Environmental Attributes of Electric Vehicles in Australia

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Executive Summary

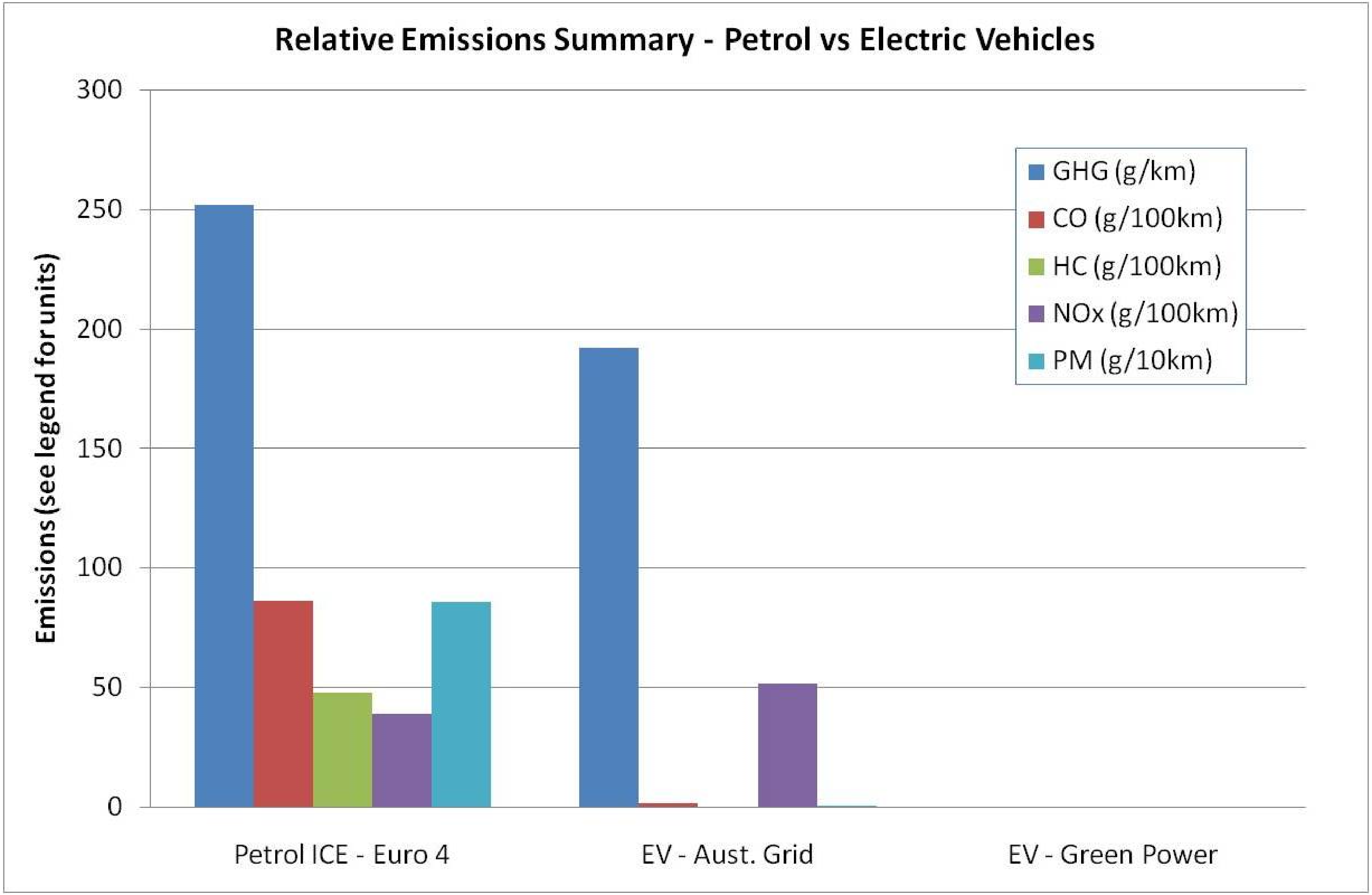
This position paper studies electric vehicles (EVs) in the Australian context to outline some of the relevant environmental attributes as well as the associated impacts on the electricity grid. The key findings are:

1. A fleet of one million EVs (8% of the national vehicle fleet) would reduce toxic air pollutant emissions by 150,000-300,000 tonnes annually compared to a same-sized fleet of new petrol vehicles.
2. The same fleet of one million EVs would reduce national greenhouse gas (GHG) emissions by:
    - 0.9 Mt CO_2-e (24% per vehicle) when recharged from the current national average grid
    - 3.8 Mt CO_2-e (100% per vehicle) when recharged with 100% green power
3. Through vehicle-to-grid (V2G) ancillary services linked to a smart grid, the distributed batteries in these one million EVs could enable almost 45,000GWh of renewable energy generation – the same amount as required by the Federal Renewable Energy Target. This would produce a 11X reduction of combined GHG emissions from the stationary energy and transport sectors.
4. The total annual GHG reduction for one million EVs with V2G enabling renewable energy would be 41Mt CO_2-e or 8% of total national emissions.
5. There is enough excess off-peak capacity in the Australian electricity grid to power all city and urban car travel, and under this scenario, the increase in energy generated (all within off-peak periods) would be only 11% nationally.
6. A widespread Smart Charging infrastructure will be needed to provide adequate recharging coverage and sufficient V2G connectivity in order to realise all of the above benefits.

Recommendations

In light of these significant environmental benefits, the recommendations include:

1) Facilitate pilot demonstration deployments to examine local challenges for EVs and their recharging infrastructure, in particular their costs and regulatory and policy barriers.
2) Introduce comprehensive policy measures to foster local EV market development by:
    a) Promoting the supply and uptake of EVs (e.g. via manufacturer and consumer incentives/feebates);
    b) Incentivizing the use of green power for recharging;
    c) Encouraging land developers to provide smart EV recharging infrastructure in residential, commercial and government premises (e.g. via green accreditation schemes);
    d) Opening and simplifying access to core infrastructure assets (power grid, telecoms, etc) to which EV infrastructure will connect, including streamlining of approval and permit processes.
3) Further research into:
    a) The product lifecycle and total environmental impact for EVs;
    b) Local applications of V2G technology;
    c) Global EV policy developments.


