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Electrified Transport Opportunities for Low Carbon Mobility in Australian Cities

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Abstract

Transport is responsible for over 17% of total Australian greenhouse emissions, the third largest sector for emissions behind electricity and direct combustion (Commonwealth of Australia, 2017). To meet our Paris Agreement commitments, the transport sector must start to decarbonise. Electromobility is one method to reduce carbon emissions and local pollution in urban areas, while also potentially facilitating renewable energy integration and therefore broader decarbonisation in the electricity sector. It is rapidly growing across all mode types – from heavy to light vehicles for transport and freight – around the world (IEA, 2018b); (BNEF, 2018). Yet in Australia, electric cars currently represent ~0.2% of the fleet (Climate Works, 2018) and the markets for other modes are yet to emerge meaningfully. The low adoption in Australia has been widely blamed on insufficient federal and state policy (Climate Works, 2018); (IEA, 2018a). Various public policies at all levels of government have been used to facilitate the uptake of electric passenger vehicles globally, and their effectiveness and applicability for the Australian context have been comprehensively studied. Yet similar research for other modes is sparse. While passenger vehicles represent 45.8% of Australia's transport emissions (Commonwealth of Australia, 2017), their scope to reduce emissions is limited and dependent on the decisions of individuals. Centrally managed modes such as buses and light commercial vehicles as well as lighter two or three wheeled vehicles represent new opportunities, albeit with their own unique challenges and policy needs.

This paper reviews Australian and global drivers and barriers for each electromobility mode, and public policy efforts that have been used to promote deployment. It provides estimates of electricity consumption, decreased fossil fuel consumption and carbon emissions for Australian electromobility, as well as a summary of electromobility deployment in selected countries. The unique barriers of each mode are discussed in the context of the existing Australian market, regulatory and policy landscape. Global policy examples for each mode are evaluated for relevance for Australia, and the potential interplay between mode and policy choices are examined. This work highlights the need for coherence in policy across state and federal governments, and policies that consider each mode's unique barriers.

1. Introduction

Mobility is fundamental to human society and the efficient and cost-effective movement of people and goods is essential to almost every sector of the economy. Yet mobility is also a significant contributor to greenhouse gas emissions. As we transition towards a low carbon world in order to avoid the worst impacts of human-induced climate change, we must change the way we use and plan for mobility. The impacts of mobility depend on the technology used (the vehicle mode and fuel type), how it is used (distance travelled, speed etc.) and the number of users. The shift to vehicles fuelled by electricity, or electromobility (e-mobility), is just one option in a broad suite of low carbon mobility actions, but a particularly promising one. Policy support for large-scale adoption of electromobility is largely driven by the goal of decarbonisation of the transport sector but offers additional benefits such as reduced local and noise pollution in urban areas, reduced reliance on foreign liquid fuel imports and therefore improved energy security, new economic development and increased possibility for smart and autonomous transport systems. As with any emerging technology, electromobility brings unique challenges and market failures, which can be somewhat mitigated by well-designed public policy efforts.

The effectiveness of public policy for electric passenger cars (e-cars) has been the subject of numerous academic, industry and government studies. Some have reviewed the e-car policy suites of specific countries and their effectiveness, such as Wee et al. (2018) for the USA or Mersky et al. (2016) for Norway. Others have compared the effectiveness of policy suites across multiple countries such as van der Steen et al. (2015) and Usmani et al. (2015) who compared European countries' policies, or Broadbent et al. (2018), Z. Yang et al. (2016), Leurent and Windisch (2011) or Lieven (2015) who compared the policies of miscellaneous countries with high e-car penetrations. These studies however mostly ignore other transport modes that can be electrified, and which offer considerable opportunities to improve mobility outcomes.

Compared to that on e-cars, the literature on other modes is relatively limited. For electric bicycles (e-bikes), Dill and Rose (2012) and Johnson and Rose (2013) investigated the purchasing decision making and barriers of e-bike users, Weinert et al. (2007) investigated the drivers of Chinese e-bike adoption and the European Cyclists' Federation (2016) compared e-bike policies across Europe. For electric motorcycles and scooters (referred collectively to as e-motorcycles in this paper), Huang et al. (2018) modelled the diffusion of e-motorcycles with and without subsidies, finding that they are required to reach market competitiveness and Jones et al. (2013) conducted a stated preference survey on households, finding that reduced sales taxes would increase willingness to purchase significantly. J. Yang et al. (2018) investigated policy settings for electric taxis (e-taxis) finding that subsidising the purchase price was necessary, but a mixture of government policies was the most effective means of promoting them. A recent report by Bloomberg New Energy Finance (2018) outlines global drivers and barriers for electric buses (e-buses) as well as policy options to overcome them, Ou et al. (2010) investigated e-buses in China, recommending more policy to support research, and Gallo (2016) outlined barriers for buses and heavy vehicles focusing on modifications required by electricity retailers. Urban logistic vehicles and light commercial vehicles including vans and trucks (e-LCVs) have been investigated particularly thoroughly for Europe due to various demonstration projects, such as in (Morganti & Browne, 2018), (Quak et al., 2016) and (Mirhedayatian & Yan, 2018).

These studies however do not consider the policy approach for more than one mode of vehicle. A small number of studies have considered multi-modal policies. Altenburg et al. (2012) reviewed the policies of multiple countries for vehicles capable of over 50km in range, but mainly considered e-cars. Thiel et al. (2016) modelled the effect of policies on total transport sector emissions, but only considers policies relating to cars. Leibowicz (2018) used insights from historical transport technology diffusions to recommend low carbon mobility policies across varying modes. Trip et al. (2012) compared policies of Northern European countries across all modes and Shi et al. (2015) analysed different modal policies in China. The most recent EV update report by the International Energy Agency has included most road based modes in its analysis (IEA, 2018c). These studies however do not assess the interaction of mode-specific policies or the impact on other policy aims such as reduced congestion or increased ridership of public transit. Nor are they necessarily relevant in the Australian context. Australian specific papers, such as (Cass & Grudnoff, 2017), (IEA, 2018a), (Climate Works, 2018) and (Energeia, 2015) also almost exclusively cover e-cars.

