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# Impacts of Electric Vehicles on Australian National Electricity Market and Household Expenditure under Different Charging Regimes

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## Abstract

In the rapidly changing energy landscape of Australia, the technology choices made by individual customers have had a significant cumulative impact on the electricity industry. In the past decade, for example, the rise of household air-conditioning and the rapid deployment of small scale PV have both significantly impacted the size of peak system demand, and the time that it occurs as well as overall levels of consumption. The implications for generation, network and retail participants have been profound. Electric Vehicles (EVs) represent another possible technology choice with significant future impacts on the electricity industry. EV charging patterns are likely to be correlated according to typical patterns of office hours and commute times. As a result, the possible cumulative effects of widespread EV deployment might be considerable. In particular, the timing of EV charging is likely to influence whether electric vehicles increase or decrease the load factor of Australian electricity networks. The timing of charging appears to be influenced by a number of factors including the available charging infrastructure, the type of charging technology and the tariff structure.

For this paper, load data from over 4000 households from one Australian Distribution Network Service Provider was used in conjunction with charging data from a number of Australian EV trials to model the potential impacts of EV charging strategies on peak loads. In addition, the financial impact of each charging strategy on individual households under current tariff arrangements is considered, and the possibility of maximising the value of PV generation through daytime charging is explored. On the basis of the analysis, tariff and charging options that would incentivise more efficient use of the network, and maximise the overall value of PV generation and EV deployment are recommended.

## 1. Introduction

The electricity industry in Australia has been markedly changed by the cumulative impact of household decisions relating to first air-conditioning (AC) and now photovoltaics (PV) over the past decade (Sandiford, Forcey, Pears, & Mcconnell, 2015). Individual household choices relating to electric vehicles (EVs)[1] seem likely to have a cumulative impact of similar magnitude over time. Like AC, EVs are likely to increase total electricity demand. Like PV, EVs are likely to change the overall demand profile across the electricity industry (Saddler, 2015). How the demand profile across Australia changes as a result of EVs will have significant impact on future electricity infrastructure investment.

[1] Within this paper, an EV is assumed to be a plug-in vehicle that receives all of its energy through electric charging (AECOM, 2012).

The demand profile of EVs is dependent on the charging pattern adopted, which is in turn dependent on the capabilities of the charger used, the available charging infrastructure and the incentives provided by electricity tariff structures. The purpose of this work is to provide a high level review of the impact of various charging strategies and the factors that will influence the likelihood of adoption of each one.

The introduction and mass deployment of AC in Australia corresponded with an increase in overall demand and, notably, peak demand (Passey, Watt, & Brazzale, 2013). In particular, AC has contributed more than its fair share to growth in peak demand, and hence infrastructure investment. Key to this has been the highly correlated operation of household air-conditioning across periods of extreme summer heat. In consequence, there has been a decrease in grid load factor with periods of peak demand often representing less than 1% of total hours. This is not an efficient use of infrastructure, and it is not desirable that this inefficiency be exacerbated.

EVs are a flexible, distributed load that can potentially charge at any time, and even perhaps discharge at any time, when the vehicle is not in use and near appropriate charging infrastructure. There is already considerable literature that investigates the opportunities provided by vehicle to grid (V2G) capabilities (Guille & Gross, 2009). If these capabilities were optimised, aggregated groups of EVs would be able to provide grid services such as load shifting, peak smoothing and FCAS services (Went, Newman, & James, 2008).

At the system level, EV charging has the potential add flexibility on the demand side, which will be increasingly valuable in wholesale energy markets and to relieve transmission congestion where there is a significant fraction of low-cost, non-dispatchable variable renewable generation capacity in the system (refs). In particular, daytime charging would be a good match to distributed and/or centralised PV generation, subject to generation variability. In addition, the aggregation of EV charging station load might be able to offer FCAS services or demand response in the wholesale market (Guille & Gross, 2009; Platt, Paevere, Higgins, & Grozev, 2014; Sioshansi, 2013). In the distribution system, control of EV charging could be used to reduce the range of distribution feeder voltage, eliminate reverse power flow on feeders when PV generation exceeds load (ENA, 2015), and potentially offer avoided augmentation and other power quality and reliability benefits.

If widely adopted, EVs would certainly add significantly to total electricity demand, and based on expected patterns of EV use and residential charging, if charging is not controlled, it is possible that EV charging would increase system peak, which often occurs close to 6pm, driven by the residential peak caused by consumers returning home at the end of the day (Nicholls & Strengers, 2015). However, EVs as a controlled load could be shifted to preferred times of the day (AECOM, 2012). The question becomes: what tariffs or infrastructure provisions would encourage EV charging at times where the grid is under-utilised?