Relative Emissions Summary - Petrol vs Electric Vehicles
Emissions (see legend for units)
300
250
200
150
100
50
0
Petrol ICE - Euro 4
EV - Aust. Grid
EV - Green Power
GHG (g/km)
CO (g/100km)
HC (g/100km)
NOx (g/100km)
PM (g/10km)

Introduction

Electric vehicles (EVs) have recently emerged globally as a favoured technological option for combating oil dependency, petroleum price volatility, air pollution and climate change emissions in the transport sector. This is evidenced by the global automotive industry's plans to bring more than 30 new EV products to market in the next 3 years. However, Australia has arguably received less exposure to EV developments and the technology has not been subjected to the same level of study locally as it has overseas. Therefore, this position paper considers the Australian context to outline some relevant environmental attributes of EVs and their associated impacts on the electricity grid. The paper considers:

- Vehicle tailpipe pollutants (or lack thereof)
- Relative well-to-wheel greenhouse gas emissions
- The vehicle lifecycle including manufacturing and recycling/disposal
- Electricity grid capacity expansion and network augmentation
- Vehicle-to-grid aggregation schemes
- Recharging using green power and other synergies with renewable energy

What are the relative urban air pollutant emissions from petrol vs. electric vehicles?

Petrol vehicle tailpipe emissions such as carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), oxides of nitrogen (NOx) and particulate matter (PM) are all contributors to urban air pollution leading to smog formation and chronic respiratory illnesses. Research at the University of Sydney has concluded that the human health cost of Sydney urban vehicle pollution exceeds $3 billion annually, and that twice as many people die from vehicle exhaust as from road accidents (Kearney, 2006).

The emission of these pollutants from petrol vehicles has been studied repeatedly by CSIRO (Beer et al, 2004) and Table 1 and Figure 1 show the relative emissions of these pollutants for a variety of petrol-fuelled vehicles based on CSIRO data.

Electric vehicles have no tailpipe and produce no direct emissions, whereas power generation does emit these pollutants. However, consideration should be given to the fact that Australian power plants are typically located away from population centres, and their large centralised nature makes them better candidates for emissions control technologies than a fleet of vehicles. Emissions from power generation can be calculated using methodologies specified for the National Pollution Inventory (DEH, 2008). These emissions can then be applied to EVs using an assumed charging efficiency. In NSW, 98% of power generation is from black-coal (ESAA, 2008), so this section conservatively assumes 100% black coal to estimate the pollutant intensities used in the analysis. The paper also assumes that EV recharging will consume 180 Wh/km at the power plug, based on a recent survey of 30+ contemporary EVs by the author. Table 1 and Figure 1 compare the relative emissions of these urban air pollutants for an EV.

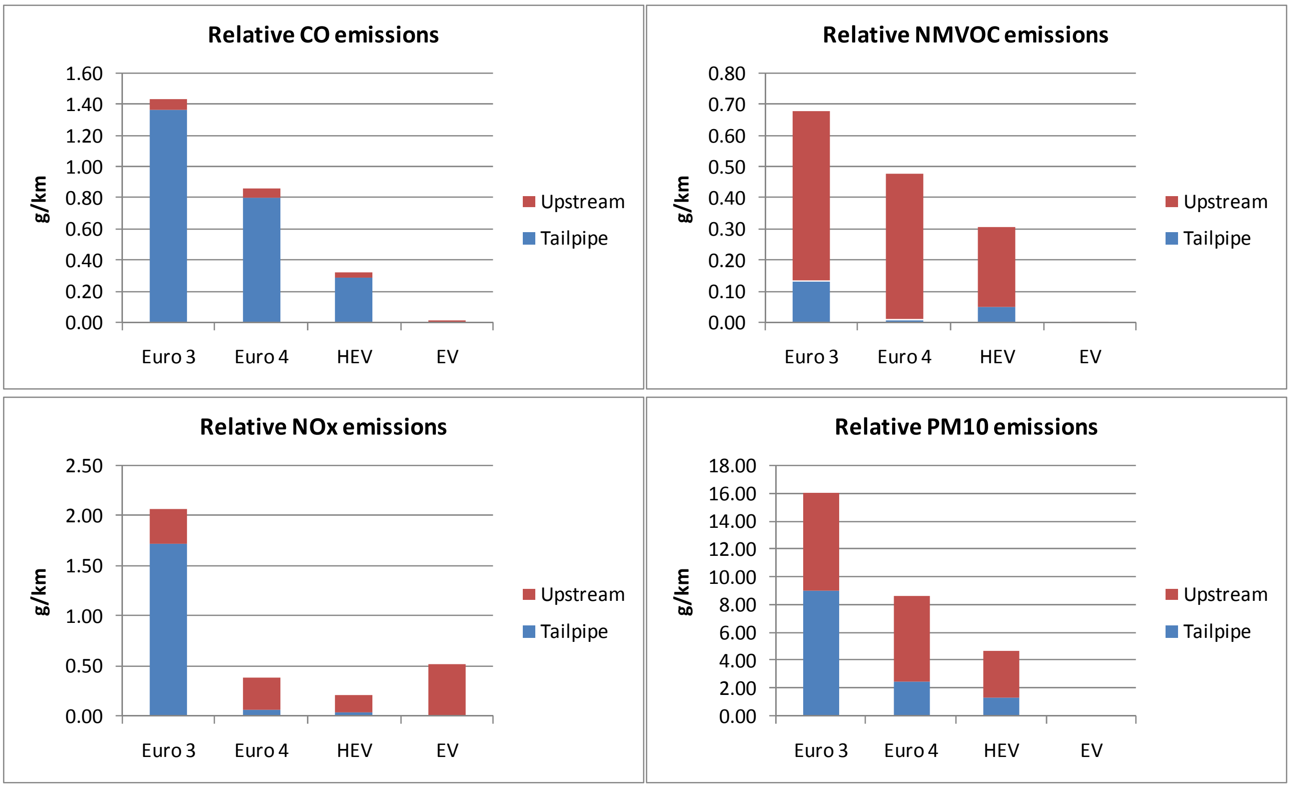


Figure 1: Relative emissions of urban air pollutants – CO, NMVOC, NOx and PM

Figure 1 clearly shows that EVs, compared to petrol vehicles, produce almost no emissions of CO, NMVOC and PM. While there are no tailpipe NOx emissions, the upstream NOx emissions are of the same order of magnitude as petrol vehicles but these emissions typically occur outside urban areas. Compared to a Euro 3 or Euro 4 combustion vehicle, the total reduction of air pollutants ranges between 10-20 g/km. Assuming annual travel of 15,000km per vehicle and extrapolating to a fleet of one million EVs (8% of the national vehicle fleet), this would equate to between 150,000-300,000 tonnes less air pollution each year.

