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Review

Electromobility in Australia: Tariff Design Structure and Consumer Preferences for Mobile Distributed Energy Storage

Nnaemeka Vincent Emodi [1,*], Scott Dwyer [2], Kriti Nagrath [2] and John Alabi [3]

[1] UQ Business School, University of Queensland, St Lucia 4072, QLD, Australia
[2] Institute for Sustainable Futures, University of Technology Sydney, P.O. Box 123, Broadway 2007, NSW, Australia; scott.dwyer@uts.edu.au (S.D.); kriti.nagrath@uts.edu.au (K.N.)
[3] School of Chemical Engineering, Faculty of Engineering, Architecture and Information Technology, University of Queensland, St Lucia 4072, QLD, Australia; j.alabi@uq.edu.au
* Correspondence: n.emodi@business.uq.edu.au

Abstract: The adoption of electric vehicles (EVs) may contribute to decarbonisation of the transport sector and has the potential to offer value to consumers and electricity grid operators through its energy storage capabilities. While electricity tariffs can play an important role in consumer uptake of EVs, little is known about how EV charging tariff design affects EV users' behaviour in participating in applications that can support the electricity grid, such as those applications classed under Vehicle-to-Everything (V2X). Examining the case of Australia, this study reviews the literature on electromobility with a focus on EV charging tariffs and its impact on consumer behaviour within the V2X context. The main findings drawn from up-to-date publications show that a well-designed EV tariff structure, available parking, and EV charging facilities can increase consumer participation in V2X. However, cooperation between EV users and grid operators is needed to establish a form of controlled charging agreement to harness the full potential of the EV electricity storage system for grid stability and battery support operations. To achieve this, the right tariff structure will have to be established to incentivise EV consumers to subscribe to V2X services. We also present recommendations for EV tariff design to support Australian consumer participation in V2G. Finally, we identify research gaps for further research.

Keywords: electric vehicles; Australia; consumer preference; tariff; V2G; V2X.

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1. Introduction

Can I charge my vehicle and bill the power grid? Recent literature suggests that the increase in charging stations is a contributing factor to consumer uptake of electric vehicles (EVs) and that bi-directional charging offers added benefits to consumers and the environment [1–6]. The global effort toward sustainable transport and the shift toward renewable energy technologies has increased interest in the exploration of mobile energy storage or Vehicle-to-Everything (V2X) through EVs [7–11]. For example, V2X—which includes Vehicle-to-Grid (V2G), Vehicle-to-Home (V2H), and Vehicle-to-Building (V2B)—enables EVs to communicate with the power grid and use their stored electricity to meet short-fall in power supply. This could revolutionise the energy and transport systems as it presents an added advantage of electromobility with battery storage compared to stationary battery systems at home. Moreover, V2X improves self-sustainability, increases independence from power supply from the grid, and can mitigate the effect of peak electricity pricing.

The literature on V2X has evolved rapidly over the last decade [12–24]. Although these studies indicate that V2X brings new technological innovation to the energy market, they also note that a cost-effective application of V2X (specifically V2G, V2H, V2B) will depend on the electricity tariff design structure. Early studies such as Zhou, Qian [25] find that the cost-effectiveness varies from China to the UK.

In Germany, two studies noted that while financial incentives were required for EV consumers to participate in V2X, significant cost reduction could be achieved via smart charging, which offers more value for consumers and electricity market operators [26–28]. Calvillo, Czechowski [29] indicate that V2X could be profitable if EV battery prices are reduced and electricity costs increase. Incorporating renewable energy supply with household battery storage systems can reduce the cost of charging EVs [30–32] while energy efficiency can reduce building electricity demand [33]. However, the uptake/profitability of electricity storage and EV charging will depend on domestic electricity prices or tariffs [34].

EV charging tariffs are electricity tariffs aimed at owners of EVs that use their home electricity to charge their car. They govern the cost of EV charging to the consumer and while they can be a tool for attracting EV owners to particular energy retail offers, they are needed to reduce pressure on the electricity network by encouraging the reduction or shifting of demand from peak times. Similar to residential customers, most grid operators use electricity pricing structures that vary across the day to influence EV charging behaviour. EV charging cost adds to the EV user's home electricity bill, however, the tariff design and thus actual costs differ significantly across different regions and is made up of fixed and usage charges [35].

Recent studies have examined how consumers respond to EV charging but little is known about how EV charging tariffs affect consumer choices to use EVs for V2X [36]. Therefore, it is essential to understand how electricity tariff structure may influence EV consumer behaviour to support the application of V2X in EVs.

This study aims to understand the relative importance of electricity tariff structure and consumer behaviour towards advancing the application of V2X in Australia with lessons for other international jurisdictions. This study reviews the literature on EV charging tariffs and how it affects consumer behaviour to apply V2X for household and grid applications. More specifically, we review the literature to address the following objectives: (i) To understand the importance of electricity tariffs and the current state of EV tariffs in Australia, (ii) to examine consumer behaviour toward EV tariff structure and its impact on electric networks, and (iii) to explore the potential for the EV consumer to support mobile distributed energy storage (V2G, V2H, V2V and V2B) in Australia.

