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The emergence of EVs: the interaction between the electricity and transport sectors

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Abstract

Electric vehicles (EVs) will play an important role in reducing greenhouse gas emissions in the road transport and electricity sector. In this paper, we explore the affect that EVs have on the wholesale electricity market under different driving patterns. We also explore potential future EV trends and relevant questions for the road transport and electricity sectors.

1. Introduction

Australia has a target to achieve net zero emissions by 2050, ie, where greenhouse gas emitted into the atmosphere is equal to the carbon removed from it (Department of Industry, Science, Energy and Resources, 2021, p. 11). Achieving net zero will require Australia to reduce its greenhouse gas emissions significantly over the coming decades (Department of Industry, Science, Energy and Resources, 2021, p. 15).

Electricity (34 per cent) and road transport (16 per cent) sectors together are responsible for around 50 per cent of Australia's greenhouse gas emissions in 2020 (Department of Industry, Science, Energy and Resources, 2021, pp. xv, 50). It follows that greenhouse gas emissions from both sectors will need to decrease significantly for Australia to meet its net zero emissions target.

EVs are expected to play a key role in reducing the greenhouse gas emissions of the electricity and road transport sector. For the electricity sector, EVs could be used as batteries to store electricity when there is a surplus of renewable energy and discharge when required by the grid (Australian Energy Market Operator, 2021a). EVs can therefore play a key role in improving the reliability of the grid. EVs can also help improve the affordability of electricity, as they reduce the need to invest in other energy storage solutions as we transition into a renewable energy future (Australian Energy Market Operator, 2022a).

For the road transport sector, EVs represent a potentially zero emissions alternative to conventional fossil-fuel-based vehicle. EVs would need to be charged from renewable energy resources in order to be a zero emissions alternative (Department of Industry, Science, Energy and Resources, 2021).

The above discussion indicates that the road transport and electricity sectors are becoming more integrated with the emergence of EVs. The remainder of this paper explores this connection and is structured as follows:

- section 2 discusses the effect EVs have on the wholesale electricity market; and
- section 3 potential areas of future research.

2. The value of EVs to the electricity grid and its effect on the wholesale market

The electricity sector is undergoing a period of rapid change, with several reforms underway to facilitate the integration of distributed energy resources (DER), including EVs (Australian Energy Market Commission, 2021a; Australian Energy Market Commission, 2021b). These reforms include the ability for the grid to support bi-directional flow and updates to pricing methodologies to ensure that payments received for providing DER services align with the value being provided (Australian Energy Market Commission, 2021a).

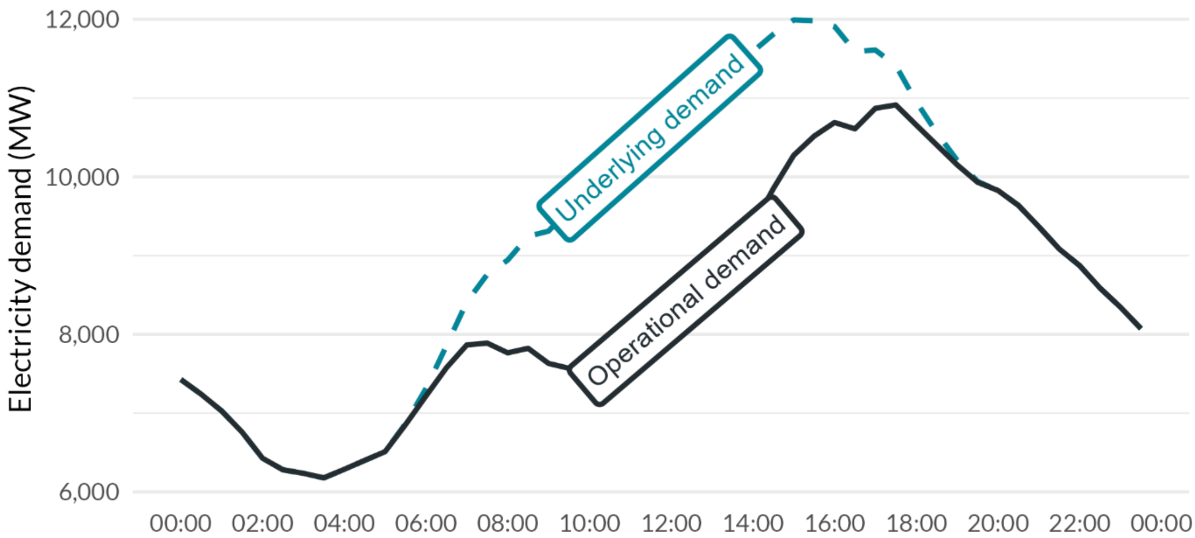
A significant driver of required electricity infrastructure and overall electricity costs to consumers is the need to meet peak demand (Kemp, et al., 2014). Put simply, the electricity grid needs to be able to support the periods of highest coincidental electricity consumption, which presently occur during summer periods but could potentially shift to winter months in areas like Victoria where consumers are expected to transition from gas home heating to electricity (Australian Energy Market Operator, 2021b).