Consideration should also be given to other pollutant emissions not discussed in this paper, such as SOx and heavy metals that can both emit from petroleum refining and power generation, although these are also expected to be lower for EVs (EPRI et al, 2007). Overall, it is clear however that EVs are expected to produce a majority reduction in urban air pollutant emissions relative to petrol vehicles.

Table 1: Relative emissions of urban air pollutants – CO, NMVOC, NOx and PM

	Urban air pollutant emissions factors											
	Tailpipe (combustion) (g/km)				Upstream (pre-combustion) (g/km)				Total (g/km)			
	CO	HC	NOx	PM	CO	HC	NOx	PM	CO	HC	NOx	PM
ICE (Euro 3)[1]	1.37	0.13	1.72	9.0	0.07	0.55	0.35	7.1	1.44	0.68	2.07	16.1
ICE (Euro 4)[1]	0.80	0.01	0.06	2.5	0.07	0.47	0.33	6.1	0.87	0.48	0.39	8.6
HEV[1]	0.29	0.05	0.04	1.4	0.04	0.26	0.18	3.3	0.33	0.31	0.22	4.7
EV[2]	---	---	---	---	0.02	0.002	0.52	0.08	0.02	0.002	0.52	0.08

References:

1 CSIRO (Beer et al, 2004)

2 Calculated by author using National Pollution Inventory (DEH, 2008)

What are the relative well-to-wheel greenhouse gas emissions for petrol vs. electric vehicles?

Greenhouse gas (GHG) emissions result from both petrol and electric vehicles on a well-to-wheel basis (even though there are no tailpipe emissions from EVs). The gases concerned include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), plus a host of synthetic fluorocarbons that are not normally associated with the petroleum or power generation sectors. Total emissions of these GHGs are reported in terms of their equivalent climate change potential relative to a certain weight of CO_2 – for example, equivalent kilograms of CO_2 ($kgCO_2$-e).

GHG emissions from petrol vehicles in Australia can be calculated using a methodology outlined in the National Greenhouse Accounts (NGA) Factors (DCC, 2008), and these emissions have also been studied by Simpson (2005) and CSIRO (Beer et al, 2004). These methods all use assumed GHG intensities for petroleum fuel (emissions per unit volume, or $kgCO_2$-e/L) which can then be multiplied by a vehicle's fuel consumption (fuel volume per unit distance, or L/100km) to calculate GHG emissions per unit distance ($kgCO_2$-e/km). For conventional vehicles, this paper assumes a typical fuel consumption of 8.8 L/100km (representative of a 2.4L mid-size sedan e.g. Camry or Accord) based on the average petrol passenger vehicle fuel consumption reported for the 2007 model year (FCAI, 2008). For hybrid vehicles, this paper assumes 4.5 L/100km which is the average fuel consumption of the two mainstream hybrid models currently sold in Australia (Prius and Civic). Well-to-wheel GHG emissions using these two fuel consumption values and the three emissions methods (NGA, Simpson and CSIRO) are presented in Table 2 and Figure 2.

Table 2: Relative GHG emissions for petrol vs. electric vehicles

Vehicle	Reference[1]	Fuel Consumption	Energy Content	GHG Emissions per Unit of Energy			GHG Emissions per Unit of Fuel			GHG Emissions per Unit Distance		
				Scope 1/2	Scope 3	Total	Scope 1/2	Scope 3	Total	Scope 1/2	Scope 3	Total
		(L/100km)[2,3]	(MJ/L)	(g/MJ)			(g/L)			(g/km)		
Petrol ICE	NGA (2008)	8.8	34.2	66.9	5.3	72.2	2289	181	2470	201	16	217
Petrol ICE	Simpson (2005)	8.8	32.3	71.1	17.7	88.8	2295	571	2867	202	50	252
Petrol ICE	CSIRO (2004)	8.8	34.4	72.4	14.1	86.6	2492	486	2978	219	43	262
Petrol HEV	NGA (2008)	4.5	34.2	66.9	5.3	72.2	2289	181	2470	103	8	111
Petrol HEV	Simpson (2005)	4.5	32.3	71.1	17.7	88.8	2295	571	2867	103	26	129
Petrol HEV	CSIRO (2004)	4.5	34.4	72.4	14.1	86.6	2492	486	2978	112	22	134
		(Wh/km)[4]	(MJ/kWh)	(g/MJ)			(g/kWh)			(g/km)		
EV Aust.	Simpson (2005)	180	3.6	297		297	1069		1069	192		192
EV Aust.	MRET 20%	180	3.6	254		254	914		914	165		165
EV Aust.	Green Power	180	3.6	0		0	0		0	0		0
EV NSW	NGA (2008)	180	3.6	249	47	296	896	169	1066	161	30	192
EV VIC	NGA (2008)	180	3.6	340	23	363	1224	83	1307	220	15	235
EV QLD	NGA (2008)	180	3.6	252	38	290	907	137	1044	163	25	188
EV SA	NGA (2008)	180	3.6	233	39	272	839	140	979	151	25	176
EV WA	NGA (2008)	180	3.6	242	29	271	871	104	976	157	19	176
EV TAS	NGA (2008)	180	3.6	35	2	37	126	7	133	23	1	24

Notes:

1 References define GHG emissions factors per unit of energy as well as energy content of fuel.
2 Petrol ICE assumes average petrol passenger vehicle fuel consumption reported for the 2007 model year (FCAI, 2008).
3 Petrol HEV assumes average fuel consumption of the two mainstream hybrid models currently sold in Australia (Prius and Civic).
4 EV recharging consumption based on a recent survey of 30+ contemporary EVs by the author.

