Electric Vehicles in Australia's National Electricity Market: Energy Market and Policy Implications

EVs would represent a new load, and would represent a sizable increase to the aggregate demand of an individual household. But EV take-up rates are likely to be gradual, and therefore changes to the NEM's aggregate demand will be equally incremental, not radical. For this reason, EV loads should not be considered either as a problem or a panacea for the grid over the short to medium term.

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I. Introduction

Australia is a relatively small country in relation to the world population and by implication, global influence. As energy policies are often geopolitical in nature, some components of Australian policymaking could be argued to be ''policy taking'' rather than ''policy making.'' It is in this context that the electric vehicle (EV) market is likely to develop in Australia. Globally, there are sign posts that point toward a long-run shift in transportation policy away from liquid fossil fuels, and toward electricity. The reason for this is straightforward; while the CO_2 intensity of the existing power system may present only modest environmental gains from consumers switching from internal combustion engines to EVs, over the very long run, the gains are potentially very significant compared to business as usual. The success or failure of EVs to imbed within transportation paradigms is likely to be decided globally, and so we believe that Australia is likely to be an adopter of policies that are consistent with the rest of the world.

There are two main public policy drivers which are likely to result in the increased uptake of vehicles that are not powered conventionally (i.e., by gasoline and diesel). These relate to constraining anthropogenic greenhouse gas emissions with a view to reducing CO_2-equivalent concentrations in the atmosphere to limit climate change; and reducing the reliance of economies on imported liquid fuels, which are becoming scarcer and are sourced from volatile regions in the world. Policies aimed at achieving these objectives are being increasingly adopted. Vivid Economics (2010) found that there were 32 operating greenhouse gas emissions trading schemes in different countries in 2010. Renewable portfolio standards are also common with policies established in regions as diverse as Texas and China.

Transportation comprises around half the global emissions produced by the combustion of fossil fuels (Baumert, Herzog and Pershing, 2005). It is clear that reducing emissions from the combustion of fossil fuels by any material amount to 2050 is not compatible with simply improving the efficiency of petrol and diesel engines. The long-term solution to reducing emissions within the transportation sector requires substitution of the internal combustion engine with alternative power systems. This is evidenced by the decision of the European Union to include transport in its renewable energy requirements of member nations by 2020.

Energy security will also remain a primary concern of policy makers. **Figure 1** outlines the distribution of global energy reserves by geographic region. Oil and gas are primarily located in two regions: the Middle East and Russia (Europe). With 61 percent of oil used for transportation, the geographic distribution of liquid fuels creates significant risks for developed and developing economies. Supply disruptions may arise due to regional conflict and price pressures due to cartel structures. Around the world, countries are beginning to establish policies to reduce their reliance on ''foreign oil.''

The physical distribution of global energy reserves is not the only concern of policymakers in relation to energy security. Fossil fuels are finite resources and will be depleted at some unknown point in the future. The concept of ''peak oil'' has been around for decades yet it is impossible to accurately predict when supplies will eventually run out. Reserve to production ratios can be used to accurately determine temporal supply capacities based upon current consumption rates, production technologies, and known reserves. In relation to oil and gas estimates:

- Oil: There are currently known global reserves of 1,331 billion barrels of oil. Based upon production rates of around 80 million barrels of oil per day, there is around 45 years of supply left. However, production of oil has increased by only 7 percent over the past 10 years whereas known reserves have increased by 20 percent over the same period (BP, 2010).

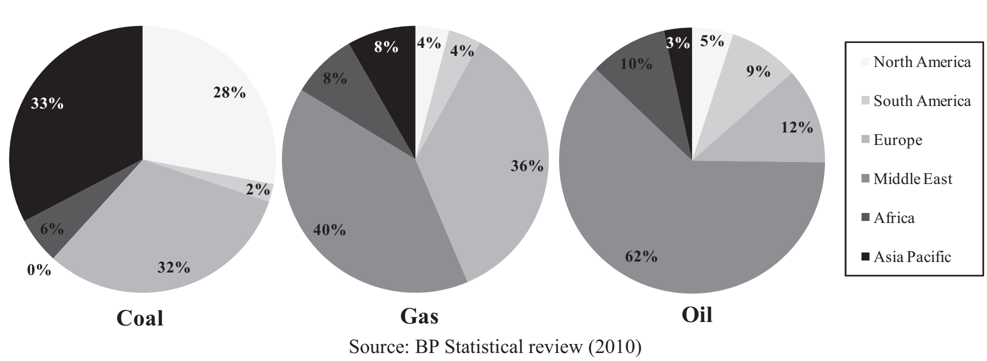

Figure 1: Distribution of Global Energy Reserves

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• Gas: There are currently known global reserves of 187 trillion cubic meters. Based upon current production rates of 2,987 billion cubic meters per year, there is about 62 years of supply remaining. Both production of gas and known reserves have increased by around 20 percent since the year 2000 (BP, 2010).

While production-to-reserve ratios of 45 years and 62 years for oil and gas respectively seem to be far enough in the future ''not to worry,'' policymakers in developed economies are acutely aware of the rising consumption of the developing world. China's oil consumption has roughly doubled over the past 10 years and India's consumption has increased by around 50 percent over the same time period (BP, 2010).

Australia is not an ''energy-secure'' nation in relation to liquid fuels. As far back as 1974, Australian policymakers considered whether EVs should be encouraged to reduce Australia's reliance on ''foreign oil.'' In value terms, Australia imports as much oil as it exports coal. **Figure 2** outlines the value of coal exports and oil imports since 1980. The significant increase in value associated with coal exports and oil imports over the last decade is largely due to commodity prices increasing substantially due to unprecedented global demand. It is clear that Australia faces the same physical supply risks associated with oil supplies as other nations.

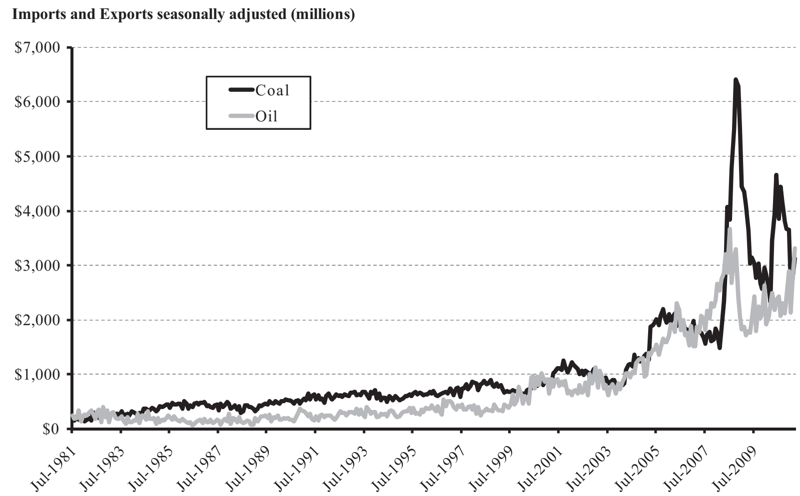

Figure 2: Imports of Oil and Exports of Coal since 1980[1]

Another significant implication of Figure 2 relating to Australia's macroeconomic policy objectives is the structure of our international trading position. Around half of Australia's export income comes from coal (18 percent) and minerals such as iron ore (30 percent). Conversely, half of Australia's imports are related to household consumption (30 percent) and liquid fuels (20 percent). Accordingly, our international trading position is highly exposed to commodity price fluctuations and global demand for commodities. Furthermore, our ability to pay for imported household items depends upon the continued success of our mining and energy sectors. Policymakers are generally not concerned with international trading positions (even large current account deficits) if they are enhancing the productive capacity of the nation. However, Australia's trading position is to some degree structurally problematic because it is not biased toward enhancing the productive capacity of the economy. Reducing our reliance on imported liquid fuels would be an important step in improving our structural trade position.

Based upon an analysis of global energy markets and Australia's position therein, over the medium to long term, our view is that policymakers are likely to increasingly favor forms of transportation that are not reliant upon oil. An obvious substitute for oil is the EV. The world has around 120 years of coal supply left based upon current production rates and electricity can also be sourced from low-emissions gas, nuclear, and renewables. An EV that is cost-comparable with current internal combustion engine vehicles would be a solution to many of the concerns of energy policymakers around the world. Based upon this macroeconomic policy environment, various international governments have introduced targets for EVs, as summarized in **Table 1**.

Table 1: Global Government EV Targets.

Country	Electric Vehicle Targets		
	Vehicles	% of Total	Date
U.S.	1,000,000	0.4%	2015
China	500,000	0.3%	2012
UK	100,000	0.4%	–
France	2,000,000	6.2%	2020
Germany	1,000,000	2.2%	2020
Spain	1,000,000	4.4%	2014
Israel	500,000	25.0%	–
Japan	34,583,670	50.0%	2020
Denmark	–	–	–
Netherlands	200,000	2.6%	2020
Ireland	250,000	10.3%	2020
Australia	–	–	–

Source: Energeia (2010).

Australia does not have a government-imposed EV mandate. However, the fact that targets and mandates exist in other countries should help to drive technology improvements and cost reductions elsewhere, and *ceteris paribus*, help facilitate adoption in Australia over time. If the international situation is any guide, it is probable that local, state or federal governments may pursue EV targets, mandates, or incentives to address climate change, energy security, or to stimulate domestic automotive manufacturing; we explore this further in Section VI.

The purpose of this article is to review the electricity load impacts arising from growth in the passenger EV market, the implications for the NEM, and to begin to explore the role that policies, regulations, and companies can play in the EV marketplace. In Section II, the dominance of the internal combustion engine vehicle market is examined and various alternatives to the current vehicle fleet, including EVs, are introduced. Section III shows how the barriers to EV adoption are being overcome. Section IV discusses the opportunity for decarbonizing the transportation fleet. Section V explores scenarios for EV adoption and forecasts the potential additional electricity load, and the possible shape of that load depending on when EVs are charged. Section VI discusses why these scenarios could be too pessimistic, considering the likelihood of government incentives to accelerate the EV market. The difficulties of using EVs to feed electricity back into the grid at times of peak demand are reviewed in Section VII. Section VIII explores neighborhood-level issues and how best to deal with this. Section IX puts the discussion into context for policy and regulatory settings and highlights how governments and companies might act in the interests of the market and electricity consumers, and concluding remarks follow.

II. EVs: Substitutes and Complements

The vast majority of vehicles on the road today have conventional internal combustion engines (ICEs), fueled by gasoline and diesel. Alternatives to these fuels, such as compressed natural gas (CNG), liquefied natural gas (LNG), and liquefied petroleum gas (LPG) have found a limited place amongst commercial fleet and freight vehicles and are not as popular for passenger vehicles. Only 3 percent of all vehicles registered in Australia are *not* fueled by gasoline or diesel (ABS, 2010a,b). To date, EV adoption has been very low: only 112 EVs were sold in Australia in 2010, comprising 0.02 percent of new vehicle sales (Ottley, 2011). There are several types of EVs:

- **Hybrid electric vehicles** (HEVs) combine a conventional ICE system with an electric motor. Adding the electric power train to an ICE vehicle can boost fuel economy or enhance performance. The battery is charged only internally, by the vehicle, not by an external source. An example of this type of vehicle is the Toyota Prius.
- **Plug-in hybrid electric vehicles** (PHEVs) can use either fuel or electricity; both the fuel and electricity may be replenished from sources external

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to the car. Depending on how they are configured, these cars are either regarded as battery electric vehicles (BEVs) with a driving range that is boosted by an ICE, or as an HEV with a battery that can be recharged from the grid. An example is the Chevrolet Volt.