We examine the case of Australia as a high potential country for grid management using additional energy storage options with potential lessons for other countries because: (a) the embryonic nature of the market with the uptake of EVs in Australia still being relatively low with a limited number of EV tariffs on offer; (b) many Australian energy consumers already have experience of innovative tariffs for managing peak demand for pool pumps, reversible air conditioners, and water heaters; and (c) Australia has the highest penetration of rooftop solar PV in the world and is highly active in managing the challenges of increasing levels of renewable penetration on their grid.

To retrieve research articles for this paper, we used the following search engines: Scopus, Web of Science, Google Scholar, and ScienceDirect. The literature search was concluded on 13 April 2022. The keyword search included *electric vehicles* and *Australia* combined with *tariff* or *charging*. We also supplemented our search with the snowballing technique. We limited our search to studies published after January 2010 to align with the technological development trend of EVs [37]. Article selection was based on their relevance to the research aim and objectives. Although we focus on Australian case studies, other country cases were included for context. Our review focuses on two types of EVs: battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). Studies on hydrogen fuel cell electric vehicles (FCEV) were excluded as we only focus on EV charging tariffs and not hydrogen refuelling stations.

This paper is arranged as follows: Section 2 introduces the pattern of household electricity consumption and EV use in Australia. Section 3 explores consumer behaviour to

EV tariff charging structure. Section 4 examines V2X potential in Australia. The discussion and policy recommendation are presented on Section 5 while Section 6 concludes the study.

2. Pattern of Electricity Consumption by Household and Electric Vehicles in Australia

2.1. Household Structure in Australia

Australia has a of population 25.8 million people, consisting of 10.6 million households [38,39]. A standard household in Australia is defined as a private dwelling with one or more persons who is at least over 15 years old [40] [40]. The dwelling can be characterised by type and size of the house, including the number of occupants and average energy consumption. At the last census conducted in 2016, 72.9% of all dwellings were found to be detached houses, 12.7% were semi-detached, terrace, or townhouses, and 13.1% were apartments [41]. The ability of households to access vital services and employment can be linked to available transport services. While there are variations in car ownership within Australia, about 51% of Australian households have access to two or more vehicles, while 47% of households living in apartments have one vehicle [41].

Residential housing structures with parking provisions act as incentives for vehicle ownership. This supports EV charging and recent studies suggest that consumer uptake of EVs increases with the availability of parking space [42,43]. Past reviews have found that between 50% and 80% of EV charging occurs at home [44]. This highlights the importance of off-street parking as a critical determinant of the degree of EV adoption. This also impacts on the opportunity for managed and bi-directional charging of EVs at home. No current statistics exist for the different dwelling types and their access to off-street parking, although it can be inferred that this will be lower for higher density dwellings where available land remains at a premium. This is important because for those dwellings without off-street parking, or those with access to car parking spaces that are not in proximity to their electricity meter board, charging at home may be impossible or too costly to provide.

2.2. Electricity Consumption Profile

Energy consumption in the residential sector accounts for 1228 petajoules (PJ) out of 4042 PJ. This is equivalent to 30% of its total energy end use and this exceeds other sectors such as manufacturing (22%), transport (15%), and mining (14%) (see Figure 1). As transportation undergoes electrification, the share of transport electricity consumption is likely to increase while the share for residential electricity consumption is likely to decline with efficiency improvement and availability of distributed energy systems.

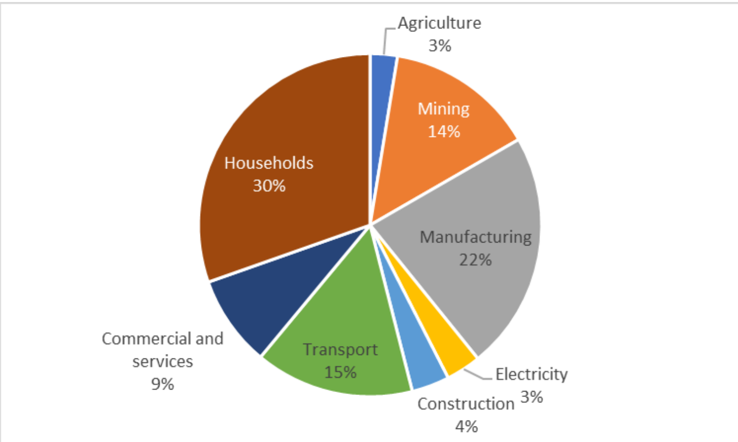

Figure 1. End-use energy consumption by industries and households in Australia, 2019–2020. Source: ABS [45].

According to the World Bank, Australia is the 13th highest average residential electricity consumer in the world at 10,000 kilowatt hour (kWh) a year, more than Saudi Arabia, Singapore, and Japan [46]. This is due to the high heating and/or cooling demand attributed to climatic factors, the typically larger average home size, and lower energy efficiency standards of residential dwellings (see Table 1). By adding EVs to the load of a house, home EV charging could add another 30–50% to the annual electricity consumption (based on a 10 kWh/100 km and 19 kWh/100 km rated EV driving 20,000 km per year and only charging at home).

Table 1. Average household electricity consumption in Australia.