GHG emissions from EVs can be calculated using a methodology outlined in the NGA Factors (DCC, 2008) and these emissions were also studied by Simpson (2005). Both methods use assumed GHG intensities for electricity (emissions per unit energy, or $kgCO_2$-e/kWh) which can then be multiplied by an EV's recharge electricity consumption per unit distance (kWh/km) to calculate GHG emissions per unit distance ($kgCO_2$-e/km). As stated previously, this paper assumes EV recharging consumption of 180Wh/km at the power plug, based on a recent survey of 30+ contemporary EVs by the author. This figure is slightly moreconservative than the 160Wh/km determined by the AutoCRC from their own survey (Albrecht et al, 2009). Table 2 and Figure 2 show the GHG emissions for EVs using these two emissions methods. Note that NGA Factors provide emissions on a state-by-state basis, whereas Simpson provides a single national average value.

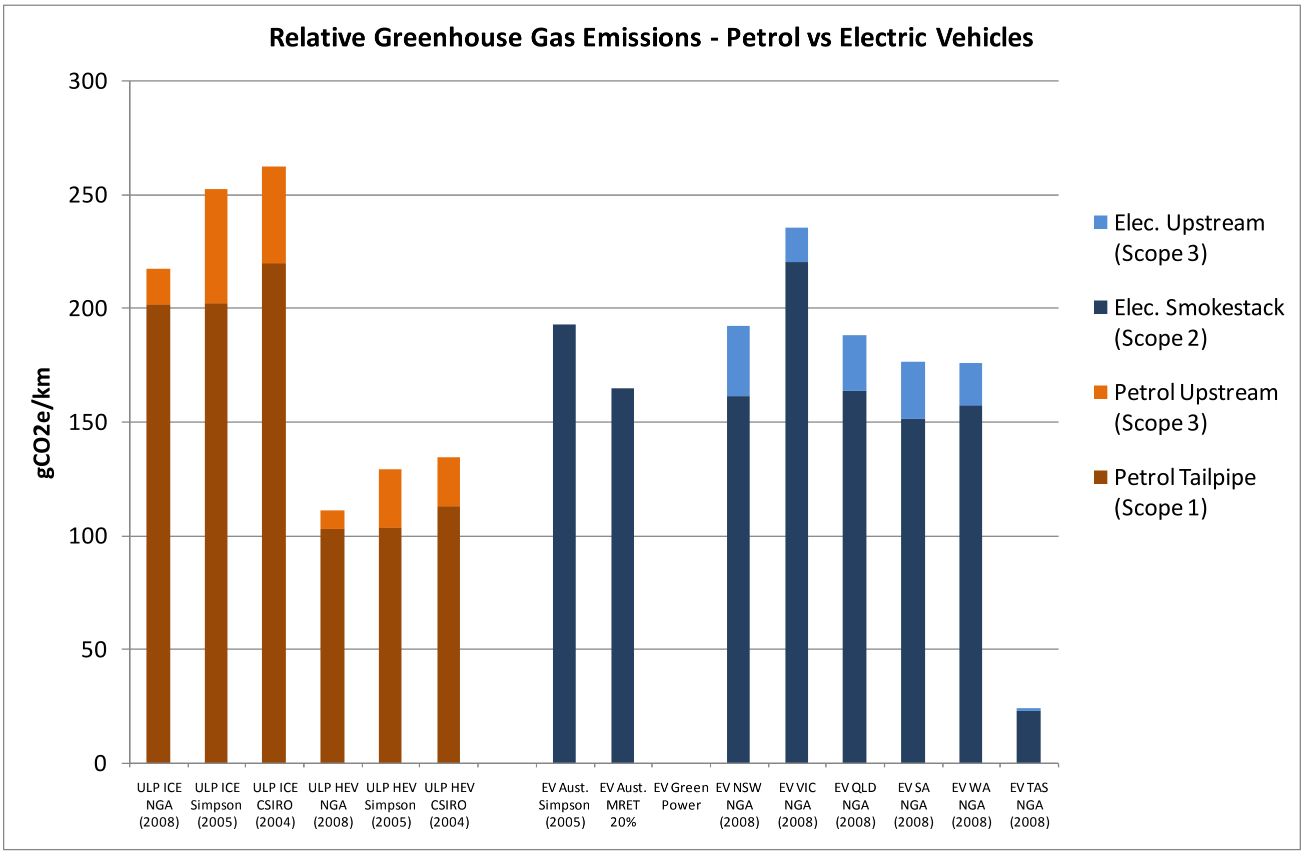


Figure 2: Relative GHG emissions for petrol vs. electric vehicles

Figure 2 shows that the GHG improvement of EVs is highly dependent on the assumed source of electricity as well as the assumed vehicle efficiencies. In most cases (including the national average grid), the relative GHG emissions of EVs are lower than conventional petrol vehicles. The exception is Victoria, given its reliance on brown coal for power generation with high greenhouse emissions. Figure 2 also highlights that hybrid vehicles achieve lower GHG emissions than either conventional petrol or electric vehicles. The exception here is Tasmania, where the state's predominant use of hydro-electric power results in a very low level of well-to-wheel GHG emissions.

A number of estimates have been published that found relatively higher greenhouse gas emissions from EVs. Garnaut (2008) found that an EV would generate about 30 per cent more emissions than a petrol-fuelled car of similar dimensions if the electricity had the average emissions intensity of the Australian grids. While the methodology for this calculation was not disclosed, it appears that this conclusion is a result of comparing EVs with only the smallest, most-frugal petrol vehicles on the Australian market, rather than typical petrol vehicles. If a Toyota Yaris (6L/100km) is compared to an EV consuming 180 Wh/km using the NGA emissions factors, then the Garnaut result can be reproduced. However, as noted by this paper, there are more than 30 EVs coming to market across all segments (medium and large passenger and light-commercial, as well as small passenger) and when their average consumption as surveyed (180Wh/km) is compared to the average consumption of typical petrol vehicles (8.8L/100km) the result favours the EV, as shown in Figure 2.