Therefore, this paper seeks to explore, through an Australian lens, the current drivers and barriers of urban, road-based vehicle modes, global examples of public policy designed to overcome the barriers and the potential interaction between them. In Section 2, the uptake of e-mobility globally is compared to Australia. Sections 3 and 4 outlines the drivers and barriers for e-mobility uptake in Australia and provides results of analysis quantifying potential electricity consumption, fossil fuels avoided and carbon emissions from e-mobility in Australia. In section 5, best practice in global e-mobility policy is discussed and compared with practice in Australia. The paper concludes with a discussion on the likely suitability of various policy instruments for the Australian context and areas for future work.

2. Uptake and Indicators of Electromobility

The uptake of e-mobility technology is growing globally across all modes. For e-cars, the proportion of plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) currently in use in different countries ranges between 0% to 6.4% (in Norway), and new sales can be as high as 39%, also in Norway (IEA, 2018b). Electric buses now represent over 13% of the global municipal bus fleet, predominately located in China (BNEF, 2018). For other modes, the proportion of the fleet is typically smaller but growing. Available models of light commercial vehicles are growing (Morganti & Browne, 2018) and being trialled across Europe (Leonardi et al., 2012), and global electric two and three wheeled fleets were estimated at over 250 million and 50 million respectively in 2017 (IEA, 2018b). Figure 1 compares the estimated electric vehicle proportion by mode for three dominant countries in e-mobility with Australia. Data points with “n/a” indicate insufficient information to provide an estimate.

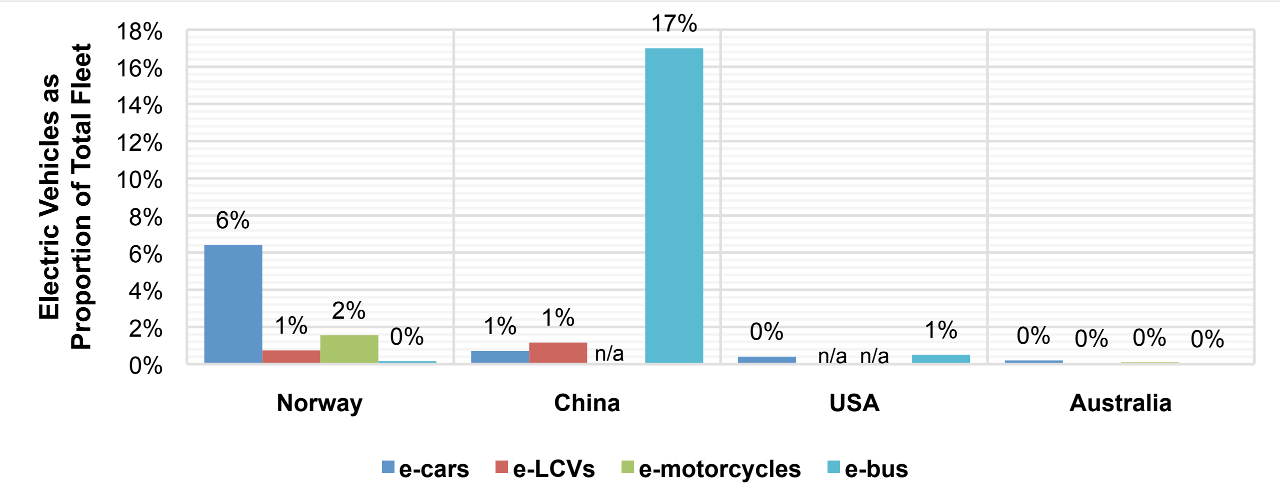

Figure 1: Proportion of BEVs and PHEVs by Vehicle Mode across selected Countries[1]

3. Drivers for E-Mobility in Australia

3.1. Societal Drivers

Societal benefits from e-mobility uptake include reduced carbon emissions and local pollution, improved fuel security, economic development opportunities and improved utilisation of the national electricity grid (Energeia, 2015). The carbon intensity of electric vehicle travel is already less than that of the incumbent Internal Combustion Engine (ICE) vehicle technology, despite Australia’s present emissions intensive electricity sector. The impact of road transport electrification was previously calculated by the authors for a submission into Senate Select Committee on Electric Vehicles (Purnell et al., 2018), and is reproduced in Table 1. The upper limit

[1] Estimates only and derived from numerous sources including (IEA, 2018c), (BNEF, 2018), (ABS, 2017), (Statistics Norway, 2018), (National Bureau of Statistics of China, 2018) and (U.S. Department of Transportation, 2017).

of carbon reductions from a transition to electric road transport alone[2] is calculated as 40 $MTCO_{2\text{-eq}}$ per annum, equivalent to 42% of total 2017 domestic transport emissions (including domestic air and shipping, which makes up around 15% of transport sector emissions). The largest absolute reduction comes from passenger vehicles, but the contribution of LCVs and trucks is also significant. As the energy sector transitions to low carbon renewable energy generation, the carbon reduction scope for electromobility increases to 85% of road transport emissions under a 100% renewable energy generation scenario, demonstrating that the economic and environmental benefits of a transition to electromobility can be maximised by high renewable energy penetrations in the electricity sector.

Table 1 also shows that transitioning to 100% BEVs could save in the order of 33,000ML of fuel[3] each year, compared to approximately 58,000ML crude oil consumed domestically in 2016 (DOEE, 2017). Per vehicle, trucks and buses have of course the largest potential to decrease fuel consumption annually. Reducing total oil consumption would increase energy security, decreasing exposure to international fuel imports, geopolitical risks and price fluctuations while reducing our IEA stockpiling requirement.

