Will Flipping the Fleet F**k the Grid?
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Overview
High penetration of EVs could lead to a substantial increase in total electricity load in car-dominated transport systems countries such as New Zealand (Transpower 2018). As an example, it has been predicted that if all current light private vehicles were electric, annual New Zealand residential electricity consumption would increase by ~30% (Concept Consulting 2018). In part this assumes concurrent charging, especially in the early evening when many motorists return home from work (Speidel and Bräunl 2014; Langbroek, Franklin, and Susilo 2017). This in turn could negatively impact the operation of a low-carbon renewables-based grid by increasing peak loads (Azadfar, Sreeram, and Harries 2015). In low-carbon electricity systems this could put additional pressure on non-dispatchable generation such as wind and ultimately lead to the prolonged use of carbon intensive peaking plants. In New Zealand’s case, such peaks are usually met through hydro generation running at close to full capacity (Khan, Jack, and Stephenson 2018) and it is currently unclear if hydro, in the absence of storage, can adequately meet these potential increases. There is a risk therefore that one of the key policies intended to reduce transport emissions could, inconveniently, lead to increased electricity related emissions.

However, recent analysis of time use data has suggested that commuting patterns may be more temporally heterogeneous than usually assumed (Mattioli, Anable, and Goodwin 2019) so that synchronised evening peak period charging may not occur. In addition, EVs have been proposed as a peak shaving mechanism due to their ability to feed electricity into the grid at times of peak demand. This could offer a form of demand response (Kempton and Tomić 2005) that may even reduce the need for expensive peaking generation and local network capacity investment (Strbac et al. 2016). Management and, if necessary, modification of the home charging behaviour of EV owners is therefore a key opportunity for electricity system flexibility. Unfortunately modelling of the potential impact of future EV uptake is hampered by a lack of real world data on EV users’ charging behaviour (Rezvani, Jansson, and Bodin 2015).

In response, this paper utilises EV charging data collected from a sample of ~ 50 electric vehicles over an extended period of time to provide preliminary insights into the potential effects of a dramatic increase in domestic EVs on the New Zealand electricity grid. In doing so we focus on two key research questions: 1) how much EV charging tends to occur in (evening) peak demand periods and 2) to what extent could pre-charged EVs be used to feed electricity into the system during peak demand periods?

Methods
Anonymous data was collected from 19 24kWh Nissan Leafs, 21 30kWh Leafs and 7 eNV200 vans voluntarily monitored from 2018-04-05 to 2019-03-01 by members of Flip The Fleet, a New Zealand based EV community project. The monitoring devices decode signals from the Leafs electronic systems and transmit data on vehicle performance, distance travelled, charging times and rates and battery capacity to a centralised database every minute. It has therefore been possible to observe details of EV charging behaviour for a convenience sample of the predominating model of small and early EVs in New Zealand conditions. Obviously, different charging patterns will occur for EVs with much larger traction batteries, so utmost caution is needed to extrapolate the details to set wider and future expectations of electricity demand across all of New Zealand’s EV fleet.

The data reported here consisted of 1,882,040 1 minute interval observations of timestamped measurements of charging power (kW) and battery charge state (% charged). The data received contained all available observations but charging was set to 0 kW if the vehicle was non-stationary (speed > 0 km/h) prior to analysis. This enabled the exclusion of charging through regenerative braking from the analysis. Further we defined...
standard charging as a charging rate of < 7kW and ‘rapid charging’ as a charging rate of > 7kW based on the maximum available AC charging rate of 6.6 kW for Nissan Leafs and eNV200s.

It should be noted that these EVs have on-board timers that allow a user to restrict when their car charges. Users can simply come home and plug-in and confidently expect the main traction battery to be charged by some designated time (usually early the next morning). It is also possible on most models to set the maximum State of Charge (SoC) of the traction battery, at which point the charging is automatically terminated. We discuss how these technologies manifest themselves in the data below and it may also be possible that some owners were deliberately controlling the timing of charging beyond this simple ‘ready now’ setting. Unfortunately, we have no additional data on such behaviour.

**Results**

Our results show that standard charging sequences were longer with a median duration of 210 minutes compared to rapid charging events (14 minutes).

Rapid charging events were comparatively rare in this sample and tended to occur during the day beginning at 08:30 on weekdays and peaking around 11:30 before declining towards early evening (see Figure 1). Standard charging events dominated and occurred with the greatest frequency between 20:00 and 08:00, with much lower occurrences of charging during the morning peak demand period (07:00 – 09:00). Standard charging steadily increased from this morning low through the afternoon but did not substantially increase until 21:00.

![Figure 1: Time of initiation of rapid and standard charging events in 45 Nissan Leafs and eNV200 vans being monitored by Flip the Fleet. (Known peak demand periods shaded)](image)

Figure 1: Time of initiation of rapid and standard charging events in 45 Nissan Leafs and eNV200 vans being monitored by Flip the Fleet. (Known peak demand periods shaded)
There is little difference between weekends and weekdays in terms of the distribution of energy (kWh) drawn across peak/non-peak periods with overnight/early morning standard charging dominating as we would expect (see Figure 2). Consumption during morning peak periods is low but slightly higher in the evening peaks as the charging timing results above would imply. Rapid charging plays a larger role in day-time energy consumption but its rarity in this sample means that despite higher power demand (kW) it’s energy impact (kWh) is relatively low. As a consequence, \((38.6 + 15.2) = 54\%\) of the total energy drawn during charging was overnight off-peak standard charging. Day time standard charging was 19% of the total and day-time rapid only 8%, while evening peak standard charging was 12% of total energy while evening peak rapid charging was only 2%.

