Electric Vehicle Infrastructure Strategic Planning

The University of Western Australia
Renewable Energy Vehicle Project

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(Photo from fastned.nl)

Table of Contents

Terminology

AC	Alternating Current Used for slow, low-powered charging stations
BEV	Battery Electric Vehicle A car with only an electric drive train, plug-in charging, but no combustion engine range extender
DC	Direct Current Used for fast, high-powered charging stations
EV	Electric Vehicle (BEV or PHEV) A car with electric drive train, plug-in charging, with or without range extender
EVSE	Electric Vehicle Supply Equipment An EV charging station
GHG	Green House Gas
GIS	Geographic Information System
ICE	Internal Combustion Engine Petrol or Diesel drive train
Mild Hybrid	A car with a dual drive train, ICE and electric (for typically only ~1 minute). Cannot be charged from a power supply (no plug-in), not considered in this study
OEM	Original Equipment Manufacturer Automotive Company
PHEV	Plug-in Hybrid Electric Vehicle A car with an electric drive train, plug-in charging, and a combustion engine range extender. A PHEV can be driven electrically for a limited range, then continues to drive as an ICE car
SAPS	Stand-Alone Power Supply Typically from a mix of diesel generator, renewable energy generation, and batteries
SWIS	South-West Interconnected System Perth metro and south-west regional electricity grid in Western Australia
TCO	Total Cost of Ownership Vehicle cost including purchase price, fuel, service, maintenance, etc. over vehicle's lifetime
VTOL	Vertical Take-Off and Landing Electric aircraft that can take-off and land like a helicopter

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Executive Summary

Necessity of a State-Wide EV Charging Infrastructure

1. This report was compiled at the request of the WA EV Working Group – Infrastructure Sub-Committee in response to the MOU for Sub-National Collaboration on Electric Vehicles.
2. All stakeholders interviewed have acknowledged the significant potential economic, technical, and health benefits of Electric Vehicles (EVs).
3. It is generally accepted that a state-wide DC fast-charging infrastructure is required to make EVs mainstream and to allow EV owners to travel state-wide. It will give potential EV buyers more confidence in the technology and boost EV uptake.
4. WA has currently just 13 publicly accessible DC charging sites, plus 1 Tesla-only site:
   - UWA operates one site in Crawley with 1 x 50kW
   - City of Swan operates one site with 1 x 50kW
   - RAC funded 11 sites between Perth and Augusta with 1 x 50kW
   - Tesla has one site in Bunbury with 6 x 125 kW *(exclusive use for Tesla vehicles)*

   In comparison, the whole of Australia has 57 DC charging sites (plus 22 Tesla-only), while New Zealand has 169 DC charging sites (plus 6 Tesla-only).
   In Australia, 43 BEVs share a DC charging site, in NZ 26, in Japan 14, and in China only 11.
5. There is a necessity to act now on EV charging infrastructure, as new generation EVs with longer range, shorter charging times and lower total cost of ownership are being imported.

Electric Vehicle Uptake in Western Australia

6. The current uptake of EVs/PHEVs in WA is still very low (about 0.1% of new passenger vehicle sales), but major growth is likely, as in most other countries. Without introducing any incentives, we expect that EVs/PHEVs sales will reach 1% of all new vehicles in WA in the year 2022, and that they will reach 1% of the WA vehicle fleet around 2025/2026. If incentives are introduced, then these uptake rates can be reached significantly earlier.
   At present, WA is behind the rest of Australia in terms of EV uptake rate by a factor of two.
7. Published predictions of future EV uptake show large discrepancies. This reflects the current high level of growth uncertainty in this market. Favourable policies can quickly change EV growth scenarios, as best demonstrated in Norway (with EVs being 52% of all new vehicle sales) and California (5% of all new vehicle sales).
8. Availability of EVs in the low and medium price ranges, including second-hand cars, and the variety in EV models play a major role in customer purchase behaviour.
9. Many automotive OEMs are reluctant to introduce their new EVs into Australia as they perceive the market to be weak due to the lack of subsidies and the lack of political support.
10. Truck electrification is expected to occur at a slower pace than the electrification of the light and passenger vehicle market. The short-haul truck segment (up to 200 km) will be first to be electrified, while the long-haul truck segment will rely on fossil fuels for a longer period, and may adopt other EV technologies, such as overhead power lines.
11. Electric buses are expected to enter the market before electric trucks and possibly even before electric light vehicles. Specific charging stations for buses will be required. Depending on their daily routes, these can either be slow-AC for night-charging or fast-DC for charging during operational hours.
12. Fuel-cell electric vehicles (FCEV) are emission-free if their hydrogen is generated with renewable energy and may play a role in long-haul trucks, but face a number of challenges:
    - FCEVs require about 3 x the energy per km compared to an EV and cannot be charged at home
    - FCEVs require an expensive station network at ~$2 million per station (~$5 million incl. H_2 gen.)
    - FCEVs and modern EVs are about on par in terms of range and filling times

Charging Station Technology

13. Only fast-DC charging technology can enable longer daily trips for EVs.
14. Standards Australia has so far not proposed any EV charging standard.
15. Combined Charging System Type 2 (CCS-2), norm IEC 62196-3, is the recommended choice for the proposed state-wide charging grid. All new fast-chargeable EVs (incl. Tesla 3) currently being imported into Australia support this standard. Power levels for CCS-2 range from 50 kW to 350 kW per station (with prototypes at 475 kW).
16. Japanese standard CHAdeMO (currently limited to 50 kW) is suggested to be included as an additional charging outlet to support legacy cars. All charging station manufacturers offer combined CCS-2 / CHAdeMO stations that meet the requirements of all fast-chargeable EV models currently on the Australian market. This is also installed in other jurisdictions.
17. A power level of 150 kW or above should be used wherever the existing electricity grid is capable of supplying this.
18. With charging stations placed at a 200 km grid, driving this distance will require around 37 kWh (at 185 Wh/km). The recharging time under ideal conditions (constant energy flow, no cooling requirements) will then be:
    - 44 min at a 50 kW station
    - 15 min at a 150 kW station
    - 6 min at a 350 kW station

    In practice these times can be significantly higher, as many EVs cannot sustain charging at the highest power level, e.g. due to batteries heating up from driving and charging. DC charging normally stops at an 80% charge level, as any further charging will take disproportionally long.
19. While most 2019 EV models are limited to charging at 150 kW, it is expected that most 2020 EV models and onwards will be able to charge at 350 kW (already confirmed by some OEM).
20. Multiple (minimum of two) charging bays per site are required in order to have some redundancy against equipment failure, sufficient capacity for sites with higher EV through-put, and to reduce site cost for surveillance and potential amenities (e.g. toilets and shops).
21. Charging sites for long distance travel should be chosen close to the highways. The ideal sites are service stations that offer amenities, as these sites will also have a certain level of security. Placing charging stations in regional city centres or off-highway locations in remote areas will make them unattractive for long-distance travellers. A landline phone or mobile communication is required for billing purposes and potential load balancing.
22. Consistent state-wide and nationwide EV signage displaying directions and types of charging stations will give essential information to users as well as reassurance for potential new adopters. Signage should include all relevant technical details, such as connector-type, max. power available, number of chargers, and any amenities on site.

EV Charging Infrastructure and Geographic Locations

23. It is being proposed to establish a state-wide EV charging grid along the major highways of WA with sites not more than 200 km apart and two or more charging stations per site with 50 kW – 350 kW power level.
24. EV uptake and installed charging infrastructure level are influenced by government incentives or by the direct investment that governments make in EV charging infrastructure
25. Most of the proposed sites will be grid-connected, however, several proposed locations, such as remote roadhouse sites, are not connected to any electricity supply network and need to rely on stand-alone power supply systems (SAPS). Extending the electricity network

to these locations is unlikely to be financially viable. For these sites, the lowest cost option is either upgrading an existing SAPS or installing a separate hybrid power supply system, comprising solar-PV generation coupled with battery storage and a backup diesel generator. Still, any of these off-grid charging solutions will create less emissions than a diesel car.

26. Supplying the required electricity for EV charging stations in many grid-connected regional locations may be problematic. In many cases the electricity is supplied via weak electricity radial distribution feeders that may be unable to support DC charging. The cost of upgrading the network in these locations may be prohibitive.

Immediate Needs and Proposed Rollout Plan

27. The majority of EVs will be in the Perth metro area. We can expect between 80%–90% of all charging events to occur at home (overnight) or at work (daytime). Public charging facilities will be required for only the remaining 10%–20% of EVs.
28. Four full capacity sites with 6 x 350 kW stations should be established in the Perth metro area, two North of the river and two South of the river.
29. An additional 57 sites with 2 bays each should be established in WA's regional and remote areas to create a state-wide grid. Each bay will have a power level between 50 kW and 350 kW, depending on grid support and initial demand.
30. It is recommended that EV public charging infrastructure be rolled out in a route-by-route fashion, so more and more regions will become reachable for EVs. The number of locations, the number of stations per site and the power levels should be reviewed and updated on an annual basis to meet the requirements of increasing EV uptake and charger use.
31. A common payment system for all newly installed charging stations should be mandatory. This could be as simple as accepting standard credit cards for payment or one standard mobile app. for payment (as opposed to proprietary apps or individual tokens for each network).
32. There is a need for coordination of public charging station installations, as low regulatory hurdles for installation approval may lead to a non-optimal distribution. Government should use its planning powers to seek integration of EV charging stations into new or existing service stations and to generally ensure that a coherent approach for station placement and billing interoperability across the state is achieved.

Identifying Partners for EV Infrastructure

33. Shared usage of service stations for EV charging could be an ideal scenario, as service station owners/operators have strategically located sites, the infrastructure and amenities. While future electricity sales may make this model attractive, the current commercial situation may require subsidies to get service stations involved.
34. National charging network operators Chargefox and Fast Cities, have recently been established in Australia, however, their activities will be predominantly in the Eastern States. Chargefox has firm plans for installing chargers in 3 sites (2 x 350 kW) in the Perth metro and South-West WA area in 2019. Fast Cities is considering 2-3 sites for the Perth metro area, but may be affected by first mover Chargefox. Both companies are looking for co-funding from various sources, incl. government, automotive OEMs and ARENA grants and are unlikely to install stations in regional or remote WA.
35. Tesla Motors has installed one charging site near Bunbury with 6 x 125 kW DC chargers for exclusive use by Tesla drivers and is planning another site in the Perth metro area. No other EV-OEM has plans to establish public EV charging infrastructure outside of their dealerships. However, some are planning to support an EV charging consortium by signing charging

subscriptions with a consortium on behalf of their customers, funded through a higher vehicle purchase price.

36. Owners of large commercial properties such as shopping centres are currently assessing opportunities for installing public DC fast charging from 'behind the electricity meter', as potential business opportunities. However, these businesses will not invest until it is clear that the investment would be profitable. Most will likely install stations only at those sites with a sufficient throughput of EVs to justify the commercial investment.
37. Internationally, power utilities (network operators and retailers) are one of the major investors and driving forces in establishing EV charging infrastructure networks, as they anticipate to be a major beneficiary of the electrification of transport. However, larger investments in EV charging infrastructure by WA power utilities have not happened, which could be because there is no provision for an EV charging infrastructure in the current budget of the WA government.
38. EVs offer an array of benefits in terms of management of electricity network operators, including the creation of new large controllable charging loads and managing high penetrations of variable renewable energy generation (solar PV systems and wind turbines). Furthermore, the additional energy demand for EV charging could help with problems caused by declining usage of some customer groups and solar PV oversupply ("death spiral of the grid" and "solar peak").
39. The expected electricity demand created by a 1% EV penetration will be 44 GWh/year, which is approximately 0.1% of the current total electricity demand in WA.

    A 10% EV penetration would increase electricity demand by 440 GWh/year, which is approximately 1% of current total electricity load in WA, and a full EV fleet will add 4,400 GWh/year or 10% to the current total load.
40. The total revenue for WA in electricity sales from a future 100% electric vehicle fleet will exceed $1 billion per year (including home solar-PV charging), when assuming a standard home tariff. This represents a significant flow-on effect for the local economy, as these funds will no longer be invested into imported petroleum products.

Recommendations for Complementary Policies for EV Uptake

41. It is strongly recommended that all stakeholders, all major government contract fleets and all electricity utilities introduce a substantive EV fleet target policy, e.g. 25%. This could be achieved at moderate cost because of the buying power of the state vehicle fleet – and is offset by the economic and health benefits of EVs.

    This would create a major positive impact on the uptake of EVs in WA by creating a second-hand EV market and by increasing the number of EV models available.
42. In the absence of any other financial incentives, the WA government could consider other options, such as temporary zero stamp duty and free EV registration, as have been implemented by governments of other countries and Australian states.

Map of Proposed Charging Infrastructure for WA with estimated cost of $23.6 million *(not including land value)*. It comprises a total of 61 sites (138 stations), with 4 sites (24 stations) in Perth metro ($5.4 million), and 57 sites (114 stations) in regional WA ($18.2 million).

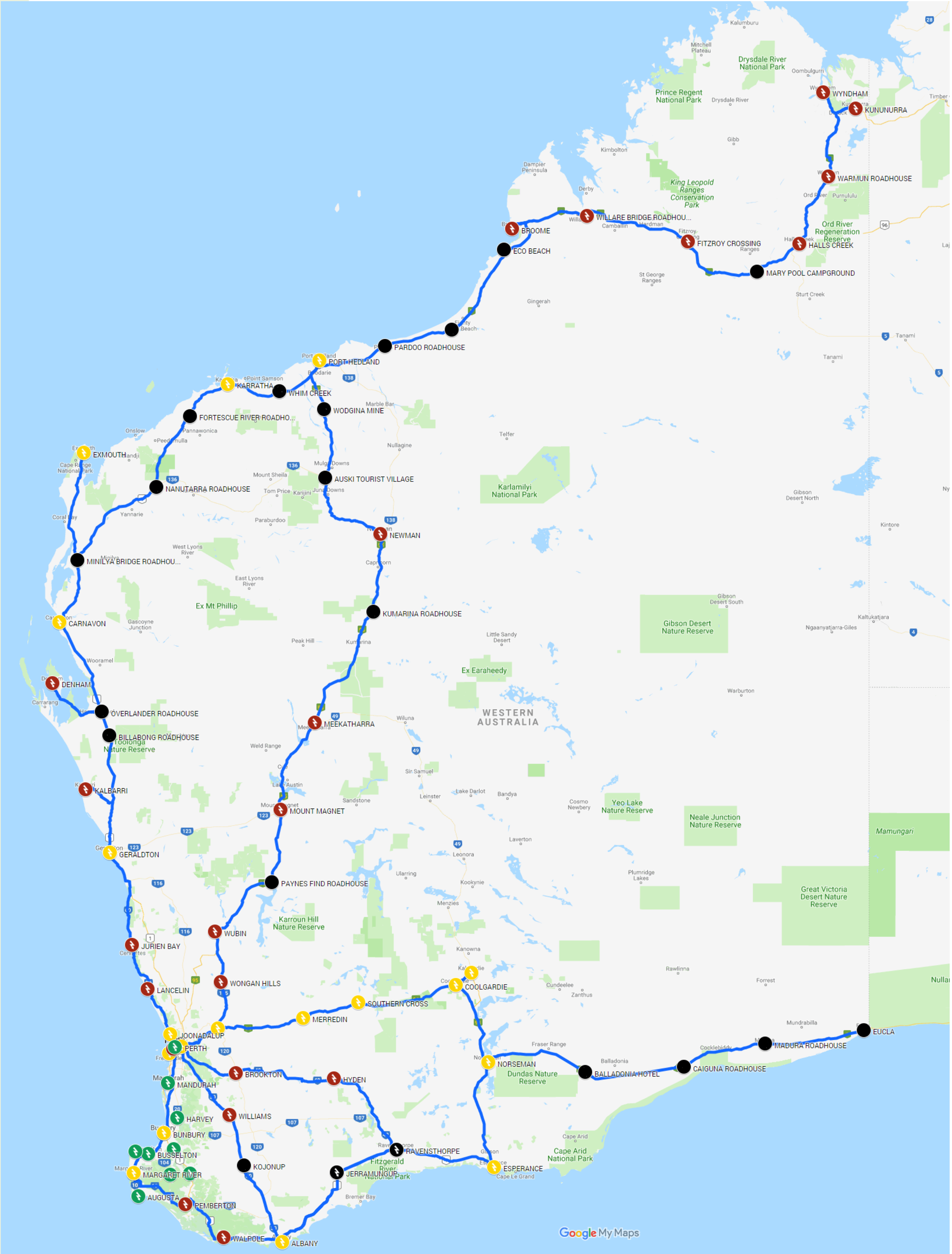


Fig. A: **Proposed** 200 km charging grid for WA, green: existing 1x50 kW,
black: proposed 2x50 kW, red: proposed 2x150 kW, yellow: proposed 2-6x350 kW.
all black sites without power symbol are off-grid; Ravensthorpe, Jerramungup have a weak grid.

Map of Minimal Charging Infrastructure for WA with estimated cost of $18.9 million *(not including land value;* savings of $4.7 million compared to proposal). It comprises a total of 61 sites (138 stations), with 4 sites (24 stations) in Perth metro ($5.4 million), and 57 sites (114 stations) in regional WA ($13.5 million).

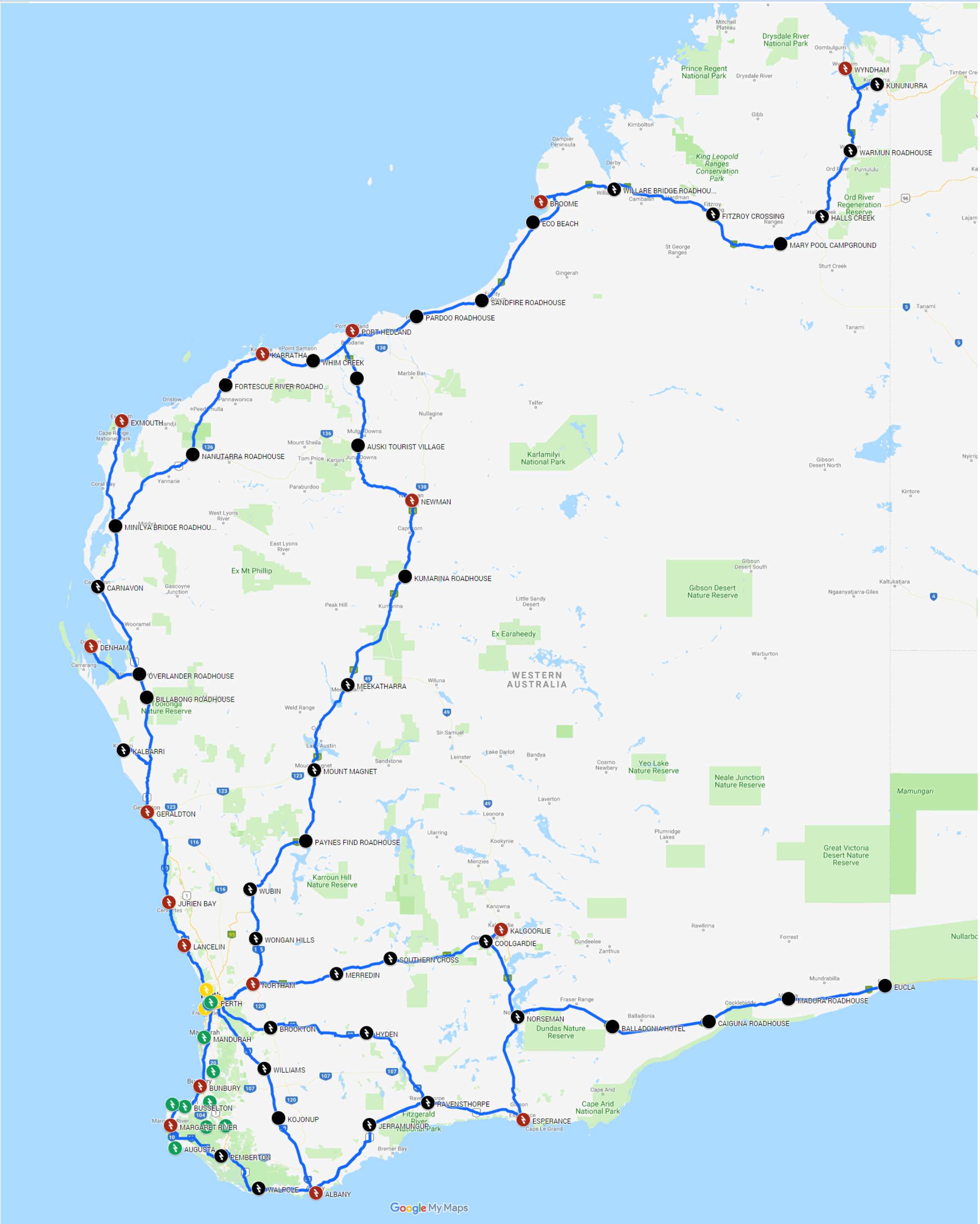


Fig. B: **Minimal** 200 km charging grid for WA, green: existing 1x50 kW, black: proposed 2x50 kW, red: proposed 2x150 kW, yellow: proposed 2-6x350 kW, *sites without power symbol are off-grid*

Map of Extended Charging Infrastructure for WA with estimated cost of $28.4 million *(not including land value*; additional cost of $4.8 million compared to proposal). It comprises extended highway coverage of a total of 70 sites (156 stations), with 4 sites (24 stations) in Perth metro ($5.4 million), and 66 sites (132 stations) in regional WA ($23.0 million).
All stations are either 150 kW or 350 kW, there are no entry-level 50 kW stations.

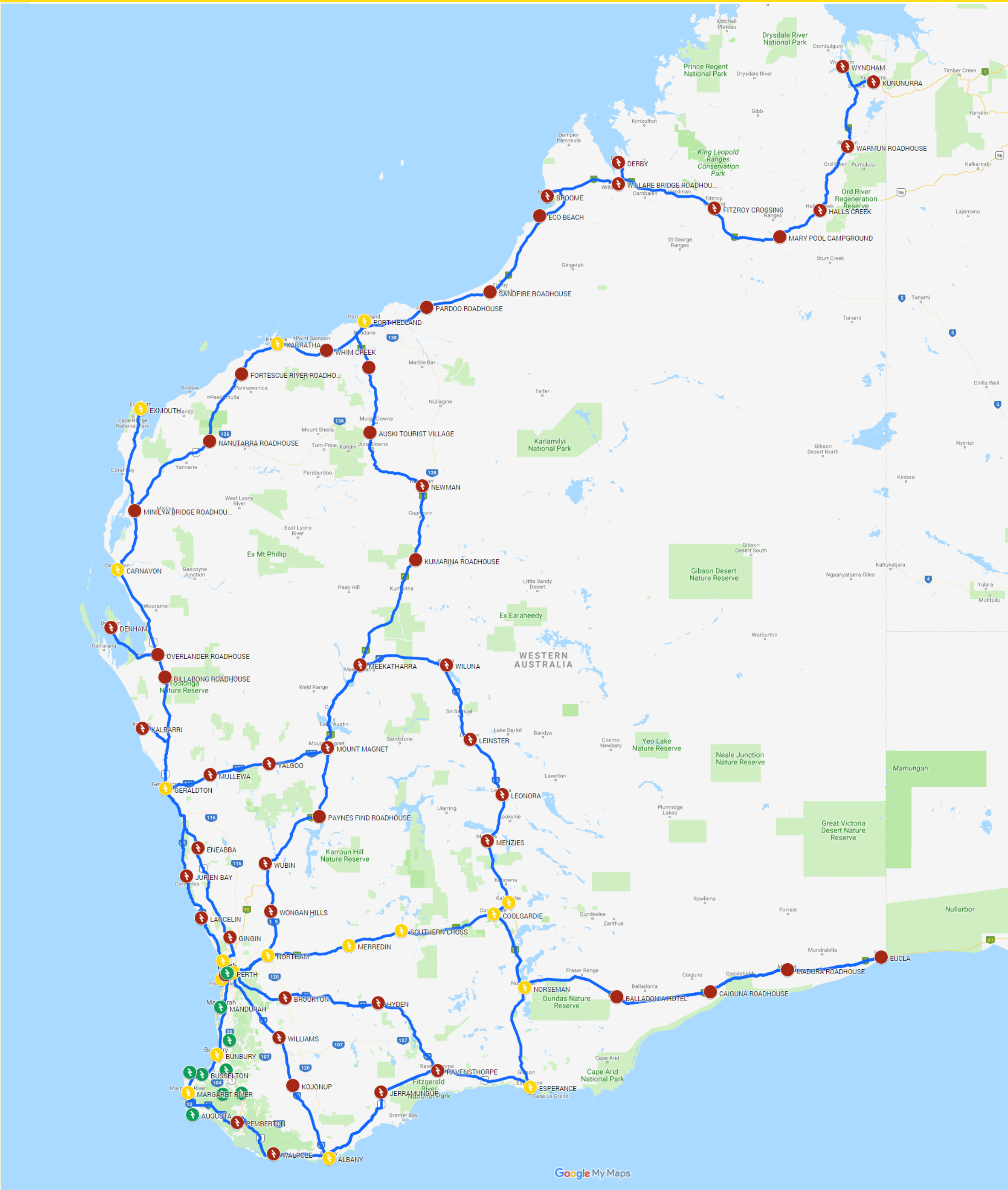


Fig. C: **Extended** 200 km charging grid for WA, green: existing 1x50 kW,
red: proposed 2x150 kW, yellow: proposed 2-6x350 kW,
sites without power symbol are off-grid