The value or risk of EVs to the electricity grid is in their ability to:

- export to the grid or be used by a household as a battery during periods of high demand, thereby avoiding dispatch of another generator and reducing the peak; and/or
- contribute to peak demand by charging during these periods.

This is related to the existing relationship between demand and renewable resources, especially small-scale solar PV, which is leading to later evening peak demand relative to a world without solar PV. Figure 1 shows that ‘underlying’ demand, which is all the electricity used by consumers, peaked at around 3:30pm, whereas operational demand, which is the electricity supplied by from the grid peaked later in the day. The difference between the two forms of demand is the electricity needs that are met by alternative sources such as rooftop solar PV and small-scale battery storage.

Figure 1: NSW electricity demand, 17 January 2022



Source: HoustonKemp analysis, **(Australian Energy Market Operator, 2022b)**.

A number of studies, in Australia and internationally, have considered the benefits that batteries can provide to the electricity network, particularly as the network decarbonises. (Csereklyei, et al., 2021; Keck, et al., 2019; Ertugrul, 2016; Merrington, et al., 2022). In these contexts, an EV is usually considered through the lens of its ability to act as a battery. However, EVs also act as a means of transport, which means that:

- owners may prioritise transport uses of EVs (such as a daily commute) over use as a battery to support to electricity grid;
- EVs will also consume significant electricity to power trips, and their consumption will be linked to travel behaviour; and
- batteries within EVs will be less 'available' and 'predictable' than a standalone battery owing to the two points above and the disconnection of the battery when used for travel.

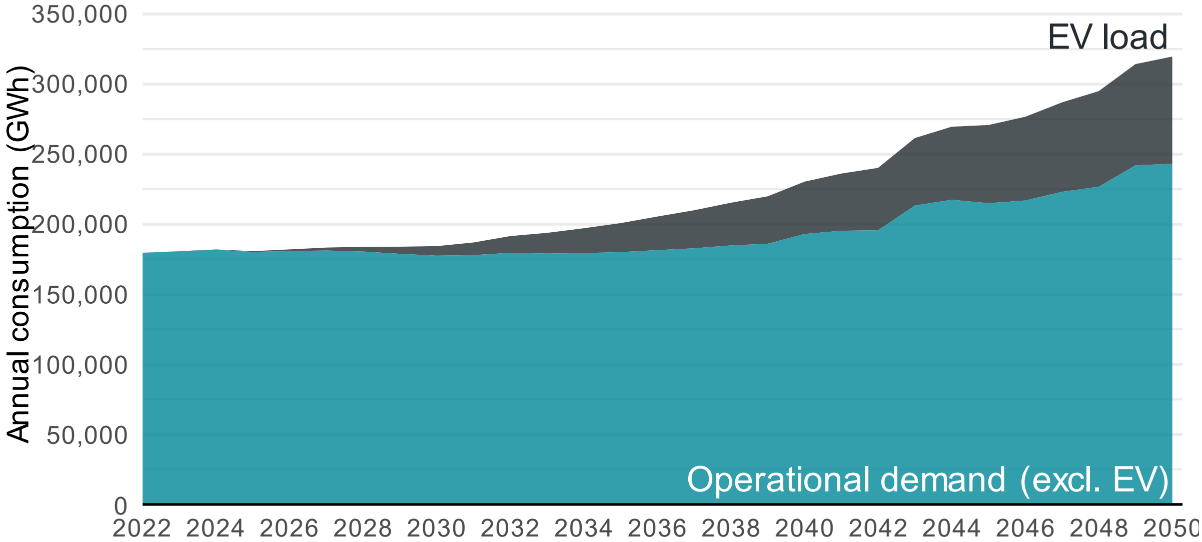
Reforms are currently underway to ensure that EV owners are compensated for the value EVs provide to the grid. It follows that the value of the battery-storage component of electric vehicles will play an important role when consumers decide between purchasing a conventional fossil-fuel-powered vehicle (internal combustion engine, ICE) or an EV. We explore EV's potential value to the grid below.