State	Average Household Electricity Consumption (Per Year)
Australian Capital Territory	6407 kWh
New South Wales	5662 kWh
Queensland	5535 kWh
South Australia	4950 kWh
Tasmania	8619 kWh
Victoria	4615 kWh
Average (all)	5470 kWh

Source: Economics [47].

Australia has previously been estimated to be 10–15 years behind the energy efficiency standards compared to countries such as Canada, USA, the UK, and other countries in Europe [48]. However, Australia has excelled in the area of residential-scale renewable energy with the highest PV generation per capita in the world at 644 Watts Peak (Wp) per person, more than Germany at 589 Wp, and Japan at 500 Wp .

Electricity generation from solar PV systems peaks during the middle of the day (when solar irradiance is generally high) and declines after sunset. While minimum electricity demand of the power system once occurred in the middle of the night, the growth of rooftop solar generation in Australia has led to minimum demand increasingly occurring during the middle of the day (especially on sunny days when temperatures are mild). This can lead to challenges for maintaining the stability of the electricity grid [49]. Ways of better matching the generation of solar electricity with demand are being explored to address this issue by utilising energy management, load control, and energy storage technologies [50] . EVs also offer a potential solution with their ability to operate as a form of mobile storage and shift demand through managed charging.

2.3. Electric Vehicles in Australia

Australia has been slow to adopt EVs and has been lagging behind many other similar economies [51]. In 2021, 20,655 plug-in EVs were sold, reflecting 2% of new car sales sold that year, up from 0.8% in 2020 [52]. For comparison, in North America, that share was 4% for the US, although it is considerably higher in some states, such as California with 250,279 sales in 2021 or 16% of new car sales [53] and 5% for Canada [54]. In Europe in 2021, EVs accounted for 18.5% of new car sales in the UK, 26% in Germany, and 86% in Norway [55]. In total, 6.6 million plug-in EVs were sold worldwide or equivalent to 8% of all new car sales [56]. Table 2 shows number of PHEVs sold in selected countries and share of new car sales.

Table 2. Sales of EVs and share of new car sales in selected countries in 2021.

Country/Region	Sales of Plug-in EVs	Share of New Car Sales
Australia [1]	20,655	2%
United States [2]	608,000	4%
Canada [3]	65,253	5%
United States (California, only) [4]	250,279	16%
United Kingdom [5]	305,281	18%
Germany [5]	681,410	26%
Norway [5]	647,000	86%
Global [6]	6.6 million	8%

Source: [1]EVC [52]; [2]Press [57]; [3]Government of Canada [54]; [4]CEC [53]; [5]EC [55]; [6]Paoli and Gül [56].

This rapid growth in the market for EVs has the potential to create challenges for the electricity grid through the addition of demand at peak times, with implications for grid stability and energy costs for consumers [58]. Different approaches have undergone trials (see Section 4) to investigate how to mitigate the challenges of additional demand due to EV charging, while attempting to create additional benefits for consumers. Managed charging is one approach, altering when—and how much—EVs charge. For example, delaying the charging to the middle of the day (when rooftop solar output is at its highest and demand is low), rather than when the vehicle returns to the home in the early evening (when demand is highest and solar output has declined) and is first plugged in.

Bi-directional charging is another approach, where the EV is used like a mobile battery energy storage device to charge and discharge electricity when the vehicle is not in use, but when the home or the electricity grid needs it. Through managed bi-directional charging, EVs can be used to support energy system stability and create value for EV owners, energy retailers, and grid companies. However, cooperation by EV owners will be needed and electricity tariffs are one way to encourage them to participate in these activities. For example, making it most expensive to charge your vehicle at peak times through a higher tariff between 4 p.m. and 7 p.m., while making it less expensive to charge between 11 a.m. and 3 p.m. when Australia's rooftop solar PV generation is at its peak.

2.4. Electric Vehicle Tariff in Australia

The Australian Energy Regulator defines an electricity tariff as "the amount charged for providing energy under your contract" [59]. With switching between energy suppliers in unregulated markets typically permitted, energy consumers will often base such decisions on the tariff with the lowest unit price of electricity on offer. As EV charging is a significant source of energy consumption for households with EVs, dedicated tariffs to appeal to those types of consumers have started to emerge as EV ownership has increased.

Time of use (ToU) tariffs are increasingly becoming 'EV friendly'. For ToU, different usage rates are charged at different times of day and week which can encourage or discourage EV charging when it is most or least beneficial for the customer. Some of these 'static' ToU tariffs may provide a fixed time when the tariffs are higher or lower. For example, charging EVs is most expensive on weekdays in the afternoon and early evening, while it is least expensive in the middle of the day and late at night. In contrast, 'dynamic' ToU tariffs provide ever-changing periods when tariffs are higher or lower based on real-time events, such as unplanned power outages or low probability events, such as storms.

Although the number of available EV charging tariffs is still limited, energy retailers are responding to the increasing uptake of EVs by providing EV-related energy tariffs. In Australia (where 2% of new car sales are EVs), there are presently five residential EV tariffs on offer, but availability is not uniform across all states and territories. For comparison, in the UK (where 18% of new car sales are EVs), there are currently 15 EV tariffs (see Table 3).