Table 1: Charging infrastructure configuration

Site	Location	Population	Local Evs at 1% uptake	Residents charging [kWh]	Residents peak hour power [kW]	Traffic peak hour power [kW]	Total req. peak hour power [kW]	De-rated Installed power [kW]	Installed power [kW]	Total Bays	Bays [kW] 350	Bays [kW] 150	Bays [kW] 50
PROPOSED													
METRO		*2'300'000*	*14'030*										
1	PERTH / WEST PERTH / LEEDERVILLE	575'000	3'508	3'315	398	100	498	1'470	2100	6	6		
2	JOONADALUP	575'000	3'508	3'315	398	100	498	1'470	2100	6	6		
3	FREMANTLE	575'000	3'508	3'315	398	100	498	1'470	2100	6	6		
4	SOUTH PERTH / VICTORIA PARK	575'000	3'508	3'315	398	100	498	1'470	2100	6	6		
SOUTH-WEST													
5	BUNBURY	72'403	442	417	50	116	166	490	700	2	2		
6	MARGARET RIVER	7'654	47	44	5	39	44	490	700	2	2		
7	PEMBERTON	974	6	6	1	27	28	240	300	2		2	
8	WALPOLE	439	3	3	0	18	18	240	300	2		2	
9	ALBANY	29'373	179	169	20	146	166	490	700	2	2		
10	KOJONUP	1'298	8	7	1	40	41	490	700	2	2		
11	WILLIAMS	948	6	5	1	83	84	240	300	2		2	
SOUTH COAST													
12	BROOKTON	756	5	4	1	20	21	240	300	2		2	
13	HYDEN	377	2	2	0	17	17	240	300	2		2	
14	RAVENSTHORPE	498	3	3	0	34	34	88	100	2			2
15	JERRAMUNGUP	356	2	2	0	9	9	88	100	2			2
16	ESPERANCE	12'107	74	70	8	28	36	490	700	2	2		
GOLDFIELDS													
17	NORTHAM	6'548	40	38	5	68	73	490	700	2	2		
18	MERREDIN	2'636	16	15	2	25	27	490	700	2	2		
19	SOUTHERN CROSS	638	4	4	0	13	13	490	700	2	2		
20	COOLGARDIE	878	5	5	1	18	19	490	700	2	2		
21	KALGOORLIE	30'509	186	176	21	9	30	490	700	2	2		
22	NORSEMAN	581	4	3	0	14	14	490	700	2	2		
NULLARBOR													
23	BALLADONIA HOTEL	10	0	0	0	11	11	88	100	2			2
24	CAIGUNA ROADHOUSE	10	0	0	0	14	14	88	100	2			2
25	MADURA ROADHOUSE	10	0	0	0	10	10	88	100	2			2
26	EUCLA	53	0	0	0	13	13	88	100	2			2
MIDWEST													
27	LANCELIN	714	4	4	0	51	51	240	300	2		2	
28	JURIEN BAY	1'761	11	10	1	64	65	240	300	2		2	
29	GERALDTON	37'432	228	216	26	77	103	490	700	2	2		
30	KALBARRI	1'557	9	9	1	10	11	240	300	2		2	
31	BILLABONG ROADHOUSE	10	0	0	0	27	27	88	100	2			2
32	OVERLANDER ROADHOUSE	10	0	0	0	6	6	88	100	2			2
33	DENHAM	754	5	4	1	11	12	240	300	2		2	
GASCOYNE / PILBARA													
34	CARNAVON	4'426	27	26	3	25	28	490	700	2	2		
35	MINILYA BRIDGE ROADHOUSE	10	0	0	0	8	8	88	100	2			2
36	EXMOUTH	2'514	15	14	2	20	22	490	700	2	2		
37	NANUTARRA ROADHOUSE	10	0	0	0	12	12	88	100	2			2
38	FORTESCUE RIVER ROADHOUSE	10	0	0	0	16	16	88	100	2			2
39	KARRATHA	15'828	97	91	11	11	22	490	700	2	2		
40	WHIM CREEK	32	0	0	0	10	10	88	100	2			2
41	PORT HEDLAND	13'828	84	80	10	14	24	490	700	2	2		
KIMBERLEY													
42	PARDOO ROADHOUSE	10	0	0	0	8	8	88	100	2			2
43	SANDFIRE ROADHOUSE	10	0	0	0	7	7	88	100	2			2
44	ECO BEACH	10	0	0	0	11	11	88	100	2			2
45	BROOME	13'984	85	81	10	9	19	240	300	2		2	
46	WILLARE BRIDGE ROADHOUSE	3'511	21	20	2	21	23	240	300	2		2	
47	FITZROY CROSSING	1'297	8	7	1	16	17	240	300	2		2	
48	MARY POOL CAMPGROUND	10	0	0	0	11	11	88	100	2			2
49	HALLS CREEK	1'499	9	9	1	18	19	240	300	2		2	
50	WARMUN ROADHOUSE	10	0	0	0	17	17	240	300	2		2	
51	WYNDHAM	780	5	4	1	10	11	240	300	2		2	
52	KUNUNURRA	5'308	32	31	4	9	13	240	300	2		2	
INLAND													
53	WONGAN HILLS	898	5	5	1	10	11	240	300	2		2	
54	WUBIN	103	1	1	0	4	4	240	300	2		2	
55	PAYNES FIND ROADHOUSE	10	0	0	0	5	5	88	100	2			2
56	MOUNT MAGNET	470	3	3	0	10	10	240	300	2		2	
57	MEEKATHARRA	708	4	4	0	6	6	240	300	2		2	
58	KUMARINA ROADHOUSE	75	0	0	0	6	6	88	100	2			2
59	NEWMAN	7'238	44	42	5	7	12	240	300	2		2	
60	AUSKI TOURIST VILLAGE	10	0	0	0	7	7	88	100	2			2
61	WODGINA MINE	210	1	1	0	8	8	88	100	2			2
	Major cities					combined routes			Total power [MW]				
	Major holiday destinations				1.79	1.73	3.52	20.52	27.90	138	56	42	40

Table 2: Estimated charging infrastructure costs

PROPOSED Site	Location	Station cost	Install cost	Grid Provider	Grid connect or SAPS	Grid cost 700kVA	Grid cost 300kVA	Grid cost 100kVA	Site cost	Route Subtotal
	METRO									**METRO**
1	PERTH / WEST PERTH / LEEDERVILLE	$762'000	$90'000	Western Pow	$628'000	$436'000			**$1'480'000**	
2	JOONADALUP	$762'000	$90'000	Western Pow	$448'000	$273'000			**$1'300'000**	
3	FREMANTLE	$762'000	$90'000	Western Pow	$448'000	$273'000			**$1'300'000**	
4	SOUTH PERTH / VICTORIA PARK	$762'000	$90'000	Western Pow	$448'000	$273'000			**$1'300'000**	$5'380'000
	SOUTH-WEST									**SOUTH-WEST**
5	BUNBURY	$254'000	$30'000	Western Pow	$255'000	$255'000	$215'000	$198'000	**$539'000**	
6	MARGARET RIVER	$254'000	$30'000	Western Pow	$274'000	$274'000	$231'000	$213'000	**$558'000**	
7	PEMBERTON	$140'000	$16'000	Western Pow	$231'000		$231'000	$213'000	**$387'000**	
8	WALPOLE	$140'000	$16'000	Western Pow	$231'000		$231'000	$213'000	**$387'000**	
9	ALBANY	$254'000	$30'000	Western Pow	$255'000	$255'000	$215'000	$198'000	**$539'000**	
10	KOJONUP	$254'000	$30'000	Western Pow	$274'000	$274'000	$231'000	$213'000	**$558'000**	
11	WILLIAMS	$140'000	$16'000	Western Pow	$231'000		$231'000	$213'000	**$387'000**	$3'355'000
	SOUTH COAST									**SOUTH COAST**
12	BROOKTON	$140'000	$16'000	Western Pow	$231'000		$231'000	$213'000	**$387'000**	
13	HYDEN	$140'000	$16'000	Western Pow	$231'000		$231'000	$213'000	**$387'000**	
14	RAVENSTHORPE	$60'000	$10'000	Western Pow	$213'000		$70'000	$213'000	**$283'000**	
15	JERRAMUNGUP	$60'000	$10'000	Western Pow	$213'000		$70'000	$213'000	**$283'000**	
16	ESPERANCE	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	$1'799'000
	GOLDFIELDS									**GOLDFIELDS**
17	NORTHAM	$254'000	$30'000	Western Pow	$255'000	$255'000	$215'000	$198'000	**$539'000**	
18	MERREDIN	$254'000	$30'000	Western Pow	$274'000	$274'000	$231'000	$213'000	**$558'000**	
19	SOUTHERN CROSS	$254'000	$30'000	Western Pow	$274'000	$274'000	$231'000	$213'000	**$558'000**	
20	COOLGARDIE	$254'000	$30'000	Western Pow	$274'000	$274'000	$231'000	$213'000	**$558'000**	
21	KALGOORLIE	$254'000	$30'000	Western Pow	$255'000	$255'000	$215'000	$198'000	**$539'000**	
22	NORSEMAN	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	$3'211'000
	NULLARBOR									**NULLARBOR**
23	BALLADONIA HOTEL	$60'000	$10'000	SAPS	$34'000		$110'000	$34'000	**$104'000**	
24	CAIGUNA ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
25	MADURA ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
26	EUCLA	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	$416'000
	MIDWEST									**MIDWEST**
27	LANCELIN	$140'000	$16'000	Western Pow	$231'000		$231'000	$213'000	**$387'000**	
28	JURIEN BAY	$140'000	$16'000	Western Pow	$231'000		$231'000	$213'000	**$387'000**	
29	GERALDTON	$254'000	$30'000	Western Pow	$255'000	$255'000	$215'000	$198'000	**$539'000**	
30	KALBARRI	$140'000	$16'000	Western Pow	$231'000		$231'000	$213'000	**$387'000**	
31	BILLABONG ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
32	OVERLANDER ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
33	DENHAM	$140'000	$16'000	Horizon Power	$175'000		$175'000	$175'000	**$331'000**	$2'239'000
	GASCOYNE / PILBARA									**GASCOYNE / PILBARA**
34	CARNAVON	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	
35	MINILYA BRIDGE ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
36	EXMOUTH	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	
37	NANUTARRA ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
38	FORTESCUE RIVER ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
39	KARRATHA	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	
40	WHIM CREEK	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
41	PORT HEDLAND	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	$2'252'000
	KIMBERLEY									**KIMBERLEY**
42	PARDOO ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
43	SANDFIRE ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
44	ECO BEACH	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
45	BROOME	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
46	WILLARE BRIDGE ROADHOUSE / DERBY	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
47	FITZROY CROSSING	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
48	MARY POOL CAMPGROUND	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
49	HALLS CREEK	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
50	WARMUN ROADHOUSE	$140'000	$16'000	Horizon Power	$175'000		$175'000	$175'000	**$331'000**	
51	WYNDHAM	$140'000	$16'000	Horizon Power	$175'000		$175'000	$175'000	**$331'000**	
52	KUNUNURRA	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	$2'733'000
	INLAND									**INLAND**
53	WONGAN HILLS	$140'000	$16'000	Western Pow	$231'000		$231'000	$213'000	**$387'000**	
54	WUBIN	$140'000	$16'000	Western Pow	$231'000		$231'000	$213'000	**$387'000**	
55	PAYNES FIND ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
56	MOUNT MAGNET	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
57	MEEKATHARRA	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
58	KUMARINA ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
59	NEWMAN	$140'000	$16'000	BHP	$175'000	$175'000	$175'000	$175'000	**$331'000**	tentative
60	AUSKI TOURIST VILLAGE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
61	WODGINA MINE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	$2'183'000
	Major cities	**Stations**	**Install**		**Grid / SAPS**				**Grand Total**	
	Major holiday destinations	$11'252'000	$1'376'000		$10'940'000				**$23'568'000**	*$23'568'000*

Scope and Methodology

This report was compiled at the request of the WA EV Working Group – Infrastructure Sub-Committee in response to the MOU for Sub-National Collaboration on Electric Vehicles.

The scope of the report is to provide the information required to develop a coherent and effective strategic plan for investment in public electric vehicle charging infrastructure in WA. This will be achieved by identifying where there are likely to be gaps in the electric vehicle public charging infrastructure network that would have the effect of contributing to electric vehicle 'range anxiety' and impede the take-up rate of electric vehicles in WA. The scope of a report with this intended outcome needs to address a number of inter-related questions. At the highest level, the starting question is the problem statement of what level of investment in public EV charging infrastructure will be required in WA. The first part of this report addresses this question through a series of related sub-questions:

- What are the likely future take-up rates of EVs in WA?
- How will future uptake rates be influenced by investment in public EV charging infrastructure?
- What are likely proportions of EVs charged from (i) home, (ii) work place, (iii) public recharging stations?
- What EV models are available and what are the charging levels?
- What EVs will be available in the near term and what will be their charging levels?
- What EV charging stations (EVSEs) are available?
- What EV charging stations (EVSEs) are likely to be available in the future?
- What is the current and expected future level of private sector investment in public EV recharging stations and in which locations?

This first part of the report is informed by the policies and strategies that have or are being adopted and implemented by governments and the private sector elsewhere, both within Australia and overseas, in regard to investment in public EV charging infrastructure and the rationales underpinning those policies and strategies.

The second part of the report focuses on providing the more detailed information that will be required in order to identify where the gaps in terms of public EV recharging infrastructure are likely to occur in WA. That is, it attempts to address the questions of what the optimal investment strategy would look like in terms of the locations of public EV recharging stations, the types of recharging stations, the optimal number of bays at recharging stations, and the likely locations in which the required investment may not occur. The answer to those questions will be dictated by a number of critical factors, the first being the traffic flow volumes and the numbers of EVs likely to need/use public EV recharging stations along high usage routes. Overlaying information on numbers of EVs likely to require/use EV charging stations will be information on the capacity of the existing electricity supply systems to supply electricity to a site, the cost of upgrading the electricity infrastructure to enable the required amount of electricity required at a site to be supplied, and the availability of suitable sites (site areas, site tenure/ownership, proximity to other amenities, etc.). A set of criteria is developed for selecting EV charging station locations, charging station types, charging station levels, and the number of bays per site at a charging station.

The third part of the report will discuss some of the remaining specific planning issues that will need to be considered. These will include:

- Technical challenges that need to be considered
- The need for coordination of investment in EV recharging infrastructure
- The identification of priority on-line maps for inclusion of EVs regarding station information (locations, pricing, other amenities, etc.)
- Pathway for transitioning of government funded EV charging infrastructure to private investors
- Public EV charging pricing options
- Signage requirements for public EV recharging stations

The methodology if this report will be to use various sources of information to address the series of questions outlined in the scope above. These sources will include:

- information obtained from literature reviews
- stakeholder consultation
- OEMs

Topic	Detail		Methodology
Background			
	Electric vehicles and future trends Alternatives to EVs (hydrogen EFCVs)		Stakeholder consultation
Problem Identification			
	What is the need for public investment in public EV charging infrastructure?		Literature review + Stakeholder consultation:
	What EVs will be available in the near term		Literature review + Stakeholder consultation: TOCWA, AEVA and literature review (Car Advice, etc.)
	What EV charging stations are available		Literature review
	What EV charging stations will be available in the near-term		Literature review
	What private sector investment in EV charging stations is currently occurring or planned?		Literature review
	Review of policies, strategies and investment in public EV charging stations elsewhere (Australia and O/S)		Literature review
Identification of locations			
	Urban traffic flow data		Stakeholder consultation: Dept. Transport, MainRoads WA
	Regional traffic flow data		Stakeholder consultation: Dept. Transport, MainRoads WA
	Rural traffic flow data		Stakeholder consultation: Dept. Transport, MainRoads WA
	Remote area traffic flow data		Stakeholder consultation: Dept. Transport, MainRoads WA
	User expectations		Stakeholder consultation
Site electricity supply capacity			
	Western Power supply areas (SWIS)		Stakeholder consultation: Western Power
	Horizon Power regional supply areas		Stakeholder consultation: Horizon Power
	Off-grid / remote areas		Review and analysis of options + stakeholder consultation (gas pipeline operators, WALGA, roadhouse operators, …)
Land availability			
	Criteria for site requirements		Stakeholder consultation
	Identification of potential suitable public sites		Stakeholder consultation: Landcorp, MainRoads, WALGA, ….
Site selection criteria			
	Criteria for site requirements		Literature review + Stakeholder consultation
	Identification of potential suitable public sites		Stakeholder consultation: Landcorp, MainRoads, WALGA, Horizon Power, …
Planning Issues			
	Proposed (staged) roll-out time frame		Stakeholder consultation: MainRoads
	Permitting (planning permits, building permits, electricity connection applications, …)		Stakeholder consultation: WALGA Western Power, Horizon Power
	Technical Challenges - Different EV charging rates - Need for dynamic charging levels - Pricing vs EV charging rates		Stakeholder consultation + synthesis from above info4rmation
	Coordination issues - Private and public investment		Literature Review + Synthesis from above information
	Signage – requirements for EV charging station signage		Literature review and Stakeholder consultation
	On-line Maps - Priority on-line maps - Information (locations, no of bays, charging levels, price, other amenities)		Literature review and Stakeholder consultation
Financial Issues			
	Potential investment partners		Stakeholder consultation
	Transitioning ownership of public charging from public funded infrastructure to private sector		Stakeholder consultation
	EV recharging pricing options, cost recovery, equity		Stakeholder consultation and literature Review
Summary			

1. Technology

Key findings:

- EV Technology has matured and now equals petrol cars in range and charging time
- EVs will substantially improve air quality and population health, even if charged from grid
- EVs have higher purchase price, but significantly cheaper running cost
- Exponential EV sales increase over next decade
- 1% new car market share for EVs expected for 2022 in Australia
- Electric buses and light trucks may soon enter the market

Electric vehicles (EV) using current generation Lithium batteries were first introduced into the Australian market in late 2010, but have so far failed to achieve a significant market share. Although it is generally accepted that EVs will reduce emissions and improve air quality in urban areas, have significantly cheaper running and maintenance costs, and reduce reliance on imported petroleum, high EV purchase prices, lack of range (initial models), and lack of charging infrastructure have hindered a widespread uptake of EVs.

Table 1.1 Electric vehicle facts

- Annual savings[+]: fuel $1,900
  with solar PV $2,500
  service $200

- 500 EVs in WA at end of 2017
  15,800 EVs in WA in 2025/2026 (1% of fleet)
  1,580,000 EVs in WA in 2037-2045 (100% fleet)
  1,000,000 EVs sold worldwide in 2017
- Many countries will ban new ICE cars from
  2040 UK, France, Spain, China, Taiwan
  2030 Denmark, Netherlands, Ireland, India, Israel
  2025 Norway
- 300 - 400km is the driving range of a modern EVs
  6 - 10min. charging time for 200km on a modern DC charger
- $1 Billion annual charging market for WA
- Government incentives and intervention help:
  52% EV market share in Norway
- State-wide charging grid is necessary for growing EV numbers

[+] 20,000km/year, 8l/100km, $1.55/l; 150Wh/km; $0.198/kWh; photo: Tesla

1.1.Electric Vehicle Technology

The term EV comprises "pure" battery electric vehicles (BEV) and the transitional technology of plug-in hybrid electric vehicles (PHEV). Figure 1.1 shows their conceptual differences compared to internal combustion engine cars (ICE) and fuel-cell electric vehicles (FCEV). Only BEV and PHEV are "plug-in", i.e. can be charged using electric energy.

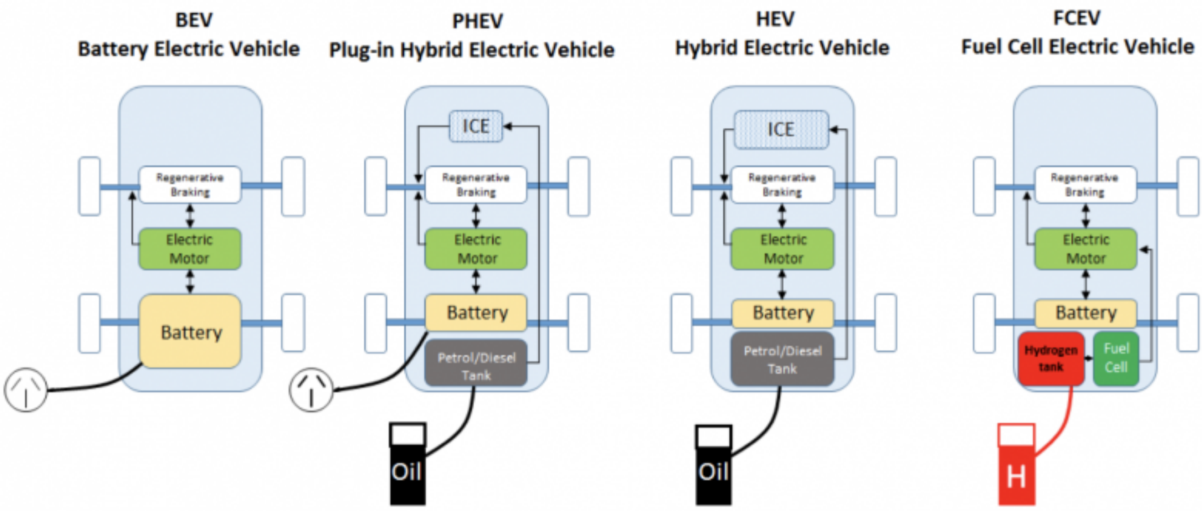


Fig. 1.1 Electric vehicle types BEV and PHEV, compared to ICE and FCEV
(source: [The Driven 2018])

EV Types

- Battery Electric Vehicles (BEV) have a large battery that can be charged from mains power and have only an electric drive system. No local emissions are produced. Modern BEV have a realistic rage of 300+km on a single charge and can either be slow-charged from a standard AC power outlet or an AC charging station (e.g. at home over night or at work during the day) or fast-charged on a modern DC charging station within about 10 min.
- Plug-in Hybrid Vehicles (PHEV) have a dual electric/petrol drive train and can be driven either in electric mode or in petrol mode. They have a smaller battery pack that gives them a battery-range of up to 70km. For longer drives, PHEVs use their built-in petrol engine. Most PHEVs can only be slow-charged using an AC outlet or station.
- Hybrid Electric Vehicles *"non plug-in"* (HEV) are petrol cars that have a secondary electric drive system with a very small battery, which cannot be charged from the outside. The battery serves as buffer to energy recuperation and overall reduces the fuel consumption of the vehicle. The battery range of a HEV is around 1 km or 1 minute.
- Fuel Cell Electric Vehicles (FCEV) are the equivalent to HEV, but using a hydrogen fuel cell and a compressed hydrogen tank instead of a petrol engine and fuel tank. They have an electric drive system with a relatively small battery that cannot be charged from the outside.

A BEV drive system is a lot simpler and much more efficient than that of an ICE (internal combustion engine) car, where most of the energy is lost as heat. It comprises battery, motor controller and electric motor. There is only a single gear, so no complex gearbox or clutch are required, a much smaller radiator is sufficient, and neither an exhaust system or catalytic converter are required. Typical battery capacity ranges from 40kWh – 100kWh, typical energy consumption is between 150Wh/km – 200Wh/km.

EV Benefits

- Zero local emission.
- Can be conveniently charged at home or work from grid or emission-free from solar PV.
- If charged from the grid, their emission balance depends on the energy mix of the energy provider. But EVs have even then a positive effect on air quality and population health, as power generation emissions happen outside of densely populated areas. Several international studies have confirmed that more people die from ICE vehicle emissions than from road accidents [Uni Melbourne 2018].
- Electric vehicles are silent at low speeds up to about 20km/h.
  Above that, wind and tyre roll noises dominate and they have a similar noise level only slightly below ICE cars [Bräunl 2012]. Synthetic noise generators for EVs driving at low speeds are now mandatory in some countries, to protect especially children and blind people [Guardian 2018].
- Significant reduction in transport costs (see below).
- Large new revenues for power utilities.
- Greatly reduced liquid fuel and lubricant imports; major improvements in national energy security [Wei et al. 2010], [Mullan et al. 2010].
- EV batteries will outlast the lifetime of a car [Lawrence Berkeley National Lab 2018], so they do not generate any servicing cost during the car's lifetime and can later be repurposed for stationary applications.

EV Cost

- EVs are significantly more expensive to purchase than ICE. Prices for an equivalent EV are around $20,000 above that of an ICE. However, depending on vehicle usage, EV total cost of ownership can match or be lower than that of an ICE.
- When charging an EV using electricity from the grid costs $2.97 for 100km (assuming 150Wh/km and using Synergy's EV tariff of 19.77ct/kWh).
  When charging from a home's solar PV system, charging is virtually free.
  As a comparison, driving an ICE car using 8 l/100km costs $12.40 (at $1.55/l), which is over **4 times as much**.
- As most regular service cost of an ICE car is around the motor and EV electric motors are service free, EVs have much less service requirements and much cheaper service costs.
- When slowing down or braking, EVs use a process called "recuperation", where the electric motor changes its role and becomes a generator. This will slow down the car while charging the battery. Therefore, EVs are especially efficient in stop-and-go city traffic. As a nice side effect, brake pads last a lot longer, as they are only required for hard braking.

1.2. Electric Vehicle Charging

EVs can be charged in many different ways. Possibly the most convenient way is to slow charge an EV at home or at work using an AC "wallbox" (a simple home-charging stations) or an "occasional use cable" at a standard power outlet (Figure 1.2). In combination with roof-mounted solar PVs, an EV can be charged from renewable energy during sunshine hours. McKinsey estimates that for the EU the initial home-charging percentage will be around 75% in 2020, but that this ratio will gradually reduce to 40% in 2030, when middle- and lower income families living in apartments will buy EVs [McKinsey 2018]. As Western Australia has a larger population part living in houses instead of apartments, there will be more opportunity for home charging. Therefore, we expect the home/work charging share for Western Australia to be as high as 90% of all charging events for privately used EVs, and as much as 80% for commercially used EVs.

Fig. 1.2 Home charging "*wallbox*" and "*occasional use cable*" *(photos: BMW, Bräunl)*

The power level for AC charging is either Level 1 (2.4kW) or Level 2 (7kw single-phase or 21kW three-phase) with charging times of several hours. Modern DC fast- charging stations allow vehicle charging within minutes at Level 3 (50kW–475kW).

Given the larger range of 300km and more for all current generation EVs, and the long charging times for Level1/Level2, we see no need for installing public charging infrastructure based on AC charging. Instead, all public charging infrastructure should be fast-DC at Level 3 (50kW–475kW) and effectively decouple charging from parking. EVs will then charge in a setup very much like ICE cars refill at a service station.

Although Standards Australia has not yet recommended the adoption of any particular international standard, most OEMs have settled for the Combined Charging System Type-2 (CCS-2) [CharInEV 2018]. CCS has increased its charging power from 50 kW (first commercial installation in Australia at UWA in 2014) to 150 kW and now 350 kW. Tritium (Brisbane) has recently demonstrated a 475 kW DC charger [Electrive 2018].

In Europe at the end of 2018, Ionity had installed 38 stations with 350kW each and has plans to complete 400 such stations by the end of 2020 [Ionity 2018]. In Australia, the first 350kW station was installed by Chargefox in Victoria in 2018 [Carsales 2018], with plans for 21 locations for the initial rollout [Chargefox 2018]. Chargefox states a charging time of 15 min. for 400km range on their 350kW chargers [Chargefox 2018].