What about use of Green Power for EV recharging?

As the Tasmanian result illustrates, the use of 100% renewable energy for recharging of EVs would result in no well-to-wheel GHG emissions (Figure 2). Renewable energy can be accessed by EV motorists either via retail Green Power tariffs or via local installations of renewable energy (e.g. rooftop solar). Similarly, use of a partial retail Green Power tariff (e.g. 25%) or the achievement of the 2020 MRET goal of 20% would result in a proportional decrease in GHG emissions (Figure 2).

What are the relative lifecycle emissions for EVs?

A frequently-raised concern is the energy/emissions associated with manufacturing and recycling/disposal of EVs – particularly relating to their battery powertrain. This is a difficult issue to study given a) the highly-complex nature of automotive manufacturing industry and its supply chain industry and b) the current underdeveloped state of the EV manufacturing with only minimal empirical data to draw upon.

However, some preliminary studies of the EV lifecycle have been completed and the results are promising. The Massachusetts Institute of Technology (2000) concluded that EVs in 2020 will produce net reductions of 20-30% in lifecycle energy and GHG emissions (Figure 3). Similarly, a more-recent study by Arup and Cenex (2008) for the UK Department of Business Enterprise and Regulatory Reform and Department of Transport concluded that EVs manufactured in 2010 would result in net reduction of climate change impacts by 30% relative to average combustion vehicles, increasing to a net reduction of 53% for EVs manufactured in 2020. This study also concluded that the majority of EV life cycle emissions are associated with the in-use phase, rather than with the production and disposal of EVs. Clearly, the EV lifecycle requires significant further study in the Australian context, and the relatively high GHG intensities of Australian industry and power generation will be important factors to consider.

What about EV maintenance requirements including battery replacement?

Given the underdeveloped state of the EV manufacturing, there is little empirical data available to characterise the maintenance schedules and costs of EVs. However, EV powertrains are much simpler than combustion vehicles and have fewer moving parts. Many of the consumable items found in combustion engines (belts, seals, filters, sparkplugs, valves, lubricants, etc.) do not exist in EVs. Maintainable parts that are common to EVs include electronics, cooling fluids and radiators, fans and pumps, driveline lubricants, wheel/axle bearings, brake pads and tyres, and air-conditioning systems. For many of these parts, such as brake pads (used less during regenerative braking), the maintenance frequency will be reduced. Overall, it is generally expected that these vehicles will require less servicing and cost less to maintain, leading to reduced materials and emissions over the vehicle lifetimes. The Electric Power Research Institute (2004) has estimated 10-year maintenance costs for an EV of between US$2200-$2800; approximately half of the US$4100-$5200 estimated for maintenance of a conventional vehicle.

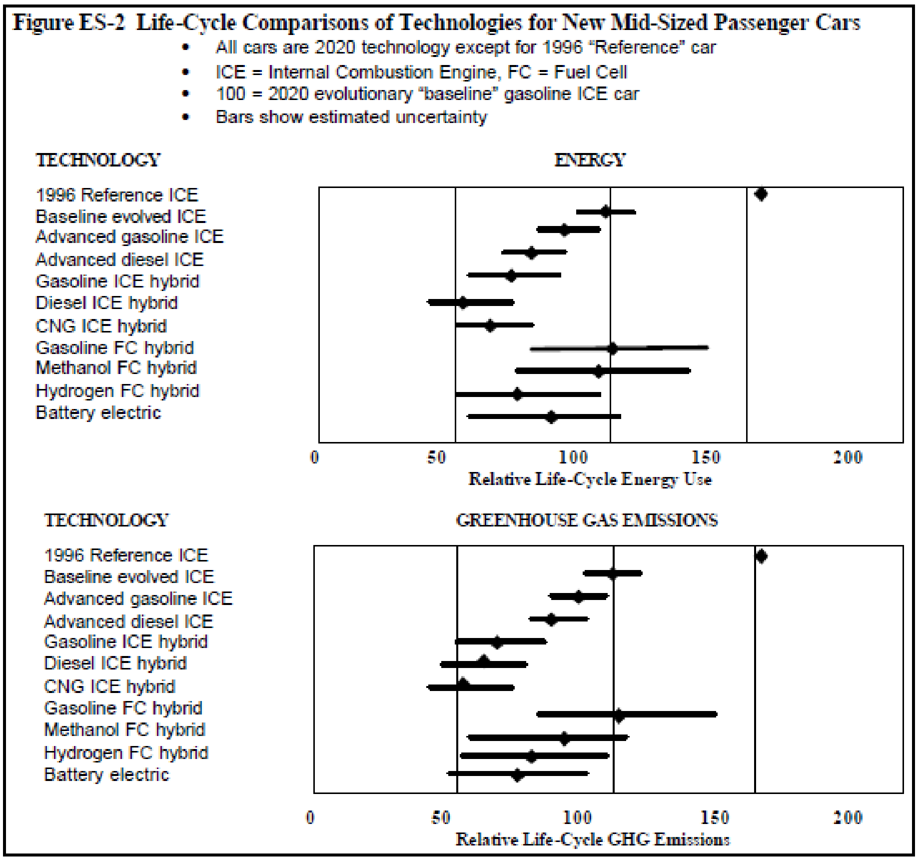


Figure 3: Relative lifecycle energy and emissions for EVs as studied by MIT (2000)

Today's state-of-the-art automotive lithium-ion batteries for most modern, commercial EVs are expected to meet industry requirements for operating lifetime (Kalhammer et al, 2007). Furthermore, these battery systems come equipped with sophisticated charge-balancing and thermal-management systems to maintain their performance and life. These lithium-ion batteries are also fully-recyclable, although a battery recycling industry must grow in parallel with the battery supply industry to ensure full recovery and reuse of these valuable materials.

Will the electric power generation capacity need to be expanded or will the network infrastructure need to be augmented to accommodate EV recharging loads?