2.1 The potential contribution from EV to support the electricity system

Electrification of road transport sector is expected to be a critical part of the transition towards net zero. The Australian Energy Market Operator (AEMO) projects that by 2050, there will be approximately over 20 million electric vehicles contributing over 70TWh to electricity market demand (Australian Energy Market Operator, 2022c). To achieve this, new passenger car sales will need to be entirely electric by the early 2040s.

Figure 2 shows the projected level of EV demand relative to operational demand (ie, effectively equivalent to demand from the wholesale market) (Australian Energy Market Operator, 2022c).

Figure 2: Projected level of EV and non-EV demand – AEMO step change scenario



Currently, batteries in EVs are materially larger than typical household battery storage – a battery in a long-range electric vehicle can have a storage capacity of up to 100kWh, compared to the average household battery size of approximately 11kWh (Graham & Havas, 2020). In addition, the energy required for the typical daily usage of an EV (approximately 6.7kWh on average, representing around 11,000km per year) is far below the capacity of the battery (Graham & Havas, 2021, p. 35). It follows that there is typically substantial capacity available in excess of the daily needs of EV owners.

EVs could support the grid in several ways, ie, they could:

- reduce overall wholesale electricity market prices by charging when prices are low and discharging when prices are high;
- reduce the need for network investment by shifting demand away from peak periods;
- reduce the need for investment in household or grid scale batteries; and
- provide ancillary services, such as network support services and discharge during periods of network outages.

In our analysis below, we have only considered the net effect EVs have on the wholesale market. That is, it will need to charge from the grid, so it has sufficient energy to support transport needs of household, but at the same time, EVs can support the grid by charging when wholesale prices are low and dispatching when prices are high.

We expect that EVs will principally be used to support travel behaviour of households, given the costs of purchasing a vehicle is significantly higher than the costs of a standalone battery. It follows that travel behaviour of a household will influence the availability (and so benefits) of EVs to support the grid. More specifically, the use of EVs for transport will influence the value that they provide to the electricity grid, principally because:

- use of the vehicle may coincide with times when the storage capacity would be valuable to the grid (ie, during the solar peak periods in the middle of the day); and
- uncertainty around usage patterns for vehicles will influence the extent to which EV batteries can be relied upon – for example, there could be periods where large numbers of EVs on the road coincide with high demand events (for example, a summer public holiday with high air-conditioning demand).

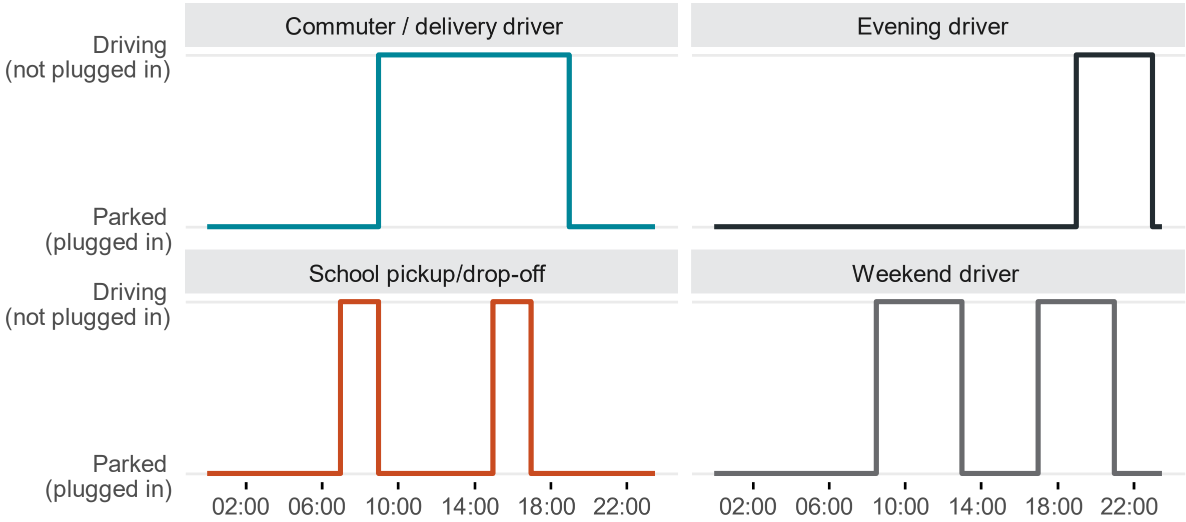
We explore the benefits provided by EVs under different usage patterns in the section below.