The Electricity Sector could also benefit from electromobility, depending on how it is integrated and market adaptations. Electromobility represents a significant new load on the electricity grid, likely to be one of the largest loads for a residential consumer charging their EV at home. Table 1 highlights that if all vehicles were electric, this would represent an approximate increase of 50TWh/year of electrical load across Australia, a 23% increase in combined National Electricity Market (NEM) and Western Australian (WEM) demand EVs could have additional benefits for reliability and transition to high renewables, by providing a flexible load resource (Mills & MacGill, 2018), reducing generator ramping requirements and providing system security services (Mills & MacGill, 2012).

3.2. Consumer Drivers

The drivers for individuals or businesses to purchase an electric vehicle can be broadly categorised as non-financial and financial. Consumers benefit financially from low fuel costs of running electric motors. Estimations of fuel savings vary depending on the fuel efficiency of both the EV and comparable ICE models chosen as well as distance travelled. **Error! Reference source not found.** presents an estimated range of possible annual fuel savings for various modes, based on average annual driving distances from blended Australian Census data (ABS, 2017), along with average fuel efficiency and average retail electricity, petrol and diesel prices. Assumptions can be found in Appendix A. The results show that e-buses and e-taxis have the largest potential for annual savings, mainly due to their high annual driving distance, but the saving is highly dependent on fuel intensity of the new and replaced vehicles. The purple range in the figure expresses the outcomes under different fuel efficiency choices, ranging from best- to worst-case scenarios.

[2] Results are displayed on 2016 levels to avoid future uncertainty of increased fleet size, potential future mode shifting or technology improvements.

[3] Includes petrol, diesel and other fuels as defined in (ABS, 2017).

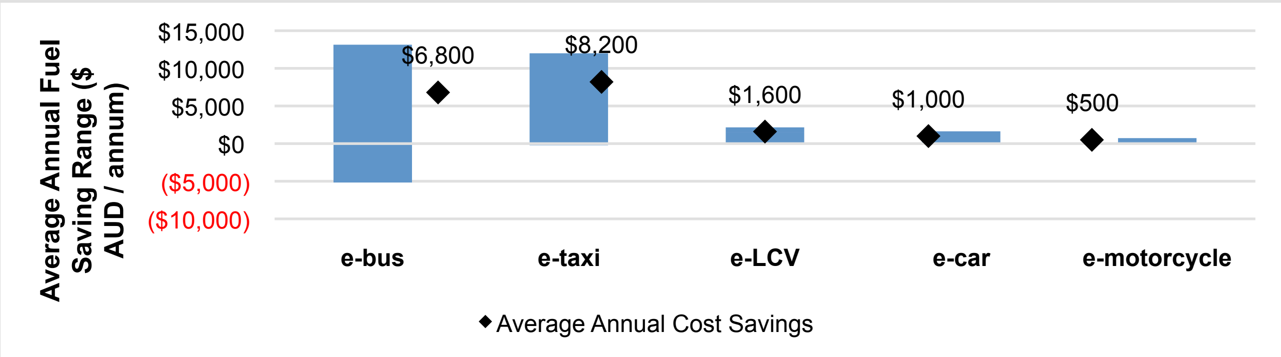

Figure 2: Fuel Expenditure Savings per Mode for EV compared with ICE vehicle.

Table 1: Indicative Road Transport Electrification Effects in Australia – Static 2017 Scenario at Various Penetrations

Note that these estimates are intended as order of magnitude estimates only to demonstrate the scale of opportunities.

Mode	# Vehicles	Electricity Consumption (GWh/a) *(% of 2015/6 total NEM & WEM demand) (1)*			Petroleum Based Fuel Avoided (ML) *(% of 2015/6 total domestic crude oil consumption) (2)*			Carbon Avoided (2016 generation mix) ($MTCO_{2-e}$) *(% of 2017 total domestic transport emissions) (3)*			Carbon Avoided with 100% RE Generation ($MTCO_{2-e}$) *(% of 2017 total domestic transport emissions) (3)*		
% of fleet electrified		*10%*	*25%*	*100%*	*10%*	*25%*	*100%*	*10%*	*25%*	*100%*	*10%*	*25%*	*100%*
Passenger Vehicle	13,712,810	3200 (2%)	8000 (4%)	32000 (15%)	1900 (3%)	4700 (8%)	19000 (32%)	1.7 (2%)	4.4 (5%)	17 (18%)	4.4 (5%)	11 (12%)	44 (46%)
Light Commercial Vehicle	2,983,034	790 (0%)	2000 (1%)	7900 (4%)	610 (1%)	1500 (3%)	6100 (10%)	0.89 (1%)	2.2 (2%)	8.9 (9%)	1.5 (2%)	3.8 (4%)	15 (16%)
Motorcycle	824,572	5.7 (0%)	14 (0%)	57 (0%)	12 (0%)	31 (0%)	120 (0%)	0.024 (0%)	0.061 (0%)	0.24 (0%)	0.029 (0%)	0.073 (0%)	0.29 (0%)
Trucks													
Rigid Truck	470,849	410 (0%)	1000 (0%)	4100 (2%)	290 (0%)	720 (1%)	2900 (5%)	0.44 (0%)	1.1 (1%)	4.4 (5%)	0.78 (1%)	2 (2%)	7.8 (8%)
Articulated Truck	96,214	460 (0%)	1100 (1%)	4600 (2%)	430 (1%)	1100 (2%)	4300 (7%)	0.81 (1%)	2 (2%)	8.1 (8%)	1.2 (1%)	2.9 (3%)	12 (12%)
Non-Freight Carrying Truck	21,581	11 (0%)	27 (0%)	110 (0%)	7.4 (0%)	19 (0%)	74 (0%)	0.011 (0%)	0.027 (0%)	0.11 (0%)	0.02 (0%)	0.05 (0%)	0.2 (0%)
Buses	82,615	90 (0%)	230 (0%)	900 (0%)	68 (0%)	170 (0%)	680 (1%)	0.099 (0%)	0.25 (0%)	0.99 (1%)	0.17 (0%)	0.43 (0%)	1.7 (2%)
Total	**18,191,675**	**5000 (2%)**	**12000 (6%)**	**50000 (23%)**	**3300 (6%)**	**8200 (14%)**	**33000 (56%)**	**4 (4%)**	**10 (10%)**	**40 (42%)**	**8.1 (8%)**	**20 (21%)**	**81 (85%)**