Today's Australian electricity grids are characterised by generating plants that are underutilised throughout large parts of the day, whereas transmission and distribution infrastructure are stressed to their limit by critical peak demand arising from air-conditioning loads in summer and heating loads in winter (Effeney, 2009). It is generally well-recognised that a large uptake of EVs with haphazard charging could exacerbate this situation.

Fortunately, the EV industry (including automakers, electric utilities and 3rd-party infrastructure providers) has embarked on a plan to manage the charging loads from the coming wave of EVs – a concept known as *Smart Charging*. Smart charging schemes manage both the rate and timing of EV recharging, with potential for various degrees of complexity and intelligence. The implementation is intended to be transparent and plug-and-play for the EV motorist, with the scheme managed so as to mitigate grid impacts and minimise overall system costs, meanwhile ensuring that the EV is recharged within the appropriate time.

Smart charging has been successfully demonstrated in a number of industry trials (Figure 4) and there are smart charging systems commercially available for implementation both on-board and off-board the vehicle. Smart charging interfaces will come as standard equipment on the Chevy Volt PHEV, Mini EV and Mitsubishi i-MiEV and an onboard smart charger controller has been developed by the Pacific Northwest National Laboratory. Commercial off board hardware and software interfaces are provided by companies such as Better Place, Coulomb Technologies / Charge Point Australia, V2Green/Gridpoint, Google, Elektromotive, ECOtality, EVOASIS and RWE. Smart charging schemes can also leverage the rollout of smart grid infrastructure that is currently underway both globally and nationally in Australia (Wolfs, 2009).

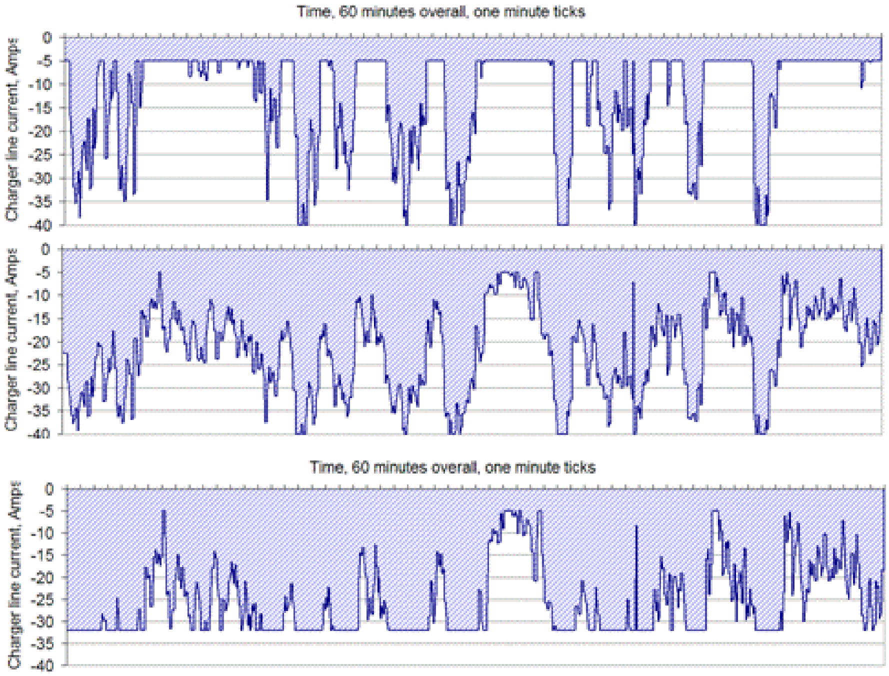


Figure 4: Smart charging of a Tesla Roadster in California (Brooks and Thesen, 2007) – *note that zero charging current is at the top of the scale, the shaded area is proportional to the energy transferred.*

Smart Charging has the potential to reduce or entirely eliminate the need for additional generation capacity that would be required to accommodate large-scale charging of EVs during electric grid peak load demand periods (Austin Energy, 2009). A recent study by AutoCRC (Albrecht et al, 2009) has shown that there is enough excess off-peak capacity in the Australian electricity grid to power all city and urban car travel. In this scenario, the total increase in energy generated (entirely during off peak) would be only 11% nationally. Similarly, a recent study for the United States (Kintner-Meyer et al, 2007) showed that the existing grid could support electrification of 73% of the US light vehicle fleet, and a recent study for the United Kingdom (Ricardo, 2009) has concluded that existing power infrastructure has capacity for significant rise in the use of EVs and is not a constraint on their deployment. Even under the assumption that EVs will be accompanied by the deployment of Smart Charging, localised grid bottlenecks could still arise – e.g. where local network capacity is marginal or where particularly high concentrations of EVs occur (Ricardo, 2009). These issues are the subject of ongoing studies overseas (Schneider et al, 2008) and Curtin University is undertaking two new research projects to study them at both the transmission and distribution levels in the Australian context.

Smart Charging schemes will also provide a number of important environmental benefits:

- The increased plant utilisation and flexibility in generator scheduling and dispatch (including preferential use of highest-efficiency plant, reduced start-up transients and ramping rates, and less idle plant online for standby power) will increase generation efficiency, minimise transmission and distribution losses, and reduce net emissions (Denholm and Short, 2006; Sioshansi and Denholm, 2009) as shown in Figure 5.
- For similar reasons, plant will experience less thermal cycling of plant leading to reduced maintenance and longer operating lifetimes (Denholm and Short, 2006; Troy et al, 2009).
- Smart Charging can match charging periods with power generation that produces the least GHG emissions, including synchronising charging with intermittent renewable energy generation such as solar and wind (Austin Energy, 2009).
- There is potential for EVs to be aggregated to provide vehicle-to-grid (V2G) ancillary services which can enable an even higher penetration of intermittent renewable energy in the grid.

However, under a large-uptake scenario for EVs, the mitigation of grid load impacts and enabling of renewable energy (discussed further below) will depend on the widespread availability of this Smart Charging infrastructure in order to provide adequate recharging coverage and ongoing V2G connectivity.