- **Battery electric vehicles** (BEVs) are propelled only by an electric motor. Batteries store chemical energy and can be recharged by the electricity grid. Examples include the Mitsubishi i-Miev, Nissan Leaf, and the Tesla Roadster.[2]

The focus of this article is on passenger electric vehicles that may be charged externally by the electricity grid (PHEVs and BEVs), and hence may impact the NEM. Henceforth, the term EV in this article will refer to plug-in electric vehicles (PHEV and BEV), not to hybrid electric vehicles. We do not consider the adoption of electric bicycles, scooters, or motorcycles, or the commercial/heavy/freight vehicle market.

Given the dominant incumbent position of existing transportation technologies, we believe that ICEs are likely to continue to hold significant market share for decades to come. Despite ICE vehicle technology being mature, there is scope for improvements; to reduce fuel consumption and lower emissions, by manufacturing lighter vehicles with more efficient engines. However, environmental factors and ''peak oil'' will still compel finding a replacement for petroleum-derived fuels.

There is enormous investment in petroleum-based infrastructure in Australia. Around $1tr is invested in pipelines, refineries, tankers, service stations, and vehicles.[3] This sunk cost is driving the search for a sustainable fungible replacement for fossil fuels, such as synthetic fuels and biofuels. Finding a substitute for petroleum-based fuels is not straightforward; starch-based ethanol competes with food production, cellulosic ethanol is not yet economic, and ethanol itself is more corrosive to engines and not as energy-dense as petroleum-derived fuels. Next-generation algae-based fuel substitutes, the so-called ''drop in'' fuels, are promising because they are completely substitutable for fossil fuel-derived hydrocarbons, but are still in the early stages of development. Oil majors, aviation companies, venture capitalists, and a raft of start-up companies are working hard to develop algae fuels to the point where they can compete commercially with fossil fuels.

Japan is progressing trials involving hydrogen-powered vehicles. However, hydrogen vehicles would require investment in an entire value chain of new infrastructure, as would the widespread adoption of CNG or LNG passenger vehicles. The only infrastructure that is currently as widespread as fossil fuel-related assets is the national electricity grid: hence, the mass adoption of passenger EVs seems, *prima facie*, an easier proposition than developing a hydrogen, CNG, LNG, or LPG passenger vehicle fleet to meet policy objectives.

Factors contributing to EV uptake include the availability of models in the Australian marketplace, vehicle cost, fuel and servicing costs, and convenience of refuelling/recharging. Large conventional automobile manufacturers have hypothesized the commercialization of various passenger vehicle technologies could potentially progress as indicated in **Table 2**.

III. Supply-Side EV Market Developments

An anticipation of the adoption of EVs is readily apparent in

Table 2: What Will We Drive in the Future?[4]

2010–2020	2020–2030	2030–2040	2050
Fuel efficiency	Widespread BEVs and PHEVs	H_2-EV	Zero emission fleet
Engine technology	Advanced biofuels	(Social change to reduce travel)	
Hybrids	(Smart grid)		
BEVs and PHEVs			

world car manufacturers' plans. Currently, the original equipment manufacturers (OEMs) are producing about 30 electric vehicle models (mostly hybrids). This is expected to expand to about 120 HEV, PHEV, and BEV vehicle models by 2012 and to more than 150 models by 2014 (Lache et al., 2009). Firms rolling out such vehicles in 2012 include, *inter alia*, BMW, Chrysler, Ford, General Motors, Honda, Hyundai, Nissan, Peugeot, Renault, Subaru, Tesla, Toyota, Volvo, and VW.

According to Nissan (Nissan, 2010), the Leaf BEV is currently manufactured at the Oppama plant in Japan, on the same production line as non-EV models; the key production differences being the installation of the battery instead of a fuel tank, and the electric motor instead of an engine. During 2011, Nissan planned to ramp up Leaf production at the Oppama plant from one in six vehicles to one in three (i.e., 4,000 Leaf vehicles per month). In 2012, Leaf manufacturing will commence in the United States (about 150,000 Leafs per annum) and in 2013 manufacturing will commence in the United Kingdom (about 50,000 Leafs per annum). All facilities will produce Leafs alongside other non-EV models, allowing the flexibility to adjust production upwards or downwards to meet regional and global demand. With this production flexibility, global supply shortages are unlikely to be an ongoing problem in the medium term. However, it is unclear when OEMs intend to import EVs into Australia in large volumes. As a small vehicle market, Australia may not be a priority in the short term and all models of EVs may not be available here immediately.

As the volume of manufactured EVs increases, costs, and hence prices, can be expected to fall. Research into payback periods for EVs versus ICEs is often derived in U.S. dollars or Euros, and the reported economics vary depending on assumptions about oil prices, electricity prices, and other factors. Suffice to say that, at the moment, EVs cost more than ICE vehicles, even ignoring battery costs. However, the total ownership cost of EVs is expected to reach parity with ICEs within around the next decade (**Figure 3**). This would be driven by the production of EVs at scale (compared with ICEs that are already being manufactured in the millions), by fuel/power costs and the simplicity of EVs, which have few moving parts to service compared with ICE vehicles (Lache et al., 2009). The U.S. Department of Energy has announced that the funding distributed under the *Recovery Act* is on track to achieve EV battery cost reductions by 70 percent between 2009 and 2015, putting lifetime EV costs on par with non-EVs.

The UKCCC (2010) expects that the significant rollout of EVs will occur in the 2020s when EVs will be cost effective compared with ICEs.[5] In Australia, AECOM has suggested that in 2010, the lifetime cost of small EVs was about the same as for ICEs (due to the fuel cost savings over the vehicle life).[6]

A key consideration in relation to the competitiveness of EVs is not just the purchase price but the performance and affordability of battery technology. Electric batteries have lower energy and power density than fossil fuels (IEA, 2009). Key battery challenges for EVs include cost, range, peak power, and durability/longevity, including

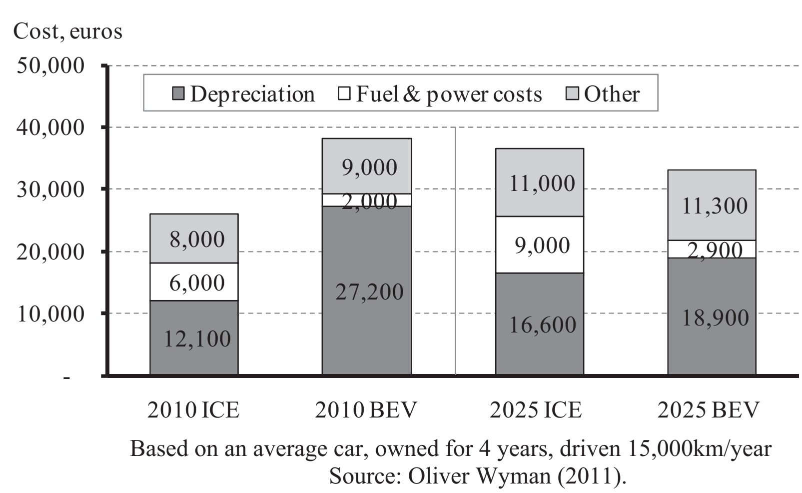

Figure 3: Total Cost of Ownership: BEV vs. ICE

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how many charge/discharge cycles are possible. These issues are being addressed by OEMs and battery manufacturers.

Battery costs have been a major barrier to the widespread adoption of EVs to date. Researchers are in wide agreement that battery costs will fall dramatically, driven by better battery configuration, density, and scale of manufacture. Research suggests current lithium ion battery prices cost up to $1,000/kWh in 2010, although are perhaps selling at volume at prices much lower than this. Nemry, Leduc, and Muñoz (2009) noted that the US Department of Energy goal is $250/kWh in 2020. A possible battery cost trajectory is shown in **Figure 4**.

Assuming a mid-range battery price trajectory, the cost of a 25 kW battery system for a mid-sized EV with a 100-mile range would fall from US$16,250 to US$8,125 including packaging, battery management system, warranty cost and 30 percent gross margin (Lache et al., 2009). Such price trajectories, if achieved, should help EV market penetration, even without any ''breakthroughs'' in battery technology (such as ultra-capacitors). Another aspect of battery affordability, and hence EV affordability, is financing. The high up-front costs of batteries could be avoided if they were separated from the vehicle purchase price, for example, if batteries were leased to EV owners.

The charge network provider, Better Place, plans to provide a pool of batteries directly to consumers using a financing arrangement structured with the company GE, and recouping the battery and ongoing recharging costs through a fixed subscription fee. These batteries could be recharged by the EV owner, or exchanged for a full battery at a battery swap station. However, some OEMs have been critical of ''battery pooling,'' citing safety and warranty issues. An issue here is that battery technology appears to be key IP for *some* OEMs, and this IP may cover not just the manufacture of batteries, but the in-car battery management system for charging and discharging the battery. OEMs may, therefore, be hesitant to embrace a commoditization of batteries if it involves giving away IP advantage. Regardless, given that vehicle financing is commonplace, it is reasonable to expect that OEMs could provide their own battery financing alongside their existing vehicle finance deals. Either way, such developments should help to overcome the upfront cost.

Range anxiety is a key issue in relation to the adoption of EVs, that is, the fear of running out of charge mid-journey. This can be overcome by several means; improving battery performance; the availability of ''visually reassuring'' public recharging infrastructure; in-vehicle displays; and public education about the fit between driving patterns and vehicle range. To demonstrate the variable nature of potential range: the Mitsubishi i-Miev can travel 100 km on a full charge while the Tesla Roadster can travel 400 km on a charge. In fact, the Tesla Roadster has driven from Alice Springs to Coober Pedy, 501 km, on a single charge.[7]

These vehicles could provide for an ''average'' motorist in Australia; for example, in 2008/09 the average motorist in Sydney traveled 55 km per day (NSW Government Transport, 2010). Xu and Milthorpe (2010) noted that for 2006, the average Sydney commuting distance was 17 km (one way), with around two thirds of commuters having a daily

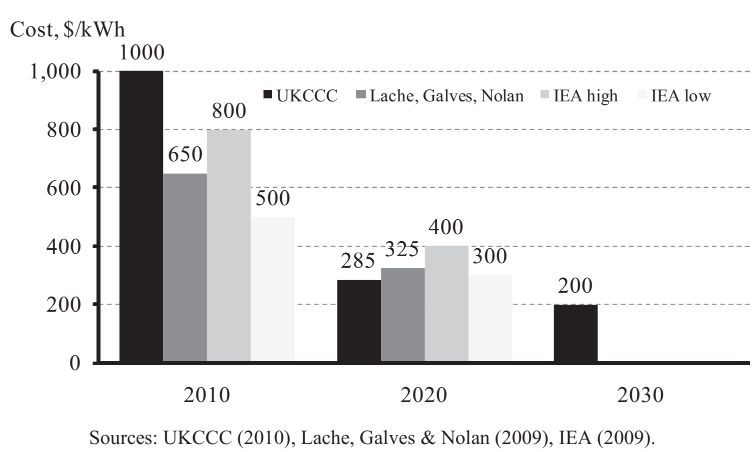

Figure 4: Declining Battery Costs

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round-trip to work of less than 75 km. Given these average journey distances traveled in Australian cities, EV range is unlikely to be an issue for *most drivers* on *most days*. Internationally, the situation is similar. In the UK, 97 percent of motorists drive less than 80 km/day; in Europe 80 percent of motorists drive less than 25 km/day; in the U.S., 85 percent of motorists drive less than 100 km/day (IEA, 2009).