Table 3. Range of EV charging tariffs and residential electricity tariffs in Australia, USA, and the UK.

Retailer	Plan name	City	State	Country
AGL	Electric Vehicle Plan	Sydney	New South Wales	Australia
		Melbourne	Victoria	
		Brisbane	Queensland	
		Adelaide	South Australia	
		Perth	Western Australia	
Red Energy	Red Energy EV Saver Plan	Sydney	NSW	
		Melbourne	Victoria	
		Brisbane	Queensland	
		Adelaide	South Australia	
Powershop	Super Off-Peak Tariff	Sydney	New South Wales	
		Melbourne	Victoria	
		Brisbane	Queensland	
		Adelaide	South Australia	
OVO	OVO Drive	Sydney	NSW	
		Melbourne	Victoria	
		Brisbane	Queensland	
		Adelaide	South Australia	
Bright Spark	Aussie Car and Home Plan	Sydney	NSW	
PG&E	Home Charging EV2-A	Sacramento	California	USA
PG&E	EV-B			
SCE	TOU-D-PRIME			
SDG&E	EV TOU-2			
Liberty	TOU-EV Rate			
Pacific Power	none			
Alamdeda Municipal Power	TOU EV Rate			
Azusa Light and Water	EV Off-Peak Charging Discount			
Burbank Water and Power	TOU			
EDF	GoElectric			UK
	GoElectric35			
	GoElectric98			
OVO	OVO Drive			
	OVO Drive + Anytime			
Octopus	Octopus Go			
	Octopus Agile			
	Intelligent Octopus			
E.ON	Next Drive			
Good Energy	Green Driver 5 h			

	Green Driver 7 h	
Bulb	EV Tariff	Trial
Scottish Power	SmartPower	Trial
British Gas	Electric Driver	

Source: Tariff data retrieved directly from energy supplier websites (Accessed on 11 April 2022).

3. Consumer Behaviour to Electric Vehicle Charging Tariff Structure

Behavioural insights into EV charging behaviour is important to understand and optimise the deployment of charging infrastructure [60]. Many factors will influence consumer decisions around where, when, and how often they charge their EVs. Knowing what these are and how to use them can ensure that customer benefit is maximised while also minimising detrimental impacts on the power grid [61]. From a technical viewpoint, the speed and frequency limits in which EV charging take place depend on multiple factors, including the size of vehicle battery, the rate of charge, the state of charge, and the charging rate of the EV charging equipment. From an economics (and policy) perspective, tariffs (as well as taxes and incentives) also influence consumer behaviour with regards to EV charging. Other factors influencing consumer behaviour are also at play (for example, emerging innovative business models) but these are not within scope of this research paper.

Due to the early stages of EV market development (as previously discussed) in Australia, much of the research on consumer behaviour has been undertaken with innovator and early adopter groups which are likely to be unrepresentative of the mass market [62,63]. Accepted norms of charging behaviour are also evolving for all types of charging, whether it is at the EV driver's home, someone else's home, their place of work, their destination, or on route to their destination. Multiple studies over the last decade have examined charging behaviour for plug-in EVs, using actual charging data to extract real world insights in multiple countries, including Australia [60,64–67].

3.1. Consumer Preferences and Acceptance of Different EV Tariff Design

A recent review by Lavieri and Domenech [68] suggests that Australian EV users mostly prefer charging from home, followed by work, supermarket destinations, and service stations. Australian EV consumers also charge their vehicles around 2–4 times per day but charge their EVs in the initial hours of time-of-use (ToU) price drops [68]. In other studies beyond Australia, EV consumers have been found to prefer to charge their EVs when they return from work around 5–8 p.m. [66,69–71]. In Australia, there is limited evidence regarding consumer preferences and behaviour concerning electric vehicles adoption and tariff design [68]. Research by the Electric Vehicle Council on Australian consumer attitudes found that the operational cost of owning an electric vehicles was the biggest determinant encouraging the purchase of an EV, with environmental credentials also featuring highly [72]. The design of an EV tariff that can encourage charging when renewable energy is abundant and wholesale costs are low (or negative) could therefore bring benefits to the energy system and energy utilities while also appealing strongly to consumers.

3.1.1. Time of Use Tariff

ToU tariffs have been identified as critical for improving the reliability of the power system, while encouraging consumers to change their electricity consumption to better match when more affordable and lower carbon electricity is available [73]. Electricity consumers in Australia are already used to shifting load to off-peak hours in reaction to price signals [74]. To address variations in daily load and price spikes, utility operators can manage consumer loads (e.g., pool pumps, reversible air-conditioners, or hot water systems) using direct load control technology [75–77]. For the early stages of EV adoption, ToU tariffs may be viewed as the most attractive to consumers due to their familiarity. Many of those countries who are early leaders in the adoption of EVs are seeing examples of special ToU tariff structures introduced [77], for example, by energy retailers in the United States (California, Hawaii, New York, Minnesota), Germany, France, and the UK.