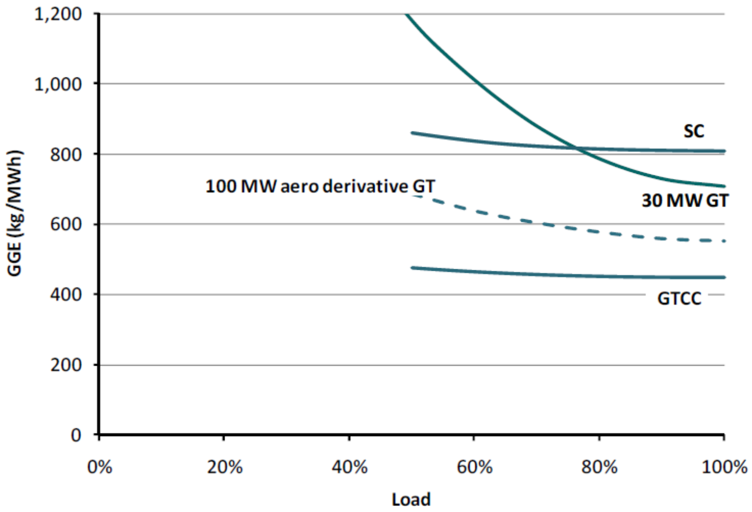


Figure 5: Effect of partial load on GHG emissions for fossil-fuel power plants (Wibberley et al, 2008)

How can EVs enable a higher penetration of renewable energy?

There are two factors relating to EVs that will encourage a higher penetration of renewables:

1. Economics of displacing petroleum vs. electricity consumption
2. EVs' potential for aggregation and provision of vehicle-to-grid (V2G) ancillary services

On an individual basis, the financial value of using renewable energy to displace transport petroleum consumption is far greater than the value of displacing fossil fuel electricity consumption. For example, if a conventional vehicle consumes 8.8 L/100km of petrol at a price of $1.25 per litre, then the displacement value of the electricity used to power an EV consuming 180Wh/km is approximately 60c/kWh. This represents a 3X increase in marginal value from using a rooftop solar array to recharge an EV rather than supplementing household electricity consumption at approximately 20c/kWh, and constitutes a far-greater incentive for use of renewable energy. This value has just recently been matched by the NSW government's announcement of a 60c/kWh feed-in tariff for renewable energy, but it should be noted that most other states do not provide this level of incentive.

On a larger scale, EVs can potentially be aggregated as a grid resource and used to provide vehicle-to-grid (V2G) ancillary services, which have been identified as a key enabler for much larger penetrations of renewable energy (Wibberley et al, 2008). Ancillary services (Figure 6) such as spinning reserves and frequency/voltage regulation refer to extra capacity that power system operators must procure (at a cost) in order to balance electricity supply and demand in real-time and maintain reliability of the system. Figure 6 shows that different ancillary services are contracted over varying time durations, and in many service territories these services are traded on open markets similar to the primary markets for power supply. It has been estimated that in the US these services cost almost $14 billion annually (Hirst and Kirby). EVs have the attributes of a rapid-response, controllable load with built-in energy storage that make them ideal as ancillary service devices. The vehicles can be aggregated into a resource of meaningful size (typically >1MW) and interfaced with the grid using commercial systems such as those described above in the section on Smart Charging. In some cases it will even be advantageous to use EVs to feed power back onto the grid, although this is not strictly required for such schemes to be viable.

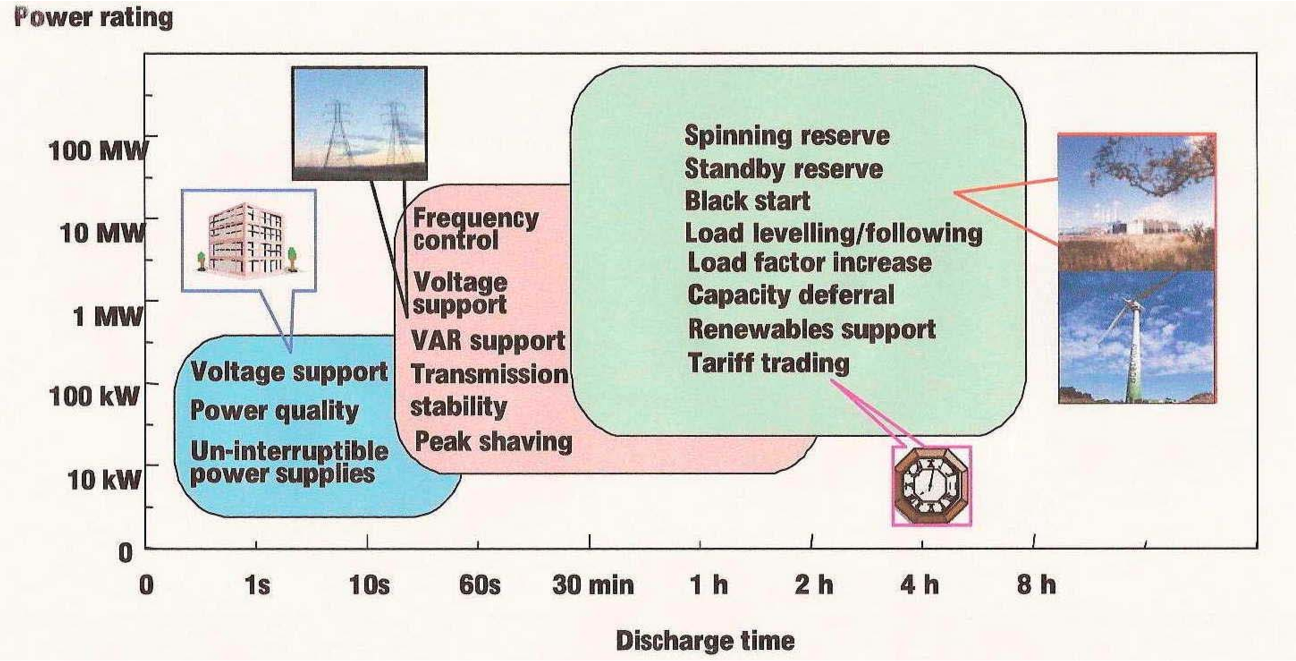


Figure 6: Various types of grid ancillary services, which can potentially be provided by EV fleets via aggregated V2G schemes.