While supply-side market developments have overcome many barriers to EV adoption, other issues remain. These include a lack of standards; for example, different vehicles have different plug types, which creates a recharging issue; there is also uncertainty about whether charging cables should come with the car (as they do with EVs now) or whether they should be part of a charging unit. Other potential issues involve the interoperability (or otherwise) between different charge network stations, availability of battery materials (rare earths and lithium), and vehicle and battery safety concerns.

IV. How Green Are EVs?

The average gasoline-powered vehicle on Australian roads today produces over 25 kg CO_2e per 100 km. New vehicles tend to be more efficient; for example, the new Holden Commodore and the new Toyota Corolla produce 23 and 18 kg CO_2e per 100 km, respectively. Very efficient petrol cars (e.g., Honda Insight) and hybrid petrol/electric cars (e.g., Toyota Prius) produce around 10 kg CO_2e per 100 km, around 60 percent lower than the average gasoline-engine car.[8]

The greenhouse gas emissions associated with EVs will vary depending on how the electricity is generated. Charging EVs using Australia's 2010 average generation mix will produce around 18 kg CO_2e per 100 km of driving, about 35 percent lower than an average petrol car. This is roughly equivalent to a new midsize petrol sedan or hatch such as the Toyota Corolla. But this is beside the point; the key issue here is switching travel from petrol into electricity, because over the very long run, electricity is likely to decarbonize at a faster rate than the petrol fleet. To be sure, however, this should be considered a ''*centennial vision*,'' not a problem to be solved in the immediate term. Regardless, **Figure 5** shows the estimated greenhouse gas emissions from charging EVs using grid electricity in 2020 (approximately 10 kg CO_2e per 100 km of driving). Beyond 2020 it is difficult to project the greenhouse intensity of grid electricity; however it is reasonable to expect generation intensity to continue to decline over the very long run.

EVs that are charged using accredited AGL GreenPower (as at 2010) would produce 2 kg CO_2e per 100 km due to losses from electricity transmission and distribution, a saving of over 90 percent compared to the average vehicle.

Some EV supporters argue that policy should be set to require some, or all, of the electricity used to power EVs to be sourced from

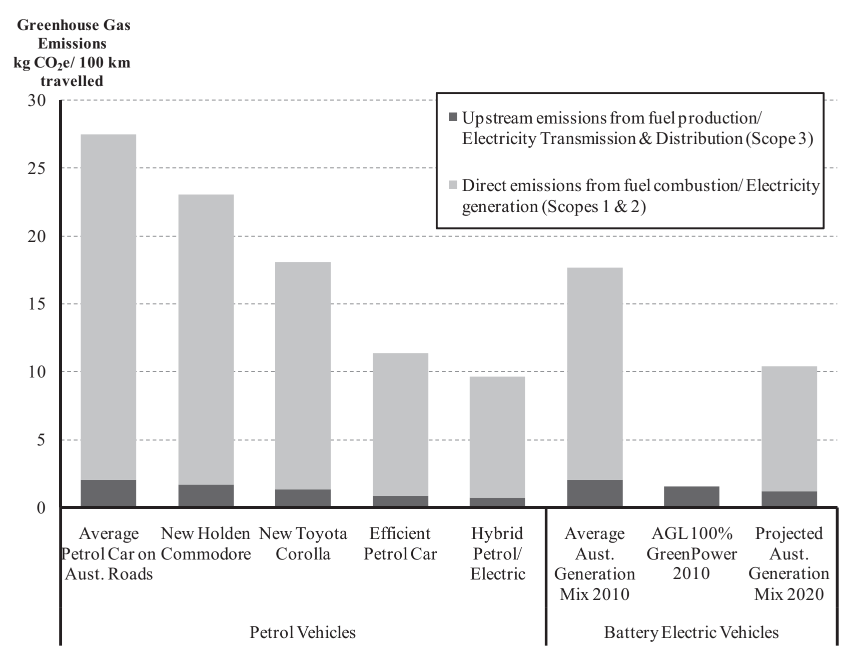

Figure 5: Greenhouse Gas Emissions from Driving Various Vehicles

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renewable generation in order to achieve the maximum greenhouse emissions saving. However, we do not believe that a mandatory approach makes sense when a Renewable Energy Target (RET) and other macro-level carbon policies exist.

There may be other ways to significantly reduce the carbon emissions associated with transport without adopting EVs. For example, diesel derived from algae has much lower carbon emissions than diesel derived from petroleum. A unique environmental advantage of EVs is that they have zero tailpipe emissions, and therefore do not contribute to air pollution or ''smog.'' Over time, high EV uptake could significantly improve air quality in urban areas. While thermal electricity generation has air quality impacts, these are concentrated at the places of generation, which typically have low population densities.

V. Modeling Electricity Demand from Electric Vehicles

There are currently around 11.5 million passenger vehicles on Australian roads, with a fleet-average age of 10 years (ABS, 2008, 2010a,b). **Figure 6** shows the age profile of Australia's passenger vehicles. Around 40 percent of passenger vehicles are more than 10 years old and 8 percent are more than 20 years old. Australia's slow vehicle turnover rate means that any technology improvements introduced in new cars will take several years to show noticeable change across the general vehicle population.

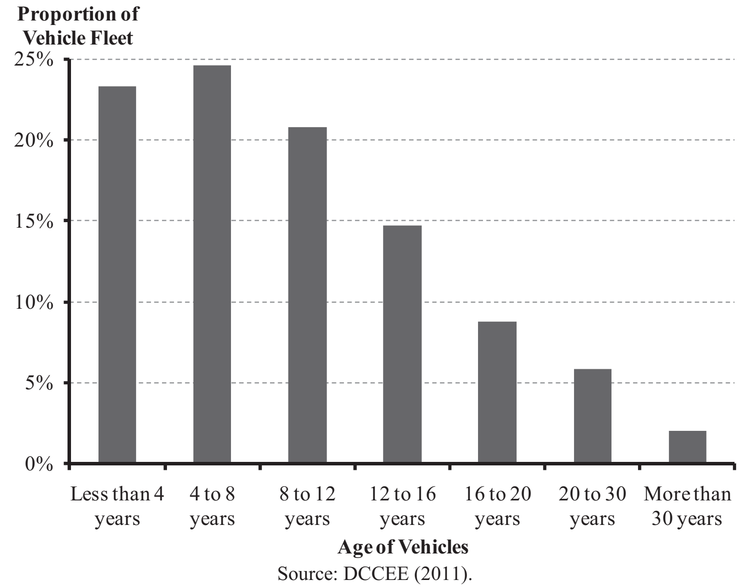

Figure 6: Age of Australia's Passenger Vehicle Fleet[9]

New car sales vary from year to year, reflecting broader macroeconomic conditions. In 2009, new passenger vehicle sales in Australia dropped by over 9 percent year-on-year, before rebounding by 9 percent in 2010. Over the past 10 years, trend growth in new vehicles has been running at about 1 percent per annum (ABS, 2011a,b). This reflects increases in Australia's population, growth in vehicle ownership, as well as turnover of retiring vehicles.

Available projections of EV sales vary enormously, from remaining very low, to making up a surprisingly large proportion of Australia's passenger vehicle fleet by 2020. Yet forecasting the uptake of a new technology is always fraught and, to complicate matters, some published outlooks have been carried out by parties with direct and vested interests. We do know, however, that all of the major car companies are developing EVs, and *some* have business plans for EVs to comprise 10–25 percent of total sales by 2020. With this in mind, we initially model three scenarios:

- Our ''High Uptake'' scenario has EV sales ramping up to 20 percent of all ''new'' passenger vehicle sales in 2020 and continuously growing to 50 percent by 2030, which translates to about 2.7 million EVs on the road in 2030;
- Our ''Medium Uptake'' scenario has EV sales ramping up more slowly to 25 percent in 2030, which translates to 1 million EVs on the road by that time; and
- Our ''Low Uptake'' scenario has EV sales remaining below 5 percent until 2030, in which just 250,000 EVs are expected to be on the road.

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For all scenarios, we assume that new car sales continue to increase at historic trend growth of 1 percent per annum to 2030. The specified proportion of these new car sales[10] are assumed to be EVs (BEV and PHEV), with the remainder assumed to be a combination of conventional ICE vehicles, HEVs and any other non-EV technologies. All EVs are assumed to have a useful life of 10 years (i.e., retired in their 11th year), which is consistent with the current average age of Australian passenger vehicles noted in Section V. Some parts of EVs may last longer than ICEs because they have fewer moving parts; however, battery performance may suffer before the 10-year mark. The uptake and turnover, and hence legacy issues of non-EV cars is beyond the scope of our analysis.

Our modeling has only considered take-up rates of passenger EVs. While some car manufacturers are developing small commercial EVs (e.g., vans), the vast majority of four-wheeled EV models currently available or in development are passenger vehicles. We do not consider this as fatal to our subsequent results because passenger vehicles comprise almost 80 percent of the vehicle fleet and so in early years, EV uptake is likely to be driven by the passenger vehicle sector (**Figure 7**).

ABS data reveals that in 2007, business vehicles comprised over 3.5 million cars on Australian roads or 31 percent of the total passenger vehicle fleet. The Australasian New Car Assessment Program (ANCAP) estimates that government and corporate vehicle fleets account for around 50 percent of new car sales in Australia. As a result, fleet vehicle procurement decisions are likely to play a vitally important role in EV uptake for a variety of reasons, including business and government environmental targets and economic savings. Decisions on whether government fleet cars will be EVs will affect not only new car sales, but will also flow through to the used car market. For example, the Government of SA (2010) noted that over one-third of the registered 1,600 hybrid vehicles in SA were once part of its fleet.

Our scenarios need to be considered within the context of existing research, which suggests that ICEs could represent less than half of new vehicle sales from the middle of the next decade, and that the currently popular hybrid vehicles will, in reality, only be an interim-step technology, as **Figure 8** notes.