Analysis of the vehicles’ state of battery charge confirmed other research (Speidel and Bräunl 2014) suggesting that half of standard charge sequences begin with battery state of charge (SoC) at \(~50\%\) and this is roughly constant across time periods (Figure 3). In contrast, half of rapid charging sequences started with SoC of 43% and a higher proportion of rapid charging events start with relatively low SoC, presumably reflecting use of rapid chargers on longer distance travel. SoC of 5% or less was observed in just 1 rapid charging event out of 455, presumably when a traveller only just made it to the next rapid charger during a long-distance journey. However, 34% of rapid charges were started when the battery was already over half charged suggesting a degree of ‘just in case’ or planned charging prior to a longer trip segment.
Figure 3: Value of State of Charge at beginning of charging sequence

Figure 4: Mean value of state of charge at start of charging sequence by time of day
Figure 5: Value of state of charge at end of charging sequence

Figure 4 shows that the mean % state of charge is generally higher in the early morning as would be expected from the previous time of standard charging results. This state at the start of a standard charging event typically then falls but remains at roughly 50% throughout the day irrespective of weekdays or weekends. For rapid charging events the mean state of charge is slightly lower and, although the number of occurrences is much smaller (see Figure 1) appears to increase slightly on weekend evenings.

Standard charging, generally undertaken overnight, mostly leads to an end state of 100% with a small number clearly capping at the recommended 80% (Figure 5). In the case of rapid charges on the other hand, the end state is generally lower perhaps reflecting (i) the tighter time constraints of their use (see median duration above), (ii) cost minimisation by users of rapid chargers, and/or (iii) the restriction of some rapid charges to 80% or 95% maximum SoC.
Making the assumption that each EV has a 24 kWh battery we can calculate the available kWh at the start of each charge for V2G purposes. The results are shown in Figure 6 and indicate that the median kWh available during the evening peak period is ~ 12 with an interquartile range of 8 to 14 kWh. We can also see that similar values are available in the morning peak period but further analysis would be required to estimate how much of this could be used during the period without impacting subsequent use. Given that the mean evening peak electricity consumption in New Zealand has been estimated to range from 5 kWh (summer) to 16 kWh (winter) (Anderson et al. 2018), this suggests that an EV could be used to provide most of the electrical energy required by a household during this period provided that no further mobility occurred before a re-charge.

Conclusions

Overall, these patterns suggest that whilst this sample added some additional consumption to the evening peak period, their energy draw tends to be concentrated in the off-peak over-night and day-time periods. It seems that many drivers appear to already minimise charging during peak electricity demand periods, presumably through the use timers to take advantage of off-peak electricity. In future larger batteries may lead to prolonged charging events and less ‘range anxiety’ so that even greater flexibility of home charging may be possible. Our results suggest that in this sample of monitored EVs at least, peak demand charging is therefore less prevalent than feared. Policy and pricing of electricity could therefore encourage even less LEV charging during peak periods than appears currently to be the case.

Rapid charging is currently much less frequent than standard charging but could have significant future network effects during the day and in the late evening and overnight if residential systems are upgraded as expected (KPMG 2019). However, if the reported temporal patterns of charging at home are maintained, even where larger batteries are available, this may not significantly impact existing periods of peak demand. The state of charge analysis demonstrate the potential for Vehicle-to-Grid (V2G) and ‘Vehicle-to-House’ (V2H) power flows during peak demand periods, as many vehicles are beginning to charge with substantial available stored energy on most days. Our calculations suggest that the median available charge could shave most of an average household’s peak electricity consumption although current technology may not be able to support the rate of power draw that may be required for some appliances. However, if V2G and V2H technology can be established, and larger batteries become more prevalent, there is ample scope for EVs to contribute their stored energy to other uses and release pressure on the local electricity network in particular. Most owners would require retention of some minimum charge in the EV and reaching some set minimum threshold by the
time the owner needs to use the car on most mornings. There may be a trade-off between these minimum storage requirements and the financial reward for contributing power back to the national grid or using it in the owners own house or business.

Further, it should be noted that maintaining the battery at higher charge than is necessary will accelerate battery capacity fade, reduce the practicality of the car as maximum range reduces reduce the lifetime return on investment and sustainability footprint of the EV. The data (e.g. Figure 4) suggest a need for an awareness programme to encourage drivers to not continually top-up their battery unless they are sure they will need the extra energy before finding the next charger. A small number of owners appear to terminate standard battery charging at around 80% using the Leaf’s control systems where this option is fitted. This is an important component of any ‘avoid, reduce, reuse, recycle’ strategies for the main EV component, its traction battery and could form part of an actively managed V2G system.

In summary, if these patterns of behaviour are maintained the results suggest that there appears to be a relatively low risk that EVs will substantially increase evening peak electricity demand with its potential to disrupt a future renewables-based electricity system. In contrast, vehicle to grid energy flows could make substantial contributions to actively reducing peak demand and enabling more efficient incorporation of non-dispatchable renewables into a low-carbon electricity system.

References


Concept Consulting. 2018. ‘Driving Change – Issues and Options to Maximize the Opportunities from Large-Scale Electric Vehicle Uptake in New Zealand’.


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Users are charged both for the time they occupy the charger (a way to reduce congestion) and for the amount of energy uploaded to the battery.