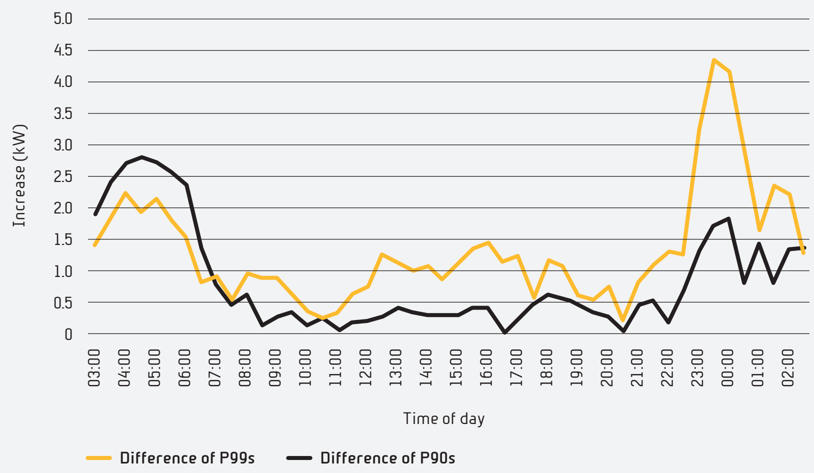
One way of looking at a highly variable parameter is to look at different percentiles of the distribution. The "P90" value of a distribution is the 90th percentile value. For example, the P90 value of the data in Figure 11.0 corresponds to the value at the 90% mark. Similarly, the "P99" value corresponds to 99%.

Figure 25.0 shows the increase in the P90 and P99 demand for customers with an EV[14]. This has a similar shape to the previous demand increase graphs, but the scale is much larger. This makes sense, as more extreme behaviour is being examined, rather than the average.

Note: Again, this is for an individual consumer basis, not an after-diversity basis.

Figure 25.0

Increase in P99 and P90 demand for individual consumers with an EV (note non-zero x-axis)



This graph can be interpreted as the expected increase in demand at a certain risk level. It is hard to quantify exactly what risk level, because this is the distribution for all customers, so it is heavily dependent on assumptions around load diversity.

14. It is slightly counterintuitive that the P90 curve is higher than the P99 curve at times, but this is correct, since this graph is showing the differences. The P99 demand is still higher than the P90 demand in all cases, but the increase in P99 demand is less than the increase in P90 demand.

1.3

Terminology

Cost Reflective Pricing

An electricity tariff which uses variable prices to signal the difference in cost between higher and lower consumption periods.

EV

Electric Vehicle.

EVB

A cost reflective TOU tariff from Wellington Electricity having cheaper night charge periods and more expensive peak demand period charges. EVB replaced EV-Nite from 1 July 2018.

EVSE

Electric Vehicle Supply Equipment – what is used as the device to charge the EV.

HHR

Half Hour resolution, a measurement from an electricity meter over a half hour period.

Kilowatt (kW)

Measurement of energy demand which when measured over an hour represents customer consumption of electricity units (kWh).

Lines Charge Tariff

Lines Companies recover their network costs through lines charges which are bundled by the customers Electricity Retailer into the customer electricity bill.

PHEV

A plug-in hybrid EV. PHEVs can connect to a power supply to recharge their battery but also use a conventional internal combustion engine to extend their range.

Off-Peak

The period of the day when there is the least demand for energy on the network. This will occur between the peak demand periods.

Peak

The period of the day when collectively there is the highest demand for energy on the network. At the residential level there is a morning and evening peak on the Wellington Electricity network.

Retailer

Electricity Retailer has the financial relationship with all customers for billing energy used, including packaging of the lines company tariff portion.

Spot Price

The actual wholesale market price of energy which changes on a half hour basis. Most customers take an average retail price for energy, however new retailers to the market are allowing customers to take a wholesale price which has the reward of cheaper energy and risk of expensive energy unlike the averaging of the retail price option.

Tariff

The charge or utility fee a lines company recovers for customers using the electricity infrastructure. The charge is packaged by electricity retailers who add this to the energy bill to customers.

Time of Use (TOU)

A Lines Charge Tariff which uses different charge rates in different time periods. Hence the time of use of electricity will attract different costs. Higher costs are assigned to higher usage periods to signal cheaper costs for shifting demand to less congested time periods.

Ngā mihi nui

Thank you