2.2 Usage patterns and effect of EVs on the wholesale market

Households have a number of different potential usage patterns. An illustration of typical usage patterns and the corresponding availability of EV battery to support the grid is illustrated in figure 3, eg:

- commute to work, with travel concentrated during the morning and evening commute periods and potentially parked on the street where vehicles is disconnected from the grid during the interim period without further investment;
- travel for picking up and dropping of children at school, with travel time concentrated around the start and end of school times;
- travel for evening activities;
- weekend activities; and
- ‘delivery’ or ‘taxi’ driver, who we assume have a similar profile as commuting to work, but drives a much greater distance each day.

Figure 3: Intraday car usage patterns and availability for use as battery



For storage to be most valuable it needs to:

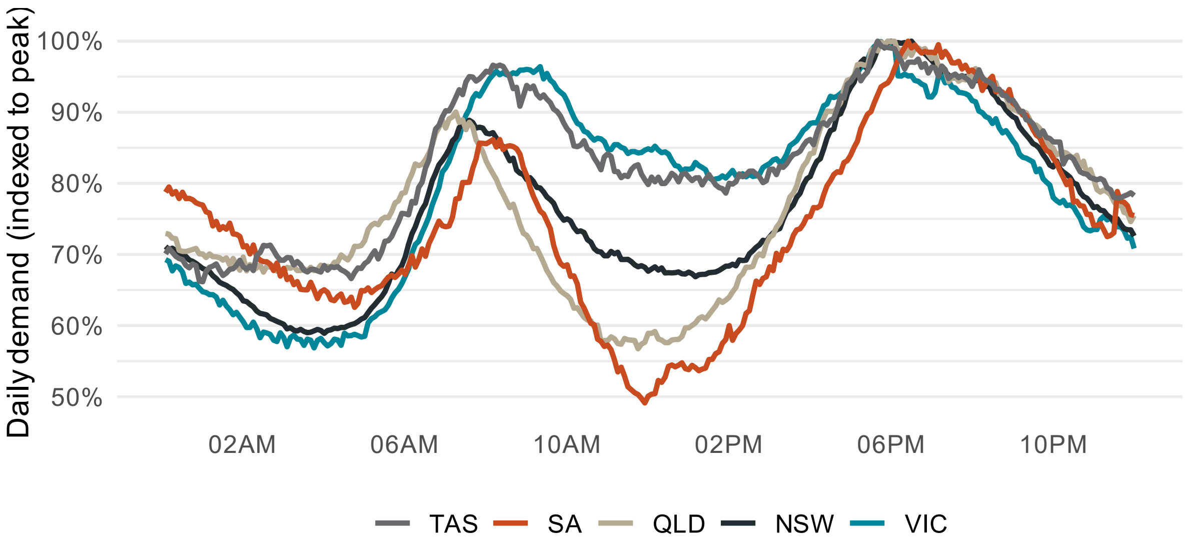
- take advantage of cheap supply and low prices to charge; and
- take advantage of periods of scarce and expensive supply to discharge.

If the vehicle is disconnected during either of these periods, this will either:

- increase the costs of using the battery for storage; or
- reduce the extent to which the battery can be used to support the electricity grid.

Figure 4 below shows that electricity demand typically peaks in the mid-morning and early evening in each state of the national electricity market (NEM) (Australian Energy Market Operator, 2022d).

Figure 4: Intraday electricity demand peaks in the mid-morning and early evening, 1 June 2022



2.2.1 Modelling the effect EVs have on the wholesale market

To quantity the effect of different electric vehicle transport usage patterns we have applied our storage optimisation simulation model. The modelling optimises the usage of the battery storage capacity from an EV to maximise profit subject to:

- technical parameters for the EV's battery, eg, round-trip battery efficiency;
- operational constraints for the EV battery, eg, power and capacity limits; and
- availability of the EV to be used as a battery, ie, intraday car usage patterns.