3.1.2. Flat Tariff

A flat tariff rate is what consumers pay for electricity consumed which stays constant irrespective of the time of day, day of week, season, or amount used [74]. An appeal of this type of rate is the simplicity in being able to use electricity at any time of day, regardless of the variability in the actual cost of the electricity that is being generated and distributed [78]. The effective management of electric vehicle integration into the energy system could be ensured if EV owners adopt non-flat tariffs [79]. However, EV integration could disrupt power reliability and security, drive an increase in generation and network demand, and subsequently lead to an increase in the cost of energy if it is not managed properly [79]. Studies such as Simshauser and Downer [80] concluded that using a flat tariff is inefficient and inequitable as some customers are gainers and some are losers, and the losers are typically the households in hardship. Hence, an appropriate tariff is one that will reflect—and be proportional to—the actual energy consumption by all categories of customers.

3.2. Relationship between Tariff Structure and Demand Management

The power grid faces challenges because of increasing renewable energy integration, aging equipment, and potential large scale EV adoption [81]. Australia had 3.04 million solar PV installations with a combined capacity of 25.3 GW by the end of 2021. Although Australian households cut across different climatic zones, space conditioning and water heating typically accounts for more than 50 percent of energy consumption. This leads to high variation during peak hours with sometimes extreme daily variations in solar generation, heating, and cooling loads. The daily variation makes it difficult to manage the supply and consequently can lead to overvoltage, frequency, and voltage instability including high energy costs [75]. The peak in customer demand for electricity plays a significant role in the cost of electricity production and supply [76]. In Australia, residential electricity consumption accounts for about 30–50 percent of the total peak demand [82]. While ToU tariff design can be used to manage peak demand, it can equally shift load to other peak periods if not efficiently managed.

By altering end-use load patterns, ToU has been found to reduce peak loads by 10–15 percent and increase off-peak loads by 4 percent [83]. Ren, Grozev [82] claimed an overall 4.5 percent total energy consumption reduction due to financial incentives offered to the customers, and about 20 percent reduction in peak loads. Similarly, studies such as Ren, Grozev [82], Herter [84], Herter and Wayland [85] reported that the introduction of advanced meter and dynamic tariffs method reduced the residential peak loads by 5 percent in California. This indicates that ToU might not totally solve the problem. As reported by Currie [75], Young, Bruce [86] , a ToU tariff offer does not work in NSW, hence another dynamic tariff structure is needed to be deployed in addition to ToU as the EV can consume more energy than household appliances.

Demand side management can be deployed to reduce consumer load, supply constraint, or peak electricity demand. Previous studies have examined the relationship between electricity tariff structure and demand management [75,76,81,86–88]. Stenner, Frederiks [76] investigated the willingness of the household to participate in a direct load control programs, finding that trust plays a critical role in the acceptance of demand management solutions. Kong, Luo [89] examine the benefits of using a home battery energy storage system (BESS) to reduce demand charge penalty risks for the residential customers. They proposed a based control dynamic programming scheme for residential BESS to establish optimal charging and discharging decisions over a billing cycle. The base control scheme will help to reduce customers' energy costs based on time of use and demand charges.

Not all demand charge tariffs are able to reflect the true cost of electricity, which can be considerably higher at times of peak demand. Passey, Haghdadi [87] found that a typical demand charge tariff proposed within the Australian National Electricity Market (NEM) would not be cost reflective but proposed a method for developing ones that were [87]. In terms of EV potential for demand management, Nazaripouya, Wang [81] examined the role of EV as a mobile and flexible energy storage system that brings new opportunities in terms of tariff and solving future tariff challenges. Jeon, Cho [90] analysed the potential value of EV demand response programs for Korea through scenario analysis. Across all scenarios it was found that there were enough benefits from demand response and EV to attract the customers, with "smart control" V2G capability delivering the largest reduction in costs. The relevant applications and importance of electric vehicle consumer behaviour and tariff designs to support secondary applications such as V2G and V2H are analysed in [91]. Tariffs can play a significant role in demand management and thus lessen the impact of charging on the grid.

3.3. Expected and Observed Impacts of Tariff Structure on Behaviour

In this section, we describe the expected and observed impacts of tariff structure on EV consumer behaviour. Few studies have reviewed the relationship between EV tariff structure and expected consumer behaviour in Australia [76,77,92,93]. Using psychology and behavioural economics to facilitate appropriate demand response for the consumers, Hobman, Frederiks [92] identified how cost-reflective pricing can be designed, represented, and delivered to enhance customer uptake and optimal usage. Many Australian residential customers choose (or remain on) flat-rate tariffs despite the potential benefits. Therefore, to improve the ideal usage of cost reflective pricing, a deeper understanding of the consumer psychological behaviour and decision making is needed.

A report by Energy Consumers Australia recommends introducing incentives that might influence customers to adjust their consumption from peak to off-peak hours to reduce their overall electricity bills [77]. Most EV home charging occurs in the evening but could take place at a different time on a control load tariff. For fleet charging, this could be influenced by the vehicle's possible return to depot time and the commercial electricity tariffs scheme available. Table 4 shows the start and end hour of load control tariff and the minimum hours of service of all the states and capital territory in Australia. One of the factors that determines the adoption of new demand management and tariff structure is customer distrust [76]. Many customers do not trust the new tariff structure introduced by utilities and this makes it difficult for consumers to adopt cost-reflective pricing.