Also in use in Australia is the Japanese CHAdeMO standard [CHAdeMO 2018], which in its current version is limited to 50 kW, but an upgrade of this standard to higher power levels is being considered. The advantage of CCS over CHAdeMO is that the same vehicle inlet can take DC plugs (from a charging station) or AC plugs (for home charging). Vehicles with CHAdeMO require a second socket for AC charging, which makes vehicle production more expensive.

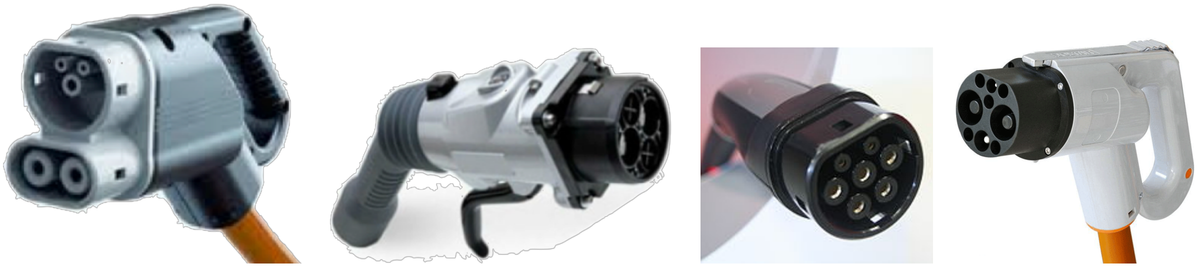


Fig. 1.3: DC charging connectors CCS (Australia, Europe), CHAdeMO (Japan), Tesla (USA), GB/T (China) *(photos RWE, Yazaki, Wikipedia, Electway)*

Fig. 1.4 Ideal charging times for home charging, AC slow-charging, DC fast-charging

Table 1.2 EV Charging times

Charging Level		Ideal Charging time for 37kW (200km)
Level 1	2.4kW AC	~16 hours
Level 2	7 kW AC	~5 hours
Level 2	21kw AC	~2 hours
Level 3	50kW DC	44 min
Level 3	150kW DC	15 min
Level 3	350kW DC	6 min
Level 3	475kW DC	5 min

Charging times for a 200km distance, equalling 37kWh at an energy consumption of 185 Wh/km, assuming ideal conditions (constant energy flow, no cooling requirements).
In practice, charging times can be significantly higher, e.g. due to batteries heating up.

Especially for longer trips exceeding the EV range of 300km–400km, fast-DC charging infrastructure becomes an absolute necessity for travellers. Fast-DC charging allows recharging of a 200km distance (suggested state-wide charging grid) within six to seven minutes, while AC charging (single phase) for the same distance would take about five hours.

There are only a small number of Electric Vehicle Supply Equipment (EVSE, "charging station") manufacturers active in the Australian market. These are:

- Tritium (brand name Veefil), Brisbane, Australia
  Tritium is the only Australian manufacturer of EVSEs and has been highly successful with its charging stations on the international market. Tritium has been selected by European consortium Ionity to install over 1,000 of 350kW chargers in Europe as well as about 18 chargers for the Queensland "Electric Highway".
  Tritium is a highly innovative company and has been first to market with a 350kW charger and recently demonstrated a 475kW model.
  Currently, Tritium does not produce middle range 150kW chargers.
  Cost for a 50kW charger is around AUD30,000 plus install
  Cost for a 350kW charger is around AUD127,000 plus install

- ABB, Switzerland
  Currently has 50kW and 150kW chargers in their portfolio
  Cost for a 150kW charger is around AUD120,000 plus install. ABB also recently introduced a 175kW charging module, two of which can be combined to form a 350kW charger.
  ABB has tested prototypes of a 460kW charger.

- Circontrol, Spain
  Currently only have 50kW chargers in their Australian portfolio.
  Cost for a 50kW charger is around AUD40,000 plus install
  Cost for a 150kW charger is around AUD70,000 plus install
  Cost for a 350kW charger is not yet available

Fig. 1.5 High-powered DC charging stations from Tritium (Veefil), ABB and Circontrol; *(photos from Tritium, ABB, Circontrol)*

Installation costs are not included for the indicative station prices mentioned above, neither are software costs for monitoring and billing or annual maintenance. Especially for high-powered stations and multiple stations per site, the cost for providing power at the required level to the site can be substantial.

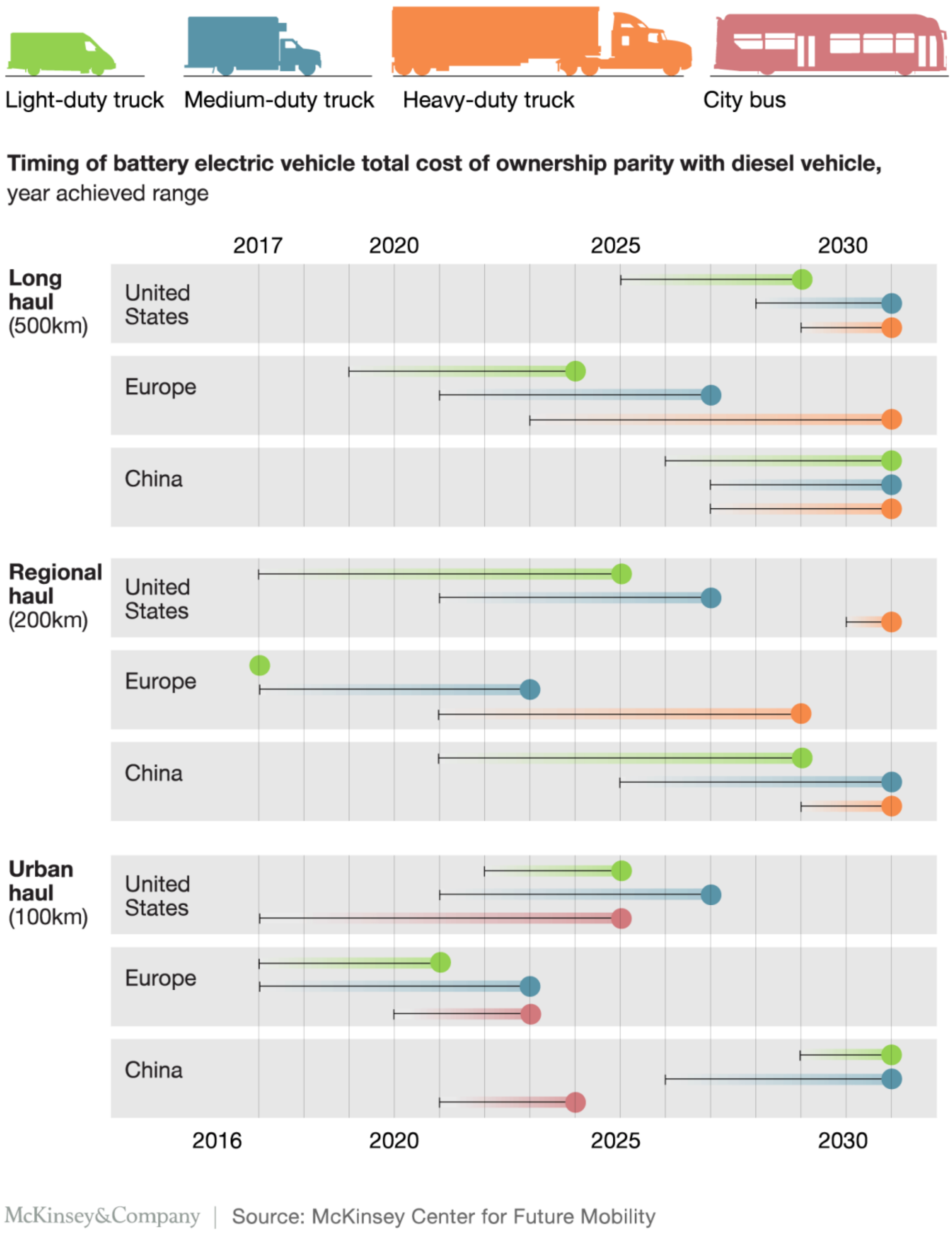


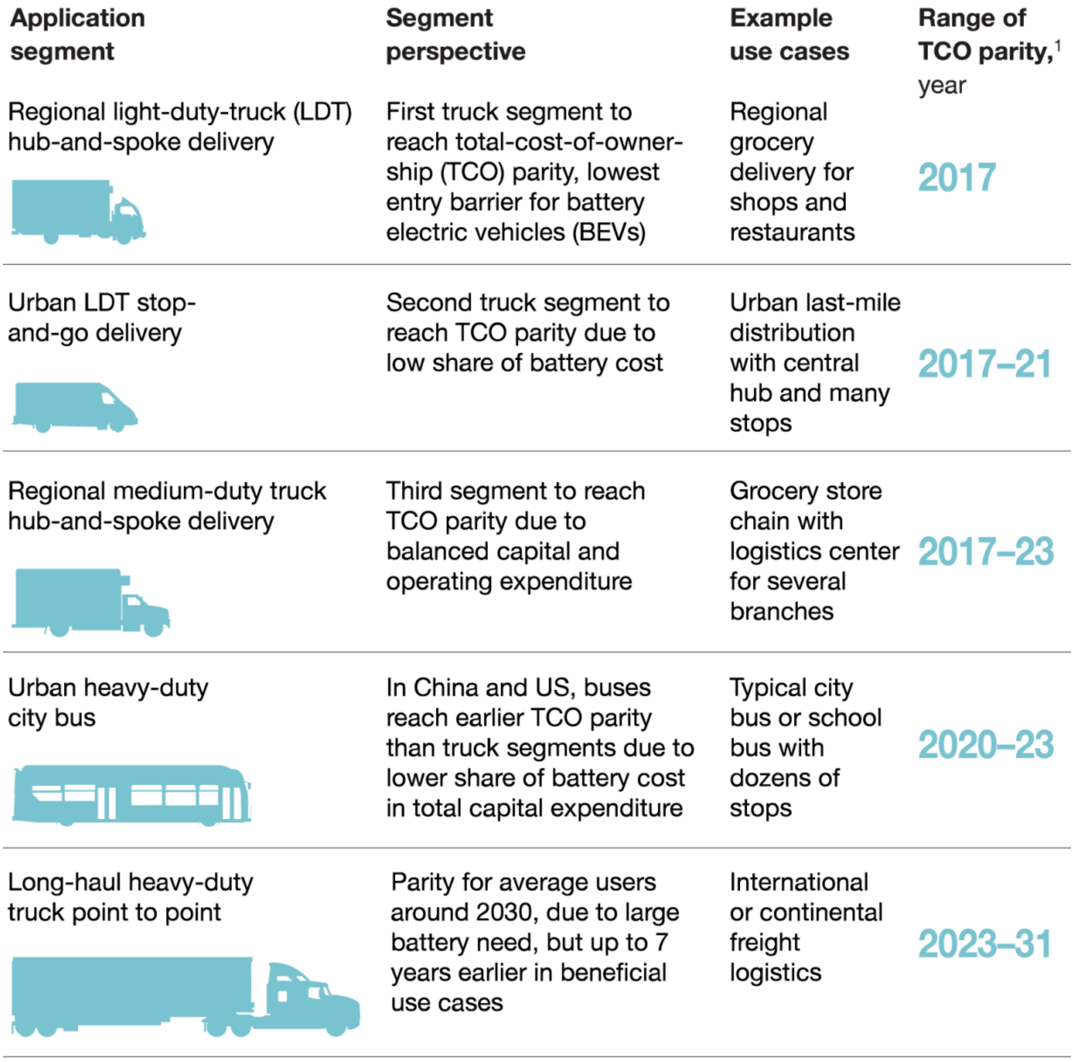
Fig. 1.6 Predicted electric truck and bus adoption *(source: [McKinsey 2017])*

1.3. Commercial Vehicles

Trucks are mainly operated in fleets and therefore have bulk order advantages. Most short-haul trucks are used on return-to base duties, which makes electric trucks more competitive than their ICE counterparts [IEA 2018]. The first short-haul trucks being electrified are public bus fleets and other heavy vehicles with regular routes and schedules, such as municipal waste trucks and street-cleaning vehicles.

1.3.1 Buses

Despite the costs and challenges associated with installing electric bus charging infrastructure, the global stock of electric buses in 2017 increased to 370,000. While over 99% of electric buses were in China (mainly in Shenzhen, Beijing and Tianjin), electric bus registrations in Europe and India also increased rapidly. In the case of China, the increases were driven by subsidies to the bus manufacturers. Electric truck and bus segments will achieve major adoption rates over the years 2020-2030 (Fig. 1.6), following their total cost of ownership (TOC) parity with ICE vehicles (Fig. 1.7), [McKinsey 2017].



Application segment	Segment perspective	Example use cases	Range of TCO parity,[1] year
Regional light-duty-truck (LDT) hub-and-spoke delivery	First truck segment to reach total-cost-of-ownership (TCO) parity, lowest entry barrier for battery electric vehicles (BEVs)	Regional grocery delivery for shops and restaurants	2017
Urban LDT stop-and-go delivery	Second truck segment to reach TCO parity due to low share of battery cost	Urban last-mile distribution with central hub and many stops	2017–21
Regional medium-duty truck hub-and-spoke delivery	Third segment to reach TCO parity due to balanced capital and operating expenditure	Grocery store chain with logistics center for several branches	2017–23
Urban heavy-duty city bus	In China and US, buses reach earlier TCO parity than truck segments due to lower share of battery cost in total capital expenditure	Typical city bus or school bus with dozens of stops	2020–23
Long-haul heavy-duty truck point to point	Parity for average users around 2030, due to large battery need, but up to 7 years earlier in beneficial use cases	International or continental freight logistics	2023–31

[1] Depending on region; example shown: Europe.

McKinsey&Company | Source: McKinsey Center for Future Mobility

Fig. 1.7 Predicted total cost of ownership (TCO) parity *(source: [McKinsey 2017])*

In 2015, the Chinese government's total subsidy for the purchase of commercial electric vehicles was approximately A$11.6 billion [Wang *et al*. 2017]. In addition to the subsidies provided by the central government directly to manufacturers, bus companies received subsidies from regional and municipal subsidies, which in many instances matched central government subsidies [Wang *et al.,* 2017]. In the case of Europe, the increase in electric buses was driven by a combination of public policy, such as the EU's clean vehicles directive, by cities wanting to improve air quality and by high fuel taxes. Electric buses operate in a number of Nordic cities, including Oslo, Trondheim and Gothenburg [Kane 2016]. Oslo's target is to have all buses in its fleet running on renewable energy by 2030 [IEA 2018].

Electric buses frequently operate for a full day on a single battery charge (> 250 kWh) and are recharged at night at a depot at relatively slow speed (> 22 kW) when electricity prices are low. Another strategy is to use 'opportunity charging', relying on 200-400kW fast chargers at the terminals or along bus routes with charge times from five to ten minutes. The benefits of the latter strategy are that much smaller batteries are required (around 80kWh), which reduces the purchase price, weight, and energy consumption – plus allows more space for passengers.

The majority of electric buses sold to date have been made by Chinese manufacturers for the domestic market. There are a number of Chinese bus OEMs, two major ones are BYD [BYD 2018] and Yutong [Yutong 2018]. The latter claims that its buses are used to carry 34 billion passengers per year and to travel a total distance of 43 billion km per year. Both are active in the international electric bus market and produce urban electric buses in a variety of sizes. The bestselling standard BYD 12 meter urban bus has a battery capacity of around 330 kWh and a range of 250 km. The European electric bus OEMs include Volvo, Solaris and VDL, as well as a number of new companies. The number of models available is large [ZeEUS 2017]. Some European OEMs use aluminium body components to reduce vehicle weight, extending their range or reducing battery requirements [IEA 2018]. The major electric bus OEM in the USA is Proterra, which produces only electric buses and used carbon fibre bodies with battery capacities up to 440kWh and a range of 480 km [IEA 2018].

1.3.2 Trucks

The rollout of electric trucks is at an early stage and is being driven primarily by logistics companies. Most are medium freight trucks with gross vehicle weights between 3.5 and 15 tonnes. A number of electric heavy freight truck with gross vehicle weights over 15 tonnes has been developed for pilot projects. Tesla announced an electric truck model in 2017, while Daimler announced availability of their electric truck model by 2022. A number of concept and prototype mid- and heavy-duty models are being designed. Most of the pilot projects are being undertaken in California, Sweden, Germany and the Netherlands with support from national or local governments, industry partners (including utilities, OEMs and fleet operators) and research and advocacy groups [IEA 2018].

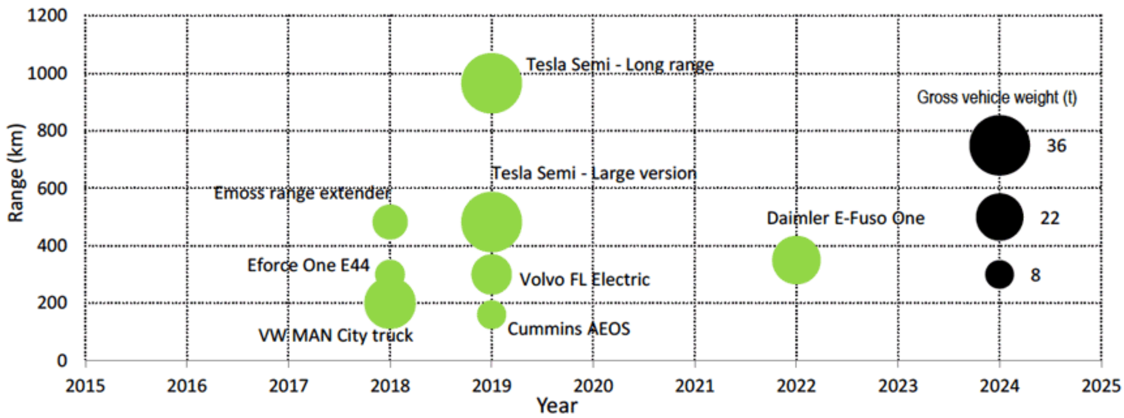


Fig. 1.8 Heavy duty electric truck commercialisation (GVW > 15 tonnes) *(Source: [IEA 2018])*

Range, load and expected year of introduction of BEV/PHEV and fuel cell trucks for the commercial market, are shown in Figure 1.8. The short-haul truck segment (up to 200 km) will be the first trucks to be electrified, while the long-haul truck segment will rely on fossil fuels for a longer period, or may adopt other EV technologies as the large amounts of batteries required become too expensive. As outlined below, alternative charging techniques are evolving for long-haul trucks, which mainly concentrate on conductive methods delivering electricity on the road using overhead wires, similar to electric trains.

Another group of future commercial users of EV charging infrastructure will be electric aircraft, especially VTOL air taxis (vertical take-off and landing), which are not bound to traditional airports.

Fig. 1.9 Volocopter VTOL aircraft, and "traditional" electric plane at Jandakot airport
(photos: Volocopter, Electro.Aero)

1.4. Alternative Charging Methods

The following EV charging methods are not suitable for an initial state-wide EV charging infrastructure in Western Australia. They either have a too low power level (inductive charging) or are prohibitively expensive, given the long distances in WA and the relatively low number of EVs travelling across the state (conductive power rails).

Fig. 1.10 Inductive charging over a plate, [Clean Technica 2018]

Inductive charging is a contactless way of charging EVs through inductive coils in both the car as well as the parking bay (e.g. as a plate or even under the bitumen). Inductive charging has the convenience of no longer having to plug-in a car (or in the case of AC carrying one's own cable), but comes at a higher price per station and with some losses in energy transfer. The US Department of Energy's Oak Ridge National Laboratory (ORNL) has recently demonstrated a lab setup to perform inductive energy transfer up to 120kW at 97% efficiency [Elektor 2018]. However, current commercial inductive charging systems work on a much lower power setting between 11–30kW.

While inductive charging is typically used in a stationary situation in a parking garage or a parking bay, Qualcomm has conducted experiments along a strip of highway to allow inductive charging while driving with up to 20kW.

Fig. 1.11 Inductive charging while driving on highway, image Qualcomm , cnet.com/ roadshow/, May 2017

However, the prohibitive costs involved with this technology have lead OEMs and suppliers to look at alternative conductive methods, especially for long-haul trucks. Currently, these are either power rails inside one lane of the road (eRoadArlanda pilot scheme near Stockholm, Sweden) or overhead power rails, similar to those for electric trains (Siemens, Scania, Mercedes-Benz).

Fig. 1.12 Conductive charging through a power rail in the road, *(photo [CNN 2018])*

A 5 km long section of the German Autobahn A5 has been equipped with overhead power rails in both driving directions. It was opened for test drives on 27 November 2018 [Automobil Produktion 2018].

Fig. 1.13 Overhead power rails for electric trucks,
(photo Siemens/Daimler-Benz [Wired 2017])

1.5. Fuel Cell Electric Vehicles

Fuel Cell Electric Vehicles (FCEV) or "*Hydrogen cars*" have been promoted for over 30 years and several OEMs have not only built fuel-cell research cars, but also small series of production vehicles. Currently available fuel-cell cars in California include Hyundai Tucson Fuel Cell, Honda Clarity Fuel Cell, and Toyota Mirai [Wikipedia 2018a]. None of these vehicles is available in Australia, however, Hyundai has announced the Nexo for 2019 in Australia [Hyundai 2018a], [RAC 2018].

Until 2017, the worldwide sales of FCEVs were 6,364 vehicles (2013-2017) [Globe News Wire 2018]. In comparison, at the end of 2017, there were of 3 million EVs on the road, with 1 million EVs being sold worldwide in 2017 [Forbes 2018].

During the first generation of modern EVs from around 2010, EVs had a rather limited range and lengthy charging times. This is when FCEVs had an advantage in usability. However, as of 2018, FCEVs and EVs are largely on par in terms of range and charging times.

- Range: Mirai 500km, Nexo 750km; Kona Electric 450km, Tesla Model S 600km [H2Live 2018], [Hyundai 2018c], [Engadget 2019]
- Filling/Charging times: Mirai 1min. 45s per 100km; Porsche/BMW 3 min. per 100km [Cars 2016], [TheVerge 2018]

FCEVs have a number of advantages:

- FCEVs are emission-free if the hydrogen is generated using renewable energy
- FCEV have a driving range comparable to ICE cars
- Energy can be stored in hydrogen tanks to be used in FCEVs at a later time

FCEVs face a number of challenges:

- FCEVs are significantly heavier than comparable ICE cars (curb weight of Toyota Mirai FCEV is 1,848kg [Toyota 2018], Hyundai Nexo FCEV 1,814kg [Hyundai 2018b]).
- While EVs can be charged from any power point, at home, work, directly from solar PVs, hydrogen cars require a very expensive refilling infrastructure. The National Renewable Energy Laboratory lists the cost after 2016 between USD 3.1 million and USD 5.1 million per hydrogen filling station [NREL 2013].
- To generate hydrogen and then use it in a fuel cell requires 2–4 times as much energy as driving an EV directly with electric power. Calculations range from twice the amount of energy [PWC 2017] to four times as much, as calculated by Prof. Lienkamp from TU Munich [Lienkamp 2018]. This calculation does not include the energy required to store and transport hydrogen to the filling station.
  Porsche CEO Oliver Blume stated *"We at Porsche build on pure electric vehicles with battery storage. The energy efficiency is about three times higher than that of hydrogen and six times higher than synthetic fuel"* [Automobilwoche 2018].
- If hydrogen was not produced from renewables, an FCEV would produce three times the emissions of an ICE vehicle [Air Quality and Climate Change 2018].
- While most other parts of an FCEV are identical to an EV, service procedures for hydrogen fuel-cell stacks are quite complex [Green Car Reports 2017]..
- Hydrogen is highly explosive and is highly compressed at 700 bar in a vehicle's storage tank (Type IV [Wikipedia 2018b]). Although considered safe for vehicle use under today's testing conditions, there is the perception of safety concerns for FCEVs in heavy collisions, in fire, or simply for ageing equipment over the lifetime of the car when insufficient service is applied.

Fig. 1.14 Toyota Mirai fuel cell stack and hydrogen tank *(photo from Wikiwand.com)*

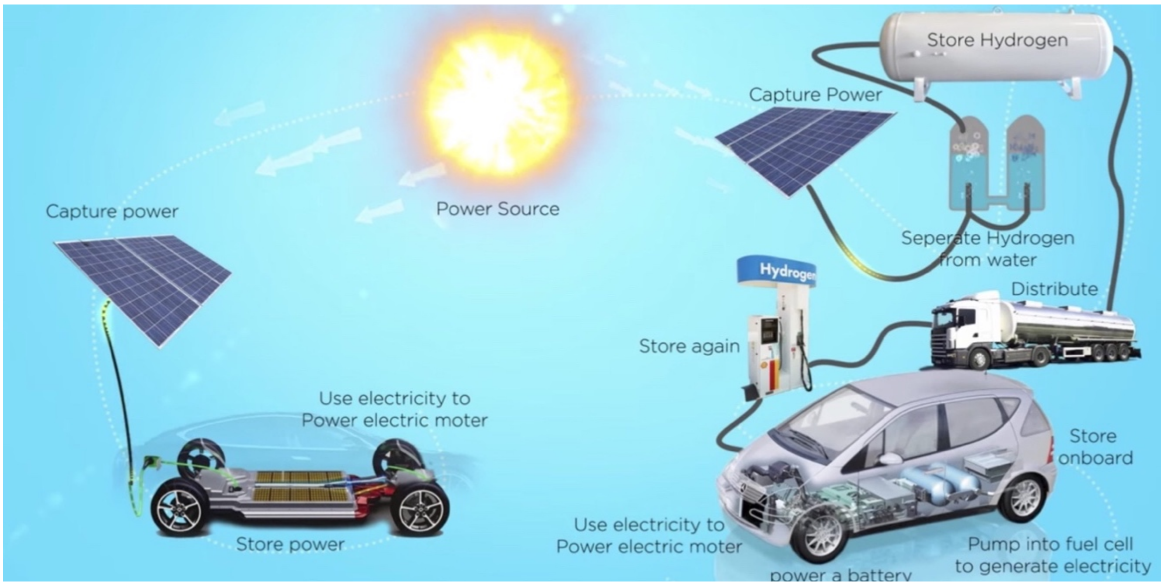


Fig. 1.15 EV versus hydrogen fuel-cell technology *(diagram from electrek.co/2017/10/26/)*

Figure 1.15 visualises the complexity of the hydrogen fuel-cell process that already includes energy storage. Storage needs to be added to the EV charging process for charging outside of sunshine hours. Figure 1.16 explains the physics behind it and calculates the required energy for fuel-cell vehicles as three times that of an EV.