(1) N.B. total electricity consumption from EVs includes vehicles in all states, % is calculated as a proportion of NEM (191,777GWh, 2016) and WEM (18,895GWh, 2015/16 (AEMO, 2017)) demand only and excludes all other electricity demand.

(2) Total domestic crude oil consumption in 2015 was converted from Australian Government figure of 2,243 PJ, or approximately 57,966 ML crude oil (DOEE, 2017). Vehicle petroleum-based fuel consumption is calculated using vehicle numbers, distances and fuel consumptions per year from ABS Survey of Motor Vehicle Use, Australia in 2017 based on 2015/16 data (ABS, 2017). *These figures are not directly comparable, and the comparison is provided for order of magnitude only.*

(3) Avoided emissions per vehicle type are calculated using average BEV energy intensity figures per mode as per (Mellino et al., 2017). Emission factors are taken from (DOEE, 2016) Australian Emission factors in August 2016, using Scope 1 factors for gasoline, diesel and LNG and Scope 2 factors for electricity. *Total domestic transport emissions of 96MTCO2 in 2017 is from* (Commonwealth of Australia, 2017)*. Please note that domestic transport refers to all domestic road-based transport as well as domestic shipping and aviation as according to (DOEE, 2017).*

Environmental benefits, while not a direct benefit to the consumer have been reported as a key decision to purchase for Australian e-bike first adopters (Johnson & Rose, 2013). Large purchasers of e-fleets may also be able to financially benefit from the carbon abatement through the existing Emission Reduction Fund (ERF) policy mechanism, whereby businesses can earn and trade Australian Carbon Credit Units by switching to EVs (IEA, 2018a). In addition to fuel and maintenance cost savings, commercial modes such as taxis and light commercial vehicles have the benefit of green marketing.

Other consumer non-financial drivers include instant maximum torque, which may be particularly attractive for stop-start vehicles such as taxis and buses (Mead, 2018). In some urban areas, there are curfews for heavy commercial vehicles such as trucks and vans, introduced to reduce noise pollutions and local emissions[4]. This has the possibility to be a financial opportunity for companies that use low noise and emission vehicles such as EVs if governments provide them with extended hours or other exemptions.

4. Barriers in Australia

4.1. Upfront Cost Barriers

Current cost premiums associated with e-mobility technology are well documented and occur across all modes. For e-cars in Australia, the purchase price can be double that of an equivalent ICE car (Energeia, 2015), small e-vans in Europe are similarly approximately double the cost at present (Quak et al., 2016). However, these costs are falling – for example,e-buses in Europe are projected to reach purchase price parity with diesel buses by 2030 (BNEF, 2018). In Australia, EVs have additional upfront costs added to the purchase price including import tax and for some e-cars, luxury car taxes. High e-car purchase prices in Australia are often blamed in part on distributor focus on premium models and lack of availability of low cost models (Climate Works, 2018). This is also found in other modes, with some e-LCV studies finding that a lack of vehicles fit for purpose was a key barrier for uptake (Quak et al., 2016).

For commercial EV fleets (e.g. e-LCVs), the total cost of ownership (TCO) represents a significant barrier. In addition to the vehicles' cost premium, drivers require additional training for the vehicle, procurement time is often longer and repairing vehicles is more difficult due to limited skilled repairpersons compared to ICE vehicles. Australian company SEA Electric notes that the additional battery weight could also push e-LCVs into a higher weight class, requiring additional registration fees (Fairweather, 2018), which was also found to be an issue in Europe, (Morganti & Browne, 2018) and is also relevant for e-buses. The operations of scheduled vehicles like e-buses and some e-LCVs will likely have to be redesigned to account for charging requirements and limited range (Quak et al., 2016), further adding to total costs.

4.2. Charging Related Barriers

Range anxiety is a commonly cited barrier for e-mobility uptake in e-LCVs (Morganti & Browne, 2018), e-cars (Energeia, 2015), e-buses (BNEF, 2018) and e-taxis (J. Yang et al., 2018). Range anxiety becomes less of an inconvenience and more of a critical risk for a commercial vehicle as any delays represent wasted labour costs and reduced revenue. Limited public charging infrastructure also becomes a risk as queuing time similarly represents wasted costs and may limit the total range of potential accessible markets. The lack of standardisation of charging infrastructure for some modes such as buses limits the resale value of the vehicle and the ability to use multiple different brands within a system (BNEF, 2018).

For commercial vehicles that charge in a central location such as bus depots, private taxi ranks or commercial vehicle car parks, grid augmentation may be necessary to support the new load. The

[4] Such as Victoria (Vic Roads, 2018)

cost of installing charging equipment represents a principal-agent problem, as the businesses are often liable for the full extent of these costs, but do not own the infrastructure (Gallo, 2016).