Section 2 of this paper will review the extent of correlation between daytime commuter charging and PV generation emerging from recent EV trials in Australia. Section 3 will investigate the likely financial impacts of typical household charging, and therefore the incentives for charging at particular times under different tariff arrangements. In Section 4 the contribution of EV charging to peak demand will be investigated. The paper will conclude by briefly discussing future research opportunities.

## 2. Potential complementarity of daytime EV charging and PV generation

The primary impact of residential PV in Australia on the electricity industry results from the increase of daytime generation, largely seen as reduced household consumption over that period. This creates both opportunity and problem: PV provides low cost supply of electricity close to the point of consumption. Its distributed nature offers potential benefits such as reduced local losses and delayed network upgrades in some areas (Olivia, MacGill, I., 2011). However, the reduced system load can also push the wholesale price of electricity during the day into low or even occasionally negative values (McConnell et al., 2013). At times of low load and high generation, PV can also contribute to voltage issues on feeder lines (Grace, 2014), while rapid ramping of conventional generation is required as PV stops generating as the sun goes down. If well managed, EVs could help reduce these negative impacts, while taking advantage of the opportunities that flexible load charging can provide.

Recent Australian EV trials have been conducted in Perth, Melbourne and also in New South Wales as part of the Smart Grid Smart City (SGSC) project. While each of these trials have been small in scale, with only a small number of vehicles and participants, they provide an initial indication of Australian consumer behaviour when using and charging EVs.

Charging data from each Australian trial shows different consumer charging habits, according to available infrastructure (Victorian Government, 2013; Mader & Braunl, 2012); Norris, 2014). It was very clear that available infrastructure makes a difference in charging habits. If charging stations were available in commercial precincts –eg shopping centres and commuter or fleet carparks – they were well utilised, and this influenced overall charging patterns. In the Perth EV trial, over 80% of EV charging took place either at home or at work (Terrence, Mader, 2012) In the both the Perth and Melbourne trials, where the infrastructure was available, consumers charged during the daytime in commercial locations. This suggests that commercial daytime charging facilities would be well utilised if available, and that EV charging load could be met by PV generation. PV is already contributing 2% of total electricity demand in Australia annually (CEC, 2014), and much higher fractions for short time periods in some regions, such as SA, where more than 25% of the load at around midday on clear sunny days is now sometimes being met by distributed PV (APVI, 2014). This share is set to rise, as the amount of PV in Australia is projected to double in the next few years (AEMO, 2015), which is likely to put downward pressure on prices in the wholesale market, as already been seen in Queensland, and more widely across the NEM (McConnell et al., 2013).

Most of the EV charging stations used in the Perth trial were able to supply the majority of the average daily energy requirements with a 2-3 hour period, so uncontrolled charging resulted in sharp morning peaks between 6:30-9am for the average charging profile, as seen below in Figure 1. However, as vehicles are often parked for the duration of the work day, allowing cars to graduate their rate of charge across the day might better match usage patterns and PV generation. This could take the form of *controlled* charging, where the timing and rate of charge is collectively managed by the infrastructure operator, or *smart* charging, where the timing and rate of charge is managed individually through the vehicle. Such smart charging could combine the car's user information, including average number of hours parked, with weather forecasts to optimise charging. By providing technology to facilitate, and incentives for, smoothed daytime EV charging, EVs could facilitate a low carbon, efficient electricity system with a high penetration of RE.