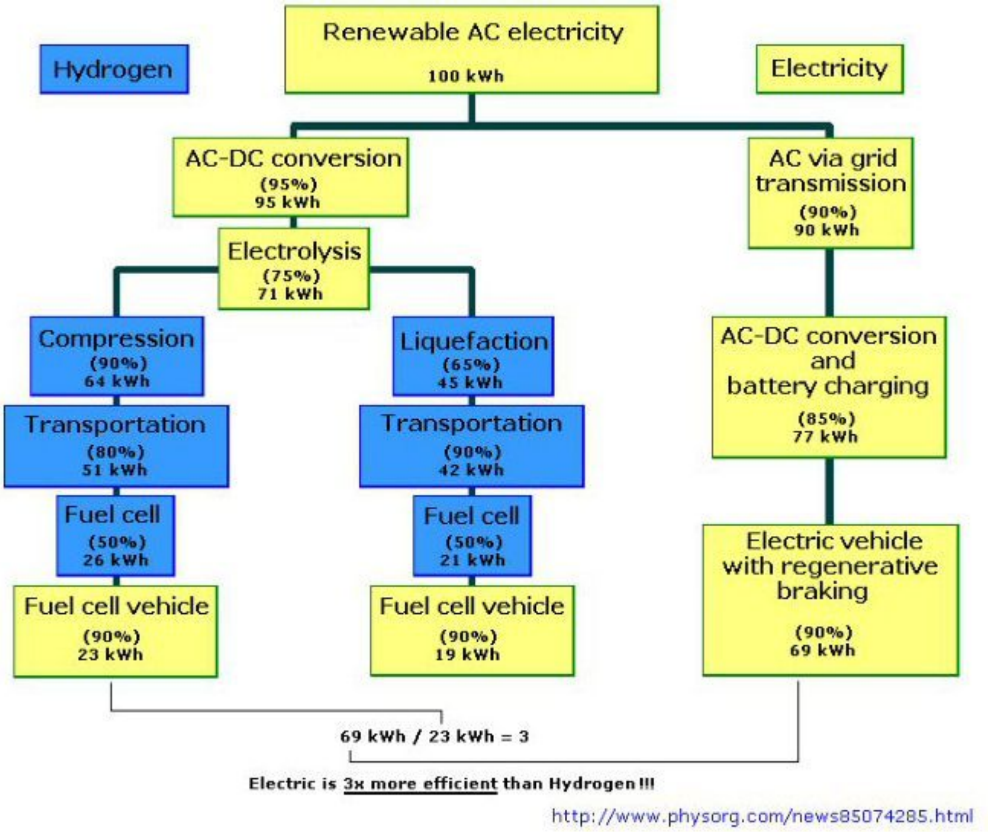


Fig. 1.16 Hydrogen fuel-cell versus EV *(diagram from PhysOrg.com)*

While hydrogen fuel-cell cars may only play a minor role in the passenger vehicle sector over the short to medium term, there may be application scenarios for long distance heavyhaulage transport. Despite recent announcements of short-haul trucks (up to 200km range) by Tesla Motors [Tesla 2018] and Daimler/Mercedes-Benz [Daimler 2018], it might still take a long time until battery electric long-haul trucks become economically viable. For these trucks, it might be a good solution to power them with hydrogen generated from renewable energy rather than diesel.

There has been sudden increase in interest in Australia in producing hydrogen from both fossil fuels and from renewable energy sources, including CSIRO and Australia's Chief Scientist [Hydrogen Strategy Group 2018]. This interest has been stimulated by public announcements in both Japan and South Korea to transition to hydrogen as a major energy source, and by investment of $500 million by a Japanese company in a demonstration project in Victoria, aimed at producing hydrogen from brown coal from the Latrobe Valley and capturing and storing the carbon produced from the process in geological sites offshore. This has led to the realisation that hydrogen production in Australia has the potential to be a very large new export industry, although it is acknowledged that Australia is in competition with other countries such as Norway, Brunei and Saudi Arabia. The Hydrogen Strategy Group has been established and has prepared a report on the opportunities for the COAG Council on Energy which was released in August 2018 [Hydrogen Strategy Group 2018]. The report highlighted that, as well as having the potential to form a new large export industry, industrial scale production of hydrogen would also have three large domestic benefits for Australia. The first was that hydrogen could substitute for natural gas and thereby address the declining gas availability and rising gas prices in the Eastern States. The second was that the production of hydrogen from renewable energy sources using electrolysis would create a new large-variable load that could assist in managing the high penetrations of wind and solar PV generation. The third was that hydrogen could be stored and used when needed to supply standby electricity generation that is needed to stabilise electricity grids as an alternative to utility scale battery storage.

While the opportunities for using hydrogen as a domestic transport fuel included light FCEVs, the initial markets or end uses for hydrogen produced in Australia were considered by the authors of the report to be export (complementing LNG exports), injection into natural gas pipelines (up to 10% hydrogen) and long-haul heavy transport (trucks, buses, trains and ships). Hydrogen as a fuel for light FCEVs was not considered to be an important end use for hydrogen until after 2030.

The paper stated that light FCEVs would compete with light BEVs, but considered that BEVs will dominate this market. This was mainly because of disadvantages compared to BEVs, including higher cost refuelling infrastructure, lower efficiencies (30% compared to 70%), and first mover advantages of BEVs (larger numbers of EV models, lower costs, larger numbers of EV charging infrastructure). Furthermore, the current costs of hydrogen at refuelling stations (A$19/kg in California) would need to be reduced to A$11/kg in order to be competitive (cost per km) with a petrol ICEV, while the cost per km of a BEV is already well below the cost per km of a petrol ICEV.

In summary, light FCEVs are not envisaged in the near term or medium term to compete with light BEVs. In the longer term (post 2030) light FCEVs may compete with light BEVs in fleets where low numbers of refuelling stations could service large numbers of FCEVs returning regularly to a base. The implications for the present study are that the emergence of FCEVs is unlikely to have any significant impact on the need for EV charging stations.

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2. Charging Infrastructure Supporting EV Uptake

Key findings:

- A state-wide DC fast-charging infrastructure is required to make EVs mainstream and to allow EV owners to travel state-wide. It will give potential EV buyers more confidence in the technology and boost EV uptake.
- Availability of EVs in the low and medium price ranges, including second-hand cars, and the variety in EV models play a major role in customer purchase behaviour.
- Current EV uptake in WA is still very low (about 0.1% market share), but major growth is likely, as in most other countries. WA's EV uptake rate is only half of the rest of Australia's.
- Most EV charging will be AC charging at home or at work, but only fast-DC charging technology can enable longer daily trips.
- National charging network operators Chargefox and Fast Cities, have recently been established in Australia, however, their activities will be predominantly in the Eastern States. Chargefox has firm plans for installing chargers in 3 sites in the Perth metro and South-West WA area in 2019. Both companies are unlikely to install stations in regional or remote WA.

Australia has a serious lack of imported EVs. Since the initial wave of EVs came to Australia in 2011/2012, only a few new models have been introduced until the time of writing this report in 2018. This lack of available EVs, especially in the lower and medium price range, and an almost non-existent second-hand market, have been identified as the major factors limiting the uptake of EVs and PHEVs in Australia.

The current uptake of EVs/PHEVs in WA is still very low (about 0.1% of new vehicle sales), but we expect major growth as in most other countries. At this stage, only a few OEMs are exporting EVs to Australia, therefore customers can only choose from a limited range of models, almost all priced in the luxury car segment. Many OEMs are reluctant to export EVs to Australia, given its small market size on the global scale, its lack if government incentives, and its lack of a coherent fast-charging infrastructure. Without introducing any incentives, we expect that EVs/PHEVs will reach the 1% mark of all new vehicle sales in WA in the year 2022, and that they will reach 1% of the WA vehicle fleet around 2025/2026. If incentives are introduced, then these take-up rates can be reached much sooner. At present, WA is behind the rest of Australian EV uptake by a factor of two.

Political support has proved successful for EV adoption in other countries. Every second new car registered in Norway is an EV, California has an EV market share of around 5%, while in the U.S. and Europe as a whole, EVs hold about 2% of all new car registrations.

Major public benefits of conversion of the vehicle fleet from liquid fuels to electric in Western Australia include: significant reduction in transport costs from higher energy efficiencies and lower servicing requirements, large new revenues for electricity system upgrades, minimal liquid fuel and lubricant imports, major improvements in energy security, and substantial decreases in noise and air pollution (net and point-source emissions, as well as hazardous particulates). Domestic clean energy development is a strategic investment in increased energy independence and security with associated environmental, economic growth, and innovation benefits [Wei et al. 2010], [Mullan et al. 2010].

2.1. Need for Charging Infrastructure

Apart from the purchase price, the availability of a coherent fast-charging network has often been identified as the biggest obstacle in EV adoption. A customer's "*EV purchase decision depends on the availability of fast-DC charging infrastructure*" [EV Council 2018]. But charging networks will only be profitable when there is a sufficient number of EVs using them, which has often been called the "chicken and egg problem".

The population concentration in the Perth metro area and vast areas with sparse population only exacerbates this problem in Western Australia. If relying on market forces alone, there will be no state-wide EV charging network for several decades, which would make it impossible for EVs to travel larger distances through the state or drive interstate.

The construction of a state-wide fast-charging infrastructure is therefore of fundamental importance for the wider adoption of EVs and will show the state's commitment for supporting this new technology. Without fast-charging infrastructure, potential buyers will not have the confidence to make the change from ICE cars to electric vehicles and Western Australia will be left behind, technology-wise and environmentally.

The importance of EVs for improving air quality in metropolitan areas and therefore improving general population health cannot be emphasised enough. Even if initially only a smaller part of the energy for charging EVs comes from renewable sources, just the shift from inner-city vehicle emissions to controlled emissions from power stations will bring significant improvements to air quality. Multiple studies have shown that emissions from ICE cars are causing more deaths than the already alarmingly high number of fatalities from road accidents. See e.g. *"Air Pollution and Daily Mortality in Sydney"* [Morgan et al 1998], *"Public Health Impacts of Combustion Emissions in the United Kingdom"* [Yun, Barrett 2012], and *"The Fort Collins Commuter Study"* [Good et al. 2016]. Especially bicyclists are suffering, as outlined in *"How to Reduce Cyclists' Exposure to Air Pollution"* [Gan 2015].

2.2. Current and Future EV Uptake

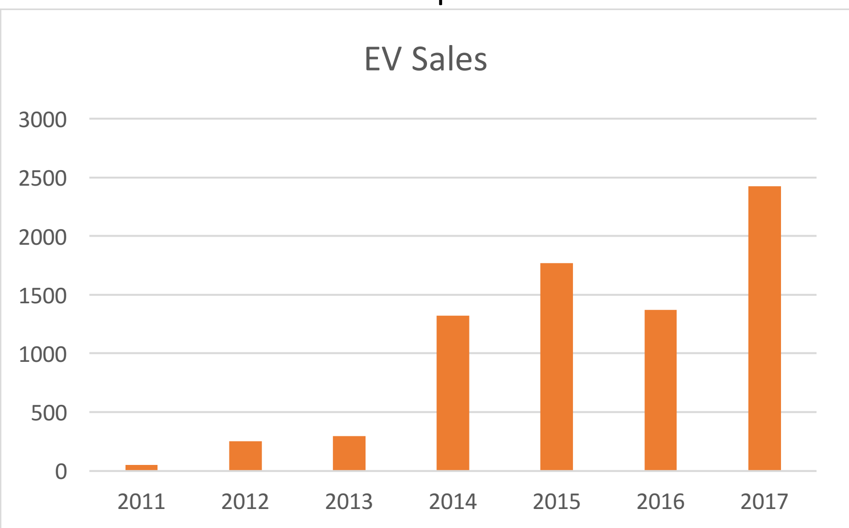

Fig. 2.1 EV sales in Australia; data from [Climateworks Australia 2017] and [NTC 2017]

Electric vehicle sales figures have been published by [Climateworks Australia 2017] and [NTC 2017]. Figure 2.1 shows a combined graph of their data. These figures include estimated sales figures from Tesla Motors, as they do not publish their sales data. The data shows a consistent growth over the last five years with the exception of 2016, but not quite an exponential increase like in many other countries.

In Western Australia, EV uptake is also steadily increasing, as documented by data provided by the WA Department of Transport (Figures 2.2). However, their percentage on all new vehicle registrations is below the rest of the country.

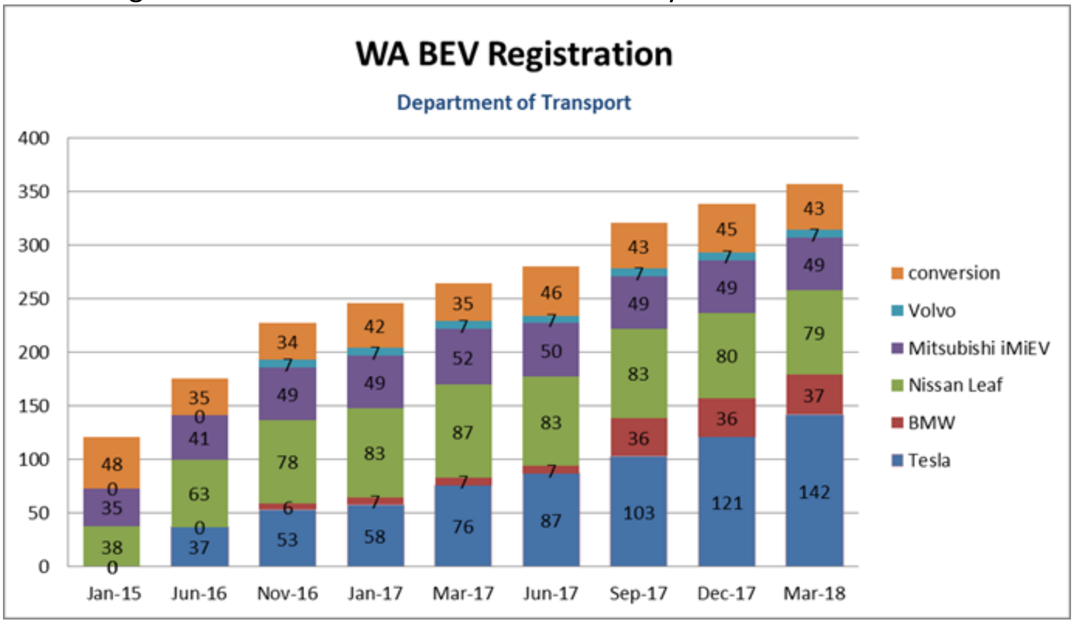

Fig. 2.2 Battery-EV fleet in WA, data provided by WA Dept. of Transport

The figures for the total number of EVs in the West Australian fleet are shown in Table 2.1 from WA Dept. of Transport, not considering EV conversions. The lack of available EV models, especially in the middle and lower price segment, as well as the lack of a coherent EV charging infrastructure, have certainly contributed to these low numbers.

Table 2.1 EV/PHEV fleet in WA, data provided by WA Dept. of Transport

WA Electric Vehicle Data for 2015, 2016 and 2017

Date	Tesla	BMW i3	Nissan Leaf	Mitsubishi iMiEV	Volvo	Cumulative BEV	Cumulative PHEV	Total BEV & PHEV, no conversion
as of Dec 2017	121	36	80	49	7	293	194	487
as of Jan 2017	58	7	83	49	7	204	143	347
as of 30 Jan 2015			38	35		73	101	174

The number of EVs available for purchase in Australia shows a shift towards the high end of the market at $100,000 per vehicle and over (Figure 2.3). While more models are available in the highest price bracket, the number of models available in the lower price bracket has diminished, and this trend continued also in the years 2017 and 2018. *"What we have in Australia is not a lack of consumer interest in electric vehicles, but a lack of suitable models to choose from",* EV Council's Behyad Jafari was quoted in [Renew Economy 2017].

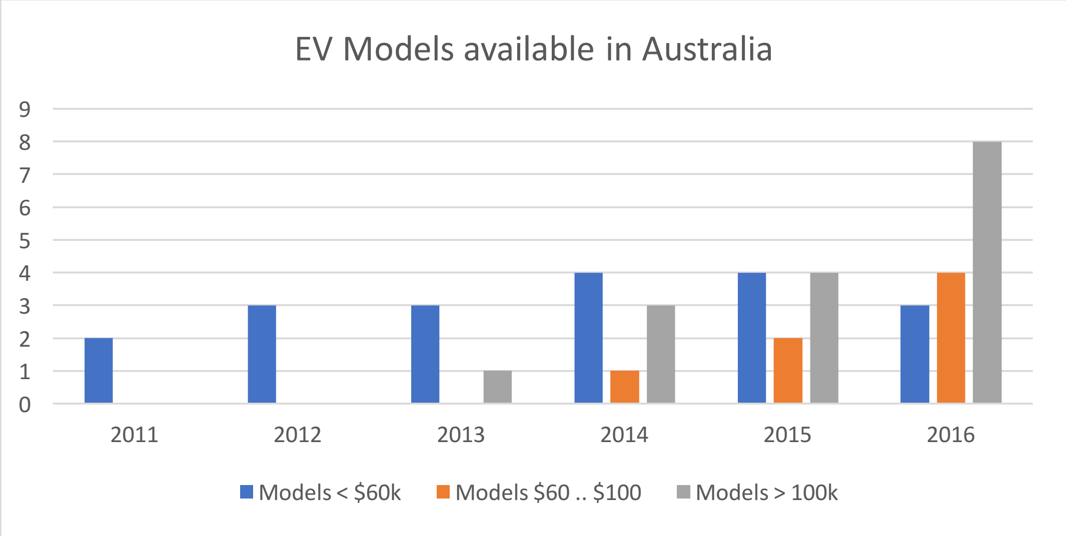

Fig. 2.3 EV/PHEV models available for purchase in Australia
(data from [Renew Economy 2017])

We expect a significant increase in EV numbers for 2018 and the following years, when a wider selection of EV models will be available in Australia.

Several studies on projected future EV uptake have been conducted by various organisations worldwide. Figure 2.4 shows the three EV uptake scenarios from Energeia. The expectation is that even a moderate government intervention will have a tremendous impact on EV uptake. According to this study, a 100% EV coverage will be reached between the years 2037 (accelerated intervention) and 2045 (no intervention). The large difference between the three scenarios in this study, as well as the differences between other studies demonstrate the high level of growth uncertainty in this area.

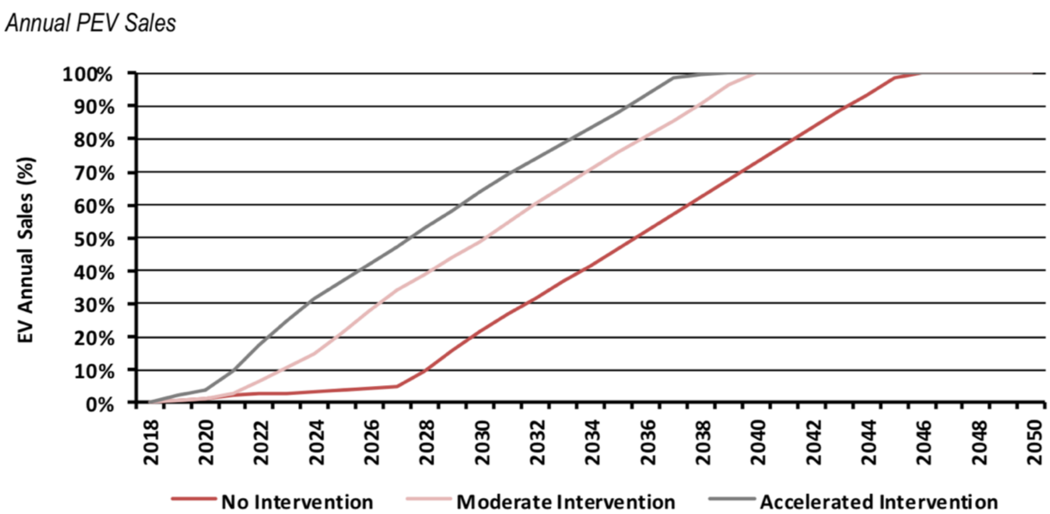

Fig. 2.4 Future EV/PHEV uptake as a percentage of new vehicle sales
(graph from [Energeia 2018])

While the future EV fleet is believed to contain 100% battery electric vehicles (BEV), today we have a mix between BEVs and PHEVs (plug-in hybrid vehicles). The number of pure BEVs available in the Australian market is even smaller than that of PHEVs, as shown below. Not a single BEV is available below $50k and the two BEVs in the lower price bracket have not been imported into Australia after their initial market introduction in 2011/2012.

<u>Existing BEVs in the Australian market:</u>

Mitsubishi iMIEV	2011/2012	no longer available
Nissan Leaf	2012	no longer available
Tesla Roadster	2011/2012	no longer available
BMW i3	2014–today	
Tesla Model S	2014–today	
Tesla Model X	2016–today	
Renault Zoe	2018–today	
Renault Kangoo Z.E.	2018–today	

There is a considerably larger number of PHEVs imported into Australia, however, most of these vehicles have a very limited electric range of realistic 25–50km (with the exception of the Holden Volt's 70km—no longer imported into Australia), which severely limits their use as electric vehicles.

Table 2.2 Excerpt from Energeia's Australian Electric Vehicle Market Study of EV/PHEV sales and fleet for WA 2015–2025 [Energeia 2018]

			2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
WA	No Intervention	Annual EVs	152	153	412	1,153	1,570	3,491	3,938	4,428	4,972	5,960
		Annual Sales Market %	0%	0%	0%	1%	1%	2%	3%	3%	3%	4%
		Cumulative EVs	505	658	1,064	2,217	3,787	7,278	11,216	15,616	20,558	26,405
	Moderate Intervention	Annual EVs	152	153	437	1,227	1,684	3,911	9,943	17,013	24,822	35,928
		Annual Sales Market %	0%	0%	0%	1%	1%	2%	6%	10%	15%	21%
		Cumulative EVs	505	658	1,090	2,317	4,000	7,912	17,855	34,840	59,631	95,447
	Accelerated Intervention	Annual EVs	152	153	461	3,492	6,393	16,127	30,261	43,061	56,330	66,412
		Annual Sales Market %	0%	0%	0%	2%	4%	9%	17%	24%	31%	36%
		Cumulative EVs	505	658	1,115	4,607	11,000	27,127	57,388	100,422	156,720	223,019

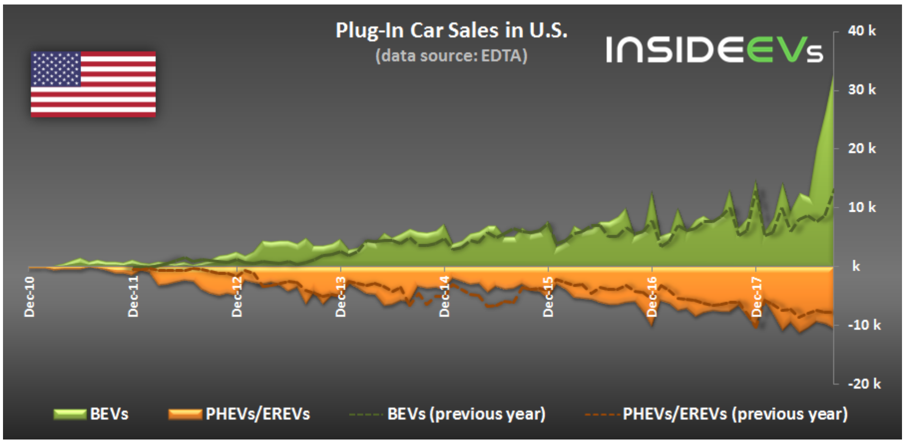

Fig. 2.5 Battery EV vs. PHEV ratio in the U.S. market [InsideEVs 2018]

PHEVs do not play any role in our fast-charging analysis, as they typically have a very small battery size and none of the PHEVs on the Australian market are DC-chargeable. The change in ratio between BEV and PHEV will be difficult to predict over the next decade. This ratio differs considerably from one country to another, and can change quite dramatically over a short period of time as a consequence of changes in government policies and incentives, investment in public fast charging infrastructure, and price changes in EVs and fuel. In the U.S., the ratio of EVs to PHEVs is currently at 3:1 and further increasing [InsideEVs 2018].

2.3. Australian EV Market

As Australia no longer has domestic vehicle production, all EV sales depend on overseas OEMs. A number of OEMs have announced they will introduce new EV models into the Australian market, however, no OEM was able to share sales prognoses for the coming years. Future development will be market-driven and will be highly dependent on political directives, such as direct or indirect subsidies. In this situation, it is only possible to estimate the future uptake on EVs in Australia, based on uptake rate developments in comparable countries. As has been shown in other countries, such as Norway (EV uptake at 52% [Reuters 2018]) and California (EV uptake at 5% [EV Adoption 2017], [LA Times 2017]), incentives and subsidies do work and could also significantly accelerate the uptake of EVs in Australia, if there was a political initiative. This was confirmed by a recent Australian study *"This case study showed clearly that financial incentives, and particularly reductions in up-front purchase costs, are the incentives that impact most strongly on PEV purchase decisions, and that non-financial incentives play a supporting rather than leading role."* [Energeia 2018].

Key incentives and their impact identified in [Energeia 2018] were:

"Vehicle Efficiency Regulations	*200–300% increase in uptake based on US experience*
Third Party Import Regulations	*200% increase in PEV models available, 800% increase in uptake based on NZ experience*
PEV Purchase Incentives	*~$4,000 increases PEV model availability by 20%, increases uptake based on UK experience*
Government Purchase Targets	*1 new PEV introduced per 300–500 sales based on Australian OEM experience*
Public Infrastructure Availability	*Increases market size by 20%, increases rate of adoption by 50%, based on UK data and Dutch experience, respectively"*

A procurement target by fleet operator of 300–500 EVs per year was suggested "*to attract Original Equipment Manufacturer (OEM) interest to import new right-hand drive models not yet made available in Australia*". This, of course would also have a significant positive impact on the second-hand EV market.

The following EV models have been announced by OEMS for the Australian market in 2018–2020.

Confirmed new EV models coming to the Australian market:

Hyundai Ioniq	Dec. 2018
Jaguar I-PACE	Dec. 2018
Hyundai Kona	Feb. 2019
Tesla Model 3	Dec. 2019
Audi e-tron	2020
Porsche Taycan	2020

A number of major OEMs are still reluctant to introduce new EVs into the Australian market. Most often, a lack of government support and the small Australian market are cited as the reasons. Talking to the Australian sales offices of some of the large international OEMs did not reveal any new information.