4.3. Regulatory Barriers

Australia has no policy to internalise of cost of carbon emissions. This in combination with relatively low transport fuel prices (GlobalPetrolPrices.com, 2018) reduces the economic incentive for e-mobility technologies compared to many other countries. Vehicles imported to Australia currently do not have to meet carbon emission minimum standards, estimated to apply in over 80% of countries (Climate Works, 2018), resulting in Australia importing a relatively high proportion of high-emitting vehicles. These regulatory settings reduce the opportunity and incentive to purchase e-vehicles. A summary of drivers and barriers for each electromobility mode, and their relative importance are shown in

., based on an estimate of the scale of financial impact on a purchasing decision.

Table 3: Drivers and Barriers for Purchase Across Modes

	e-cars	e-bicycle	e-motorcycle	e-taxi	e-LCV	e-bus
Purchaser	Individual / Business	Individual / Business	Individual / Business	Individual / Business	Business	Transit Authority / State Gov
Drivers						
Reduced operating costs	2	0	2	2	2	2
Reduced local emissions	1	0	1	1	1	1
Reduced carbon emissions	1	0	1	1	1	1
“Green” marketing	0	0	0	2	2	1
Silent operation	1	0	1	1	2	1
Barriers						
Insufficient range	1	0	1	2	2	2
High upfront cost	2	2	2	2	2	2
Access to public charging	1	1	1	2	2	2
Limited model availability	2	1	2	2	2	2
Grid infrastructure augmentation	1	0	0	1	2	2
Weight restrictions & capacity	0	0	0	0	2	2
Queuing risk	1	0	1	2	2	2

Where **0 = not significant / relevant, 1 = somewhat significant, 2 = extremely significant**

5. E-Mobility Policy Options and Global Experiences

This section outlines global e-mobility policy trends across all modes, providing global and Australian examples of their use and effectiveness. The vast majority of policies implemented globally have been designed to overcome the cost premium of EVs. Other policies are designed to combat a range of technical and regulatory barriers.

5.1. Standards and Regulations

Vehicle emission standards regulate the maximum carbon emissions from new vehicles that can be sold in a country and are often designed to decrease over time to drive the development of lower-emission vehicles. Over 80% of countries have implemented emissions standards across most vehicle modes, including the USA (APEC, 2017) and the EU (Morganti & Browne, 2018). In Australia, vehicle standards exist for pollutants such as sulphur, but not for carbon dioxide. Previous voluntary standards in place for light vehicles were discontinued in 2010 as targets were not achieved (Climate Change Authority, 2018). Emission standards have been called for by many stakeholders in Australia, including as a complement to the ERF (Climate Change Authority, 2018) and an incentive for e-cars (Climate Works, 2018). The Department of Infrastructure and Regional

Development is currently considering implementing them for light and heavy vehicles (DoEE, 2018). The policy can be easily scaled across all vehicle modes and would have low potential to conflict with other existing policies.

Standards for charging infrastructure, including plugs, communication technology, power supply and payment, can facilitate interoperability across all models within a vehicle mode (Hall & Lutsey, 2017), and also require vehicles to accommodate the standard. Charging infrastructure that can be used for light EVs such as e-cars, e-LCVs, e-bicycles and e-motorcycles has been covered by an IEC standard applied by Standards Australia[5], and the industry has committed to adopting this standard for all new models from 2020 (Wong, 2017). For heavier modes the standards are less well defined. There are currently no local standards for e-buses (Mead, 2018), which is noted as a major barrier globally as it forces lock-in to a particular charging technology for bus operators and therefore reduces competition (BNEF, 2018). There has been some agreement by e-bus manufacturers on charging infrastructure interoperability (BNEF, 2018) and four standards are currently under development ((Wilson, 2018); (Kosowski, 2017)).

5.2. *Discounts and Exemptions for Road-Related Taxes and Charges*

In most countries, road users contribute towards road maintenance and upgrades through a combination of taxes and fees, based on fuel consumption and/or vehicle weight for heavy vehicles (e-buses, e-trucks and some e-LCVs). As these are existing mechanisms, they are a popular option around the world for e-mobility incentives. Registration fees and stamp duty contribute 23% and 9% of road related revenue respectively in Australia (BITRE, 2017) and apply to almost all vehicle modes. Registration fees for road-access are collected yearly by state and territory governments, while stamp duty is a once-off fee payable at purchase of vehicle (new or transferred). Providing discounts or exemptions of these fees is a common policy incentive used to reduce upfront or ongoing costs of e-cars and e-motorcycles, and has been applied in some Australian states and territories, including NSW for e-cars, VIC for e-cars, heavy vehicles and e-motorcycles and QLD and ACT for e-cars and heavy vehicles (Climate Works, 2018). There is scope to extend these discounts for e-LCVs, e-buses and other heavy vehicles as well.

The term tax incentives has been used to describe various policy instruments (discounts, credits, rebates or exemptions) applied to taxes at different points in a products lifecycle; sales tax (applied at the point of sale), value added tax (VAT) (applied at each stage of a product where value is added), income tax (applied on an individual's or business' annual tax return) as well as import duties (applied on a product on entry to a country). They have been used widely for all modes. Sales tax exemptions were used in Norway for e-cars (van der Steen et al., 2015) and China for e-buses (Shi et al., 2015), Belgium and Norway had company income tax deductions for e-cars, as do e-vans in the UK (van der Steen et al., 2015) as well as company owned e-bikes in the UK and Germany (ECF, 2016). Australia previously had a federal import tax concession for e-bike but this was removed in March 2018 (Gilfillan & Chapman, 2018) in an effort to protect the Australian e-bike manufacturers. Studies for e-cars suggest that tax incentives are beneficial to improve EV adoption, with some noting that they are most effective if applied upfront rather than as credits (Hardman et al., 2017).