Other research backs up the view that HEVs will continue to dominate the non-ICE market to 2015 given the acceptance of current models (e.g., Toyota Prius). After 2015, the growth in HEVs could slow, giving way to EVs, driven by falling battery costs and a rise in fuel prices. By 2020, Lache et al. (2009) argue that EVs could represent 11–12 percent of U.S. market sales, and 20 percent of European sales. Ottley (2011) argued that while only 112 fully electric vehicles were sold in Australia in 2010, there could be 109,000 EVs on Australian roads by 2020, and 3.4 m by 2030, in line with our

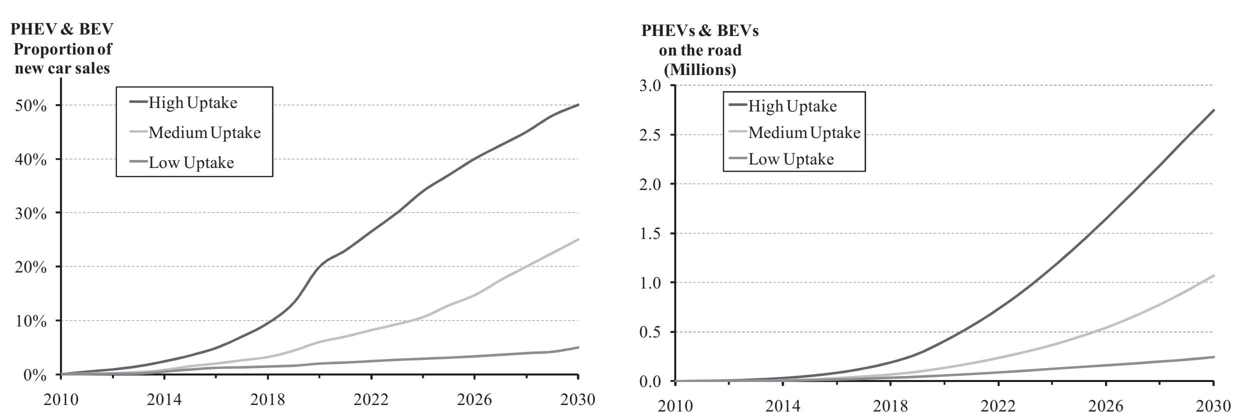

Figure 7: EV Uptake Scenarios in Australia

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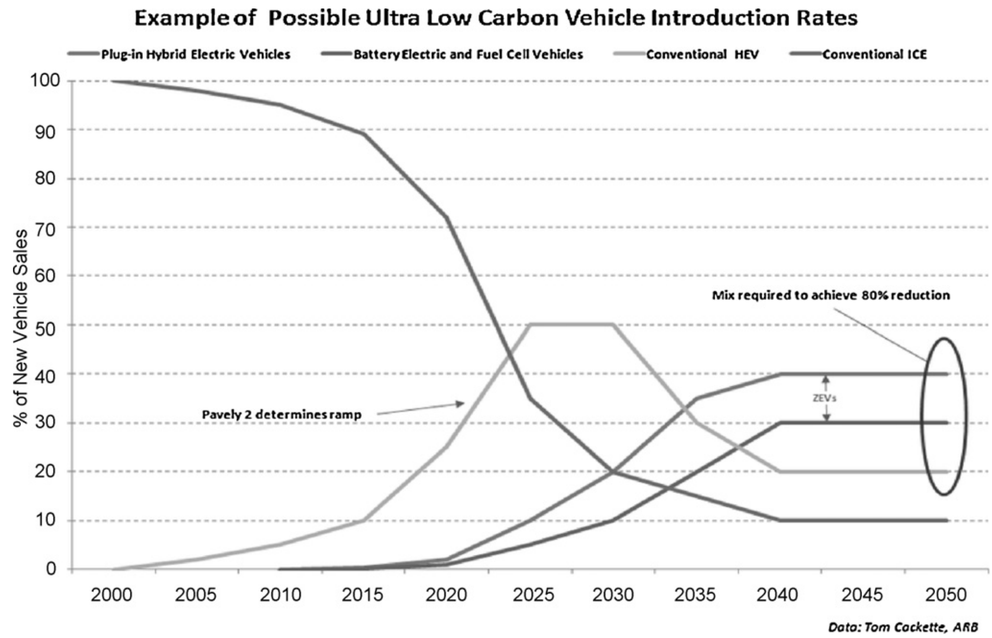

Figure 8: Possible Introduction of Electric Vehicles[11]

High Uptake scenario. Analysis by ESAA (2011) forecast that there will be up to 7,000 EVs on Australian roads by 2013, and that globally by 2020, EVs will comprise around 5 percent of cars on the road, increasing to around 15 percent by 2030. These figures track between our Medium and High Uptake scenarios for Australia.

In addition to forecasting sales of new vehicles, a critical variable requiring estimation is the amount of power each EV is likely to require. OEMs are developing a variety of EV models with different power requirements. Compact and hatch cars tend to be small and light and, as a result, are more efficient than full-sized sedans. For the purposes of our analysis, we have assumed that a mix of large and small EVs will be taken up in Australia, with an average energy consumption of 170 Wh/km.[12]

We noted at the outset that we expect the EV market will consist of a mixture of BEVs and PHEVs. Regardless of the type of EV, it is likely that the vast majority of all kilometers driven in EVs will be electric, since the daily use of vehicles in Australia is usually well within the electric range of most EVs. In this analysis, we have assumed that 90 percent of all kilometers traveled in any type of EV will be electric (which in turn allows for the non-electric component of all PHEV vehicles within the EV fleet).

According to ABS data, the average passenger vehicle in Australia travels 14,300 km per annum. Within this aggregate, privately owned vehicles typically drive further than business vehicles (i.e., 15,900 km vs. 8,900 km pa). When considering system-wide effects of EVs for the purposes of assessing future half-hourly electricity load impacts, we have assumed that they will be driven the average distance of 14,300 km per annum to account for the mix of business and private vehicles. When assessing the impacts and basis of individual residential electricity consumers, we have assumed that their vehicles will travel an average of 15,900 km, since they are likely to be private vehicles, primarily charged at home.

For an average private EV traveling 15,900 km per year, we have assumed that, on average, EVs will travel 45 km per weekday and 41 km per weekend day, which has been extrapolated from NSW Government travel survey data. This means household EVs will consume an average of 7.6 and 6.9 kWh per day, respectively. This equates to an additional household load of approximately 2.7 MWh/year.

The volumes and costs of electricity required to operate

Table 3: Battery Specifications for a Range of EVs

Vehicle	Vehicle Type	Battery Capacity (kWh)	Energy Consumption (Wh/km)[13]	Range per Charge (km)[14]	Annual Electricity Use (MWh)[15]	Annual Price to Charge[16]	
						Off-peak	Peak
Mitsubishi i-MiEV[17]	Plug in Electric (BEV)	16	125	150	1.8	$189	$798
Tesla Roadster[18]	Plug in Electric (BEV)	53	231	394	3.3	$349	$1,475
Chevrolet Volt[19]	Plug in Hybrid Electric (PHEV)	16	224	80	3.2	$338	$1,429
Nissan Leaf[20]	Plug in Electric (BEV)	24	211	161	3.0	$319	$1,349

each EV for a year included in Table 3 compare favorably to ICE vehicles, but only when EV charging occurs during off-peak periods (we assume, quite crucially, that all EV owners are required to install a smart meter at the home and default to a time-of-use tariff[21]). An average new Toyota Corolla requires approximately 1,000 liters of petrol per annum, which at current petrol prices ($1.44 per litre) would cost around $1,500. This cost is comparable to charging EVs at peak times. During off-peak periods, however, significant savings can be achieved with all of the listed EVs having a fuel cost *at least* 75 percent lower than the new Toyota Corolla. Put another way, for one Australian dollar spent on fuel/charging costs (not capital costs), a Toyota Corolla can travel 10 km, but a Mitsubishi i-MiEV can travel up to 75 km using an off-peak tariff (or 18 km assuming peak tariffs).

To complete our analysis on how EVs will impact on the electricity market, assumptions about when charging occurs at the household level have also been developed. In particular, our analysis considers two charging scenarios:

- ''**Convenience charging**,'' where drivers can recharge their vehicles at any time when they are not driving (i.e., charging patterns are the inverse of driving patterns). The convenience charging scenario has been compiled based upon data from the NSW Government 2008/2009 Household Travel survey, which represents driving patterns that are broadly applicable across Australia.
- ''**Off-peak charging**,'' which could arise if drivers are incentivized through time-of-use tariff structures supported by smart metering technology (including dynamic, or critical peak pricing structures[22]) to charge their EVs during off-peak electricity tariff hours, or at the very least, to avoid charging during critical system events. For simplicity, the ''off-peak charging'' scenario assumes that all EV charging will be evenly distributed across the off-peak hours between 10 pm and 7 am daily (**Figure 9**).

An average residential customer in Australia's NEM states currently uses between 6 and 7 MWh of electricity per year. We noted earlier that where an EV is driven 15,900 km per year, the average distance for privately owned passenger vehicles in Australia, it will consume an additional 2.7 MWh each year. Ownership of an EV could therefore increase an average household's electricity consumption by up to 40 percent.[23]

We have made use of the household load data from Simshauser and Downer (2011) in **Figure 10**, and have combined this with EV load to show how daily household electricity demand is likely to change for EV drivers, assuming that *all* EV charging is done at home (at 10 or 12 amp[24]), and that charging is conducted primarily during off-peak periods as consumers respond to price signals. The light section of the chart shows existing consumption for each period throughout an average day. The dark section shows additional usage for an individual household from an EV, for charging beginning at midnight with the battery requiring around three hours to fully recharge from the average day's driving. The

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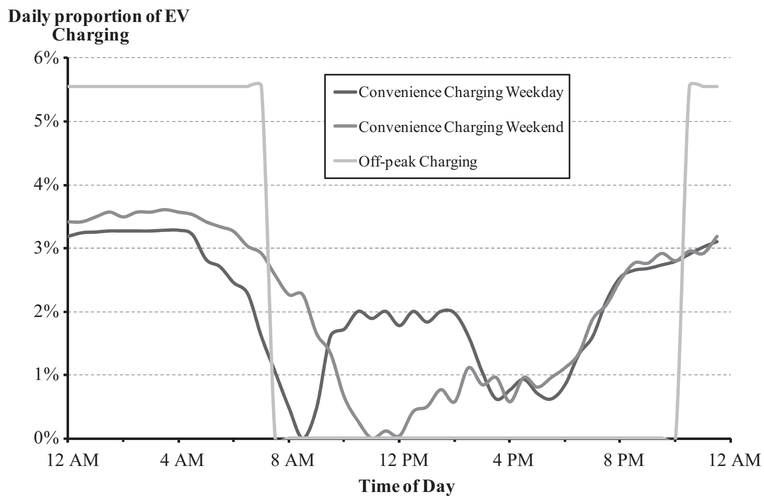