Possible future EV models coming to the Australian market:

BMW iX3, i4, iNext	to be determined
Mercedes-Benz EQ	to be determined
Volkswagen eGolf, I.D.	to be determined
Holden/GM Bolt	currently no plans

Besides the well-known brand names, there may be an influx of EVs from currently not well-known new Chinese OEMs. Many of these brands are already in production and are looking at exporting to the international markets.

All new EV models after model year 2019 will have a realistic range of over 300km on a single charge. Most of them will be able to charge at least at a power level of 150kW, and it is expected that most new EVs from model year 2020 onwards will be able to charge at the 350kW level.

As studies have shown, battery capacity and therefore vehicle range does maintain an 85% performance over the first 8-10 years. Frequent fast-charging does not noticeably deteriorate battery performance [Fleetcarma 2017].

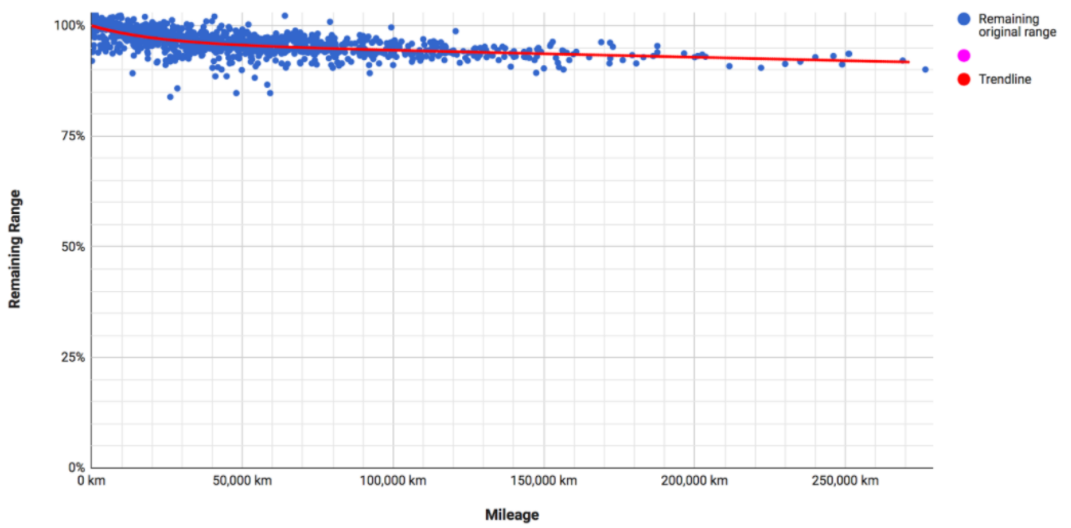

Fig. 2.6 Tesla S/X battery capacity (range) over driven kilometers, [Fleetcarma 2017]

2.4. Charging Consortia

Tesla is the only automotive OEM that installs its own proprietary charging network. The current generation of Tesla Superchargers charge at a rate of 120kW; their unit price is unknown. Tesla typically installs 6–8 charging units per site. At the time of writing this report in Dec. 2018, Tesla is operating a single fast-DC charging site in Western Australia with 6 x 120kW Supercharging units in Eaton, near Bunbury.

Fig. 2.7 Western Australia's first Tesla Supercharger site near Bunbury
(photo: Tesla Owners Club WA, TOCWA)

None of the other OEMs has any plans to roll out their own charging network or become a member of an OEM-driven charging consortium. However, there are nationally and internationally a number of EV charging consortia that OEMs may join either directly or indirectly. In Europe, Ionity is one of the largest players [Ionity 2018], counting BMW, Daimler, Ford, Volkswagen, Audi, and Porsche to its members. Ionity has announced that it will install charging stations at 400 new locations in Europe by the end of 2019. Each site will have 6–8 charging bays at 350kW each. The tender for supplying these stations was won by Australian company Tritium.

Funding for EV charging infrastructure can come from various sources:

- OEMs
  OEMs can fund charging sites for their customers, in order to increase EV sales. Tesla Motors is currently following this model, however its case is special, since it *only* produces EVs and not ICE vehicles. None of the other OEMs is funding charging stations apart from within their dealerships, as EVs make up only a very small fraction of their vehicle sales.

- Energy utilities
  In a sense, energy companies will be the big winners of the electrification of transport. The funds that now are still being spent on petrol and diesel will go towards electric energy in the future. This will grow to a billion-dollar industry over the next decades with only marginally higher cost on the generation side. Charging on public stations is predominantly during midday, when there is an excess of solar energy, and home charging is predominantly at night, when there is an unused base

load of the larger power stations.
While most major energy utilities are funding the roll out of EV charging sites, there are no plans at Western Australian utilities to do likewise. One reason for this could be that there is no provision for an EV charging infrastructure in the current budget of the WA government. None of the WA utilities has an EV inclusion policy for their fleet.

- EVSE manufacturers or EV charging consortia
  Manufacturers of charging stations can decide to invest into installation and operating their own network, in order to increase their sales and kick-start the market. This is currently happening for Australia's Tritium manufacturer, backed by the St Baker Innovation Fund [St Baker 2018]

- Service station operators or roadhouse operators
  Service stations already have the right vehicle infrastructure, i.e. several bays, tyre-pumps, water for windshield wipers tanks, toilets, convenience store, food and drinks. Reportedly, service stations make more profit from convenience store sales than from fuel sales.
  With future diminishing sales on fuel, service stations could be incentivised to become EV charging sites—with attached convenience stores. Even for a future complete fleet of EVs, only a fraction of today's service stations will be required as charging sites, so becoming a first mover could be an additional incentive.

- Government
  A political directive can be given by state or federal government to establish a basic EV charging infrastructure. This will be especially important for areas with low EV traffic/low population density, which are nevertheless required to link regional and metro centres, such as e.g. Perth and Geraldton. Because there is no business case for infrastructure in areas of low EV traffic/low population density, no commercial operator will provide EV charging services in these areas. This would be a case for government to step in.
  Reasons for government intervention are:
    - to provide a general modern road infrastructure, or
    - to improve population health through better air quality.
      This is a very powerful argument for providing EV infrastructure to enable EV uptake. Recent studies have shown that more people die from vehicle emissions than from road accidents [Yim and Barret 2012], [Stölzel et al. 2007], [Morgan et al. 1998].

The upcoming model for EV charging consortia will get OEMs on board as partners, who will purchase subscriptions on behalf of their EV customers. These subscriptions can either be by a flat-fee, fixed amount of km (or kWh) per month or a pay-by-use model. In this scenario, customers would be bound to use predominantly one charging consortium, but the consolidated income stream would guarantee the charging consortium the financial backing to further extend their fast-charging network.

Since all commercial operators have to look at their return of investment, it is quite clear that commercial charging sites will only be established were a sufficient number of EVs can be expected within the next few years. This will only be in the Perth metro area and to a lower degree at major regional centres, such as Rockingham, Mandurah, Bunbury, and at end-points of popular holiday destinations, such as Margaret River and Albany.

In order to allow EVs to travel through the whole state of Western Australia, additional fast-DC charging sites are required at major highway routes, spaced not more than about 200km. Although there will be no business case for operating these stations in the near future, it is a basic road infrastructure requirement for the next decade and can be considered a government task for the public good. Allowing EVs to travel the same routes and distances as petrol cars will make EVs more popular as the choice for the single family car.

Two EV charging consortia have been forming over the last few weeks in Australia:

Fast Cities [St Baker 2018] is funded in part by a $7 million investment from the St Baker Energy Innovation Fund and partnering with EVSE manufacturer Tritium Pty Ltd. Fast Cities has announced it will install 350kW chargers along highways in the Eastern States, no more than 200km apart. Their plans for Western Australia are to install two to three charging sites in the south west corner of WA as part of their initial rollout of 42 stations nationwide between 2019 and 2021. An additional 12 sites may follow within five years in the directions from Perth to Bunbury, Albany, Geraldton and Kalgoorlie. Fast Cities plans to closely collaborate with MainRoads WA on network design and rollout. No further details have been disclosed at this stage.

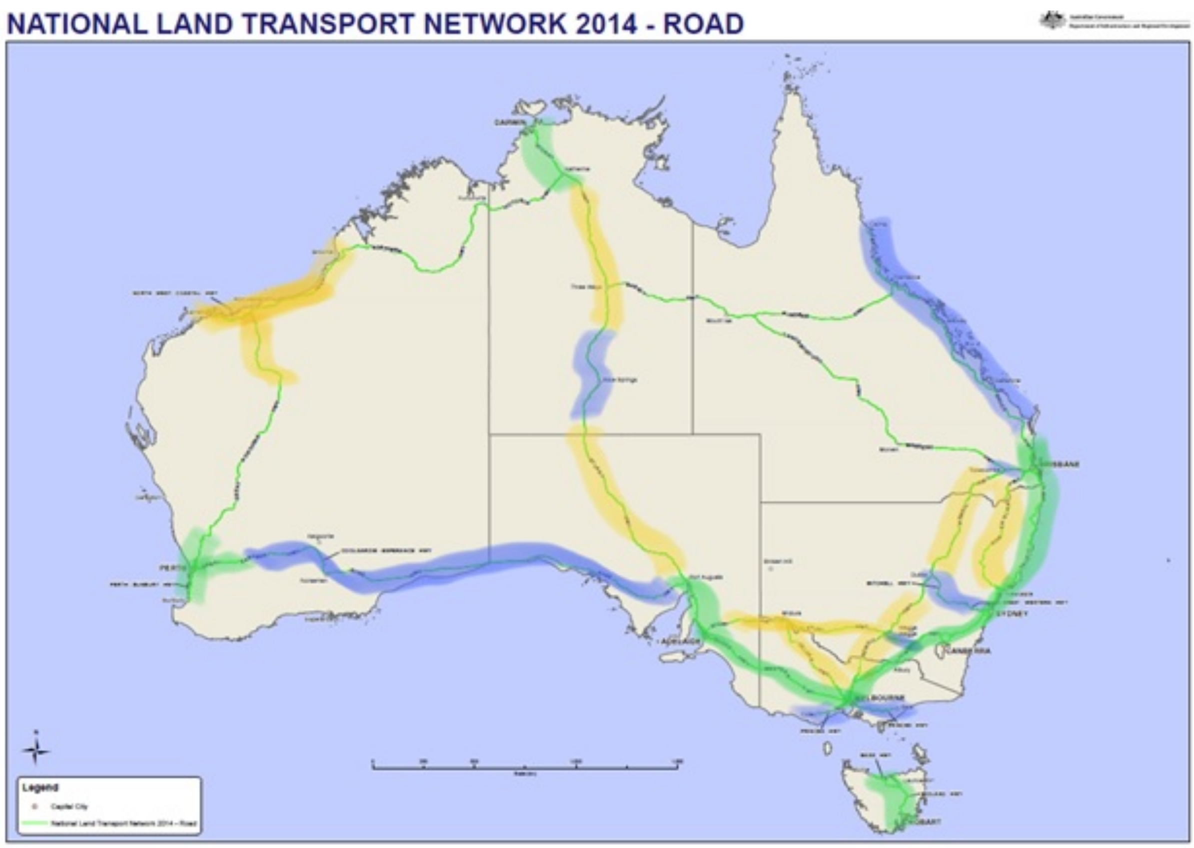

Fig. 2.8 Proposed EV charging sites along major highways by Fast Cities, with 2 x 350kW stations per site (image: stbenergy.com.au)

Chargefox is co-funded by JetCharge using investment from Australian Motoring Services (jointly owned by NRMA, RACV, RACQ, RAA and RACT), Wilson Transformer Company and Greg Roebuck, the founder of CarSales.com.au [Reichert 2018]. Chargefox plans to build 21 ultrafast charging stations across Australia at a cost of $15 million using a A$6 million ARENA grant. It has concrete plans of establishing three DC charging sites in WA, however, the proposed locations have recently changed and no longer match their published map in Fig. 2.11. The new proposed locations are central Perth, Bunbury and halfway between Perth and Albany. The idea of a site north of Perth has been abandoned for now. Each initial setup will be 2 x 350kW. Site scouting has commenced in Nov. 2018 and the three Perth stations are fully funded. Chargefox has close contacts with the RAC, Synergy and Western Power. The company maintains its own software platform, is independent of any charging station vendor and supports several different EVSE platforms, incl. Schneider and Circontrol.

Chargefox has implemented a versatile billing system, which includes:

- Credit-card "pay-wave"
- Mobile phone app
- RFID token
- In the future: direct vehicle and billing identification without any tokens

Chargefox has an interest in partnering with WA government departments and industrial partners for setting up charging stations in regional areas, provided that co-funding can be provided. Otherwise, there is no commercial business case for these locations.

Fig. 2.9 Proposed EV charging sites by Chargefox – note that site shown North of Perth is now proposed at half way between Perth and Albany (image: chargefox.com)

2.5. Commercial Charging Infrastructure

Besides the charging consortia mentioned before, there are further organizations investing in DC fast charging infrastructure in Australia [Energeia 2018]:

- One City (City of Adelaide)
- Motoring associations (NRMA, RAC WA)
- One EV OEM (Tesla)
- One state electricity business (Energy Qld, which owns electricity generation, electricity network and electricity retail businesses), and
- Third party EV charging infrastructure operator businesses (JetCharge, ChargePoint, Everty).

ChargePoint [Chargepoint 2018] has partnered with EV OEMs BMW, Holden, Mitsubishi and Nissan, and the group has installed more than 100 charge stations throughout Australia, however only two fast-DC stations, one each in Sydney and Melbourne.

A number of other players have recently announced their own plans to invest in public DC fast charging stations.

- Jaguar Land Rover is partnering with JetCharge to install 50 kW DC fast charging stations at all of its dealer networks in Australia that will create the single largest electric vehicle charging infrastructure in the country [Latimer 2018a].
- Nissan has also partnered with JetCharge to roll out electric vehicle charging infrastructure at 89 of its dealerships across the country and plans for one-third of all its cars sold to be EVs. The company also wants to work with local governments to increase the number of charging stations [Latimer 2018b].
- The ACT Government has also committed to investing $456,000 to install 50 standard dual electric vehicle charging stations [Back 2018].

Furthermore, a number of businesses are looking to include EVs in their vehicle fleet. These include Australia Post and AusGrid. And in 2017 the South Australian, West Australian, ACT and Tasmanian governments signed a Memorandum of Understanding with the Electric Vehicle Council to push towards a common goal and plan of EV fleet adoption and public promotion of EVs [EVSE 2018].

The roll out of DC fast-charging infrastructure in Australia is therefore happening, but it is being undertaken in a relatively uncoordinated manner by a disparate group of businesses, consortia, associations, governments and cities. That is not problematical per se, and having large numbers of businesses owning and operating EV charging is great in theory. However, in practice it makes life pretty complicated for an EV driver, as each individual network requires them to register and carry a network-specific swipe card in order to use their charging points [Rosamond 2018]. This lack of a common charging system platform would mean that on long distance trips, EV drivers would be unable to charge from any public EV charging station platforms, unless they carry different payment cards for stations operated by different businesses. According to a recent survey, complex and variable pricing structures cause uncertainty to consumers seeking to fast-charging networks [Transport and Environment 2018]. The solution is to do what was done for telecommunication roaming fees. That is, public EV charging station operators should be required to grant universal access to their charging services.

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3. Traffic

Key findings:

- Only fast-DC charging technology can enable longer daily trips for EVs
- Combined Charging System Type 2 (CCS-2) is the recommended choice for the proposed state-wide charging grid; power levels are 50kW, 150kW and 350kW
- Actual EV charging rates are somewhat lower than nominal charger rates
- Peak traffic for remote charging stations can be relatively high
- Charging sites need to be able to charge all customers during peak hour
- Peak load and total energy demand for urban traffic are more difficult to predict than regional traffic
- A power level of 150 kW or above should be used wherever the existing electricity grid is capable of supplying this, as customer expectations on charging speed are higher than what is currently available.

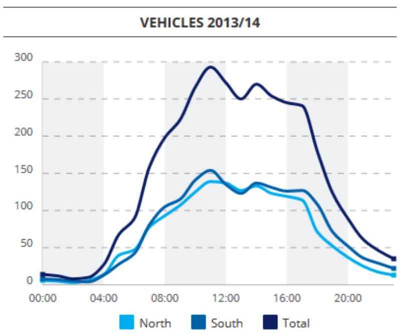
This chapter outlines and discusses the need for charging infrastructures for regional and remote traffic in Western Australia (WA). It further explains why and in what locations recharge stations are being proposed. It discusses charging power levels and how the peak power demand, peak energy demand and overall energy demand are estimated. The scenarios are presented for 1% to 100% EV fleet take-up and for charging power levels of 50kW, 150kW and 350kW, respectively.

3.1. Regional and Remote Traffic in WA

For shorter drives around their home, EV drivers have the option to charge at home, at the workplace or at a public charging station. For long distance highway driving, EV drivers have no other option than using public fast-DC charge points.

The required number of chargers and their power level were calculated on the basis of available fast-DC charging technology (50kW, 150kW and 350kW) and the daily peak traffic flow for each site. Fig. 3.1 (a) shows a typically hourly traffic volume (peak traffic) observed, as example, for the town of Williams along the Perth–Albany route. From the observed overall traffic volume in Fig. 3.1 (b) the proportion of passenger cars was calculated and adjusted for the assumed EV take-up. Table 3.1 provides an indication of the number of EVs driving through the towns along the proposed routes.

(a)



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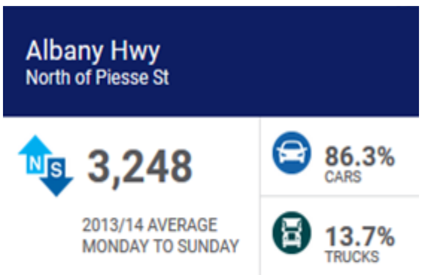

Fig. 3.1 Hourly traffic volume and total traffic per day for Williams WA *([Mainroads 2018])*

For an energy and peak demand estimate, the overall and peak traffic volume was multiplied by the estimated energy consumption required to drive the distance from the previous charging station to the next. For this study, a conservative energy consumption for 110km/h highway driving of 200Wh/km was assumed. Table 3.2 provides an indication for peak traffic hour during the day and Table 3.3 shows the overall energy demand for the Albany Inland Route, depending on EV uptake percentage and the parameters discussed above.

Table 3.1: Expected number of EVs on the Albany depending on market shares

EV SHARE (NUMBER OF CARS) WITHIN THE PEAK HOUR

EV SHARE [%]	WILLIAMS	KOJONUP	ALBANY
1	3	2	3
5	13	11	15
10	25	21	29
20	51	42	58
50	126	106	145
100	253	212	290

Table 3.2: Indication for peak loads along the Perth to Albany Inland Route

ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	WILLIAMS	KOJONUP	ALBANY
1	83	40	91
5	417	201	453
10	834	402	906
20	1669	804	1812
50	4172	2011	4530
100	8344	4022	9060

Table 3.3: Estimate of overall energy demand for the Albany Inland Route

ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

EV SHARE [%]	WILLIAMS	KOJONUP	ALBANY
1	925	378	1020
5	4625	1889	5098
10	9250	3779	10196
20	18500	7558	20391
50	46250	18895	50978
100	92500	37789	101957

Although current fast-DC chargers available on the market have e.g. a nominal power of 350kW, the stated nominal power is different to the charge rate an EV can absorb. While EVs with a relative large battery, such as the Tesla Model S with a 85kWh battery, can absorb most of the energy from a relatively small DC charger of 50kW power (Fig 3.2), EVs with smaller batteries on a more powerful charger may not reach the nominal charge power (Fig 3.3).

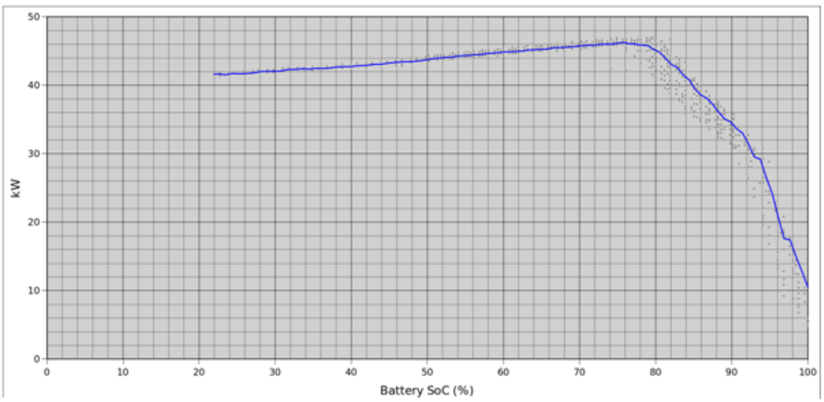

Fig. 3.2 Charging curve for Tesla model S on a 50kW DC charger *(courtesy of Matt Kemner)*

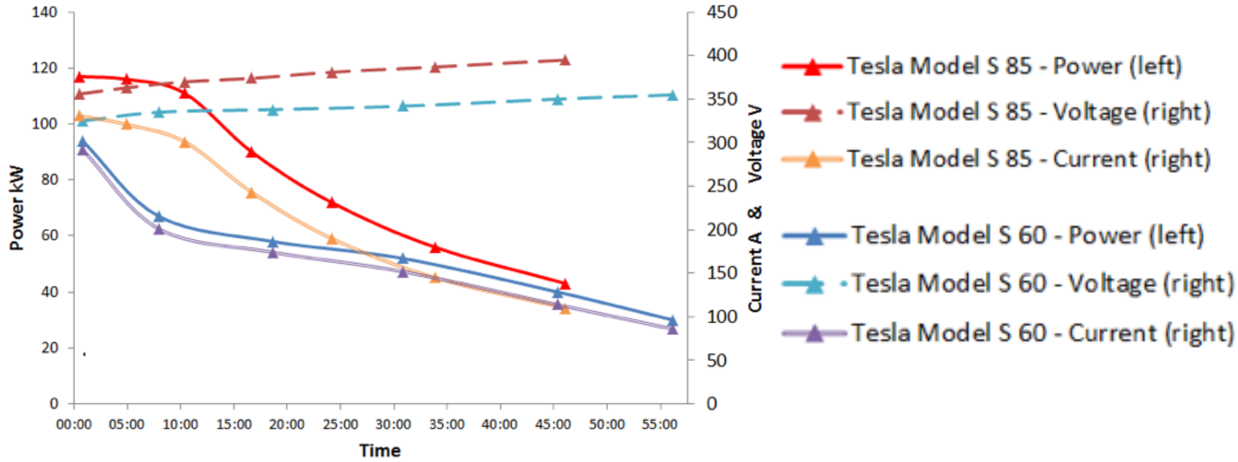

Fig. 3.3 Charging curve for different battery sizes on a 120kW charger *([Inside EVs 2014])*

The actual charge rate can be significantly lower and depends not just on the EV's battery capacity but also on the battery state of discharge, battery temperature, and on information sent from the battery management system to the fast-DC charger. If a battery management computer receives information, for example, of a high battery temperature, it will send information to the charger to reduce the charge rate. Such a control strategy is important to protect the battery from further heat gain due to the charging losses and eventually from overheating. Such a scenario can be expected under high discharge rates from high driving speeds and loads and under the impact of high environmental temperatures. Therefore, the nominal stated fast-DC charging power for the calculations has been assumed to 88% of the stated charge rate for 50kW chargers, 80% for 150kW chargers and 70% for 350kW chargers.

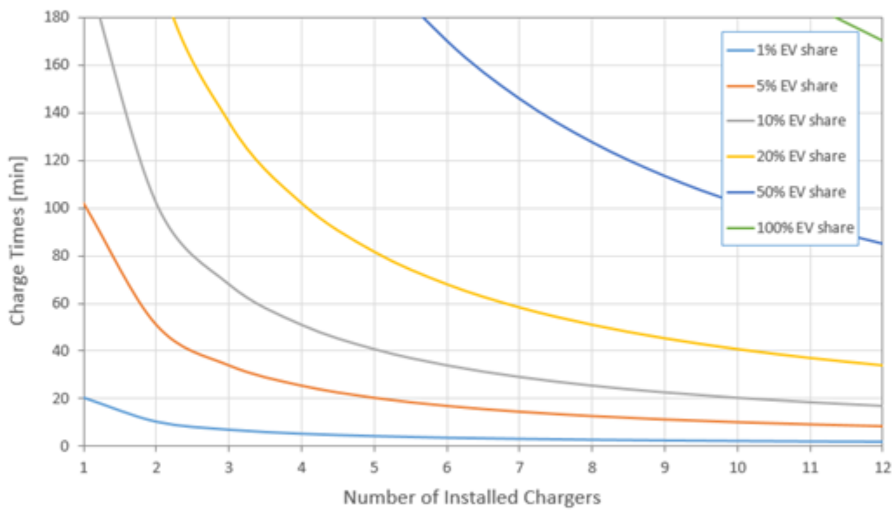

Fig. 3.4 Calculated charging times for EVs driving through Williams, depending on EV uptake and the number of installed 350kW chargers

Figure 3.4 shows the peak hour charging times for different EV fleet uptake scenarios (1% to 100%) for different numbers of charging stations (1 to 12) at a single site. Whenever a value exceeds 60 minutes, then the cars arriving at peak time cannot be charged in time and longer waiting queues will build up. In this case, either more stations or more powerful stations need to be provided. So e.g. for the 10% uptake scenario (grey line in Fig. 3.4), at least 4 stations have to be installed to stay below the 60 minute mark.

Figure 3.4 also contains data extracted from the calculations outlined in Table 3.1 Based on the numbers of how many vehicles arrive in Williams, the charging demand increases proportionally. By installing just one charger, it is estimated it will take around 20 minutes to charge all EVs within a market share of 1%. With a market share of just 5% the charging time for all vehicles during peak hour would be around 100 minutes – during which more vehicles would queue up. This would create long waiting times for customer and would be against customer expectations. It would also create the problem that after 60 minutes, new cars would drive into the town and add to the already unacceptable long waiting time.

While the previous figure looked at multiples of 350kW station for various EV uptake scenarios, in Figure 3.5 we are now looking at different charging station power levels of 50kW, 150kW, and 350kW for the fixed uptake scenario of 1%. It is assumed that EVs stopping at this site (in this graph again, the town of Williams) can absorb the proposed power level. So for the future 1% EV uptake scenario, it would take around 20 minutes to charge all EVs with a single 350kW charger during peak hour. With a 150kW charger it would already take more than twice as long, almost 50 minutes, while a 50kW charger could not cope with the load (blue line off the chart: charging time over one hour). This would have the consequence of unacceptable long waiting times.