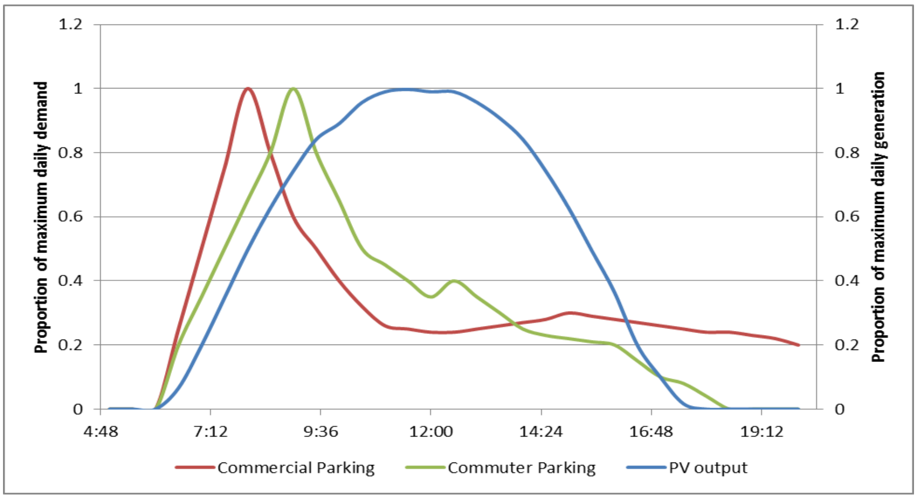


**Figure 1: Comparison of sunny PV generation output vs Recorded daytime charging patterns for commercial fleet and commuter cars in Perth EV trial (Source: EV charging data from Perth EV trial, PV data from APVI map)**

## 3. The Influence of Household Tariffs on Efficient EV Charging

In the Australian electricity industry, retail electricity prices have increased significantly over the past 5 years, largely as a result of significant recent network expenditure, including that required to meet increasing peak demand (regulatory arrangements have also incentivised overinvestment in network infrastructure during this period). These price rises have been accompanied by concerns that cross-subsidies exist between some customers, particularly AC owners and PV owners (Passey, Watt, & Brazzale, 2013), while improved metering and control technologies are emerging to enable demand-side response. These factors have driven the introduction of regulation that requires cost-reflective network pricing (AEMC, 2014), with the aim of incentivising efficient use of the network, and reducing augmentation requirements, although it is worth noting that thus far, the definition of cost-reflectiveness, and the tariffs proposed by the DNSPs thus far are not well-resolved, while the network tariff is bundled by the retailer with energy and retail costs, which may act to dilute the price signal.

As discussed in section 2, ideally, EVs would charge at times of low load or high PV generation, and should not contribute to peak demand. Research suggests that consumers will respond to price signals to a limited extent as long as they receive clear feedback about the pricing (Faruqui & Sergici, 2010; Ito, 2012; Nicholls & Strengers, 2015). In this section, we examine various household tariff structures to understand the extent to which they could encourage efficient EV charging behaviour.

### *3.1. Method*

Expected charging outcomes for EV customers with and without controlled loads were modelled under residential retail tariffs structures that are currently widespread in Australia, including time of use tariffs, flat rate tariffs; and also tariffs with a demand charge, which have been widely advocated (APVI, 2015; Mountain & Szuster, 2014; Davis, 2015) and adopted in some of the new DNSP tariff proposals. The tariffs (listed in Table 1) were selected from the standing offers by Australian electricity retailers (Momentum, 2015; AGL, 2015) to provide an indicative comparison of the cost impacts of each type of tariff. A demand charge is where a user is charged at a given rate per kW for their peak demand for a stated interval over a given time period. In the case of this study, users are charged according to their maximum demand within a half hour period between 4pm and 9pm for each month of the year. Controlled loads are on a separate circuit that can be managed by the grid operator, and are not expected to contribute to peak demand.

The selected tariffs were applied to 12 months' worth of household consumption data from the SGSC project for over 4000 households with half-hourly load data available. Level 1 chargers are able to deliver 2.4kW from a normal outlet, 3.3kW from a modified charge point. Level 2 chargers can deliver up to 7kW on a single phase – the highest charging rate considered in this study. Charging rates above 7kW are considered unlikely in a residential context and were not considered in this analysis. Possible charging rates of 2.4kW, 3.3kW and 7kW were modelled. The cost impact of EV charging was modelled by assuming that cars would receive 5.83kWh at the different charging rates. Where not stated, assume at 2.4kW.