Figure 9: Electric Vehicle Charging Time Assumptions

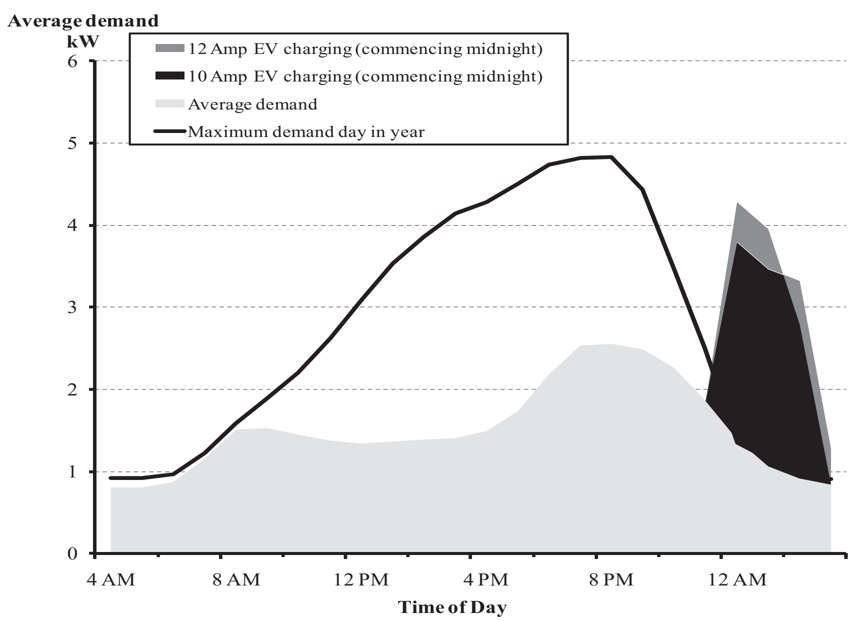

Figure 10: Individual Household Demand with EV Charging[25]

dark line shows the existing demand for each period of the day on the day when the household has its maximum demand during the year (typically a very hot or cold day).

While it is true that on an average day, charging is likely to create a new daily peak for individual households with an EV, of critical importance is the fact that this new average daily peak remains below the maximum peak demand for an individual household during the year. Additionally, this incremental demand would only apply to those households with an EV, which even in a high scenario would only account for roughly one household in four. These findings are very significant and underscore the notion that there should be more than sufficient *existing* generation, transmission, and distribution network capacity to manage such spikes, provided that the combination of smart meters and critical peak pricing form part of the energy market policy fabric for EV owners. To be sure though, such an outcome is dependent upon households with EVs installing smart meters and adopting ToU pricing, and even with this, there may well be localized ''hot spots'' in streets where EV uptake is concentrated at rates greater than societal average. And as an aside, commercial and industrial loads have a *very* strong influence over aggregate system peak demand on an average day, which is why our subsequent modeling demonstrates that new household peaks are not a material problem in aggregate for generation and transmission capacity.

Typical private drivers will not require faster home charging in excess of 10–12 amps (2.4–3 kW). The analysis that follows assumes faster home charging does not occur. However, charging in excess of 3 kW cannot be ruled out, since OEMs and charge service providers are making such vehicles and infrastructure available. Higher charge rates could obviously adversely impact the individual household load curve in Figure 10. Conversely, if for example only 1 in 4 households has an EV, then in reality, the incremental EV load could be reduced by three-fourths when assessing whole of power system capacity impacts.

Following the analysis through to the whole of system level, the

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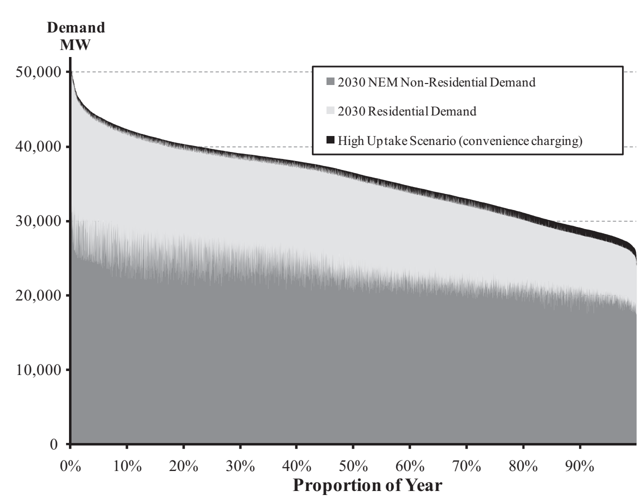
introduction of EVs is unlikely to have any material effect on the load duration curve for the NEM by 2030, even if EV adoption follows our High Uptake trajectory. Total energy demand in the NEM in 2020 would be only 0.3 percent higher and less than 1.7 percent higher in 2030 as a result of a High EV Uptake scenario. In short, year-on-year fluctuations in weather are likely to impact future expected energy demand much more significantly than EVs over the medium term.

The load duration curves in **Figure 11** show our projections of NEM aggregate demand under a High Uptake of EVs in 2030. Non-EV demand in 2030 has been predicted by extrapolating underlying demand in 2009/2010 by 2.1 percent per annum (in line with the medium growth scenario in AEMO's 2010 Statement of Opportunities).

When charging is conducted during off-peak periods, EV charging does not contribute to peak demand, but instead, is concentrated during periods when demand is lowest. This in turn has quite a beneficial effect; it improves the overall utilization of electricity infrastructure in the NEM by around 1 percentage point. In other words, the adoption of EVs may lower unit pricing through an improvement in the capital utilization rate.[26] When convenience charging occurs, the additional demand is spread more evenly throughout the year, and marginally increases peak demand. In this case, the utilization rate improvements are still present, but are lower than when off-peak charging (as may be incentivized by ToU pricing) is employed.

The results in Figures 11 and 12 would occur if EV charging was well distributed across the specified hours for either off-peak or convenience charging (as per Figure 9), rather than the coincident charging that would occur if all electric vehicles were switched on for charging at the same time. If in 2030, all electric vehicles in the High Uptake trajectory were charged at the same time (commencing at 10 pm when off-peak tariffs begin), the charging would not create new annual peak demand, however the charging would be significantly ''peakier'' than shown in the Figures 11 and 12. This would be a worst-case scenario, assuming complete coincidence of all vehicle charging, and that neither grids nor households become any ''smarter'' at managing demand over the next 20 years, which seems unlikely. In the short term, the issue of coincident charging will be less problematic at an aggregate level, because there will be fewer EVs requiring charging, and hence a lower power demand during coincident charging.

Stripping out non-residential demand, **Figure 12** shows how residential demand in the NEM may be affected by the High Uptake of EVs in 2020 and 2030. In 2020, High Uptake of EVs would increase aggregate residential



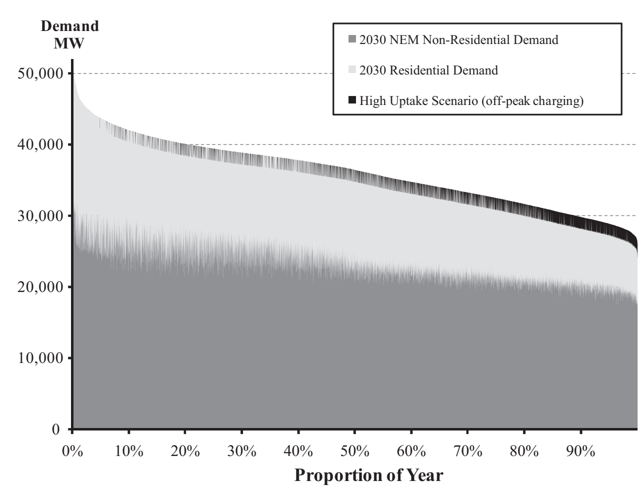


Figure 11: Impact on the NEM Load Duration Curve in 2030 of High EV Uptake (L: convenience charging; R: off-peak charging)

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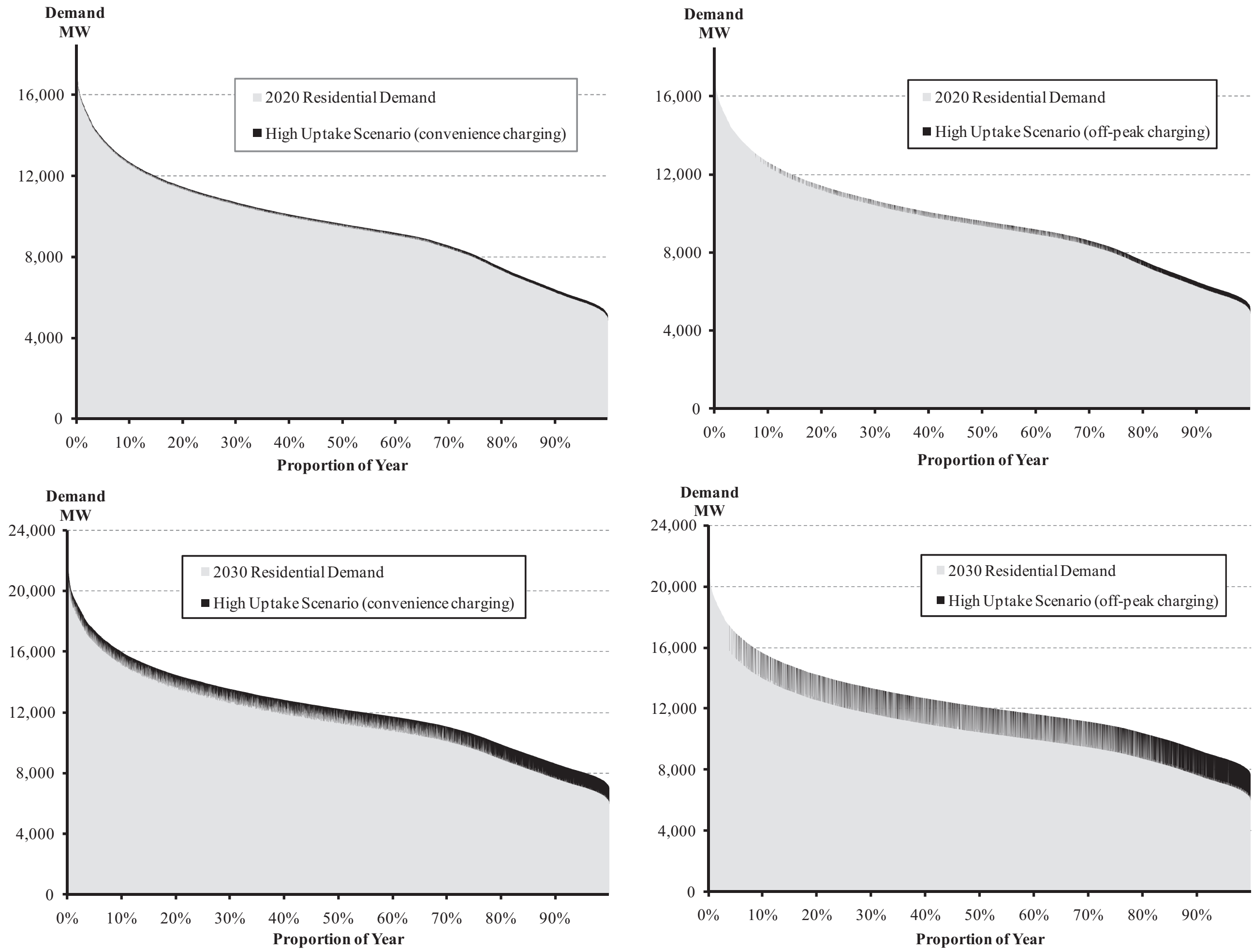

Figure 12: Impact on the NEM Load Duration Curve (Residential Demand Only) of High EV Uptake (Clockwise from top left: 2020 with convenience charging; 2020 with off-peak charging; 2030 with off-peak charging; 2030 with convenience charging)

demand in the NEM by 1 percent, increasing to 5 percent by 2030. In 2030, Medium and Low EV Uptake scenarios increase residential demand by approximately 2 percent and 0.5 percent, respectively (**Table 4**).