Table 4. Control load tariff hours.

State	CL-State Hour	CL-End Hour	Minimum Hours of Service
Victoria	8:00 p.m.	7:00 a.m.	9
Australian Capital Territory	10:00 p.m.	7:00 a.m.	7.5
Western Australia	10:00 p.m.	7:00 a.m.	7.5
Western Australia	9:00 p.m.	7:00 a.m.	6.5
Queensland	10:00 p.m.	7:00 a.m.	8
South Australia	11:00 p.m.	7:00 a.m.	6
Tasmania	4:30 p.m.	1:30 a.m.	5.5

Source: AEMO and Energeia [93] .

Another observed behaviour customers exhibit that might impact the acceptance of cost-reflective tariffs is perceived fairness and equity [92]. Here, cost reflective tariffs are believed to harm the vulnerable groups with limited capacity in the community to reduce their electricity usage [80]. In general, cost-reflective tariffs are viewed as unfair and harmful to the public but are supported by utilities [92]. Frederiks, Stenner [92] also found that most consumers are resistive to innovation tariff schemes despite the potential success of a cost-reflective tariff. This is because they do not meet the consumers' expectations and voluntary adoption is exhibited by few customers [92,94]. Further, Stenner, Frederiks [74] discovered that customers find cost-reflective tariffs to be less attractive than the traditional flat rate tariff and resist real time capacity pricing. Therefore, better knowledge of the customers preference and behaviour will make the adopted tariff structure effective and efficient. Table 5 shows some customers' behaviours due to different tariffs structures.

Table 5. Customers' behaviour based on different tariffs structures preference.

Factors Considered	Tariff Schemes			
	Flat Rate	Time of Use	Critical Peak Charges	Cost Reflective
Technology (Automation technology with EV)	Higher income earner encourages with automation technology	Higher income earners increase the likelihood of accepting ToU	Large commercial consumers	It favours high income earner
Education level (Educated and less educated)	Uneducated or less educated customers are more interested	Postgraduate and bachelor's degree holders are interested		People with degree and postgraduate are interested
Employment and age (Part-time and full time)	Aged and retirees' preference because of perceive risks	Full time employee preference	Part time employee will be enthusiastic about peak time rebate	Favours all employment type
Household size (Large and small)	Generally, both small and large prefer flat rate, e.g., childless couple favours flat rate tariffs		This favours large consumers as well	Large household favours cost reflective tariffs or real time pricing
Home ownership (Renters and owner)	Homeowners prefer flat rate tariffs	Most renters' choice	Most renters' choice	Most renters' choice
Dwelling type (Semi-detached and others)	Most common in Australia	Mixed choice among customers	Large house choice	Most customers' choice

Source: Stenner, Frederiks [74].

3.4. Impact of EVs on Electric Distribution Networks

The mass adoption of EVs will negatively impact the electricity grid without some form of managed charging. However, they do have the potential to serve as grid support in the context of a mobile and flexible energy storage system [81]. For example, charging large numbers of EVs in a particular area or location can cause overloading of the distribution networks and equipment, which affects electricity supply reliability [37]. This may cause network disturbances and can subsequently require additional investment to augment grid infrastructure.

Power grid regulation, reactive power, spinning reserve, and peak load compensation are among the potential grid benefits discussed for EVs if charging is managed [95]. However, adding additional load at peak times of both electrical demand and charging demand is one of the major challenges of the integration of EVs into the distribution networks [96]. Controlling the charging times could reduce the impact of large EV integration into the distribution network with many studies reporting the benefits that EVs could offer to the grid [95–103]. These include power quality improvement if solar PV is used as the energy source [98], the eradication of tailpipe greenhouse gas (GHG) emissions if charged with clean energy sources [103], maintenance cost reduction, increased simplicity and reliability [97,104], addressing the "duck curve" problem on the electricity networks [105], and boosting energy security [99].

4. Mobile Distributed Energy Storage Potential in Australia

4.1. Global Perspective of V2G, V2H, and V2X

The potential of EVs as mobile energy carriers is well recognised. The International Renewable Energy Agency (IRENA) forecasts over 1 billion EVs on the road by 2050, with these parked 95% of the time. The 14 TWh of storage offered by these mobile batteries will dwarf the 9 TWh of stationary batteries projected over the same time period [106]. Their mobile nature makes them uniquely different from other locationally fixed household loads such as lighting, air conditioning, or appliances. In emergency situations, EV batteries can be a backup power source to a home through V2H or with a coordinated EV fleet to a whole building by V2B; and in large enough numbers of EVs through V2G, EVs can provide auxiliary services for the power grid such as peak load regulation, frequency modulation, and spinning reserve [107]. EVs can also act as distributed generators in microgrid systems to effectively reduce the user's electricity costs and environmental pollution while achieving economic management of batteries of EVs [108].