### *3.2. Results*

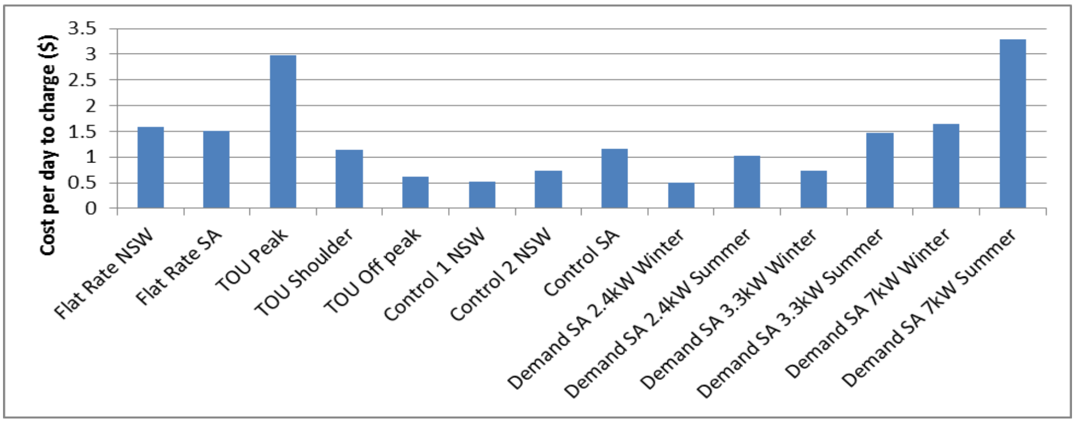


**Figure 2: Household cost per day to charge EV with 5.83kWh**

Flat-rate tariffs are widely understood to have little impact on time of electricity consumption, as they do not reflect the different costs of supplying the energy at different times (Simshauser, Downer, & Street, 2014). As can be seen in **Error! Reference source not found.** and Table 1, for TOU charging, the time of charging played a significant role in the cost impact of charging an EV, and there was value to the customer in moving to off peak charging periods under a TOU tariff, or to a controlled load arrangement. The low cost associated with controlled and off-peak charging should help to incentivise charging at times away from peak demand.

**Table 1: Modelling the impact of charging 5.83kWh under a number of tariffs**

| Tariff Type | Rate (inc GST) | Cost per Day |
|---|---|---|
| Flat Rate – NSW | $0.2727/kWh | 1.589 |
| Flat Rate – SA | $0.2586/kWh | 1.507 |
| TOU peak – NSW AGL Ausgrid | $0.5117/kWh | 2.98 |
| TOU Shoulder NSW AGL Ausgrid | $0.1964/kWh | 1.145 |
| TOU Offpeak NSW AGL Ausgrid | $0.1074/kWh | 0.626 |
| Controlled 1 NSW (10pm-7am) | $0.0881/kWh | 0.513 |
| Controlled 2 NSW (8pm-5pm) | $0.1245/kWh | 0.726 |
| Controlled SA | $0.2098/kWh | 1.167 |
| Demand Charge Winter, charge @ 2.4kW | $7.414/kW peak | 0.509 |
| Demand Charge Summer charge @ 2.4kW | $14.828/kW peak | 1.018 |
| Demand Charge Winter charge @ 3.3kW | $7.414/kW peak | 0.731 |
| Demand Charge Summer charge @ 3.3kW | $14.828/kW peak | 1.463 |

| | | |
|---|---|---|
| Demand Charge Winter charge @ 7kW | $7.414/kW peak | 1.646 |
| Demand Charge Summer charge @ 7kW | $14.828/kW peak | 3.292 |

When demand based-charges were investigated, the EV charging rate became the most significant determinant of the cost of EV charging per day. Demand charges could act to encourage low charging rates, or charging outside of the periods to which the demand charge applies. Both of these responses would improve peak load outcomes. Currently, residential demand charges are coupled to flat rates, but based on the tariffs now being proposed by DNSPs under new regulatory arrangements, this expected to change by 2016, and further analysis will be needed to investigate these.

### Investigating the Impact of EV Charging on the NEM

In this Section, we examine the overall potential impact of EV charging on peak demand in the NEM, according to different charging strategies, which will have implications for both network and generation investment.

#### *Method:*

At present, EVs make up a very small proportion of vehicles in Australia (ABS, 2015) and it is not possible to estimate the rate of EV uptake with a high degree of accuracy. Uptake will depend on factors including government policy, consumer sentiment and product availability. EVs popularity has increased significantly in recent years, but this is from a very low base, and sales still make up less than 0.05% of all new car sales (ABS, 2015).

For this study, a projected year was calculated for varying EV penetration levels in Table 2, based on projections made by AECOM, but this should not be considered as anything other than a loose estimate (AECOM, 2012)., The relative impact of different levels of EV deployment explored in this study is of most interest.

**Table 2: Projected demand based on penetration of EVs in Australia**[2]

| Projected year | % of Australian car fleet size | Number of Vehicles | Est annual demand (GWh) |
|---|---|---|---|
| 2014 | 0.01% | 2000 | 4.25 |
| 2018 | 0.1% | 20,000 | 42.5 |
| 2024 | 1% | 200,000 | 425 |
| 2028 | 2.5% | 500,000 | 950 |
| 2033 | 10% | 2,000,000 | 4250 |
| 2036 | 25% | 5,000,000 | 9500 |
| 2050+ | 100% | 20,000,000 | 42500 |

In order to estimate the impact of EV charging on the NEM, the charging patterns found in the various trials from Victoria, NSW and WA were scaled up according to the estimated demand from various penetrations of EVs. These charging load profiles were then added to the demand curves for peak days in Winter and Summer in NSW to demonstrate the potential impact of various penetrations of EVs on peak day loads under different charging patterns.