VI. What If We're Wrong? *The Shock scenario*

Acknowledging that forecasting the uptake of any new technology is often wrong, it is useful to consider what factors might artificially alter the pure cost-benefit analysis when buying an EV to see if such actions would materially impact our view of the impact of EVs on the NEM. Factors that might alter the

Table 4: Summary of EV Impact on NEM and Residential Demand in 2020 and 2030

	2020			2030		
Scenario	EV Electricity Consumption per Annum (GWh)	Increase in NEM Demand	Increase in Residential Demand*	EV Electricity Consumption (GWh)	Increase in NEM Demand	Increase in Residential Demand*
High Uptake	790	0.3%	0.9%	5,300	1.7%	5.1%
Medium Uptake	260	0.1%	0.3%	2,100	0.7%	2.0%
Low Uptake	110	0.05%	0.1%	500	0.2%	0.5%

* In NEM regions.

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economics of EV ownership, beyond technological advancement, might arise from government policy or mandates:

- The federal government might introduce EV subsidies or tax breaks, such as removing import duties or sales taxes on electric vehicles. The U.S. government provides a federal tax credit of up to US$7,500 for energy-efficient cars; and the UK government announced a US$8,200 subsidy for the purchase of EVs from 2011 (Credit Suisse, 2009).
- The federal government could introduce strict vehicle emission targets or mandates, not only for CO_2 but for ICE particulate emissions that reduce air quality, accelerating the turnover of the vehicle fleet. Furthermore, government could stimulate EV uptake by mandating that all government fleet vehicles be electric. The Chinese government provides a subsidy of US$8,800 to public services and taxi companies for purchasing EVs; Paris and London also have EV fleet plans (Credit Suisse, 2009). In May 2011, U.S. President Obama issued a memorandum stating that, by the end of 2015, ''all new light duty vehicles leased or purchased by [government] agencies must be alternative fueled vehicles, such as hybrid or electric, compressed natural gas, or biofuel'' (The White House, 2011).
- Governments are also offering research funding for electric vehicles: the Chinese government is providing US$1.5bn to auto companies to develop new EV engines; the U.S. government granted US$2.4bn to support next generation EVs and loans of up to US$8bn to various companies (Credit Suisse, 2009).
- Market incentives could combine with government incentives to encourage EV adoption. For example, an oil shock would drive up gasoline and diesel prices; electricity retailers could offer very attractive off-peak tariffs to households with EVs.

If any or a combination of these incentives arose, a 'shock scenario' may become plausible in addition to our High, Medium and Low Uptake scenarios. Our shock scenario has EVs making up around 20% of Australia's passenger vehicle fleet by 2020 (and continuing to grow to over 50% of the passenger vehicle fleet by 2030). Due to the existing vehicle fleet, EV sales would need to increase dramatically, to around 90% of new car sales by 2020 to achieve this. While this may appear unlikely (and difficult due to vehicle supply), this scenario is within the envelope of predictions that have been made by consultants and technology proponents for EV uptake (Figures 13 and 14).

The shock scenario would change the shape of demand in the NEM in a much more significant way than any of the other scenarios. By 2020, total demand in the NEM would increase by 1.8 percent and residential demand in the NEM would increase by 5.5 percent.

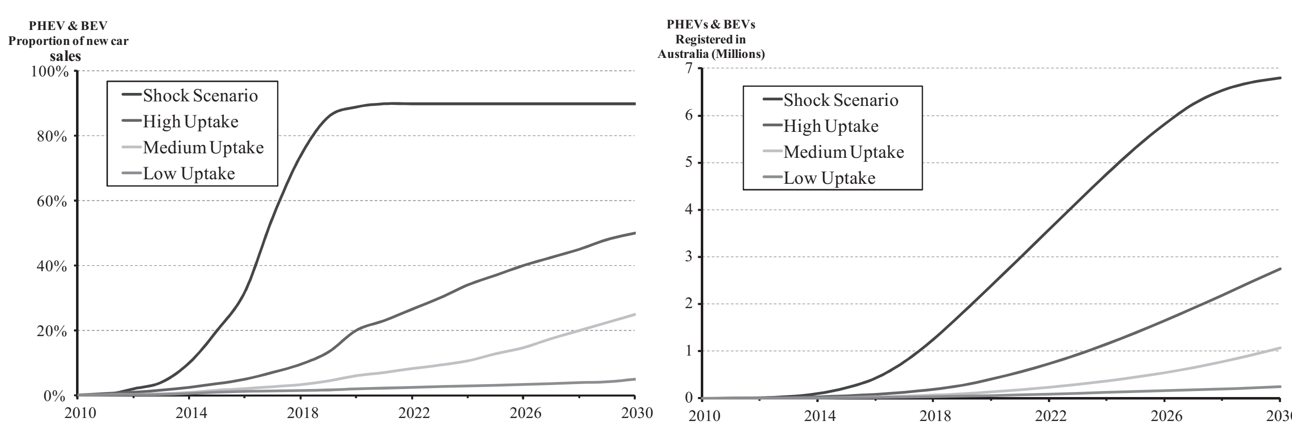

Figure 13: Electric Vehicle Uptake in Australia, Including a Shock Scenario (L-R EV as a proportion of new car sales; number of EVs on the road)

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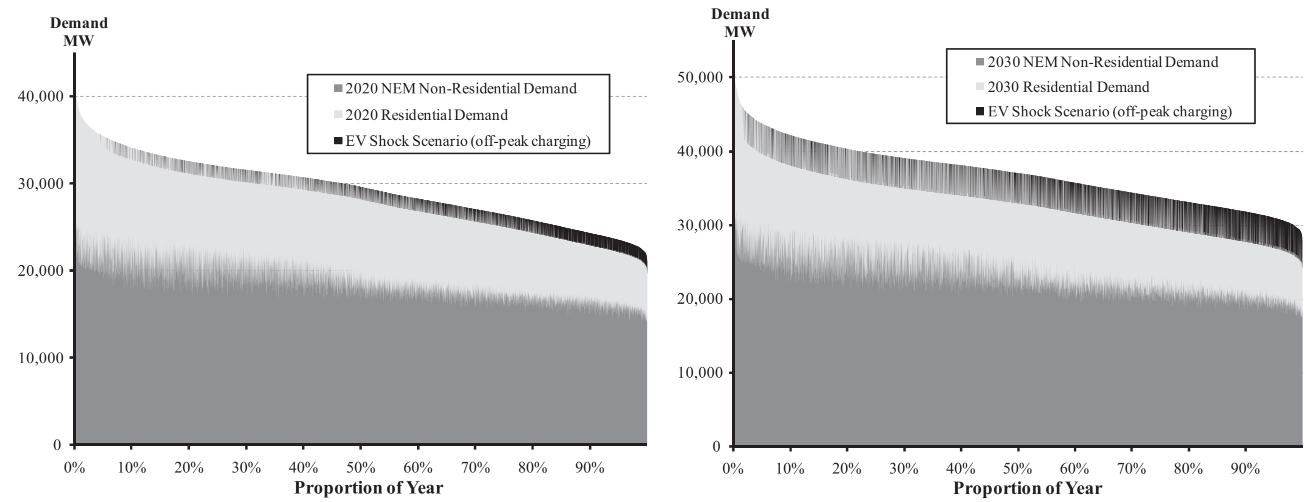

Figure 14: Impact on the NEM Load Duration Curve under the Shock Scenario, in 2020 and 2030

These figures increase to 4.2 percent and 12.7 percent respectively by 2030. Even with EV charging occurring only in off-peak periods, the load duration curve for residential demand will have its shape changed considerably by 2020, and completely by 2030 (**Table 5**).

EV uptake is unlikely to require significant investment in new generation and transmission network capacity, so long as EV drivers can be sufficiently incentivized not to charge their vehicles at peak times, because at the aggregate system level, EV charging will not create a new peak demand (even for this ''shock'' scenario).

Even if all EVs from the shock scenario (6.8 m vehicles by 2030) were to hit the NEM on the highest winter demand day in 2009/2010, residential demand during EV charging would still have been lower than the peak that day, provided no charging occurred during critical peak times. This is demonstrated in **Figure 15**, for which we have assumed that the charging of the 6.8 million EVs (for their average daily driving) is evenly spread across non-peak hours (10 pm to 7 am). Furthermore, the utilization rate of this infrastructure would increase, which would help to drive down the unit price to the benefit of all electricity users. This is a positive market externality that should be considered by policymakers.

Usher (2011) found that there was sufficient spare capacity in the Victorian electricity grid for charging 146 percent of the entire Victorian passenger vehicle fleet, if they were EVs driving 33 km/day on average, on the peak demand day in 2009. On an average day in 2009, there was sufficient spare grid capacity to charge 450 percent of the Victorian passenger fleet.

While the grid may *in theory* be able to cope in terms of generation capacity and network assets, this overlooks local issues that are likely to occur at the

Table 5: Summary of EV Impact on NEM and Residential Demand, Shock Scenario Only, in 2020 and 2030

Scenario	2020 EV Electricity Consumption per Annum (GWh)	2020 Increase in NEM Demand	2020 Increase in Residential Demand*	2030 EV Electricity Consumption (GWh)	2030 Increase in NEM Demand	2030 Increase in Residential Demand*
Shock Scenario	4,600	1.8%	5.5%	13,200	4.2%	12.7%

* In NEM regions.