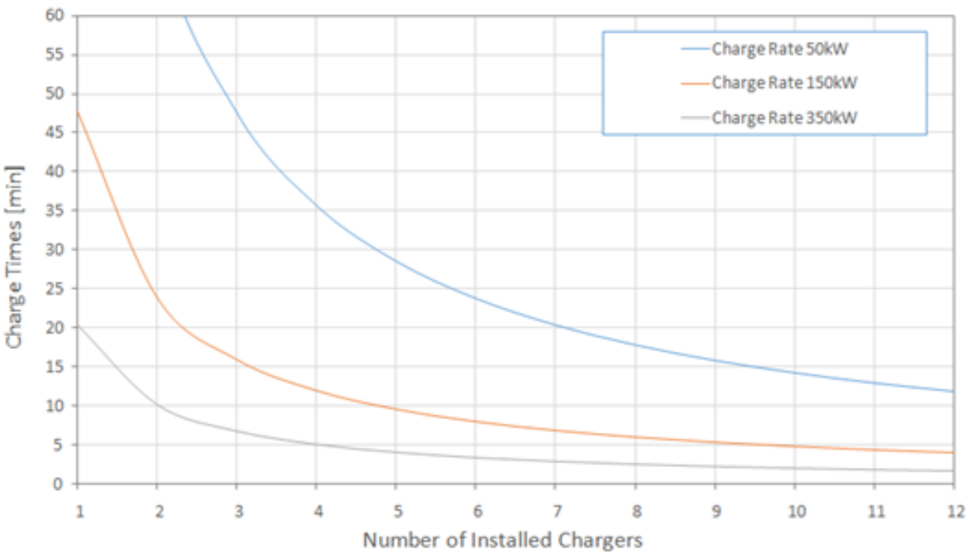

Figure 3.5 Charging times for Williams WA at 1% EV uptake for different charger numbers and power levels

The data from tables 3.1 to 3.3 and graphs Figures 3.4 and 3.5 are just an example for one route through Western Australia. The full data set is available in Appendix C and (even more complete) online at: http://REVproject.com/traffic/regional.xlsx .

For the calculations above it has been assumed that all EVs will recharge on every available station, drive through towns and do not stay overnight, there are no seasonal events, no EV club events and there is no change in the percentage of vehicle ownership among the general population.

Although traffic flow in regional and remote areas are similar in both directions, current public available data provides no information on how EVs would be distributed among current traffic flows along the proposed routes. This study assumed EVs are distributed evenly throughout the week.

The energy and peak load demands, such as recharge times are calculated for one direction only. As a consequence, some distances and hence energy demands between stations might vary slightly. This study does not take influences on increased energy consumptions from prevailing winds or other climate impacts into account. For future EV uptakes larger than 1%, these unknowns may become significant. A more accurate calculation for energy demand is recommended.

3.2. Urban Traffic in Perth

Determining charging requirements for the Perth metropolitan area is a much more complex task compared to regional and remote areas. In the metro area, EV drivers have the option to charge at home, charge at the workplace, or charge at existing slow AC public charging stations or at the proposed fast-DC charging stations. Although traffic flow data for Perth is available, this does not provide an indication, where and how far from home EVs will travel for charging. It is also unknown how many of these EVs will have the option to charge at the workplace or have enough battery capacity to drive to work and back home on a single charge.

For the proposed fast-DC charger locations and charge levels around the Perth metro area it is recommended to use the latest 350kW charging technology. Although many cars in 2019/2020 will only charge at 150kW, most EV manufacturers are likely to adopt this new charging level soon. Based on the current Perth population, the ratio of vehicles per resident, and an assumed EV fleet share of 1% of all vehicles, it is expected to have around 14'000 EVs driving around Perth metropolitan areas. Based on the estimated traffic through Perth (North/South and vice versa), it is recommended to distribute fast-DC charging locations to Perth central, northern, southern and eastern areas. Calculations shown that in order to cover the peak loads and energy demand for 1% market share, a minimum of 6 charging bays with 350kW chargers should be installed for each of the proposed 4 sites.

3.3. Customer Expectations of Charging Infrastructure

Consumers are looking for less expensive and greener modes of transportation. Many major automotive manufacturers responded and are offering several models of EVs. Customer have relatively high expectation for such vehicles, which include large range and short recharging times. These expectations are not met by all car manufacturers and infrastructure providers. Many customers believe that EVs have a much larger range and shorter home charging times than currently available from mainstream EV manufacturers [Businesswire 2017]. EV customers also have high expectations on recharging infrastructure, similar to that of fuel stations.

Besides high reliability and short waiting periods, a charging station should appear welcoming and well illuminated, safe and clean. Ideally, it should be with some amenities, such as shade, toilet, water and maintained rubbish bins. The chargers and payment system should be trustworthy and easy to use. Many market players entering the fast DC charge market provide their own payment methods and force customers to sign up for contracts and upfront payments. Several different and overcomplicated payments systems may constitute a barrier for long distance EV driving. As with fuel stations, an EV payment system should be designed that every individual can use, even occasionally, without specific preparations, such as downloading specific mobile phone apps or purchasing specific RFID tokens. Instead, a self-explanatory, easy to use payment system, such as for example the credit-card "pay wave" system should be used.

3.4. References

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Inside EVs 2014 — *Supercharging Tesla Model S 60 kWh Versus 85 kWh* – Video and Graphs, Inside EVs, Nov, 2014, online: https://insideevs.com/supercharging-tesla-model-s-60-kwh-versus-85-kwh-video-graphs/

Main Roads 2018 — *Traffic Map*, Main Roads Western Australia, 2018 online: https://trafficmap.mainroads.wa.gov.au/map

4. Energy Supply for Charging Infrastructure

Key findings:

- In many countries and in some other Australian states, such as Queensland, electricity supply companies are leading the investment in public EV charging infrastructure due to the many benefits that EV charging loads will provide in terms of increased revenues and new opportunities created for managing electricity supply loads and systems.
- Charging from public charging stations may account for as little as 10% in the Perth metro area, but will be close to 100% for long-distance travel.
- The SWIS requires significant upgrade investment, but the investment amount required could be reduced by using EV charging loads as a new controllable load.
- EV batteries could potentially play a significant role the WA's future electricity supply systems.
- In non-urban areas that are supplied via weak electricity grids, off-grid charging solutions may be a cheaper alternative to network upgrades.
- Investment in new renewable variable generation and energy storage to supply new DC fast charging loads in regional areas could provide a number of other social and economic benefits including supply diversity, strengthening of weak regional feeders and networks.

In many countries around the world, electricity supply companies (network operators and retailers) are the ones investing in EV charging infrastructure as they recognise they will be a major beneficiary of the electrification of transport. In some cases, such as California and the UK, governments have amended their electricity regulations to allow this to occur. Not only are electricity companies the best place to know where the optimal locations of EV charging stations should be from an electricity network perspective, but high penetrations of EVs offer electricity network operators a large new source of revenue, the ability to control large new loads, and better manage high penetrations of renewable energy generation. However, electricity utilities in Western Australia (WA) are not currently driving investment in EV charging infrastructure. Not only are these businesses constrained by capital expenditure budgets and the current regulatory framework, but investment in EV charging infrastructure is perceived to be outside of their current business models.

The expected increase in electricity demand in WA that will be created by 1%, 10% and 100% EV penetrations of will be around 0.1%, 1%, and 10% (4,400 GWh/year), respectively, of the current total electricity demand in WA. Revenue from electricity sales in a 100% WA EV fleet scenario will exceed $1 billion per year and will result in a major cost saving by reducing reliance on imported petroleum products.

EV operational costs ($/km) are already lower than those of internal combustion engines and EVs are parked for on average around 90% of the time. The idle EV batteries amount to significant storage capability and could potentially play a significant role in the future of WA's electricity supply infrastructure [Markel *et al.* 2009, McHenry 2013, Mullan *et al.* 2011].

The WA South West Interconnected System (SWIS) is an electricity network that spans a very large geographical area and is characterised by high demand variability, which makes it highly susceptible to large climatic variables. Like many networks around the world, the SWIS is in need of large investments to accommodate growth in peak demand, to be able to accommodate larger penetrations of distributed energy technologies, and to cater for a growth in demand [McHenry 2009, 2012a, 2012b; McHenry *et al.* 2011].

The single most important determinant of SWIS electricity peak demand is the daily ambient temperature. Daily peak electricity demand on hot summer days can be double the peak demand on cold days. Maximum electricity demand occurs after a sequence of hot days, and SWIS overnight loads are markedly lower than daytime loads. In the context of EVs, this seasonal, inter and intra-day demand variability provides an opportunity to explore new technology investments, demand side management (DSM) techniques, electricity storage, and related electricity market options.

Drivers of the growing technological diversity in the electricity sector include new market entrants, greater energy efficiencies, lower emissions, enhanced supply security, and the need for higher quality and quantities of electricity [Chicco & Mancarella 2009]. Coupled with a range of electrical technologies that are at different stages of development [Foxon *et al.* 2005], these drivers are impacting on and changing the roles and operations of both electricity utilities and electricity network infrastructure [Chicco & Mancarella 2009].

New energy policies can enable new technologies (such as EV supply equipment, EVSE) to improve electricity network power quantity and quality by establishing cost recovery mechanisms in bilateral electricity markets, short-term markets, load balancing markets, and capacity markets. However, at present, electricity markets generally favour conventional spinning reserve options, or DSM, rather than new automated technologies suitable for rapid demand response on the distribution network and smaller transmission network lines. For example, EVs have the potential to benefit the distribution network by shifting loads, even at relatively low EV penetrations [Mullan *et al.* 2011].

Rapidly advancing technical abilities of power electronics and electricity storage will mean little, however, unless policy-makers, electricity utilities, and markets attempt to distribute the costs and benefits of new investments effectively and fairly. The benefits of innovation in the publicly owned electricity utilities are distributed to all connected customers; preventing private entities from excluding people that are unable to pay for such benefits [Jaffe *et al.* 2005]. At present, the lack of parallel advancements in electricity policy and pricing mechanisms alongside the technological advancements are stifling beneficial investments that enable electricity networks to meet the growing diversity of new loads and generation within regulated standards of power quality [McHenry *et al.* 2016].

4.1. Energy Supply for Urban EVSE

The majority of EVs in WA will be used and charged in the greater Perth metropolitan area. Because residential charging is convenient and inexpensive, it is expected that most EV drivers will do most of their charging at home. The estimates vary and will differ from country to country, but many state that in countries in which off street parking and garages are common (such as the UK, the USA, NZ and Australia) over 80% of EV charging (kWh) will occur at the home [Chargedev 2018, US Office of Energy Efficiency and Renewable Energy 2018]. Home and work charging combined could therefore account for up to 90% of all EV charging (mostly overnight at home and during the day at work). If that is the case, public charging facilities will be required for only 10% to 20% of EV charging events. Fast-DC public EV charging technology power levels currently range from 50 kW to 350 kW per EV. Without additional EV electricity demand occurring in off-peak periods, significant penetrations of EVs would simply compound the already existing SWIS distribution network issues [McHenry, 2013]. However, urban areas in the SWIS have relatively good electricity capacity and availability, and moving a significant portion of passenger vehicle energy supplies from liquid fuels to electricity are not expected to be an issue on the SWIS in urban areas. There is a growing recognition of the opportunity to shift EV charging to off-peak periods, and also enabling the large storage capacity in EV batteries. The potential return to EV owners in participation in electricity markets can be simply calculated using time-resolution and electricity price data (Markel *et al*. 2009, McHenry, 2013, Mullan *et al.* 2011].

4.2. Energy Supply for Regional and Remote EVSE

In many non-urban areas the electricity networks have designed to supply relatively small amounts of electricity at the lowest cost. This usually means long, weak radial feeders with little or no spare capacity, which severely limits the ability to supply any potential new loads [Morton *et al.* 2005]. While charging EVs at night at low power levels will likely be of little importance at moderate EV penetrations, fast-DC charging in many locations will put pressure on the SWIS network. The large 'power' (in terms of kW) required for fast-DC charging EVs to supply a relatively small amount of electricity (in terms of kWh) is a challenge for conventional electricity systems. Many of the regional and remote areas of WA supplied by the SWIS are unable to supply the high power levels that fast-DC EV chargers can deliver (50-350 kW per EV). Network upgrade costs to enable fast-DC charging is sensitive to the distance from the zone substation, and will likely be prohibitively expensive for more than a few kilometres. Remote off-grid roadhouses are highly unlikely to receive new network services to support fast-DC charging. Likely energy supply options in remote areas include upgrading existing stand-alone power supply systems (SAPS), or new hybrid combinations of solar-PV, battery storage and diesel generators.

The traditional electricity network in WA (and most industrialised jurisdictions) were designed for radial, centralised generation, dependent on manual restoration [McHenry 2013, Sood *et al.* 2009]. Electricity networks themselves are becoming a major limiting factor in the provision of efficient and cost-effective electricity services, particularly for non-urban customers with high-consumption devices that exacerbate daily and seasonal peak demands.

The high impedances of many distribution networks (particularly in rural areas) are generally less able to tolerate load and generation imbalances relative to low impedance networks. Traditional means of managing distribution network voltage deviations are not designed to tolerate the rapid changes in electricity generation or demand [Willard *et al*. 2012]. Loads on the SWIS are shed at a frequency of 48.75 Hz, lower than the nominal 50 Hz, with a normal fluctuation between 0.4%. Most (>80%) electricity system faults on the SWIS occur in distribution systems, 80% of which are grounding faults, and 90% of which are instantaneous grounding faults [McHenry *et al*. 2011, Zeng et al. 2004]. These short term abnormal currents (sometimes large amperages) require rapid-response technologies to maintain supply [McHenry *et al*. 2016].

Traditional centralised/manual methods of voltage control in radial networks include using tap changers located at the distribution branches to increase or decrease voltages, and also parallel capacitor banks along the distribution line between tap changers. While traditional approaches do improve voltage control and capacitors emulate spinning reserve to provide additional reactive power, they are known to generate unwanted step-changes in voltage along the distribution line. Traditional capacitor bank switching also creates propagating transients along the line. Such approaches are becoming increasingly outmoded and insufficient for modern electricity networks, particularly for extreme/emergency situations [McHenry *et al.* 2016].

Incentives to promote geographic and technological diversity of variable generation and storage could reduce network augmentation costs for remote locations. In terms of new generation, the availability of both prospective gas and excellent solar resources in the north of WA will likely attract feasibility investigations. Additionally, unlike the complex correlation with wind and temperature, in practical terms there is a clear relationship between average solar PV generation and temperature in WA. More precisely, there are regionally differentiated positive correlations between the peak electricity demand and solar generation output. As an example, there is a better match between the solar resource with peak loads in Geraldton then there is in Kalgoorlie [Senergy Econnect 2009]. These known correlations provide an opportunity to better match PV output to supply increased electricity demand from EVSEs in specific regional areas, and avoid costly electricity network expansions. While variable generation in remote areas will provide system diversity, it may also require substantial network augmentation to connect to the SWIS. Those investing in new generation are currently required to bear the costs of such network augmentation. It could be argued that this investment should be rewarded in proportion to the benefits that they provide: the additional generation investment that occurs in the region subsequently, and the diversified security benefit that it provides to the network. One option for reducing network augmentation from new distributed generation is to utilise electricity storage.

Akin to peak shaving from DSM measures, electricity storage can increase system efficiency by keeping electricity network ratings lower than would otherwise be required and achieve higher marginal economic efficiencies [Xu *et al*. 2009]. The present lack of large electricity storage technologies requires generation and load to be balanced at all times [Kazemi & Andami 2004]. Newer generations of electronically-enabled storage devices now enable the ability to de-couple 'power' and 'energy' elements. In the recent past, traditional electrochemical battery systems were expensive and extremely limited by their depth of discharge, and expired after a relatively low number of charge/discharge cycles [Manfredi & Pagano 2011, Robbins & Hawkins 1997]. Battery-based storage systems are now extraordinarily fast, and many can ramp up to full capacity in the hundreds of kW in less than a second. This de-coupling of 'power' and 'energy' with modern power electronics provides additional flexibility and reliability of high power with stable output while maintaining system integrity and quality of service [Brunelli *et al.* 2009, Miller & Sartorelli 2010, McHenry *et al*. 2016].

The profitability of investment in electricity storage is dependent on the electricity market characteristics [Exarchakos *et al.* 2009]. Intertemporal arbitrage through storage of electricity is a possible mechanism to profit from fluctuations in demand and respective prices

[Borenstein *et al*. 2005]. Unfortunately, most electricity markets at present underappreciate and undervalue the benefits that storage can provide to an electricity system, which results in low levels of storage investment.

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5. Charging Infrastructure Benchmarking

Key findings:

- Current installations of publically accessible DC fast charging sites are:
  13 sites (plus 1 Tesla-only) in Western Australia (all in the South-West corner),
  57 sites (plus 22 Tesla-only) Australia-wide and
  169 sites (plus 6 Tesla-only) in New Zealand
- Tesla sites always have multiple charging stations, typically 6-8 chargers per site.
- For highway routes with long driving distances, numbers and locations will be determined primarily by distances between towns and the driving ranges of EVs.
- Different methods can be used to assist in determining the numbers, locations and types of public charging stations, including traffic flow analysis, engineering modelling, stakeholder engagement and feedback and requests.
- EV infrastructure benchmarking studies reveal that there is no ideal ratio of EVs to EV charging stations and that only general statements that can be made to guide policy makers and planners.
- A comprehensive and detailed benchmarking analysis that incorporated the amounts of incentives offered and the policy drivers behind the incentives may be useful in guiding policy makers and planners.

Policy makers and planners are required to make decisions on how to support the development of the EV market in their own particular jurisdictions, particularly in the early stages of EV market development. One of the common support options used, is to invest in, or to provide funding support for public EV charging infrastructure. In seeking guidance to answer questions such as how many charging stations will be required, or what will be the best mix of public AC and DC fast-charging stations, policy makers and planners often look to EV charging infrastructure benchmarking as a means of informing those decisions. For that reason, a number of such international EV infrastructure benchmarking analyses have been undertaken over recent years, including a recent analysis included in the EV study for ARENA and the Clean Energy Finance Corporation to inform Australian policy makers [Energeia 2018]. In the sections below, our own brief EV infrastructure benchmarking analysis is provided, followed by a discussion of the limitations of these benchmarking analyses to inform or guide policy makers. We begin by looking at the charging infrastructure that has been installed to date in Australia and New Zealand, as there are many similarities between these countries [Energia 2018].

5.1. Australia and New Zealand

There are inconsistencies in the available data on the EV charging infrastructure that has been installed in Australia to date. This stems in part from differences in terminology, such as low power vs high power, slow versus fast, and what types and sizes (kW) are included or are not included in those terms. According to the [IEA 2018], the number of publicly accessible charging stations that had been installed in Australia by the end of 2017 was 476, however, according to [PlugShare 2018], the number of fast-DC charging sites in Australia is currently only 79. Most of these have been installed on the Eastern seaboard in QLD, NSW, the ACT and Victoria. Of the 79 DC fast-charging sites, 57 are general usage sites, while the remaining 22 are proprietary Tesla-only superchargers (Fig. 5.1).

Fig. 5.1 Fast DC chargers installed in Australia as of Nov. 2018 *([PlugShare 2018])*

There are only 13 general access fast-DC charging sites in Western Australia, all of which are equipped with a single 50 kW charger. In addition, there is one Tesla Supercharging site with 6 x 125kW charger. Of the 13 general access sites, one is located at The University of Western Australia, one at the City of Swan, and 11 RAC-funded charging points are located at sites between Perth and Augusta. All of these stations are located in the Perth Metro and South-West WA region (Fig. 5.2).

Fig. 5.2 DC chargers in Western Australia (Source: [PlugShare 2018])

There are currently 169 public DC fast-charging sites plus 6 Tesla supercharger sites in NZ (Figure 5.3), which is a much denser infrastructure than in Australia.

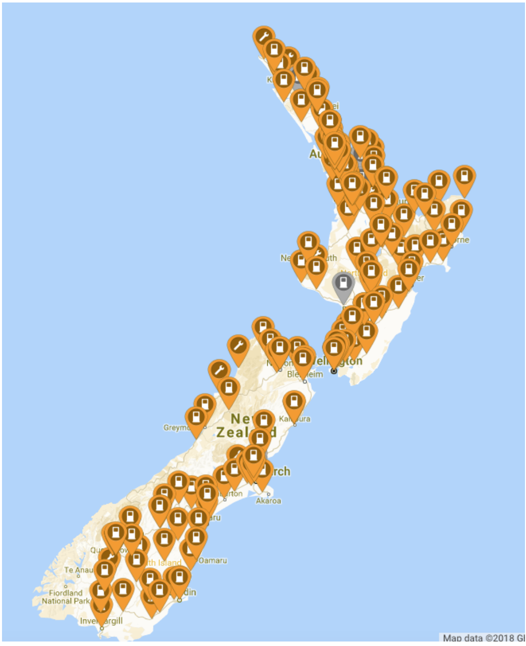

Fig. 5.3 DC chargers in New Zealand (source [PlugShare 2018])

5.2. Charging Station to EV Ratio

It was already one of the findings of the WA Electrical Vehicle Trial [Mader, Braunl 2013] that the main focus in public EV charging infrastructure should be on fast-DC stations and not on slower AC stations, even in metro areas. For regional long-distance travel, there is no alternative to DC charging. The ratios of fast charging stations to BEVs in the passenger vehicle are shown in Figure 5.4 for 13 countries with high EV penetration – plus Australia, whose ratio is not easily comparable to that of other countries, because of the low EV uptake.

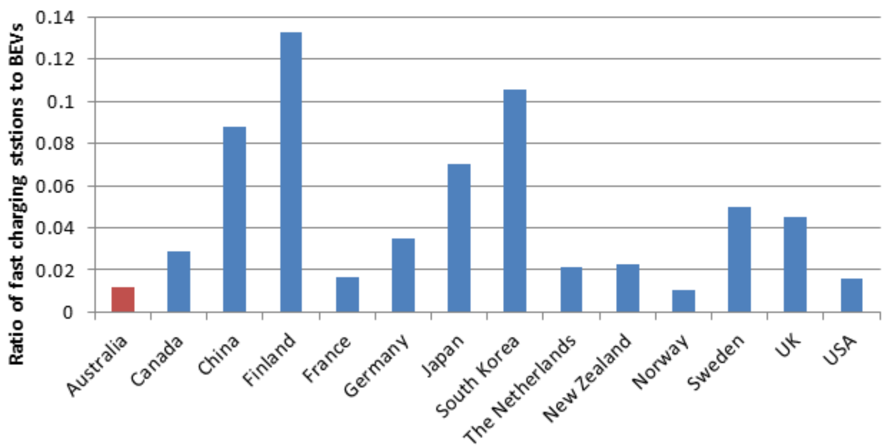

Fig. 5.4 Ratio of publicly accessible fast charging stations per BEV in the passenger vehicle fleet for fourteen countries (Source: [IEA 2018]).

It can be seen from Figure 5.4 that there are large differences in the ratios of fast-charging stations to BEVs between the fourteen countries for which data was provided. There are also significant differences between AC to EV, and DC to BEV ratios. In the case of Finland, for example, the ratio of the number of fast charging stations to the number of BEVs is much higher than the ratio of number of charging stations to the number of EVs. The primary reason for this is that PHEVs make up a large portion of the EV fleet in Finland, which means that the public fast chargers that have been installed in that country are used to service a relatively small portion of the EV fleet. There are likely to be a number of reasons for the high proportion of PHEVs in Finland’s EV fleet (88%), one being the significantly longer average driving distances in Finland compared that in highly urbanised countries, such as The Netherlands. By comparison, the Netherlands have a very high ratio of charging stations to EVs, but a low ratio of fast-charging stations to BEVs. One reason for that is that BEVs make up 82% of the EV fleet in the Netherlands, which is most likely due to the differences in incentives provided by The Netherlands government for BEVs and PHEVs.

The fact that the USA has a low ratio of fast-DC stations to BEVs is likely to be due to the very large differences between the US states, which also holds true for Canada. Some states in the USA, especially California, and some provinces in Canada, especially British Columbia, have high take up rates of EVs and high ratios of the number of EV charging stations to the number of EVs. Other states and provinces have very low EV uptake rates and low investment in EV charging infra-structure, which pulls the national averages down.

Norway is a particularly interesting case. It is the country with the highest uptake rate of EVs in the world (i.e. the country with highest percentage of EVs in new vehicle sales and the highest percentage of EVs in the passenger fleet). Despite this, it has a relatively low ratio fast-DC charging stations to BEVs. The reason for this relates primarily to a deliberate policy position adopted by the Norwegian government that if it provided strong incentives for the EVs, the stock of EVs would be increased sufficiently for investment by others in EV charging infrastructure to automatically follow. This provides an example of how government policy is a significant determinant of the ratio of the number of EV charging stations to the number of EVs in any country. A second reason is that BEVs make up 66% of the EV fleet in Norway, despite having average driving distances comparable to those in Finland. This is supported by the strong Finnish electricity distribution grid that facilitates home and work charging, and the importation of low cost, second hand BEVs from other European countries.

Another problem associated with EV charging infrastructure benchmarking is the definition of a ‘fast charger’. Most organisations, such as the IEA and the European Alternative Fuel Observatory, distinguish between ‘normal chargers’ or ‘slow chargers’ (≤ 22 kW or less), and everything else, both AC and DC, as a ‘fast chargers’ or a ‘high power chargers’. Published information on the numbers of DC fast chargers (≥ 50 kW, 3-phase, DC) that have been installed in each country is not as readily available. It would be possible, with some difficulty, to use data sources such as PlugShare, to obtain the *current* numbers of DC fast charging stations installed in some countries, but for others it would be quite difficult to do so as the numbers are large and delineation between countries is difficult. However, an indication of the large differences between countries in terms of the numbers of DC fast chargers that have been installed was provided in an analysis undertaken by [Hall and Lutsey 2017]. Figure 5.5 shows the number of publicly accessible EV charging stations per 1,000 of population, and the proportion of the public charging stations that are DC fast charging stations, for fifteen selected countries.