Four different charging strategies, outlined in Table 3, were considered. Smart charging was deemed to be too complex to model within the available scope, but expected to display similar results to controlled charging. In the case of TOU and uncontrolled charging, this was done by

[2] According to current numbers and growth trends, Australia is likely have a vehicle fleet of around 20 million cars in future (ABS, 2014)

scaling up the charging patterns seen in the EV trials. The residential controlled load charging operated between 10pm and 7am, but Control 2 loads can be operated between 8pm and 5pm.

**Table 3: Charging strategies investigated**

| Charging strategy | Details |
|---|---|
| Uncontrolled | Vehicle charges at maximum allowable rate according to connection type as soon as it is plugged in. |
| Time of Use (TOU) | Similar to uncontrolled charging, but start of charging is delayed until tariffs drop from peak to either shoulder or off-peak rates |
| Controlled | Vehicles are connected to a dedicated circuit that is activated under the control of the network operator, similar to off-peak hot water |
| Smart Charging | Flexible charging that responds to user-defined criteria, such as (but not limited to) wholesale market price, hours needed until next use or amount of charge required |

From the SGSC trial data on charging times, amounts and kilometres travelled, a value of 0.15 kWh of energy required for each km of travel was derived. As EVs become more efficient, it is likely that this value will drop, but it provides a useful benchmark. Using data from the NSW transport survey (Transport, 2015a) and work by (Mills & MacGill, 2014), an average car travel distance of 14,000km/year was calculated. Based on the SGSC charging data, this yields an average of 2.5MWh per vehicle added to annual demand. This estimate was used to scale the load pattern for EV charging under different strategies and the impact on peak demand days from both summer and winter in NSW in 2014 were investigated (Figure 3). The EV trials that have carried out in Australia to date have been very small, with less than 60 vehicles per trial. Due to the small sample from which charging pattern data is drawn, and the range of emerging/unsettled factors that influence charging behaviour the results should be viewed as indicative only.

### *3.3. Results*

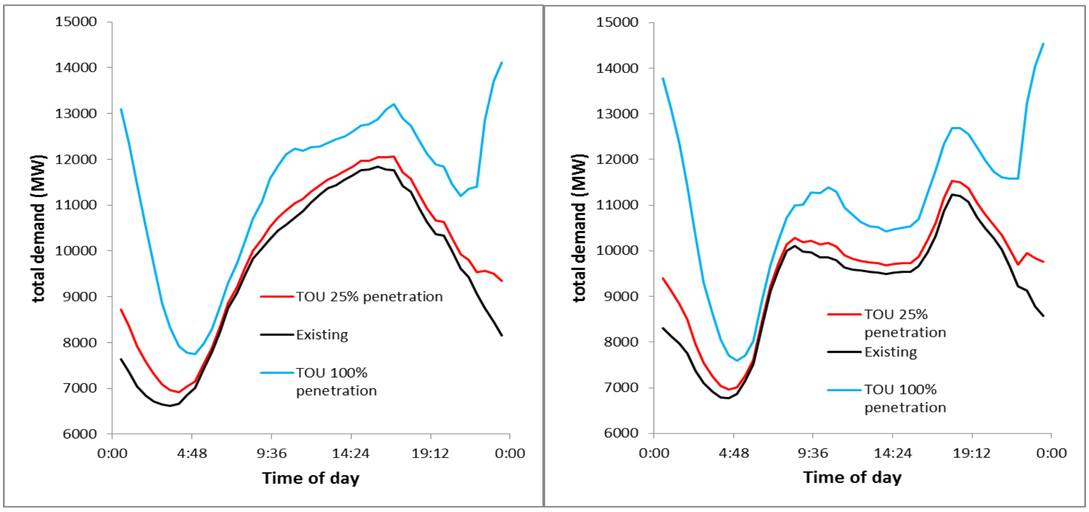


**Figure 3: Peak summer and winter demand profiles with the application of uncontrolled TOU charging at 25% penetration of EVs and 100% penetration of EVs.**

Figure 3 shows that TOU price-driven charging under the current tariffs modelled creates a second peak in evenings, as the prices drop to off-peak rates. The results for uncontrolled charging are similar as most customers return home between 5pm and 7pm. With high EV uptake, this second peak under uncontrolled charging with or without TOU tariff price signals would become larger than the current evening peak, assuming no other growth in demand. This is an implausible scenario, particularly as tariffs would likely evolve in response to EV charging impacts, but the results still provide some useful insights as discussed below.