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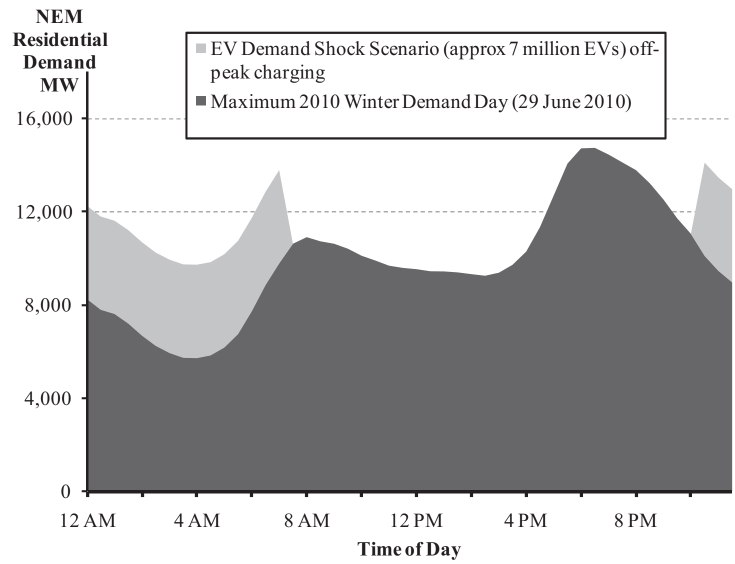


Figure 15: NEM Winter Peak Demand and the Shock Scenario

household and neighborhood level, as we discuss in Section VIII.

VII. Vehicle to Grid?

Much has been made of the potential for EVs to act as energy storage devices, allowing the battery to feed electricity back into the house or the grid at times of high demand. Batteries are expensive, so vehicle to grid (V2G) or vehicle to house (V2H) scenarios would increase battery utilization, provide additional return on investment, and may have load management benefits.

While the promise of V2G is material, the timing of this is uncertain; it seems highly unlikely within the next five years, and probably longer. In the first instance, state governments would need to adhere to commitments in the *Australian Energy Market Agreement* and fully deregulate retail pricing to facilitate the widespread adoption of such innovative technologies. In any case, there would need to be a critical mass of EVs on the road before V2G would meaningfully alleviate peak demand.

CSIRO's Electric Driveway project is conducting some research in this area, but vehicle manufacturers are not necessarily on board with the concept yet, citing battery warranty issues. Drivers may also be wary about the possibility of coming back to a parked vehicle that has been discharging, rather than recharging, its battery. V2G would need to be managed meticulously well with excellent vehicle battery management protocols and driver communications.

In summary, the grid will need to be smarter before V2G could commence in earnest, OEMs will need to do more work on vehicle battery management protocols and on understanding driver behavior, and there would need to be a substantial number of EVs for V2G to materially benefit electricity networks. Consequently, the possible benefits of V2G have not been considered in this article.

Vehicle to home may happen earlier than V2G. As a result of the interruptions to power supply that followed the March 2011 Japanese earthquake, Nissan, Toyota and Mitsubishi have announced that V2H will be available on some models in the Japanese market by 2012.[27,28,29]

There is some exploration of whether EV batteries that have ceased to be used in vehicles might have a ''second life'' as energy storage systems on the grid[30]; however, this is not germane to the adoption of EVs and stationary energy storage is outside the scope of this article.

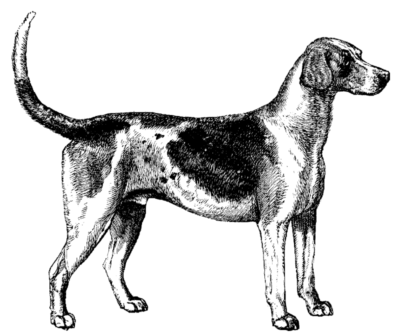
VIII. The Grid Can Cope in a Macro Sense, But What About Neighborhood-Level Issues?

Sections V–VII showed that generation assets should be able to cope with significant EV uptake. However, this overlooks household and neighborhood issues. Every house is theoretically able to draw 6–7 kW[31]; in practice, suburbs can only cope with an average draw of around 4–4.5 kW[32] per house. Any house with an EV may exceed this load during charging, creating issues for distributors.

 1040-6190/$–see front matter doi:/10.1016/j.tej.2012.02.014

EPRI (2011) argues that ''short-term PEV impacts for most utility distribution systems are likely minimal and localized to smaller transformers and other devices where the available capacity per customer is already low.'' Locally, research says that there is no standard level of EV penetration at which network feeders will be at risk: some feeders will be fine with high EV penetration, others might struggle with low penetration (Usher, 2010). This risk is best mitigated by sending price signals to EV owners to encourage charging during off-peak periods when other appliances are not in use. The impact of convenience charging depends on the state of charge of the vehicle, and it is a worst-case assumption that all cars arrive home and start charging at the same time, or that all cars will need a full charge every day. Research from EPRI (2011) suggests that while the most common timeslot for cars to arrive home is between 5 pm and 6 pm, only 12 percent of vehicles actually arrive during that one-hour window, so charge start times will naturally be staggered, and so ''diversity of vehicle location, charging time, and energy demand will minimize the impact to utility distribution systems.''

Another way to facilitate off-peak charging, in addition to price signals, is to centrally control charging. However, EPRI (2011) doesn't believe that managed charging is needed for EVs in the near term, noting that ''a proactive utility approach of understanding where EVs are appearing in their system, addressing near-term localized impacts, and developing both customer programs and technologies for managing long-term charging loads is most likely to effectively and efficiently enable even very large-scale [EV]



adoption.'' In other words, government and industry should not overreact to the adoption of EVs by mandating or controlling when vehicle charging should be allowed to occur.

Aside from wondering whether it is fair to treat EV customers differently from other users of NEM infrastructure, there are many stakeholders who face different incentives if charging was to be centrally controlled:

- Energy retailers, who have an incentive to manage wholesale market peak loads and customer bills;
- Renewable electricity generators, who could time EV charging to suit the output of renewable energy facilities;[33]
- Charge network companies, which see the charging needs of EVs in their network, but not non-networked EVs or other loads in the NEM;
- Other wholesale market intermediaries who manage wholesale positions; and
- Energy distributors, who are likely to have very different load throttling criteria to retailers, renewable power generators and charge network companies, due to potential localized system constraints in limited areas of their network.

Drivers may not accept that they are not in control of the driving range of their vehicle unless they have the right to override central control systems. Technology already allows air conditioners and other appliances to have bi-directional control. While customers may not mind if the air conditioning is cycled if there is no loss of comfort, they may object to their EV being undercharged when they expect otherwise. Customers should reasonably expect compensation for any loss of control. This leads us back to ensuring that well-managed, effective price signals exist to reduce potential wholesale market and network loading issues, thus leaving customers in control.

IX. Policy Recommendations

In any industry, effective policies and regulations need to be based on evidence. However,

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evidence to support EV policy will be in short supply until EVs start being driven at scale in Australia. We cannot confidently assert a real-world scenario (versus lab-tested) for EVs under different driving conditions; this includes actual driving ranges, and precisely when drivers will charge – the time of day, or how often. Similarly, we are uncertain as to whether EVs will cluster in certain neighborhoods, for example, based on income levels or geographic proximity to business districts. Until the industry understands these issues, it will be difficult to formulate specific EV policies with confidence.

The rationale for government policy will depend upon whether market failures can be identified, and can only be reasonably overcome by domestic government policy. We have been able to identify only two claims in relation to ''market failures'' for transportation which have resulted in various industry segments articulating a particular policy prescription:

- The requirement (or not) for EVs to be powered by ''zero emission'' electricity generation;
- The requirement (or not) for EV charging to be incentivized by pricing and facilitated by smart metering.

We have also been able to identify a positive production externality that is dependent upon the introduction of smart metering. The introduction of EVs in combination with ToU pricing facilitated by the introduction of a smart meter has the potential to improve network and generation utilization, which in turn could lower unit costs – reducing electricity prices for all consumers.

A. Power source for EVs

Transportation pricing currently results in negative

externalities as a result of greenhouse gas emissions. In almost every case, the policy prescriptions being developed by governments to address climate change, air quality, and energy security are uniform: emissions trading; renewable energy targets and energy efficiency schemes. Australia is no different, with the Commonwealth and state governments continuing to develop policies to address these key issues.

By 2020, the High Uptake scenario identified in this article would see EVs consuming 800 GWh of electricity. If this were entirely renewable, it would comprise approximately 2 percent of the 45,000 GWh Commonwealth Renewable Energy Target (RET) in 2020. By 2030, EV electricity consumption would increase to 5,300 GWh, or 12 percent of the RET.

As a result of existing clean energy policies, and as demonstrated by Figure 5, the emissions from an electric vehicle in 2020 will be less than half those of a standard Australian vehicle (e.g., Holden Commodore) – 10 and 23 kg CO_2e per 100 km traveled respectively. Based upon this analysis, we see no reason why the generation source for electric vehicles should be mandated.

Requiring EVs to use green energy could also be difficult to enforce in practice. It would require an acceptance that EVs should be treated as different from other appliances using the grid and may require potentially expensive sub-metering. The application of this requirement might be complicated in households that already purchase some renewable energy, or that generate their own renewable energy by, say, using solar PV.

B. ToU pricing, smart meters and EVs

Offering flat electricity tariffs[34] is an easy way to market the electric vehicle concept to EV drivers. But flat tariffs do not offer an incentive for EV drivers to charge at a time that would most suit the grid, and EV drivers may

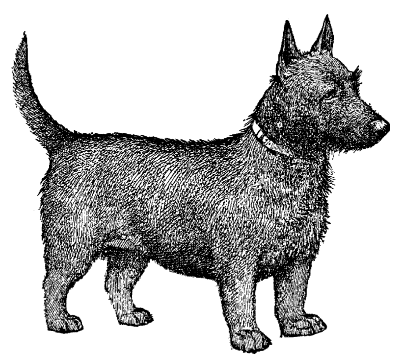
 1040-6190/$–see front matter doi:/10.1016/j.tej.2012.02.014

inadvertently exacerbate peak demand problems in some neighborhoods which could lead to all consumers indirectly subsidizing EV drivers through having to pay for localized network augmentation.

Since peak demand is already an issue in the NEM, we are not advocating that EVs should be the only devices subject to ToU pricing. Widespread ToU pricing for all loads (enabled by interval meters) will help to address peak demand more broadly, through the contributions of all consumers, not just EV owners (see Simshauser and Downer (2011)). EVs are not a panacea for wider industry issues.

In Sections V and VI, we presented analysis demonstrating the impacts of EV charging on aggregate electricity load. With appropriate pricing signals in place especially during critical load events, households will be incentivized to avoid adding to system peaks (see Figure 11). Unfortunately, there are two key barriers to the use of such pricing signals: continued retail price regulation; and the lack of meters with remote read/control capability and time of use functionality (i.e., smart meters).

It is not certain the extent to which off-peak tariffs will actually incentivize off-peak charging. Table 3 showed that an annual cost for charging at peak rates is around $1,400, compared to about $350 for off-peak charging. While we do not currently observe critical peak prices in the market, these are typically set at multiples of the average price, and thus might equate to an equivalent annual cost of $3,000+ (at least if charging on the limited number of critical event days each year).



As drivers may decide that peak charging prices of $1,400 (or at critical peak prices) are still good value compared to the cost of gasoline, ToU pricing set at these levels might not change the behavior of all consumers. The key issue is the facilitation of consumer choice. There is no public policy argument for ''controlling'' consumer behavior in this context. But by utilizing ToU pricing and in particular, cost-reflective critical peak prices, consumers will be able to determine what price they are prepared to pay for ''convenience.'' In addition, ToU pricing allows technology providers to offer innovative solutions allowing automation of this economic decision of the EV driver.