The Luxury Car Tax (LCT) in Australia is a 33% tax applied to cars above a certain purchase price threshold ($66,331) (ATO, 2018). The threshold is higher for fuel efficient vehicles. This works to reduce the relative purchase price differential between EVs and ICEs for e-cars over the threshold (the majority of e-cars available in Australia) (Climate Works, 2018), but some advocate that EVs should be exempt altogether (Climate Works, 2018). LTC exemption is limited, however, to e-cars,

[5] Namely IEC 61851-1:2017; Electric vehicle conductive charging system - Part 1: General requirements and AS IEC 62196.2:2014; Plugs, socket-outlets, vehicle connectors and vehicle inlets

while the longevity of the policy is in question (Productivity Commission, 2014), so the potential for this policy incentive may be limited.

5.3. Financial Benefits at Purchase

Common across all modes and most countries is the purchase price premium of EV technologies compared to ICEs. This can be addressed through tax incentives, or more directly through subsidies (provided at point of purchase), rebates (claimed after the purchase) and grants (applied for and provided in advance of purchase) to reduce the purchase cost. All three instruments are commonly used across all modes. For e-cars and e-LCVs, subsidy levels can be a fixed dollar value such as in China (APEC, 2017), a fixed percentage of the purchase price or rebates based on the customer's income levels such as in California (DeShazo et al., 2017). China successfully used subsidies for e-buses to stimulate uptake ((Shi et al., 2015); (BNEF, 2018)), but in other areas grants are more popular, for example the 'Low-No Grant' by the US Federal Government (BNEF, 2018) or the Green Bus Fund in the UK (Trip et al., 2012).

Huang et al. (2018) analysed e-motorcycles subsidies in Taiwan and found them to be important to reaching market competitiveness with ICEs. Subsidies for e-taxis in China were modelled and found to be important for adoption rates (J. Yang et al., 2018). Subsidy and rebate systems can be multi-modal, for example Singapore's GVR scheme rebates e-cars, e-buses, e-LCVs and e-motorcycles at a percentage of the vehicle cost (APEC, 2017). For e-cars, and subsidy design in general, the literature suggests that financial incentives are more effective at incentivising uptake when given at the time of purchase (such as subsidies or grants) rather than afterwards (such as rebates) (Hardman et al., 2017) and are effective in the short-term for market development, but other policies are required for long term success (Harrison & Thiel, 2017). Subsidies and tax incentives reduce the upfront cost of purchasing, but do not address market failures and regulatory barriers during later phases of ownership. Subsidies are also likely to become an expensive policy once a technology approaches market competitiveness and significant sales volumes.

5.4. Use Phase Incentives

The policies discussed so far have all targeted barriers that occur either before or at the purchase point. Other policies such as priority lane access, reduced or free parking and toll roads, as well as favourable electricity tariffs provide benefit during the use of the vehicle, provide visibility for e-mobility, and can influence the propensity to purchase an EV.

While not strictly a public policy issue, the design of electricity tariffs needs to be considered for all EV modes. While some electricity retailers now offer e-car specific tariff plans to incentivise individuals (usually households) to charge at specific times, there are few specific tariffs available for other modes at present. Stakeholders from other modes are calling for recognition of their different usage and charging profiles, advocating a flat rate per day per vehicle charge for e-LCVs (Fairweather, 2018), and e-trucks (Humphries, 2018), or removal of demand charges for e-bus depots (Gallo, 2016).

Priority lane access, where an EV can use bus or high occupancy vehicle (HOV) lanes has been used in New Zealand (APEC, 2017), Norway (Cass & Grudnoff, 2017) and in the ACT (Climate Works, 2018) for e-LCVs. This allows the user to avoid congestion but may cause congestion for the vehicles traditionally intended for the lane. Shewmake and Jarvis (2014) investigated HOV lane use in the US and found that the effectiveness of this policy is seemingly dependent on the space available in the priority lanes and proposed that a more effective policy would be to sell HOV lane space and use the proceeds to fund other policies. In addition, as bus ridership is linked with bus speeds (Litman, 2016), reducing these speeds through increased congestion in priority lanes could lead to mode shifting away from public transport.

Free parking and relaxed parking rules for EVs have been proposed and deployed globally, which could be a significant financial and convenience incentive in congested urban areas, particularly for e-LCVs with less flexibility on route choice or parking options. Relaxed parking rules have been used in commercial vehicle EV trials in Europe, for example allowing parking on sidewalks legally to unload in Amsterdam (Quak et al., 2016). Australian companies SEA Electric and Isuzu Australia has called for preferential delivery parking for e-LCVs, subsidized road tolls and priority road access ((Fairweather, 2018); (Humphries, 2018). The conflicting goals of reduced congestion in cities and increased public transit ridership should be considered before implementing parking incentives. For example, in Sweden, Malmo introduced free e-car parking but cancelled in less than 2 years later as it did not support congestion goals (Usmani et al., 2015).

5.5. Congestion and Emission Zoning

Some cities deal with congestion and local pollution problems by introducing zones with vehicle restrictions or discouragements to enter. Cordon Zones reduce congestion by requiring vehicles cannot to pay or be authorised to enter the zone during certain times of day, as per London or Rome, and similar to broader network-wide road pricing. To deal with local pollution in urban centres, some countries have used low emission zones, where vehicles over a threshold emission limit are restricted from entering the zone, such as in Paris or London (Morganti & Browne, 2018) or a fuel is banned, such as diesel in Paris (Morganti & Browne, 2018). As EVs will most likely fall under emission thresholds, they are afforded access, which can represent an exclusive benefit for EV taxis or light commercial vehicles. EVs may also be given authority to access or given discounts on congestion fees such as in Rome (Usmani et al., 2015). Currently Australia does not have any Cordon or low-emission zones, but they have been proposed along with wider road reforms (Deloitte, 2013).