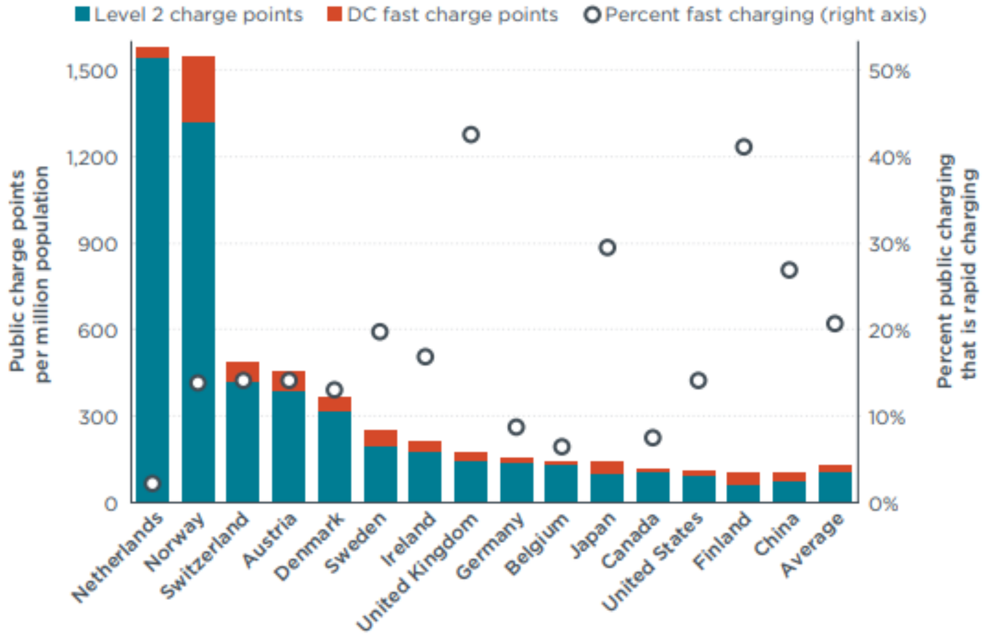

Fig. 5.5. The number of publically accessible charging stations per 1000 population, and the percentage of public charging stations that are DC fast charging stations, for 15 selected countries (Source: [Hall and Lutsey 2017])

The percentages of publically accessible charging stations that are DC fast charging stations ranges for the 15 countries in Figure 5.5 from approximately 2% (The Netherlands) to over 40% (UK and Finland). The reasons for these differences are manyfold. They include differences in government policies, differences in the levels of investment in public charging infrastructure, and differences in the degree to which electricity utilities or other businesses invest in public EV charging infra-structure. The Netherlands, for example, has a comparatively high number of EV charging stations per EV, but the percentage of EV charging stations that are DC fast charging stations is very low.

This demonstrates the difficulty in using a benchmark to determine what the number of public EV charging stations should be. The data indicates that the differences between countries are simply too large to make anything other than quite general statements.

5.3. Adopted Benchmarking Ratios.

Despite the vagaries associated with EV infrastructure benchmarking discussed in the preceding sections, a number of organisations have developed benchmark ratios of the number of charging stations to the number of EVs (Table 5.1), however, these refer to general AC or DC charging points and not specifically to DC fast-chargers.

Table 5.1. Ratios of the numbers of EV charging stations to the number of EVs set by various organisations (Source: Hall and Lutsey 2017).

Organization	Region	Electric vehicle/public charge point ratio	Source
European Council	European Union	10	European Parliament (2014)
NDRC	China	8 (pilot cities), 15 (other cities)	NDRC (2015)
IEA Electric Vehicle Initiative	Worldwide	8 (2015), 15 (2016)	EVI (2016, 2017)
EPRI	United States	7-14	Cooper & Schefter (2017); EPRI, 2014
NREL	United States	24	Wood et al. (2017)
CEC/NREL	California	27	CEC & NREL (2017)

The conclusions that Hall and Lutsey drew from their analysis of EV infrastructure benchmarking, however, was that while policy makers have looked to benchmarking to inform themselves what the ratio of the number of EV charging stations to the number of EVs should be, and some have set target ratios:

> "*Although it is widely recognized that charging infrastructure will be required to expand the electric vehicle market, there is considerable uncertainty about the precise amount of public charging infrastructure needed to reach a given market size … there is no single global answer to this question. ... The rapid development of the technology means that the situation may be quite different in a few years. Furthermore, local conditions, the availability of private and workplace charging, and the mix of electric vehicle types could also strongly influence the appropriate level of public charging infrastructure deployment in various markets*". [Hall, Lutsey 2017]

The requirements for urban EV charging infrastructure and the requirements for EV charging infrastructure on highways or regional and remote routes are very different, as they serve very different types of users. The critical issue for the former is the safe driving range of BEVs used for long intercity or inter-regional driving trips. The question that arises from this is whether or not EV infrastructure benchmarking analyses can assist or guide policy makers and planners in terms of the numbers of EV charging stations required for highway or non-urban routes, or the appropriate distances between charging stations on these routes.

Policy makers in some countries have adopted such metrics. For example, the public electricity company in Norway, Enova, adopted a policy that there should be one DC fast charging station every 50 km on the Norwegian main road network

(7,500 km), with at least two stations per site [Lorentzen *et al.* 2017]. Similarly, the Indian government has adopted a target of at least two high-charge points and one fast-charge point every three kilometres in cities and one EV station every 50 km on highway routes [Business Today 2018]. In the case of New Zealand's Electric Highway, the DC fast charging stations are located at sites approximately 75 km apart [Hunt 2018]. However, while these sorts of numbers may be appropriate or applicable in countries with large populations, high population densities and relatively short distances between cities and towns, they are not applicable to countries with regional areas with low population densities and with highway routes characterised by large driving distances between towns. To be useful for policy makers in WA the focus needs to be on cases with highway routes with large distances between regional towns.

In the case of British Columbia, EV highway corridors were created along selected (high tourism) highway routes. The guideline used to select sites for installing DC fast charging was to focus on town centres close the highways, with a preference for sites located 50 to 70 km apart [Fraser Basin Council 2015]. It is worth noting that the Fraser Basin Council report was prepared almost four years ago and that the driving ranges of new BEVs have increased significantly since then. However, the decision to install in or close to town centres was driven by the fact that these locations have the required infrastructure (telecommunications, security, amenities, power supplies, etc.), and the fact that the purpose of the electric highway was to facilitate tourist business in these towns. The important metric here is not a ratio that can be determined from any benchmarking analysis, but is simply a preference for siting DC fast charging stations in or close to regional townships, and therefore the metric becomes the distances between townships in which the DC fast charging stations are installed. However, those distances vary significantly from one country or region to another. For example, the DC fast-charging stations along the Queensland Electric Highway are on average located approximately 200 km apart, but the furthest distance between charge points is 400 km [Graham 2018].

Therefore, no metric can be derived from an EV charging benchmarking analysis to determine what the number, or in what locations DC fast EV charging stations should be installed on highway routes in WA. Those parameters are determined purely by safe driving ranges of EVs, traffic volumes on the routes, and the ability to use sites in regional townships or roadhouses. In the case of highway routes in WA, due to the low numbers of townships *en route* and the relatively large distances between townships, the distances between DC fast charging stations on non-urban highway routes will be determined largely by the driving ranges of EVs, taking into account the need for safety margins (10% or more of charge) to ensure that EVs are not stranded between charging stations. Due to the need to provide amenities, security, power, etc., at charging station sites, where ever driving ranges permit, the distances will be dictated simply by the distances to the next township or roadhouse. Only where that distance exceeds the EV driving range (with safety margins) will charging stations between townships or roadhouses need to be installed.

While the use of traffic flow data is extremely useful in determining in which locations, what types and what numbers of charging stations will be required in regional townships, it is not always simple to use traffic flow data for that purpose. In the cases of Narrogin and Collie in WA, for example, the traffic flow data available is too complex to be able to use it to readily understand how many vehicles are travelling to and from these townships, or to or from what destinations. In some cases, additional methods to determine the locations, numbers and types of public EV charging stations will have to be used. This situation is not particular to WA, as such additional methods have been used elsewhere. In The Netherlands, for example, during the early roll-out of public charging infrastructure, two different strategies were employed to determine the locations in which to install public charging stations. One of the strategies was based on requests by EV drivers (demand driven), while the other was based on requests by local or regional government bodies, which tended to be locations near public facilities (governmental buildings, shopping malls) or in strategic locations where (occasional) use was expected (e.g. sporting grounds and leisure locations) [Helmus *et al.* 2018]. What this demonstrates, yet again, is the complexity of EV charging infrastructure benchmarking analyses. In order for such analyses to be sufficiently comprehensive to be useful in informing decision making, they need to take into account many variables and factors, including the methods used in other countries to determine the locations, types and numbers of public EV charging infrastructure.

For an EV infrastructure benchmarking analysis to be useful for informing policy makers, it needs to be far more complete and far more comprehensive in scope and detail than most of the analyses undertaken to date. It needs to explain the differences in incentives, but also the differences in the policy drivers that lie behind the decisions to provide those incentives. To that end, a large amount of data was collected and analysed in order to be able to undertake a comprehensive EV charging infrastructure benchmarking analysis, which is included in this report as Appendix A. The extensiveness of Appendix A was synthesized into this brief discussion to illuminate the limitations of benchmarking comparisons between variables in other jurisdictions to policy makers in WA.

5.4. References

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6. Proposed Charging Infrastructure for WA

Key findings:

- There is a necessity to act now on EV charging infrastructure, as new generation EVs with longer range, shorter charging times and lower total cost of ownership are being imported into Australia.
- There should be a max. distance of 200km between stations of the charging grid.
- A total of 138 station at 61 sites are recommended to install. (WA has currently just 13 publicly accessible DC charging sites at 1 x 50 kW each.)
- A charging level of 2 x 150 kW or above should be used wherever the local grid is capable of supplying this.
- CCS2 (Combined Charging System Type 2, IEC 62196-3), is the recommended charging norm (with a secondary CHAdeMO output for legacy cars).
- Some off-grid charging sites will need to be SAPS powered (Stand-Alone Power System), but will still create less emissions than a diesel vehicle.
- Government coordination is recommended for ensuring optimal station placement and interoperability.
- Three variations of charging infrastructure have been prepared: Proposed, Minimum and Extended.

This chapter presents a proposal for a state-wide EV charging infrastructure roll-out, considering all factors presented in the previous chapters. The proposal lists the required infrastructure for a 1% EV fleet scenario that Western Australia is likely to reach around the year 2025/2026 in the absence of any government incentives or other outside factors. If incentives are introduced, the timing of this scenario will be brought forward.

It is generally accepted that the automotive industry will eventually shift to 100% zero emission vehicles. Several countries, including the UK and France, have proposed a complete ban for ICE vehicles from the year 2040. This will have a global effect on the types of cars being produced, and will therefore affect Australia – with or without local legislation – as Australia no longer has an automotive industry.

6.1. Assumptions

A number of assumptions had to be made for the analysis and proposal presented in this chapter. These are listed below:

- Vehicle types: Considering passenger cars only; not enough data is available for long-distance heavy vehicles.
- Fleet uptake scenario: EVs make up 1% of the total light vehicles fleet
- Charging grid: All sites should be less than 200km apart from each other
- EV charging level: 150+kW via CCS2 from model year 2019/2020
- EV range: 250+km per charge under reasonable conditions (see below)
- Energy usage: 175Wh/km for local traffic, 200Wh/km for highway traffic *(at 110km/h, use of air-conditioning or heating, no heavy headwinds, no heavy loads)*

- Vehicles per resident: 0.61 (same as ICE cars)
- Population data: As sourced from the Internet (relevant for local traffic only) No change in population is considered
- Daily distance driven: 36km (same as ICE cars; relevant for local traffic only)
- Home/work charging: 85% of total energy consumption (local traffic only)
- DC charging peak: Contributes 12% to total daily charging energy. Each site can charge its peak EV load in less than 60min.
- Station cost: $127k (350kW), $70k (150kW), $30k (50kW), as per quotes
- Installation cost: $15k (350kW), $8k (150kW), $5k (50kW), estimated (site-dependent)
- Land lease or purchase: Costs are not included
- Annual maintenance and repair: Costs are not included
- Power de-rating: 70% (350kW), 80% (150kW), 88% (50kW) effectively usable continuous power rate during charging
- SAPS cost: $17k for 65kVA (for 50kW station) or $35k for 200kVA (for 150kW station)
- Grid connection cost: Indicative cost (+/-50% margin) as provided by Western Power and Horizon Power, respectively
- Highway traffic: Traffic data as provided by MainRoads WA. It is assumed that cars drive through towns and do not stay overnight. It is assumed that EV numbers are evenly distributed throughout the week.
- Highway charging: It is assumed that EVs will stop at all stations along a route
- Other: No seasonal effects are considered No EV club activities are considered

Assumptions can be changed in spreadsheet files *"stations.xlsx"* and *"regional.xlsx"*, in order to update the scenario.

6.2. Charging infrastructure Proposal

The map in Fig. 6.1 outlines the recommend infrastructure for the 1% EV fleet scenario. This recommendation proposes to use the latest charging technology with a rating of 350 kW wherever there is sufficient grid capacity, given the fact that the EV fleet will not stop at 1%. Only a few years later, the EV fleet will have grown to 10%, requiring a tenfold increase in the amount of charging power required, and will further grow from there. Whenever a grid connection is available, at least 150 kW chargers are proposed, while 50 kW systems are proposed for locations off-grid that will need to be powered by SAPS. As the grid connection and install costs outweigh the cost of the EV chargers, it may be prudent to install stations with a higher power rating, giving a better user experience.

Table 6.1 outlines the estimated power usage per site, which comprises highway travel as well as local charging, the proposed charging equipment and cost for the 1% uptake scenario. Major cities are listed in blue, major holiday destinations in red colour. Station cost, incl. installation and grid connection costs as quoted by Western Power, Horizon Power, and BHP respectively, are shown in Table 6.2.

The South-West route has a mix pf 350 kW (grid permitting) and 150 kW stations, while the South Coast has 150 kW and 50 kW stations, due to the weak grid. The Goldfields route has 350 kW stations throughout, while the Nullarbor is restricted to 50 kW stations, powered by SAPS. The Midwest has mostly 150 kW stations and some 50 kW (SAPS). Gascoyne/Pilbara has about half the sites with 350 kW stations and half with 50 kW (SAPS), while Kimberley and the Inland route have a mix of 150 kW stations (grid) and 50 kW (SAPS).

In Table 6.2, greyed-out boxes are used in the grid connection columns, if either a connection type is not considered (e.g. 50kW/150kW for Perth metro or 350kW for SAPS) or when the power utility Western Power or Horizon Power, resp., deemed the grid not strong enough to support a certain power connection level. When the power utility had some doubt about a specific power connection, the table entry has a coloured background. If not even 2 x 150kW could be supported with grid connection, the cost for SAPS has been used. Colour usage for connection cost:

- Black: Western Power
- Purple: Horizon Power
- Green: SAPS (off-grid)
- Orange: BHP (using cost estimate, as no quote has been received so far)

Table 6.1 Proposed charging infrastructure configuration

PROPOSED				Residents	Residents	Traffic	Total req.	De-rated			Bays	Bays	Bays
			Local Evs at	charging	peak hour	peak hour	peak hour	Installed	Installed	Total	[kW]	[kW]	[kW]
Site	Location	Population	1% uptake	[kWh]	power [kW]	power [kW]	power [kW]	power [kW]	power [kW]	Bays	350	150	50
METRO		*2'300'000*	*14'030*										
1	**PERTH / WEST PERTH / LEEDERVILLE**	**575'000**	3'508	3'315	398	100	**498**	**1'470**	2100	6	6		
2	**JOONADALUP**	**575'000**	3'508	3'315	398	100	**498**	**1'470**	2100	6	6		
3	**FREMANTLE**	**575'000**	3'508	3'315	398	100	**498**	**1'470**	2100	6	6		
4	**SOUTH PERTH / VICTORIA PARK**	**575'000**	3'508	3'315	398	100	**498**	**1'470**	2100	6	6		
SOUTH-WEST													
5	**BUNBURY**	**72'403**	442	417	50	116	**166**	**490**	700	2	2		
6	**MARGARET RIVER**	**7'654**	47	44	5	39	**44**	**490**	700	2	2		
7	PEMBERTON	974	6	6	1	27	**28**	**240**	300	2		2	
8	WALPOLE	439	3	3	0	18	**18**	**240**	300	2		2	
9	**ALBANY**	**29'373**	179	169	20	**146**	**166**	**490**	700	2	2		
10	KOJONUP	1'298	8	7	1	40	**41**	**490**	700	2	2		
11	WILLIAMS	948	6	5	1	83	**84**	**240**	300	2		2	
SOUTH COAST													
12	BROOKTON	756	5	4	1	20	**21**	**240**	300	2		2	
13	HYDEN	377	2	2	0	17	**17**	**240**	300	2		2	
14	RAVENSTHORPE	498	3	3	0	**34**	**34**	**88**	100	2			2
15	JERRAMUNGUP	356	2	2	0	9	**9**	**88**	100	2			2
16	**ESPERANCE**	**12'107**	74	70	8	28	**36**	**490**	700	2	2		
GOLDFIELDS													
17	**NORTHAM**	**6'548**	40	38	5	68	**73**	**490**	700	2	2		
18	MERREDIN	2'636	16	15	2	25	**27**	**490**	700	2	2		
19	SOUTHERN CROSS	638	4	4	0	13	**13**	**490**	700	2	2		
20	COOLGARDIE	878	5	5	1	18	**19**	**490**	700	2	2		
21	**KALGOORLIE**	**30'509**	186	176	21	9	**30**	**490**	700	2	2		
22	NORSEMAN	581	4	3	0	14	**14**	**490**	700	2	2		
NULLARBOR													
23	BALLADONIA HOTEL	10	0	0	0	11	**11**	**88**	100	2			2
24	CAIGUNA ROADHOUSE	10	0	0	0	14	**14**	**88**	100	2			2
25	MADURA ROADHOUSE	10	0	0	0	10	**10**	**88**	100	2			2
26	EUCLA	53	0	0	0	13	**13**	**88**	100	2			2
MIDWEST													
27	**LANCELIN**	**714**	4	4	0	51	**51**	**240**	300	2		2	
28	**JURIEN BAY**	**1'761**	11	10	1	64	**65**	**240**	300	2		2	
29	**GERALDTON**	**37'432**	228	216	26	77	**103**	**490**	700	2	2		
30	KALBARRI	1'557	9	9	1	10	**11**	**240**	300	2		2	
31	BILLABONG ROADHOUSE	10	0	0	0	27	**27**	**88**	100	2			2
32	OVERLANDER ROADHOUSE	10	0	0	0	6	**6**	**88**	100	2			2
33	**DENHAM**	**754**	5	4	1	11	**12**	**240**	300	2		2	
GASCOYNE / PILBARA													
34	CARNAVON	4'426	27	26	3	**25**	**28**	**490**	700	2	2		
35	MINILYA BRIDGE ROADHOUSE	10	0	0	0	8	**8**	**88**	100	2			2
36	**EXMOUTH**	**2'514**	15	14	2	20	**22**	**490**	700	2	2		
37	NANUTARRA ROADHOUSE	10	0	0	0	12	**12**	**88**	100	2			2
38	FORTESCUE RIVER ROADHOUSE	10	0	0	0	16	**16**	**88**	100	2			2
39	**KARRATHA**	**15'828**	97	91	11	11	**22**	**490**	700	2	2		
40	WHIM CREEK	32	0	0	0	10	**10**	**88**	100	2			2
41	**PORT HEDLAND**	**13'828**	84	80	10	**14**	**24**	**490**	700	2	2		
KIMBERLEY													
42	PARDOO ROADHOUSE	10	0	0	0	8	**8**	**88**	100	2			2
43	SANDFIRE ROADHOUSE	10	0	0	0	7	**7**	**88**	100	2			2
44	ECO BEACH	10	0	0	0	11	**11**	**88**	100	2			2
45	**BROOME**	**13'984**	85	81	10	9	**19**	**240**	300	2		2	
46	WILLARE BRIDGE ROADHOUSE	3'511	21	20	2	21	**23**	**240**	300	2		2	
47	FITZROY CROSSING	1'297	8	7	1	16	**17**	**240**	300	2		2	
48	MARY POOL CAMPGROUND	10	0	0	0	11	**11**	**88**	100	2			2
49	HALLS CREEK	1'499	9	9	1	18	**19**	**240**	300	2		2	
50	WARMUN ROADHOUSE	10	0	0	0	17	**17**	**240**	300	2		2	
51	**WYNDHAM**	**780**	5	4	1	10	**11**	**240**	300	2		2	
52	KUNUNURRA	5'308	32	31	4	9	**13**	**240**	300	2		2	
INLAND													
53	WONGAN HILLS	898	5	5	1	10	**11**	**240**	300	2		2	
54	WUBIN	103	1	1	0	4	**4**	**240**	300	2		2	
55	PAYNES FIND ROADHOUSE	10	0	0	0	5	**5**	**88**	100	2			2
56	MOUNT MAGNET	470	3	3	0	10	**10**	**240**	300	2		2	
57	MEEKATHARRA	708	4	4	0	6	**6**	**240**	300	2		2	
58	KUMARINA ROADHOUSE	75	0	0	0	6	**6**	**88**	100	2			2
59	**NEWMAN**	**7'238**	44	42	5	7	**12**	**240**	300	2		2	
60	AUSKI TOURIST VILLAGE	10	0	0	0	7	**7**	**88**	100	2			2
61	WODGINA MINE	210	1	1	0	8	**8**	**88**	100	2			2
	Major cities					combined routes			**Total power [MW]**				
	Major holiday destinations				**1.79**	**1.73**	**3.52**	**20.52**	**27.90**	138	56	42	40

Table 6.2 Estimated cost of proposed charging configuration

PROPOSED Site	Location	Station cost	Install cost	Grid Provider	Grid connect or SAPS	Grid cost 700kVA	Grid cost 300kVA	Grid cost 100kVA	Site cost	Route Subtotal
	METRO									**METRO**
1	**PERTH / WEST PERTH / LEEDERVILLE**	$762'000	$90'000	Western Pov	$628'000	$436'000			**$1'480'000**	
2	**JOONADALUP**	$762'000	$90'000	Western Pov	$448'000	$273'000			**$1'300'000**	
3	**FREMANTLE**	$762'000	$90'000	Western Pov	$448'000	$273'000			**$1'300'000**	
4	**SOUTH PERTH / VICTORIA PARK**	$762'000	$90'000	Western Pov	$448'000	$273'000			**$1'300'000**	$5'380'000
	SOUTH-WEST									**SOUTH-WEST**
5	**BUNBURY**	$254'000	$30'000	Western Pov	$255'000	$255'000	$215'000	$198'000	**$539'000**	
6	**MARGARET RIVER**	$254'000	$30'000	Western Pov	$274'000	$274'000	$231'000	$213'000	**$558'000**	
7	PEMBERTON	$140'000	$16'000	Western Pov	$231'000		$231'000	$213'000	**$387'000**	
8	WALPOLE	$140'000	$16'000	Western Pov	$231'000		$231'000	$213'000	**$387'000**	
9	**ALBANY**	$254'000	$30'000	Western Pov	$255'000	$255'000	$215'000	$198'000	**$539'000**	
10	KOJONUP	$254'000	$30'000	Western Pov	$274'000	$274'000	$231'000	$213'000	**$558'000**	
11	WILLIAMS	$140'000	$16'000	Western Pov	$231'000		$231'000	$213'000	**$387'000**	$3'355'000
	SOUTH COAST									**SOUTH COAST**
12	BROOKTON	$140'000	$16'000	Western Pov	$231'000		$231'000	$213'000	**$387'000**	
13	HYDEN	$140'000	$16'000	Western Pov	$231'000		$231'000	$213'000	**$387'000**	
14	RAVENSTHORPE	$60'000	$10'000	Western Pov	$213'000		$70'000	$213'000	**$283'000**	
15	JERRAMUNGUP	$60'000	$10'000	Western Pov	$213'000		$70'000	$213'000	**$283'000**	
16	**ESPERANCE**	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	$1'799'000
	GOLDFIELDS									**GOLDFIELDS**
17	**NORTHAM**	$254'000	$30'000	Western Pov	$255'000	$255'000	$215'000	$198'000	**$539'000**	
18	MERREDIN	$254'000	$30'000	Western Pov	$274'000	$274'000	$231'000	$213'000	**$558'000**	
19	SOUTHERN CROSS	$254'000	$30'000	Western Pov	$274'000	$274'000	$231'000	$213'000	**$558'000**	
20	COOLGARDIE	$254'000	$30'000	Western Pov	$274'000	$274'000	$231'000	$213'000	**$558'000**	
21	**KALGOORLIE**	$254'000	$30'000	Western Pov	$255'000	$255'000	$215'000	$198'000	**$539'000**	
22	NORSEMAN	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	$3'211'000
	NULLARBOR									**NULLARBOR**
23	BALLADONIA HOTEL	$60'000	$10'000	SAPS	$34'000		$110'000	$34'000	**$104'000**	
24	CAIGUNA ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
25	MADURA ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
26	EUCLA	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	$416'000
	MIDWEST									**MIDWEST**
27	**LANCELIN**	$140'000	$16'000	Western Pov	$231'000		$231'000	$213'000	**$387'000**	
28	**JURIEN BAY**	$140'000	$16'000	Western Pov	$231'000		$231'000	$213'000	**$387'000**	
29	**GERALDTON**	$254'000	$30'000	Western Pov	$255'000	$255'000	$215'000	$198'000	**$539'000**	
30	KALBARRI	$140'000	$16'000	Western Pov	$231'000		$231'000	$213'000	**$387'000**	
31	BILLABONG ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
32	OVERLANDER ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
33	**DENHAM**	$140'000	$16'000	Horizon Power	$175'000		$175'000	$175'000	**$331'000**	$2'239'000
	GASCOYNE / PILBARA									**GASCOYNE / PI**
34	CARNAVON	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	
35	MINILYA BRIDGE ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
36	**EXMOUTH**	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	
37	NANUTARRA ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
38	FORTESCUE RIVER ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
39	**KARRATHA**	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	
40	WHIM CREEK	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
41	**PORT HEDLAND**	$254'000	$30'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$459'000**	$2'252'000
	KIMBERLEY									**KIMBERLEY**
42	PARDOO ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
43	SANDFIRE ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
44	ECO BEACH	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
45	**BROOME**	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
46	WILLARE BRIDGE ROADHOUSE / DERBY	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
47	FITZROY CROSSING	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
48	MARY POOL CAMPGROUND	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
49	HALLS CREEK	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
50	WARMUN ROADHOUSE	$140'000	$16'000	Horizon Power	$175'000		$175'000	$175'000	**$331'000**	
51	**WYNDHAM**	$140'000	$16'000	Horizon Power	$175'000		$175'000	$175'000	**$331'000**	
52	KUNUNURRA	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	$2'733'000
	INLAND									**INLAND**
53	WONGAN HILLS	$140'000	$16'000	Western Pov	$231'000		$231'000	$213'000	**$387'000**	
54	WUBIN	$140'000	$16'000	Western Pov	$231'000		$231'000	$213'000	**$387'000**	
55	PAYNES FIND ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
56	MOUNT MAGNET	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
57	MEEKATHARRA	$140'000	$16'000	Horizon Power	$175'000	$175'000	$175'000	$175'000	**$331'000**	
58	KUMARINA ROADHOUSE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
59	**NEWMAN**	$140'000	$16'000	BHP	$175'000	$175'000	$175'000	$175'000	**$331'000**	tentative
60	AUSKI TOURIST VILLAGE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	
61	WODGINA MINE	$60'000	$10'000	SAPS	$34'000		$70'000	$34'000	**$104'000**	$2'183'000
	Major cities	**Stations**	**Install**		**Grid / SAPS**				**Grand Total**	
	Major holiday destinations	$11'252'000	$1'376'000		$10'940'000				**$23'568'000**	*$23'568'000*

The **proposed solution** has 61 fast-DC charging sites (138 stations total), including 4 sites (24 stations) in the Perth metro area ($5.4 million) and 57 sites (114 stations) in regional WA ($18.2 million).