However, ToU pricing cannot be implemented without an upgrade of metering technologies. Metrology procedures should be amended to ensure that smart meters are installed at all premises with EVs. As smart meters are progressively rolled out in Australia, they will be key enablers for price signals to manage EV charging and all other material electrical loads (such as air conditioners, etc.).

To the extent that the prime peak-load issue relates to localized distribution network congestion, distribution networks would be well serviced by being able to identify where EVs are located within their service area – enabling them to identify potential ''hot spots.'' How this identification process might be facilitated to ensure accuracy is not entirely clear to the authors, but presumably energy retailers will offer attractive tariffs to households with EVs, and so this may provide a starting point for data collection (subject to privacy laws).

It is important that EV charging is not over-regulated and that EV infrastructure is not duplicated, making EVs too difficult or too expensive to adopt. Complicated or expensive charging infrastructure should not be mandated in stand-alone residential properties. The average private driver will not require faster charging at home and may not need any sub-metering, assuming that their energy provider bills their EV consumption just like any other household appliance. A pragmatic and cost effective solution for most private EV drivers charging at home is for their electrician or electricity retailer to install a 10–15 amp plug (as required by the car) and provide a simple timer switch to allow off-peak charging (if this isn't already a standard feature of the vehicle), and to take up a time of use pricing plan, facilitated by a smart meter. The Nissan Leaf already has a timer function that can start charging during off-peak periods. Furthermore, as Usher (2010) noted, ''advanced smart meters. . . such as those being rolled out currently in Victoria have the potential to enable EV charging to be remotely controlled. . .''

Australian EV trials should be encouraged to build a body of evidence to help inform the market and policymakers. However, while trials are needed to inform the debate, the way that trials are established might not be the optimum way for the industry to develop in the long term; trials should inform future EV market settings, not set a precedent for them.

Our view is that the framework should be set to allow an open, competitive National Electricity Market to continue to do its job of allocating resources efficiently, with the right rules and regulations to ensure logical market behavior, and the right incentives to encourage innovation, promote competition, and maintain customer choice. EVs will be embedded in the NEM, so rules, policies and regulations involving EVs must therefore fit with these principles.

X. Concluding Remarks

EVs form part of an emerging industry. Accordingly, their development needs should be carefully monitored so that the industry is not overly burdened with additional costs and new regulations, particularly when there is no compelling evidence to do so. EVs would represent a new load, and would represent a sizable increase to the aggregate demand of an individual household. But we expect that EV take-up rates will be gradual, and therefore changes to the NEM's aggregate demand will be equally incremental, not radical. For this reason, EV loads should not be considered either as a problem or a panacea for the grid over the short to medium term. In fact, EVs have the potential to reduce unit electricity prices for all consumers by improving capital stock utilization rates. In this context, EVs should not be singled out; they should be seen in the context of broader industry issues and opportunities, such as the rollout of a Smart Grid, the deregulation of retail energy pricing, the introduction of ToU pricing including critical peak pricing, and the rise of demand response technologies. Our modeling tends to indicate that the generation fleet and the transmission system will be able to cope with the large-scale adoption of EVs; although some localized distribution ''hot spots'' are likely to appear over time. But the grid, and households, will become smarter at the time when EVs are being rolled out. This should help neighborhood level issues, particularly if pricing incentives are used to encourage off-peak charging.

Without EV owner support, the EV industry won't take off. Customer interests should be at the forefront of the industry's thinking. Customer choice should be maintained. EV drivers should be offered simple solutions for charging, electricity provision, and pricing. Interoperable charging equipment should suit the variety of EVs expected in the Australian marketplace.

 1040-6190/$–see front matter doi:/10.1016/j.tej.2012.02.014

And with care, the energy supply industry will be able to meet the needs of EV drivers and make optimal use of the grid for all electricity consumers, avoiding unintended consequences or market failure.■

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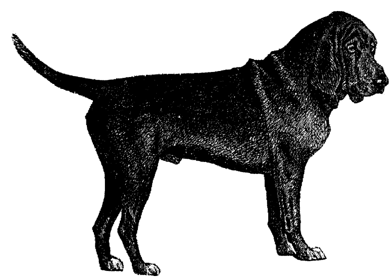

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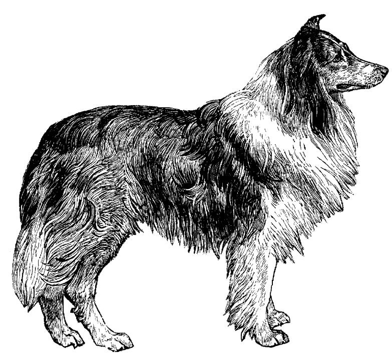

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Endnotes:

1. Data sourced from Australian Bureau of Statistics, 2011.

2. Some EVs may have a battery that is charged by a solar photovoltaic cell (PVEV) or a fuel cell (FCV), although it is difficult to find sources that indicate these vehicles would have a significant market share in the timeframe considered by this article (to 2030). For the purposes of this article, we assume that commercially available EVs will not be powered by fuel cells or solar PV internal to the vehicle.

3. Private industry briefing at the invitation of Alchemy Growth Partners, 2011.

4. Derived from Toyota Motor Corporation Australia, What Will We Be Driving in 2050? Presentation to Australia Japan Society of Victoria, Japanese Chamber of Commerce and Industry.

5. UK Committee on Climate Change, 2010.

6. Dept. of Environment and Climate Change, 2009.

7. Tesla, 2009.

8. These figures have been derived from fuel consumption data for new cars published by the Commonwealth Government on the Green Vehicle Guide Web site and by the ABS (for current average petrol vehicles), and the scope 1 and scope 3 greenhouse gas emission factors for gasoline published by the Commonwealth Department of Climate Change and Energy Efficiency in the *National Greenhouse Accounts Factors* (July 2010).

9. Data correct as of mid-2009.

10. Excluding sport utility vehicles, utilities, vans, trucks, and buses (and all vehicles classified by the ABS as ''other vehicles'').

11. Toyota Motor Corporation Australia, *supra* note 4.

12. This figure is based on a 50/50 mix of large (approx 220 Wh/km) and small (approx 120 Wh/km) EV adoption. It takes into account the likely improvement in battery efficiency that EVs will achieve over the scope of this article (to 2030). The assumption is conservative, as we did not want to overstate the impact that EVs would have on the NEM.

13. Rates of energy consumption, ranges, and battery capacities for each

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vehicle have been sourced from Australian and U.S. government fuel economy labels, and manufacturer specifications, respectively.

14. Maximum range per single charge as published by OEMs. Actual driving conditions may not achieve these ranges.

15. Based on driving the Australian average distance for passenger vehicles in electric mode (14,300 km per annum).

16. Based upon 2011 electricity regulated tariffs in NSW; peak electricity: 44.66 cents/kWh and off-peak 10.56 cents/kWh.

17. Mitsubishi Motors (2011).

18. Tesla Motors (2011).

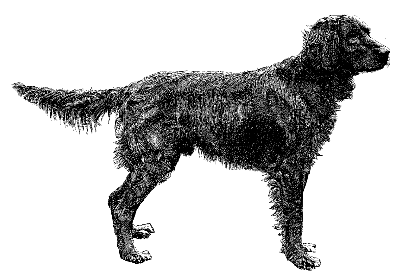
19. General Motors, 2011, based on city driving (may be lower than the ''theoretical'' range of other vehicles).

20. Nissan USA (2011).

21. Time-of-Use (ToU) is an electricity pricing structure which allows customers to be charged different prices depending on the time of day the electricity is consumed. ToU pricing encourages electricity users to shift discretionary consumption from ''peak'' demand periods when electricity is more expensive, to the cheaper ''shoulder'' or ''off-peak'' periods. Simple ToU tariffs are already in use in parts of Australia (including New South Wales and Victoria), where there are set prices charged at defined peak, shoulder and off-peak periods of the day. ToU pricing is facilitated by the installation of interval (or ''smart'') meters, which measure electricity consumption on a half-hourly basis.

22. Critical peak pricing (CPP) is a specific ToU price structure, whereby for most of the time, simple ToU tariffs apply (i.e., peak, shoulder, and off-peak), except for certain days during the year when demand is exceptionally high (generally very hot or cold days) when (sometimes much) higher prices are imposed. The critical price can occur for a limited number of days, or when the system/market meets certain conditions. CPP intends to strengthen the real-time price link between the wholesale and retail electricity markets to strongly encourage electricity users to shift load from critical peak periods where possible, which in turn will reduce demand during periods of system stress, and avoid electricity shortages (i.e., blackouts).

23. ESAA (2011) quotes estimates that a Chevy Volt and a Nissan Leaf would increase average U.S. residential



consumption by 13 percent and 19 percent, respectively. According to the U.S. Energy Information Administration, the average U.S. household uses 11 MWh per annum. Driving 15,900 km in a Chevy Volt (in electric mode) and Nissan Leaf will consume 3.6 MWh and 3.4 MWh, respectively, increasing U.S. household consumption by around 30 percent. Hence the data quoted in ESAA (2011) must refer either to annual driving distances well below the Australian and U.S. averages, or to households with much higher (non-EV) energy consumption than the average or assume the bulk of EV charging will occur outside the home.

24. The Smart Grid Smart City Project has found that Mitsubishi i-MiEVs are drawing 12 amps from a 15 amp plug (presentation given at the National Smart Grids Forum, Sydney, Sept. 2011).

25. Underlying load data sourced from Simshauser & Downer (2011).

26. Simshauser & Downer (2011) found that an increase in household load factor by 11.5 percent could reduce residential electricity bills by up to 12 percent due to improved system utilization. In 2030 the High Uptake trajectory for EVs could improve the residential load factor in the NEM by over 2.5 percent (assuming off-peak charging) which could, *ceteris paribus*, noticeably reduce unit prices for all electricity consumers. Based upon a wholesale energy market saving of $1.50/MWh, total savings to electricity consumers could be as high as $346 million per annum by 2025.

27. (Nissan Global, 2011).

28. (Liggett, 2011).

29. (Campbell, 2011).

30. National Renewable Energy Laboratory, 2011.

31. A typical house could be expected to have an actual maximum demand of 6–7 kW (a higher maximum demand can be accommodated if a larger main is installed at the house).

32. In many areas, low-voltage networks have been designed to cope with a diversified peak demand equivalent of 4–4.5 kW per house (this after diversity maximum demand (ADMD) is average across all premises; some houses will have a much higher demand and some a much lower demand).

33. IBM is developing technology so that EV charging can be coordinated with wind power availability (Garthwaite, 2009).

34. Flat tariffs are the simplest electricity pricing structure, whereby customers are charged a standard (flat) rate for each kWh consumed, regardless of the time of day. Flat tariffs offer no incentives to customers to shift consumption to any particular time of day. Flat tariffs are currently widely used for many customers that do not have an interval (smart) meter.