Due to the limited amount of public charging infrastructure currently available in the SGSC trials, the charging profiles modelled largely comprise home charging, using Level 1 & 2 chargers. The results indicate that if uncontrolled charging is encouraged to occur mainly in the residential context, it will increase the evening peak significantly as penetrations increase.

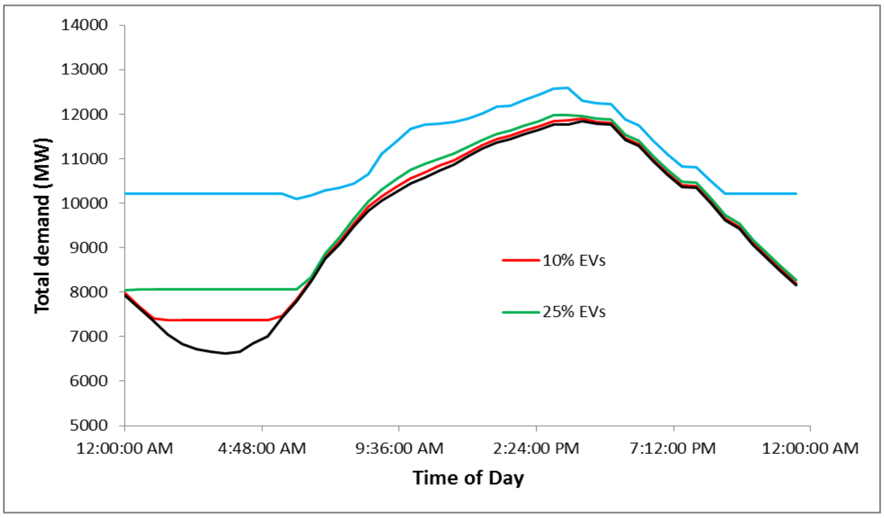


**Figure 4: Potential controlled load demand curves for the peak summer day in NSW with increased load profiles based on 10%, 25% and 100% EV penetration using a modified load profile based on the SGSC data, assuming that some load shifting is possible.**

Initial analysis of controlled (Figure 4) shows that even at high penetrations, the load from charging can be shifted, which would have the effect of smoothing out demand across the night time. These results are in agreement with those from modelling of EV charging in California (Guille & Gross, 2009). The timing of controlled loads would require some staggering to avoid sudden ramp up, such as currently seen from off-peak hot water controlled loads in some Australian regions. In order to prioritise charging of vehicles with batteries at a low state of charge, smoothing could be implemented by activating controlled charging by residential substation at consecutive time intervals, according to the average driving distance for each suburb. Under this arrangement, according to the NSW transport survey data (Transport, 2015b) the EV controlled load circuit for a car in Blacktown (daily driving distance 67km) would turn on well before the same circuit in Randwick (daily driving distance 29km). This arrangement would need to be trialled to make sure that the majority of consumers in each area could receive enough energy to charge their cars sufficiently, but has the potential to allow for excellent load smoothing. The results from this investigation highlight the potential for appropriate incentives and control of EV charging strategies to reduce the impact of EVs on peak loads. More sophisticated tariffs and control would allow for customised charging regimes that balance consumer charging preferences and willingness to pay with the cost of providing the energy both temporally and spatially.

## 4. Conclusions

This paper provides a preliminary insight into the potential impact of EVs in the NEM, and explores some of the key factors that will influence that impact, including uptake rates, infrastructure provision and tariff arrangements. The results indicate that smoothed daytime charging would be complementary to high rates of deployment of PV, which could be facilitated by providing work-based and other commercial charging infrastructure.

The results of modelling charging under different tariff arrangements indicate that controlled load and TOU tariffs can incentivise more optimal charging behaviour, which could be implemented using controlled load circuits or smart charging. Without these incentives, uncontrolled residential EV charging would begin to noticeably impact peak loads in the NEM once penetration levels exceed about 25%, or 5 million vehicles.

Further research could usefully explore optimal tariff design and smart control of EV charging such as geospatially optimised controlled load arrangements. This type of tariff analysis will also be useful more broadly to understand optimal tariff design, particularly in view of increasing distributed energy opportunities.

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