We use historical wholesale prices as the key price signal for optimising the use of the battery, although we are able to estimate value for future years based on our view from applying our ElectricBlue electricity market model. The sources for our EV storage assumptions applied are set out in table 1 below.

Table 1: Summary of battery modelling assumptions

Assumption	Sources
EV battery storage technical parameters: Capacity: 35.5kWh-79.8kWh Power: 6.6kW-11.0kW Round-trip charge efficiency: 85.5% Driving efficiency: 0.127kWh/km-0.1610.127kWh/km	HoustonKemp research, zecar.com/database
Half-hour wholesale prices for 2019[1]	AEMO data, HoustonKemp ElectricBlue market model
EV battery operational model	HoustonKemp SSBOM battery optimisation model
Driving distances per day: 31km for commuter, 11km for school pickup, 250km for delivery driver	HoustonKemp assumptions/research.

We model three different classes/sizes of EV: small, medium and large. The EV is exposed to the wholesale price. For each of the vehicles, we quantify the avoided wholesale market resource costs (using prices as a proxy for costs) that arise from different EVs and driving behaviours. This is consistent with the approach by the Australian Energy Regulator when it

[1] We note that the National Electricity Market has now transitioned to a five-minute settlement period, compared to the earlier 30-minute settlement period (Australian Energy Market Commission, 2017).

conducts assessments of the costs and benefits of network investments (Australian Energy Regulator, 2018; Australian Energy Regulator, 2020).

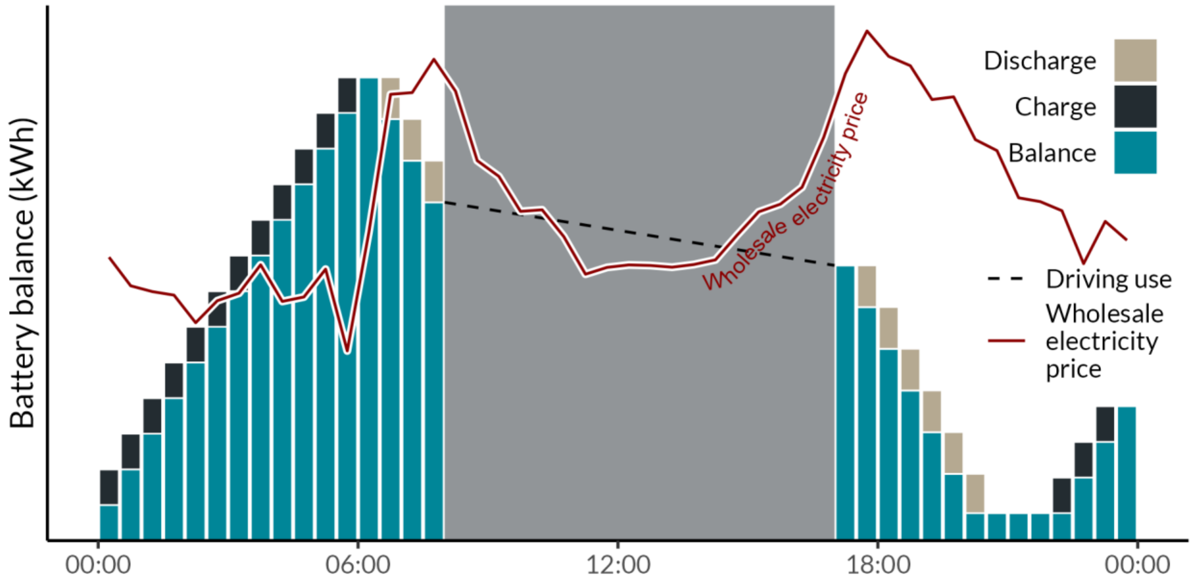
2.2 Measuring EVs affect on the wholesale market

Our modelling allows the EVs to charge from, and discharge to, the grid subject to the driving constraints and technical parameters of the EV battery. We present charge and discharge profiles for a representative modelling day for three different driving profiles in figures 4-6 below. These figures show the optimised charging (black bars) and discharging (brown bars) behaviour given the wholesale electricity price (black line).[2]

In particular, note that:

- the 'commuter' (figure 4), who is able to charge overnight before driving to work, discharges during the morning peak until departure, and discharges further to the grid upon arriving home;
- the 'delivery driver' (figure 5), whose EV is unplugged from the grid for the same period of time as the 'commuter' but uses a much larger proportion of their battery driving, does not have enough energy to discharge in the morning, but is able to discharge briefly during the evening peak; and
- the 'school pickup/dropoff' (figure 6) driver is unable to discharge during the height of the morning peak, but takes advantage of the relatively low price during the middle of the day to ensure enough energy to discharge through the entire evening peak period.