To deliver grid support services as required for energy balancing, it requires the adoption of various strategies supported by new business models. These range from influencing customer behaviour to manually move their charging from peak to off peak periods to the use of advanced IoT (Internet of Things) technology and data science approaches combined with dynamic price signals. IRENA recommends supporting this outlook through initially implementing ToU tariffs and eventually dynamic tariffs for EV charging, to allow customers to participate in ancillary service markets, enable value stacking, and avoid double charges [106]. Time of use-based strategies could displace an average of 60% of power generation capacity needs for EV charging away from peak loads, and overall smart charging could reduce grid investments by 90% (as seen in Hamburg) [106].

The ToU tariffs introduced by different utilities across the world typically offer a fixed reduction in off peak rates as an incentive for customers to charge EVs. This is combined with higher prices during peak hours to dissuade charging at these times with seasonal, monthly, or weekly variations. These encourage and have often delivered a pronounced shift in customer behaviour as seen in trials in UK and USA [109].

Dynamic pricing is based on real time supply and demand balance at the level of the wholesale market, with exposure to customers created through aggregators and intermediaries. This allows customers to derive benefit from the services their EVs can offer the grid in an emergency and strengthen the business case for V2G, as well as enhance the value of EVs as mobile energy storage. Research shows that jurisdictions where V2G interest is strongest tend to have economic mechanisms such as ToU tariffs or real time pricing in place to make the value of V2G apparent [110]. This has been tested in Europe, where since 2015, Nissan, Enel, and Nuvve have partnered and worked on an energy management solution that allows vehicle owners and energy users to operate as individual energy hubs, allowing owners of Nissan EVs to earn money by sending power to the grid through Enel's bidirectional chargers [106].

4.2. Current and Future State of Mobile Distributed Energy Storage in Australia

The Australian Government Future Fuels Strategy has identified integration of EVs into the electricity system as one of its top five priorities [111]. In the Australian context, it is expected that EV battery storage capacity can be five to ten times the size of the equivalent stationary battery capacity installed on the grid by 2050. This could theoretically meet total residential demand and potentially more than 50% of total demand [109].

As early as 2013, the Victorian Government Electric Vehicle Trial revealed that financial incentives would encourage off peak charging, that simple user interfaces allowed for better charge management, and that overall managed charging would allow the network to support in excess of 50% uptake using existing capacity and infrastructure [112,113]. In the same year, the AusNet Services V2G trial also proved in concept that a V2G capable EV can successfully reduce the evening peak demand of a house.

More recently, utilities in Queensland and Western Australia have launched trials with favourable tariffs to encourage customer charging at particular times of the day, particularly to soak up the excess solar power generated in the middle of the day. The Distributed Energy Integration Program (DEIP) EV Grid Integration Working Group has outlined that the time of day that EVs charge or discharge will be a major factor in future EV-grid integration costs [57]. The Australian Renewable Energy Agency (ARENA) Working Group on EV Grid Integration recognises that tariffs can help influence consumer behaviour by signalling the cost of their charging decisions but there are no customer facing incentives in Australia to enable efficient EV charging outcomes [114].

Orchestration and smart charging trials are underway led by AGL, Origin Energy, and Jemena. The focus of these trials is on the technical aspects of V2G technology and on customer recruitment. Preliminary insights reveal that there are concerns on the maturity and availability of V2G technology, and though interest in trials exceeded expectations, the customer cohorts are skewed towards early adopters who have a high level of understanding of smart charging and its benefits [115–117].

Commercial aspects of business models for EV drivers and fleets are not yet addressed widely. The Realising Electric Vehicle-to-grid Service (REVS) trial in Australia is demonstrating how commercially available EVs can be used for V2G by injecting power back into the grid during rare events, with EV owners paid for providing Frequency Control Ancillary Services (FCAS) [118]. Previous trials with stationary batteries showed that they can capture a substantial volume in the contingency and regulation FCAS markets and reduce costs [119].

4.3. Challenges of Mobile Distributed Energy Storage

While the potential benefits of V2X are becoming well-documented, practical and commercial experience is lacking with limited active trials in Australia. In addition to the low uptake of EVs in Australia due to economic and financial reasons, customer experience and the separateness of the energy and transport sectors play a key role [110]. Current significant barriers perceived for V2X implementation include battery degradation, maturity of technology, regulatory requirements, and compatibility of EVs and electric vehicle supply equipment (EVSE) with bidirectional charging [109]. More research and tests are needed to analyse the parameters influencing the lifetimes of batteries, including the amount of energy being drawn and recharged annually, the typical state of charge patterns over a day, and the average rate of discharge [37]. V2G technology is still at an early stage, and trials are using pre-production hardware and rudimentary software systems; V2G enabled chargers are also limited in their commercial availability [115]. Moreover, while control technology for a small group can be simple and straightforward, at scale, the ecosystem is fragmented and expensive [117].

The effective dispatch and management of EVs and their charging is challenging because of the certain randomness and distribution in time and space of the vehicles [7]. Fleet owners and managers are also anxious about maintaining business continuity, and accommodating driver routes and routines to not compromise core business activity for the potential of V2G services and their benefits [120]. Furthermore, only a limited number of vehicle models have the technical capacity to offer V2X but this is further limited by the lack of EVs available in Australia.