5.6. Charging Infrastructure

Many countries have operated, fully funded or partially funded public charging infrastructure for e-cars and some have provided infrastructure rewards for bus charging projects (Shi et al., 2015). The provision of public charging infrastructure has been statistically correlated with e-car uptake by Hall and Lutsey (2017), who perform a multivariable regression of 350 metropolitan areas. They suggest that “multifaceted and collaborative approaches have been most successful in promoting early charging infrastructure buildout” (Hall & Lutsey, 2017) to engage stakeholders while remaining flexible as the market evolves. Some have questioned the benefit of strategic government public charging infrastructure for e-cars, including Helmus et al. (2018) who comments that it is not more effective than demand driven installations at the home and Harrison and Thiel (2017) who suggest that for early markets, provision of public charging infrastructure has a poorer correlation with uptake of PHEV cars than other policies. In addition to provision of charging infrastructure, there is potential for policy support for charging related electricity grid augmentation, called for by some e-LCV stakeholders ((Fairweather, 2018); (Quak et al., 2016) and for e-buses (Gallo, 2016).

5.7. Market Creation

Beyond financial and tax incentives, other market creation policies aim to educate consumers about the capabilities and benefits of a technology through information campaigns, increase visibility through demonstration and trial projects or to create a niche market, such as through government fleet procurement. These policies are usually implemented at an early stage to encourage initial market development before market competitiveness and wide spread uptake. Fleet procurement can be implemented at any level of government and has been adopted for most modes. The city of Copenhagen have procured only EVs or PHEVs cars and vans since 2011 (Usmani et al., 2015), France has required car rental and taxi firms to purchase a minimum of 10% low emission vehicles when replacing vehicles and have set federal fleet procurement at 50% low emissions (Tiwtge et al., 2016). The Chinese government purchased BEV and PHEV buses to service the Olympic Games in Beijing (BNEF, 2018). Some state governments in Australia have also implemented fleet procurement policies for e-cars.

Demonstration projects are helpful to test technology capabilities, learn about any other institutional or regulatory barriers to deployment and increase confidence of the market in the technology. Many cities have current or completed trials across all modes such as Sweden's Hyper Bus69 project for Battery Electric Buses (BEBs) (Trip et al., 2012), electric motorcycle sharing trials in Paris, San Francisco and Barcelona (Huang et al., 2018) as well as Austria (Lesteven & Leurent, 2016) and commercial vehicles in London (Morganti & Browne, 2018). While commercially challenging, it is vital that the knowledge gained from running these projects is made publicly available and shared, and ideally, they should involve multiple industry partners to ensure dissemination. In Australia, this could be done through the National Collaboration on Electric Vehicle Memorandum of Understandsing, an agreement by various local, state / territory governments and companies (Climate Works, 2018).

6. Electromobility Policy Considerations

A range of policy instruments have been introduced in this paper, summarised per mode in Table 4, where "Y" represents polices that are applicable & widely used, "N/A" represents policies judged as 'not applicable' and "Poten." represents policies not widely used but could be applicable. Most policy instruments currently used for e-cars could be deployed for all modes, even if not currently used. The exception is the e-bike, which is not currently required to be registered or contribute to road fees.

Evaluation criteria commonly used to assess policy include effectiveness, efficiency, equity, and feasibility (IRENA, 2014). The main aim of electromobility is the goal of decarbonisation of the transport sector, while electromobility is one component in a broader suite of low carbon mobility actions. Internalising the cost of transport carbon emissions is theoretically the most efficient policy option to meet this goal, but carbon taxes and tradeable permit schemes have proven politically infeasible in Australia, even where the transport sector has been excluded due to particular sensitivities around petrol prices. Across all electromobility modes, policy that limits the worst emitting technologies is likely to be highly effective, as have minimum performance standards for appliances in Australia. Introducing vehicle emission standards that are in-line with average global practice would not impose additional product development costs and would have low implementation costs and transaction costs for consumers.

While, it is not the purpose of this paper to recommend specific policy arrangements, and it should be noted that the effectiveness of policy depends on the detailed design and implementation, it is worth considering the unique characteristics of this policy space that should be considered within policymaking processes.

Thought to multi-modal transit should be given when supporting public charging stations, including potential 'fast' lanes for e-taxis and e-LCVs, standard plugs to support e-bicycles and e-motorcycles, and charging systems for e-buses that prevent technological 'lock-in'. In addition to the policy criteria above, a goal of technological neutrality can be added such that policies should aim to apply across a variety of different transport modes and ownership types.

Most existing policies focus on incentivising deployment by overcoming barriers or providing benefits. Electromobility exists within two sectors, transport and electricity, each of which have other key objectives such as to manage urban congestion and peak electricity demand. As we see significant penetrations of electromobility, policymakers will need to focus on managing the impact on broader infrastructure and changes requited to planning, operation and regulation of these sectors. As discussed previously, e-mobility necessitates a fundamental restructuring to the road pricing model to fund and maintain the infrastructure in the long term. Incentives that aim to provide benefits to EVs during the use phase such as priority lane use and free / designated parking may perversely incentivise some modes in favour of others while interacting negatively with other policy goals such as reduced congestion. Policy support for charging infrastructure should consider supporting any resulting grid augmentation requirements. Policy designed to promote e-mobility should be designed if possible to support broader sectoral goals. It will be more important to understand the interactions between modes and broader policy goals, and design policies that take this into account beyond standard policy criteria. An additional assessment criterion of complementarity will be useful for ensuring these interactions are considered.

7. Conclusions & Future Work

Electromobility has numerous benefits for society including lower local and global pollution, reduced exposure to international liquid fuels markets and benefits for the consumer including lower fuel costs, but there remain significant barriers in Australia to wide-spread adoption. This paper reviewed Australian and global drivers and barriers for each electromobility mode and public policy that has been used to promote EV uptake.