Figure 4: Example EV wholesale optimisation for a medium car– commuter



[2] Figures 4-6 show our modelling outcomes for 1 July in the modelling year, for the medium-sized car. The model optimises over each month, and the net wholesale impact is measured across the entire year.

Figure 5: Example EV wholesale for a medium car – delivery driver

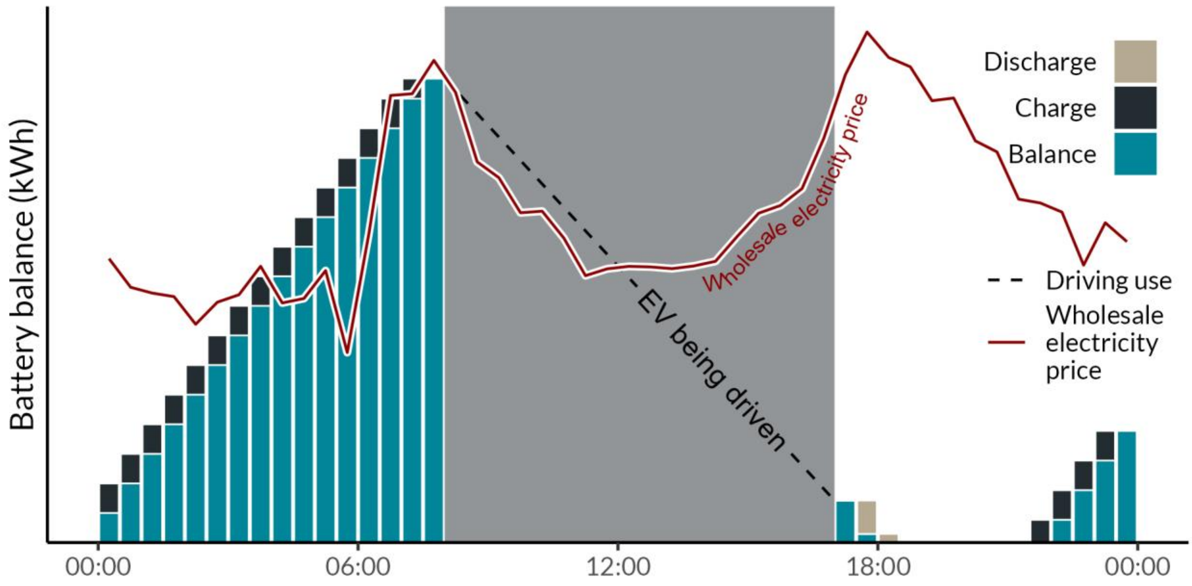
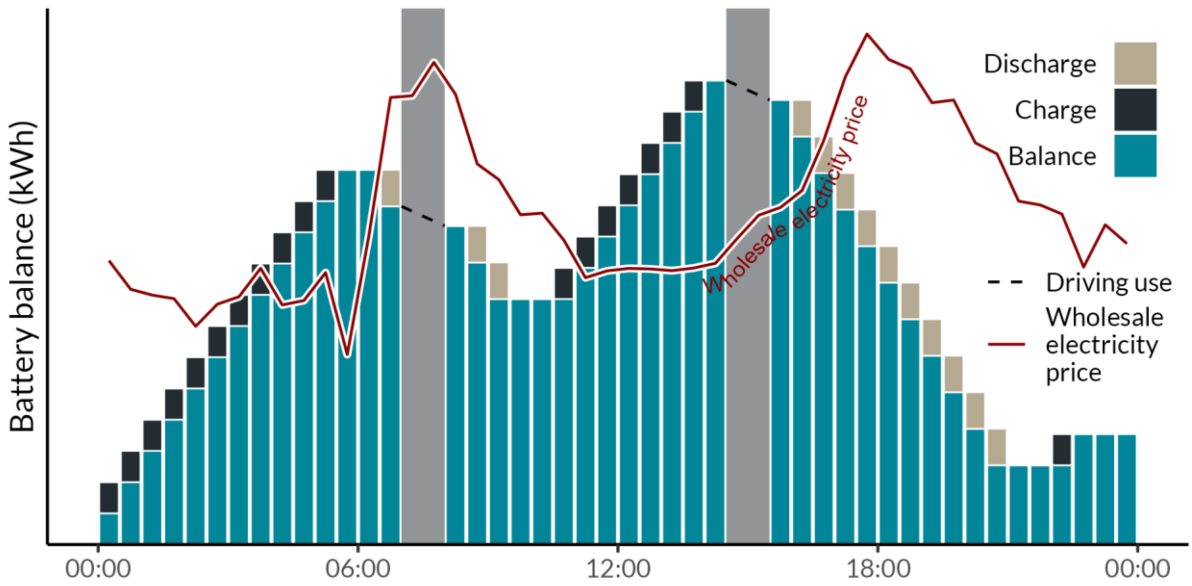