A review of 50 V2G trials across the globe show that the trials focus on technical aspects, but social and commercial aspects are not always addressed [110]. From a customer perspective, excessive fees for EV smart charging through double taxation (both for charging a vehicle and for export to the grid and network charges when electricity is consumed from and supplied to the grid with V2G technology) can discourage uses that provide system-wide benefits [106]. The trials and demonstrations (and lack thereof in Australia) highlight the gaps that will remain in terms of regulatory, customer, technical, and market understanding. There needs to be concerted action to de-risk the business models being trialled through regulatory change to encourage industry and customer participation and capitalise on the potential benefits V2X can offer the electricity system and consumers.

5. Discussion and Policy Recommendation

5.1. Clarity on Suitable Tariff Structures

The application of V2X requires a number of important preconditions which include: the number of EV users in the energy system, their daily electricity consumption pattern and daily commute, the amount of energy left in the EV battery when the EV user returns home, a suitable tariff structure for EV charging, integration of EVs in the energy system to support bidirectional charging and V2X, and greater understanding of the cost savings to Australian households. Although most of the preconditions were examined for the Australian case, it still remains unclear what is the suitable tariff structure for EV managed charging and V2X. This creates uncertainty for consumers and additional work to improve understanding by regulators, policy makers, and consumer groups is recommended.

5.2. Clarity on Consumer Preferences

We find that an increasing number of studies are investigating the opportunities and prospects for the application of V2X. These studies generally arrived at the same conclusion: that the secondary application of EVs for V2X presents a significant benefit for both EV users and grid operators. However, it remains unclear how EV users will perceive the V2X application and there has been no consensus on the additional mechanisms beyond tariffs that will encourage consumers to use such schemes. To develop policy that can fully capitalise on these benefits, greater understanding is needed by policy makers on the attitudes of Australian consumers to different V2X propositions and business models. Government policies and incentives can be used to stimulate the adoption of EVs, ToU tariffs, managed charging, and V2X. However, policy uncertainty and complexity can also be a hindrance.

5.3. Consumer Choice

Australian electricity utility companies will need to expand their range of competitive ToU tariffs to give EV users more options. This has the potential to increase EV adoption, encourage effective demand side management, and better prepare for future consumer participation in V2X. The government can also complement this effort by providing incentives that help enable EV tariffs to be integrated in state/territory-level EV tax rebates or subsidies. This can also include new tariffs for relevant V2X applications, or for initial subsidies for V2X-capable EVSE. For consumers, bi-directional charging in residential buildings can generate added revenue for EV owners but this implies increased battery storage use which increases its degradation. More studies are needed to understand the cost and benefit implications of V2X on battery degradation, including consumer attitudes. Furthermore, a new algorithm for network management can be introduced by grid operators to implement autonomous operation of EV batteries connected to the grid. This may include an investigation of the appropriate tariff structures that reflects the value of the EV battery storage by utilities while accounting for degradation costs. This should also include an investigation into consumer attitudes of these issues.

5.4. Readiness for High EV Adoption Scenarios

V2X applications can provide valuable ancillary services to the grid but a high penetration of EVs on the grid will have technical, investment, and policy implications. This will require a major commitment by electricity network service providers to manage the increase in electricity demand from new EVs and to maintain the stability and reliability of the grid system. V2X requires both intelligent control systems and the introduction of standards to account for data protection, user privacy, and legal liabilities, among others [121]. New market models and policy frameworks for V2X will be needed to ensure it can successfully be integrated into the NEM. An example includes the electricity market model that incorporates distributed energy storage such as V2G application [122].

6. Conclusions and Directions for Future Research Direction

This study reviews the literature on electromobility in Australia with a focus on EV charging tariffs and its impact on consumer behaviour to applying V2X services. The review shows that residential housing structure could facilitate EV uptake if designed to support parking and EV charging facilities but more granular data on this are required.

While the expansion of electromobility is expected to increase transport sector electricity consumption in Australia, managed charging and V2X applications can potentially support energy system stability while creating values for EV owners and utility operators.

Cooperation between EV users, the EV industry, and energy utilities will be needed to establish a form of controlled charging agreement to harness the full potential of EVs for grid stability and battery support operations. To achieve this, the right tariff structures will have to be designed and tested through further research and trials examining the issue for the Australian context (which may also differ by state/territory, and metropolitan/regional).

Despite the advances in the V2X literature, there is still a wide range of uncertainties about the expectations of Australian consumers and EV charging tariff design. Tariffs can play a significant role in demand management, but more research is needed on the attitudes of Australian consumers to different EV tariffs and their effectiveness for managing impacts on the grid.

Finally, there are challenges with V2X in Australia due to it being very early in the technology's development, while the country does not feature among the most attractive early markets for the EV industry. This means Australia is likely to have to wait longer than others for V2X-capable vehicles and EVSE. To improve the attractiveness of Australia to EV and EVSE product suppliers, attention should be paid to coherent EV policy and fit-for-purpose regulations for V2X which includes standardisation and interoperability.

Energy utilities and consumer groups should work together to improve transparency, availability, and understanding of EV tariffs. With a lack of empirical research and demonstration projects for the Australian-context, future studies should help explore the research gap posed by the legal and regulatory frameworks, technology requirements, tariff design, consumer preferences, and business models.

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