Numerous studies have examined the potential for EVs to provide V2G ancillary services and enable higher penetrations of renewable energy, and several demonstration projects have also been completed. Studies by the University of Delaware (Kempton and Tomic, 2005) have concluded that only 3% of the vehicle fleet is needed to fully-provide the highest-value, time critical ancillary services (regulation and spinning reserves). As those markets become saturated, EVs can then serve markets for peak power and storage for renewable energy, with perhaps one-quarter to one-half of the fleet being utilised for these purposes. Successful demonstrations of EVs with V2G have been performed by the University of Delaware, Tesla Motors with Pacific Gas & Electric, and AC Propulsion. Figure 4 shows the response of a Tesla Roadster to regulation signals provided at 4 second intervals by Pacific Gas & Electric. For the increased penetration of renewables, a study of US grid capacity expansion at the National Renewable Energy Laboratory (Short and Denholm, 2006) has shown that EVs with V2G can more-than-double the installed wind energy capacity (Figure 7). Similarly, an Australian study (James, 2006) concluded that a fleet of one million EVs (8% of the national vehicle fleet) could enable the addition of 10GW of wind generation capacity to the grid (6% of today's 47GW total installed capacity, assuming a 30% average capacity factor for the wind).

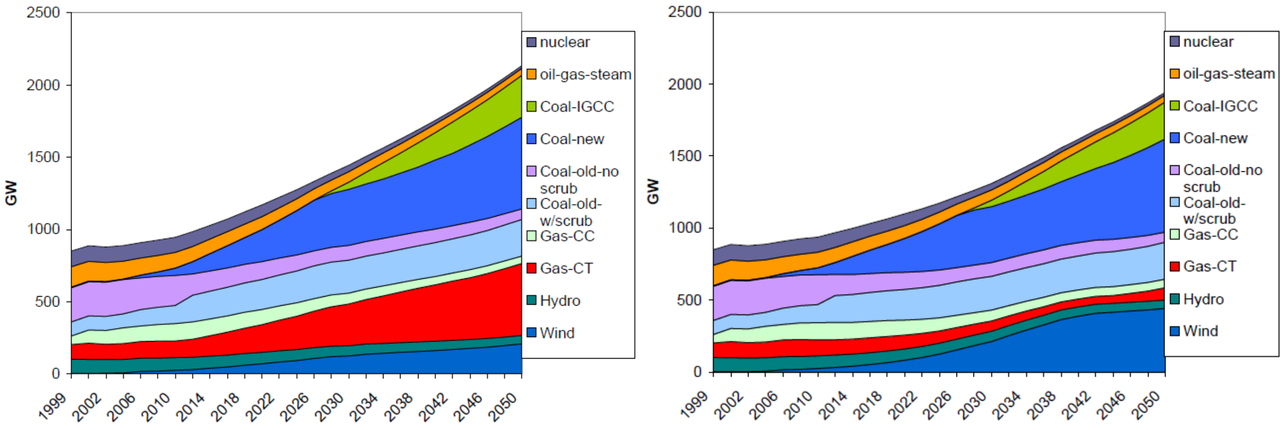


Figure 1: Base Case Projection of U.S. Electric System Capacity from WinDS

Figure 6: Capacity Expansion in the WinDS PHEV-60 Case

Figure 7: Doubling the installed wind capacity in the US grid with EVs via V2G ancillary services (Short and Denholm, 2006).

What are the total cumulative benefits of EVs plus V2G ancillary services plus renewable energy in terms of total environmental impact?

By assuming that EVs with V2G can provide spinning reserves into markets for ancillary services, a calculation can be made to determine the total system reduction in GHG emissions from the EV. This calculation draws directly upon the methodologies outlined by Kempton and Tomic (2005) and James (2006).

On the transportation side, using data provided by Simpson (2005) and assuming that the 2020 MRET target has been achieved via non-V2G means, leading to a national grid GHG intensity of 0.91 kg CO_2-e/kWh, an EV would reduce well-to-wheel GHG emissions by approximately 0.09 kg CO_2-e/km compared to a new petrol vehicle. Over 15,000km of annual driving, the electricity consumption would be 2.7MWh and the GHG reduction would equate to 1.3 tonnes. If the EV was recharged with 100% green power, the GHG reduction would increase to 3.8 tonnes annually. Extrapolating this result to a fleet of one million EVs (8% of the national vehicle fleet) with 100% green power, the GHG reduction would be 3.8Mt CO_2-e or 0.7% of Australia's total 2007 GHG emissions inventory of 540Mt CO_2-e (DCC, 2009). However, it should also be noted that Australia's current annual generation of approximately 15,000 GWh of renewable electricity

(ESAA, 2008) could supply a fleet of approximately 5 million EVs and the Federal Renewable Energy Target of 45,000GWh (DCC, 2009) could supply the entire national vehicle fleet.

In terms of enabling more renewables, each EV could provide approximately 7kW capacity of spinning reserves (Kempton and Tomic, 2005) and this V2G capacity could enable approximately 15kW of additional installed wind capacity (James, 2006). With a capacity factor of 30%, this would produce approximately 43MWh of renewable electricity annually which is a powerful effect compared to the 2.7MWh of electricity required to recharge the EV for the year. Extrapolating this result, a fleet of approximately one million EVs with V2G could enable the 45,000GWh of renewable energy required by the Federal Renewable Energy Target.

Assuming that the 2020 MRET 20% target was already achieved by other means, the net excess 40MWh of renewable energy enabled by each EV would displace a further 37 tonnes of GHG emissions each year from the stationary energy sector. The total GHG reduction per EV would be 41 tonnes annually and the results above show that the impact on the stationary energy sector could be at least 10X as powerful as the impact on transportation. Furthermore, a fleet of one million of these EVs with V2G (8% of the current national vehicle fleet) would reduce GHG emissions in total by 41Mt CO_2-e or 8% of Australia's total 2007 GHG emissions inventory (540Mt CO_2-e).

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