Figure 6: Example EV wholesale optimisation for a medium car – school pickup/dropoff



The net wholesale impact of the EV to the grid is measured by the value of discharge over and above the charging value (which includes both the charge required to support driving as well as the exports to the grid). This is compared to a base case without the EV – ie, no charging or discharging to the grid. In other words:

- a positive value represents the possibility of overall net benefit to the grid; and
- a negative value means the wholesale dispatch costs avoided due to discharging are not enough to outweigh the additional grid demand resulting from driving use.

The modelling estimates are presented in table 2 below.

Table 2: Summary of net wholesale impact – per year

Vehicle	Commuter	Delivery driver	School pickup/dropoff
Small car			
Export revenue	$1,371	$731	$1,706
Charging cost	-$854	-$1,053	-$1,006
Net value	**$517**	**-$321**	**$701**
Medium car			
Export revenue	$1,441	$751	$1,817
Charging cost	-$922	-$1,264	-$1,097
Net value	**$519**	**-$513**	**$719**
Large car			
Export revenue	$2,470	$1,985	$3,108
Charging cost	-$1,510	-$1,895	-$1,836
Net value	**$960**	**$90**	**$1,272**

The analysis above shows for that converting a commuter from an ICE vehicle to an EV could deliver $517-$960 in net benefits to the wholesale electricity market each year. This is over and above the economic and environmental benefits of reduced fossil fuel use, as well as other benefits to the electricity grid. The net wholesale market benefits are driven by the capacity of the EV battery as well as the technical parameters on charging and discharging rates.

Similarly, converting a low-use driver with a profile like the school pickup driver to an EV can have a significant net benefits to the wholesale electricity market, potentially up to nearly $1,300 per annum.

On the other hand, a ‘delivery driver’ is likely to impose a net cost to the wholesale market, because benefits arising from discharging is generally not able to offset the large electricity demand to support the driving profile.

It is important to recognise that these estimates should be interpreted in the wider context of a prevailing ‘EV premium’, ie, in the context of EVs having a higher upfront cost than a comparable ICE, but with a lower ongoing variable cost. Consumers that drive long distances therefore presently obtain a higher relative benefit of purchasing an EV than those that drive less. The V2G benefits presented above represent an additional channel of benefits which, in particular, are generated more by those lower milage drivers. This analysis shows that the effective ongoing cost can be negative if consumers can take full advantage of high-priced periods to sell energy back to the grid.

3. Potential areas for future research

Our analysis above focuses on the benefits that EVs deliver to the electricity wholesale market, eg, the benefits that arise by charging when electricity wholesale prices are low, to be used when wholesale prices are higher. We have modelled this based on historical wholesale market prices. However, we expect that this benefit will likely increase over time as we phase out coal and gas fire power plants, which is likely to increase the variability in wholesale market prices (Hirschhorn & Brijs, 2022).

Further, we also expect EVs to deliver other benefits to the grid, including:

- benefits to electricity network companies, eg, provision of ancillary services (Denhold, et al., 2015; Australian Energy Market Operator, 2021c);
- avoided investment in other energy storage capacity (Parkinson, 2019); and
- functioning as a ‘back up generator’ when there is an electricity outage (Blumsack, 2022; Purtill, 2022).

The above indicates that the benefits that EVs could provide to the electricity grid could be significantly larger than those we have estimated in the paper. Another important consideration is whether the use of EVs to support the grid may mean that the batteries will need to be replaced sooner. Our modelling does not explicitly account for this factor, although we expect that the relative degradation from supporting the grid would likely be outweighed by the financial returns that could emerge from V2G operation.

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