Many of the drivers and barriers found in the literature for e-cars are also applicable to other modes. Modes with a commercial purpose such as e-taxis, e-LCVs and e-buses are potentially more strongly impacted by cost considerations, reduced range capabilities and limited public charging infrastructure. Nevertheless, many policy instruments currently being used for e-cars can be applied to the other modes.

Across all modes, there are benefits to introducing policy that internalises the cost of carbon emissions or limits the worst emitting technologies. To account for the unique characteristics of the electromobility transition, specific policy assessment criteria have been proposed. Due to the impact of electromobility on a range of infrastructure, complementarity with broader sectoral policy goals, and recognising the potential importance of mode shifting to achieve emissions and broader goals, technological neutrality across modes is proposed.

Future work is required to evaluate potential policy economic, emissions and vehicle adoption impacts. In particular, the impact of potential policies on mode shifting across the transport sector and impacts on broader issues such as congestion, peak electricity demand and urban planning should be assessed. Robust methods that combine transport and electricity system models need to be developed to model technology and policy scenarios and their costs and benefits.

Table 4: Electromobility Policy Options per Mode & Relevant Government Level

Policy Category	Policy Instrument	Barriers/Benefits Targeted	e-car	e-bike	e-motor cycle	e-taxi	e-LCV	e-bus	Government Level
Regulatory	Vehicle Emission Standards	CO_2 externality, market availability	Y	N/A	Poten.	Poten.	Poten.	Poten.	Federal
	Standardisation of Infrastructure	Range anxiety, interoperability, 'lock-in'	Y	Y*	Y*	Y*	Y*	Y	Federal
	Weight class exceptions	Payload capacity	N/A	N/A	N/A	N/A	Poten.	N/A	Federal
Road Related Taxes and Charges	Luxury Car Tax	Cost premium	Y	N/A	N/A	Y	N/A	N/A	Federal
	Import Tax	Cost premium	Y	Y	Y	Y	Y	Y	Federal
	Stamp Duty / Registration fees	Cost premium	Y	N/A	Y	Y	Y	Y	State
Financial Benefits at Purchase	Subsidies, Rebates & Grants	Cost premium	Y	Y	Y	Y	Y	Y	Any
Other benefits for Owner / Operators	Priority (Bus / HOV) Lane Use	Preferential access to roads	Y	N/A	Poten.	Y	Poten.	N/A	Local / State
	Toll Road Exemption	Improve operating cost	Y	N/A	Poten.	Poten.	Poten.	Poten.	State
	Free / Designated Parking	Improve operating cost	Y	N/A	Poten.	Poten.	Poten.	N/A	Local
	Relaxed parking rules	Improve operating cost	N/A	N/A	N/A	N/A	Poten.	N/A	State
	Priority public charging access	Queuing risk	N/A	N/A	N/A	Poten.	Poten.	N/A	Infrastructure owner
	EV electricity tariffs	Improve operating cost	Y	N/A	Y*	Y	Y	Y	Networks / Retailers
Zoning (hypothetical)	Fuel Bans & Low Emission Zones	Preferential access to roads	Y	N/A	Y	Y	Y	N/A	Local/State
	Congestion Zone Exemptions	Preferential access to roads	Y	N/A	Poten.	Poten.	Y	N/A	Local/State
Infrastructure	Infrastructure (charging) support	Range anxiety, public good, capital access	Y	N/A	Y.	Poten.	Poten.	Y	State/Federal
	Infrastructure (grid upgrades) support	Principal-agent problem, public good	Poten.	N/A	Poten.	Poten.	Poten.	Poten.	State/Federal
Market Creation	Demonstration Projects / Trials	Knowledge gap, first mover disadvantage	Y	Y	Poten.	Y	Y	Y	Local/State
	Government Fleet Procurement Policy	Market availability, knowledge gap	Y	Y	Poten.	N/A	N/A	N/A	Any

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APPENDIX A: Fuel cost comparisons

The cost comparison of Figure 2 uses the assumptions in Table 5 to find minimum, average and maximum savings per year. Figures use the average national retail petrol price for the 2016 calendar year of 117.8c/L and national retail diesel price of 118.5c/L (ORIMA Research Pty Ltd, 2018). Electricity costs take an average of all states' 2016 residential retail standing electricity offers, 24.48c/kWh (AEMC, 2016). Average annual distances are based on census data (ABS, 2017). High and low estimates of cost savings are calculated by varying the ICE and EV fuel economy.

Table 5: Fuel cost assumptions

	e-bus	**e-taxi**	**e-LCV**	**e-car**	**e-motorcycle**
Annual Average Distance (km)	29,700	113,534	17,000	12,800	9,820
Incumbent Fuel	Diesel	Petrol	Diesel	Petrol	Petrol
ICE Fuel Intensity (L/km)	0.45	0.106	0.12	0.106	0.056
EV Fuel Intensity (kWh/km)	1.24	0.215	0.185	0.18	0.025
ICE fuel costs ($/yr)	$15,800	$14,200	$2,400	$1,600	$600
BEV fuel costs ($/yr)	$9,000	$6,000	$800	$600	$100
Average Cost Savings ($/yr)	**$6,800**	**$8,200**	**$1,600**	**$1,000**	**$500**
Low fuel economy (L/km)	0.58	0.13	0.14	0.14	0.07
High fuel economy (L/km)	0.35	0.05	0.12	0.04	0.03
Low EV economy (kWh/km)	2.40	0.26	0.22	0.22	0.03
High EV economy (kWh/km)	1.00	0.19	0.16	0.17	0.02
Cost savings – high ($/yr)	**$13,140**	**$11,790**	**$2,160**	**$1,620**	**$730**
Cost savings – low ($/yr)	**-$5,130**	**-$220**	**$1,480**	**-$10**	**$220**