The total estimated cost of this *proposal* is $23.6 million *(not including land value).*

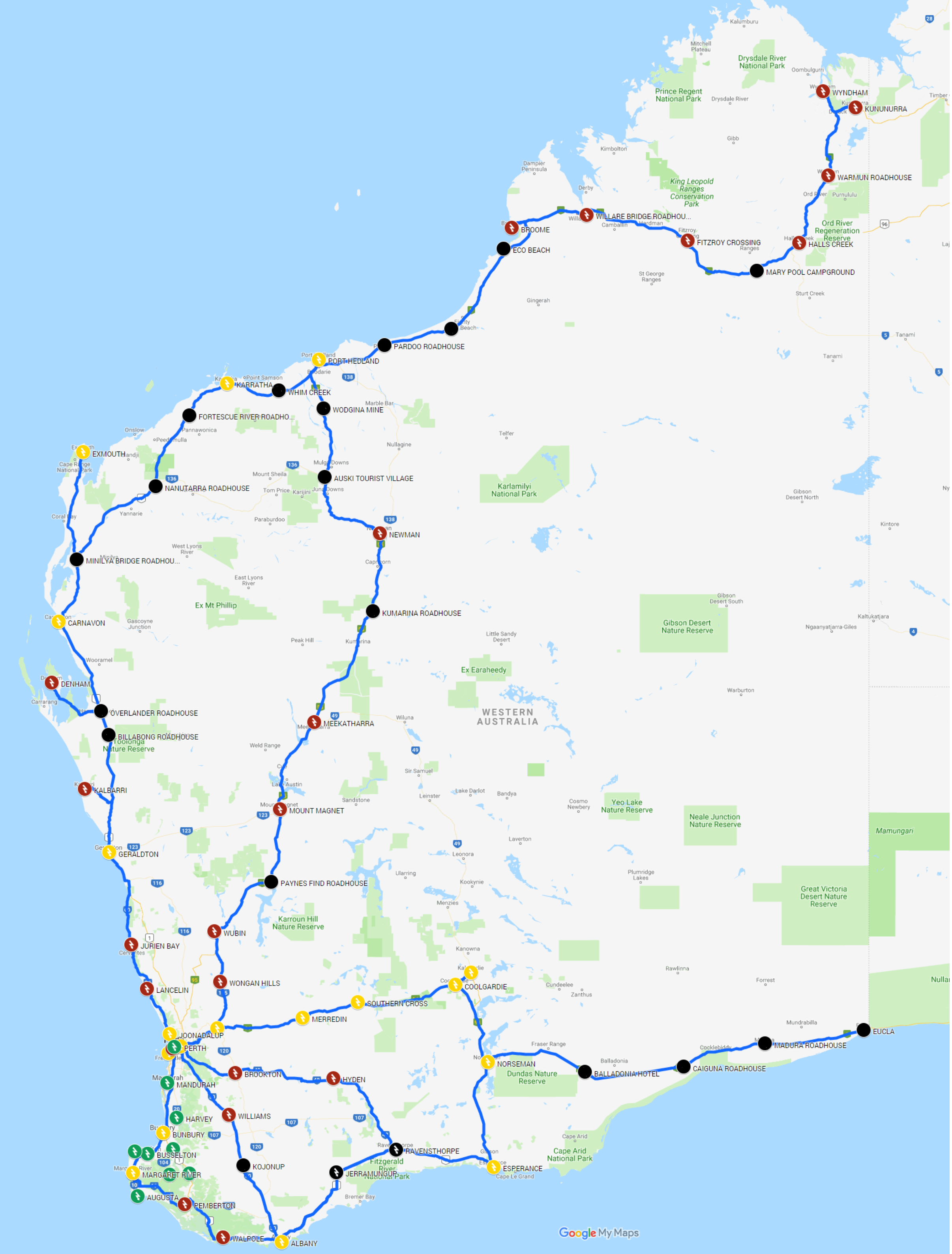

Fig. 6.1: Recommended 200 km charging grid for WA, green: existing 1x50 kW,
black: proposed 2x50 kW, red: proposed 2x150 kW, yellow: proposed 2-6x350 kW,
black sites without power symbol are off-grid; Ravensthorpe, Jerramungup have a weak grid.

Fig. 6.2 and Table 6.3 outline the **minimal infrastructure requirements**, based on charging requirements for the 1% EV fleet scenario. The number of sites and stations remain the same (total of 61 sites and 138 stations), but uses lower-specification charging stations and therefore slightly cheaper grid connection costs for an overall savings of $4.7 million.
The total estimated cost for the *minimum solution* is $18.9 million *(not incl. land value).*

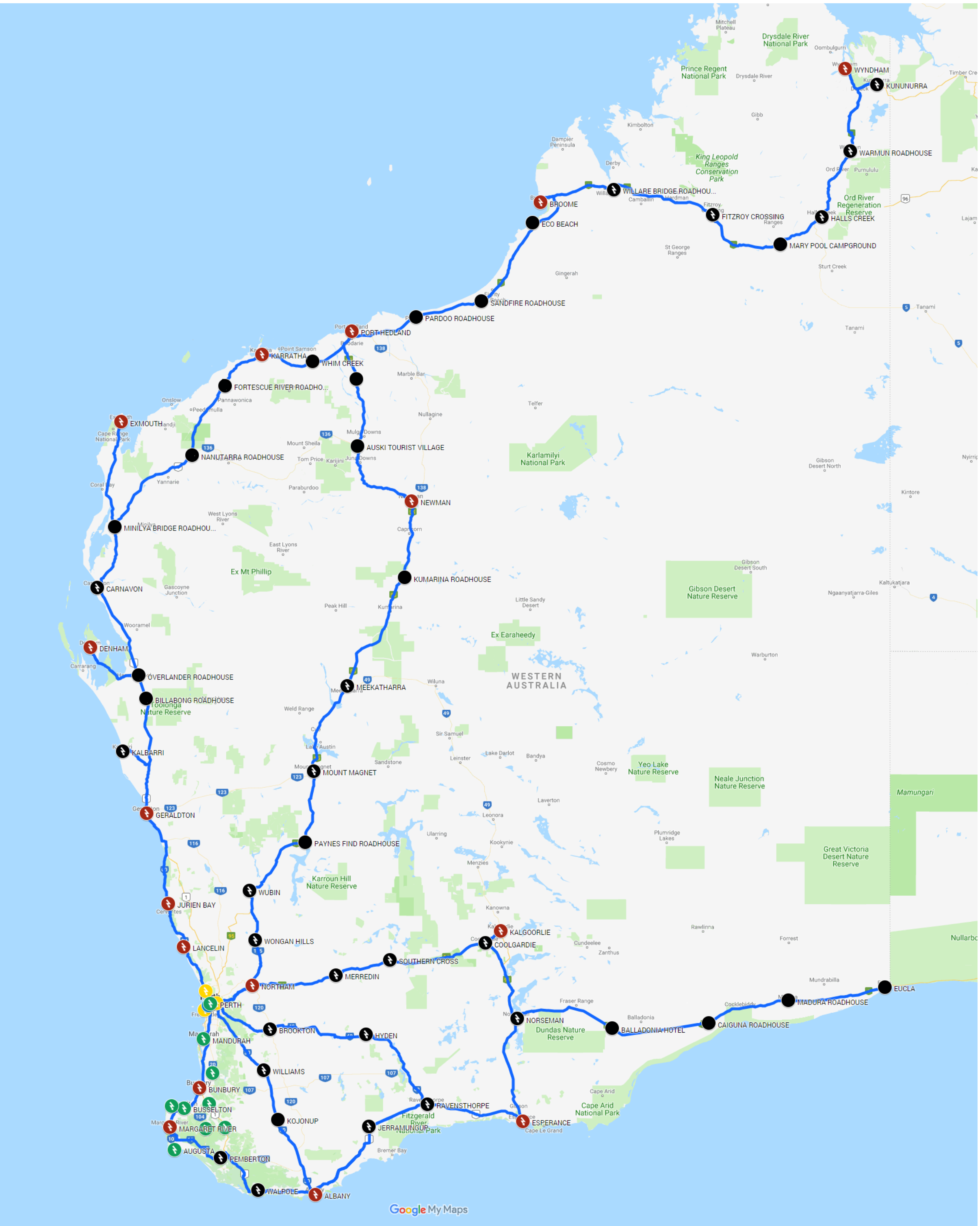

Fig. 6.2: Minimal required 200 km charging grid for WA, green: existing 1x50 kW,
black: proposed 2x50 kW, red: proposed 2x150 kW, yellow: proposed 6x350 kW
sites without power symbol are off-grid

Table 6.3 Minimal configuration

MINIMUM		Total	[kW]	[kW]	[kW]	Station	Install	Grid connect	Site	Route
Site	Location	Bays	350	150	50	cost	cost	or SAPS	cost	Subtotals
METRO										METRO
1	PERTH / WEST PERTH / LEEDERVILLE	6	6			$762'000	$90'000	$628'000	**$1'480'000**	
2	JOONADALUP	6	6			$762'000	$90'000	$448'000	**$1'300'000**	
3	FREMANTLE	6	6			$762'000	$90'000	$448'000	**$1'300'000**	
4	SOUTH PERTH / VICTORIA PARK	6	6			$762'000	$90'000	$448'000	**$1'300'000**	$5'380'000
SOUTH-WEST										SOUTH-WEST
5	BUNBURY	2		2		$140'000	$16'000	$215'000	**$371'000**	
6	MARGARET RIVER	2		2		$140'000	$16'000	$231'000	**$387'000**	
7	PEMBERTON	2			2	$60'000	$10'000	$213'000	**$283'000**	
8	WALPOLE	2			2	$60'000	$10'000	$213'000	**$283'000**	
9	ALBANY	2		2		$140'000	$16'000	$215'000	**$371'000**	
10	KOJONUP	2			2	$60'000	$10'000	$213'000	**$283'000**	
11	WILLIAMS	2			2	$60'000	$10'000	$213'000	**$283'000**	$2'261'000
SOUTH COAST										SOUTH COAST
12	BROOKTON	2			2	$60'000	$10'000	$213'000	**$283'000**	
13	HYDEN	2			2	$60'000	$10'000	$213'000	**$283'000**	
14	RAVENSTHORPE	2			2	$60'000	$10'000	$213'000	**$283'000**	
15	JERRAMUNGUP	2			2	$60'000	$10'000	$213'000	**$283'000**	
16	ESPERANCE	2		2		$140'000	$16'000	$175'000	**$331'000**	$1'463'000
GOLDFIELDS										GOLDFIELDS
17	NORTHAM	2		2		$140'000	$16'000	$215'000	**$371'000**	
18	MERREDIN	2			2	$60'000	$10'000	$213'000	**$283'000**	
19	SOUTHERN CROSS	2			2	$60'000	$10'000	$213'000	**$283'000**	
20	COOLGARDIE	2			2	$60'000	$10'000	$213'000	**$283'000**	
21	KALGOORLIE	2		2		$140'000	$16'000	$215'000	**$371'000**	
22	NORSEMAN	2			2	$60'000	$10'000	$175'000	**$245'000**	$1'836'000
NULLARBOR										NULLARBOR
23	BALLADONIA HOTEL	2			2	$60'000	$10'000	$34'000	**$104'000**	
24	CAIGUNA ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
25	MADURA ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
26	EUCLA	2			2	$60'000	$10'000	$34'000	**$104'000**	$416'000
MIDWEST										MIDWEST
27	LANCELIN	2		2		$140'000	$16'000	$231'000	**$387'000**	
28	JURIEN BAY	2		2		$140'000	$16'000	$231'000	**$387'000**	
29	GERALDTON	2		2		$140'000	$16'000	$215'000	**$371'000**	
30	KALBARRI	2			2	$60'000	$10'000	$213'000	**$283'000**	
31	BILLABONG ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
32	OVERLANDER ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
33	DENHAM	2		2		$140'000	$16'000	$175'000	**$331'000**	$1'967'000
GASCOYNE / PILBARA										GASCOYNE / PILE
34	CARNAVON	2			2	$60'000	$10'000	$0	**$70'000**	
35	MINILYA BRIDGE ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
36	EXMOUTH	2		2		$140'000	$16'000	$175'000	**$331'000**	
37	NANUTARRA ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
38	FORTESCUE RIVER ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
39	KARRATHA	2		2		$140'000	$16'000	$175'000	**$331'000**	
40	WHIM CREEK	2			2	$60'000	$10'000	$34'000	**$104'000**	
41	PORT HEDLAND	2		2		$140'000	$16'000	$175'000	**$331'000**	$1'479'000
KIMBERLEY										KIMBERLEY
42	PARDOO ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
43	SANDFIRE ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
44	ECO BEACH	2			2	$60'000	$10'000	$34'000	**$104'000**	
45	BROOME	2		2		$140'000	$16'000	$175'000	**$331'000**	
46	WILLARE BRIDGE ROADHOUSE / DERBY	2			2	$60'000	$10'000	$175'000	**$245'000**	
47	FITZROY CROSSING	2			2	$60'000	$10'000	$175'000	**$245'000**	
48	MARY POOL CAMPGROUND	2			2	$60'000	$10'000	$34'000	**$104'000**	
49	HALLS CREEK	2			2	$60'000	$10'000	$175'000	**$245'000**	
50	WARMUN ROADHOUSE	2			2	$60'000	$10'000	$175'000	**$245'000**	
51	WYNDHAM	2		2		$140'000	$16'000	$175'000	**$331'000**	
52	KUNUNURRA	2			2	$60'000	$10'000	$175'000	**$245'000**	$2'303'000
INLAND										INLAND
53	WONGAN HILLS	2			2	$60'000	$10'000	$213'000	**$283'000**	
54	WUBIN	2			2	$60'000	$10'000	$213'000	**$283'000**	
55	PAYNES FIND ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
56	MOUNT MAGNET	2			2	$60'000	$10'000	$175'000	**$245'000**	
57	MEEKATHARRA	2			2	$60'000	$10'000	$175'000	**$245'000**	
58	KUMARINA ROADHOUSE	2			2	$60'000	$10'000	$34'000	**$104'000**	
59	NEWMAN	2		2		$140'000	$16'000	$175'000	**$331'000**	tentative
60	AUSKI TOURIST VILLAGE	2			2	$60'000	$10'000	$34'000	**$104'000**	
61	WODGINA MINE	2			2	$60'000	$10'000	$34'000	**$104'000**	$1'803'000
	Major cities					**Stations**	**Install**	**Grid / SAPS**	**Grand Total**	
	Major holiday destinations	138	24	32	82	$7'748'000	$1'026'000	$10'134'000	**$18'908'000**	*$18'908'000*
									$4'660'000	**saving**

Fig. 6.3 and Table 6.4 outline the **extended infrastructure scenario**, where all stations have a power level of at least 150kW and additional inland highway routes have been included. The number of sites has grown to 70 with 156 stations at an additional cost of $4.8 million compared to the proposed scenario.

The total estimated cost for the *extended solution* is $28.4 million *(not incl. land value).*

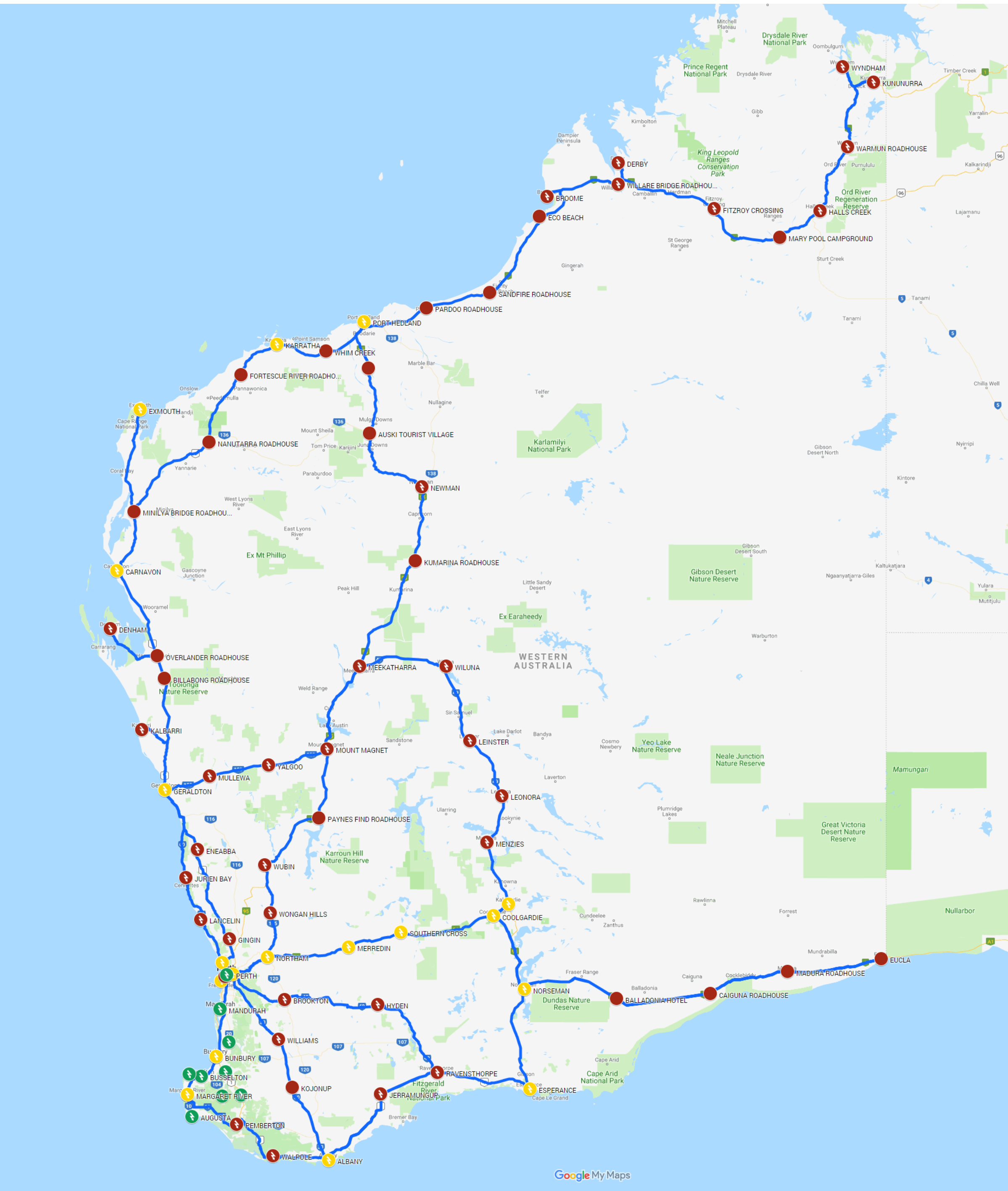

Fig. 6.3: Extended 200 km charging grid for WA including all major highways, green: existing 1x50 kW, red: proposed 2x150 kW, yellow: proposed 6x350 kW, *sites without power symbol are off-grid.*

Table 6.4 Extended coverage configuration using SAPS pricing instead of grid connection

EXTENDED Site	Location	Total Bays	[kW] 350	[kW] 150	[kW] 50	Station cost	Install cost	Grid Provider	Grid connect or SAPS	Site cost	Route Subtotals
METRO											METRO
1	PERTH / WEST PERTH / LEEDERVILLE	6	6			$762'000	$90'000	Western Pow	$628'000	**$1'480'000**	
2	JOONADALUP	6	6			$762'000	$90'000	Western Pow	$448'000	**$1'300'000**	
3	FREMANTLE	6	6			$762'000	$90'000	Western Pow	$448'000	**$1'300'000**	
4	SOUTH PERTH / VICTORIA PARK	6	6			$762'000	$90'000	Western Pow	$448'000	**$1'300'000**	$5'380'000
SOUTH-WEST											SOUTH-WEST
5	BUNBURY	2	2			$254'000	$30'000	Western Pow	$255'000	**$539'000**	
6	MARGARET RIVER	2	2			$254'000	$30'000	Western Pow	$274'000	**$558'000**	
7	PEMBERTON	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
8	WALPOLE	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
9	ALBANY	2	2			$254'000	$30'000	Western Pow	$255'000	**$539'000**	
10	KOJONUP	2	2			$254'000	$30'000	Western Pow	$274'000	**$558'000**	
11	WILLIAMS	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	$3'355'000
SOUTH COAST											SOUTH COAST
12	BROOKTON	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
13	HYDEN	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
14	RAVENSTHORPE	2		2		$140'000	$16'000	Western Pow	$70'000	**$226'000**	
15	JERRAMUNGUP	2		2		$140'000	$16'000	Western Pow	$70'000	**$226'000**	
16	ESPERANCE	2	2			$254'000	$30'000	Horizon Powe	$175'000	**$459'000**	$1'685'000
GOLDFIELDS											GOLDFIELDS
17	NORTHAM	2	2			$254'000	$30'000	Western Pow	$255'000	**$539'000**	
18	MERREDIN	2	2			$254'000	$30'000	Western Pow	$274'000	**$558'000**	
19	SOUTHERN CROSS	2	2			$254'000	$30'000	Western Pow	$274'000	**$558'000**	
20	COOLGARDIE	2	2			$254'000	$30'000	Western Pow	$274'000	**$558'000**	
21	KALGOORLIE	2	2			$254'000	$30'000	Western Pow	$255'000	**$539'000**	
22	NORSEMAN	2	2			$254'000	$30'000	Horizon Powe	$175'000	**$459'000**	$3'211'000
NULLARBOR											NULLARBOR
23	BALLADONIA HOTEL	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
24	CAIGUNA ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
25	MADURA ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
26	EUCLA	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	$904'000
MIDWEST											MIDWEST
27	LANCELIN	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
28	JURIEN BAY	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
29	GERALDTON	2	2			$254'000	$30'000	Western Pow	$255'000	**$539'000**	
30	KALBARRI	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
31	BILLABONG ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
32	OVERLANDER ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
33	DENHAM	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	$2'483'000
GASCOYNE / PILBARA											GASCOYNE / PI
34	CARNAVON	2	2			$254'000	$30'000	Horizon Powe	$175'000	**$459'000**	
35	MINILYA BRIDGE ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
36	EXMOUTH	2	2			$254'000	$30'000	Horizon Powe	$175'000	**$459'000**	
37	NANUTARRA ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
38	FORTESCUE RIVER ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
39	KARRATHA	2	2			$254'000	$30'000	Horizon Powe	$175'000	**$459'000**	
40	WHIM CREEK	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
41	PORT HEDLAND	2	2			$254'000	$30'000	Horizon Powe	$175'000	**$459'000**	$2'740'000
KIMBERLEY											KIMBERLEY
42	PARDOO ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
43	SANDFIRE ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
44	ECO BEACH	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
45	BROOME	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	
46	WILLARE BRIDGE ROADHOUSE	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	
47	FITZROY CROSSING	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	
48	MARY POOL CAMPGROUND	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
49	HALLS CREEK	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	
50	WARMUN ROADHOUSE	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	
51	WYNDHAM	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	
52	KUNUNURRA	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	$3'221'000
INLAND											INLAND
53	WONGAN HILLS	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
54	WUBIN	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
55	PAYNES FIND ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
56	MOUNT MAGNET	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	
57	MEEKATHARRA	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	
58	KUMARINA ROADHOUSE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
59	NEWMAN	2		2		$140'000	$16'000	BHP	$175'000	**$331'000**	tentative
60	AUSKI TOURIST VILLAGE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	
61	WODGINA MINE	2		2		$140'000	$16'000	SAPS	$70'000	**$226'000**	$2'671'000
EXTENDED											EXTENDED
	WILUNA	2		2		$140'000	$16'000	(Horizon)/SAF	$70'000	**$226'000**	
	LEINSTER	2		2		$140'000	$16'000	BHP	$175'000	**$331'000**	tentative
	LEONORA	2		2		$140'000	$16'000	Horizon Powe	$175'000	**$331'000**	
	MENZIES	2		2		$140'000	$16'000	(Horizon)/SAF	$70'000	**$226'000**	
	MULLEWA	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
	YALGOO	2		2		$140'000	$16'000	(Horizon)/SAF	$70'000	**$226'000**	
	ENEABBA	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
	GINGIN	2		2		$140'000	$16'000	Western Pow	$231'000	**$387'000**	
	DERBY	2		2		$140'000	$16'000	Horizon Powe	$110'000	**$266'000**	$2'767'000
	Major cities					**Stations**	**Install**		**Grid / SAPS**	**Grand Total**	
	Major holiday destinations	156	56	100	0	$14'112'000	$1'640'000		$12'665'000	**$28'417'000**	*$28'417'000*
										$4'849'000	**extra cost**

6.3. Station Type Selection Criteria

Electric vehicle technology has progressed significantly over the last few years. The first generation of modern EVs around 2010 had a rather limited range and extended charging times were the norm. "Range anxiety" was a real hindrance for enjoying a trip in an EV and EV use was practically limited to relatively short city commutes because of slow charging technology, if public charging was available at all.

All this has now changed with the second generation of modern EVs in 2018. At the time of writing this report, most new EVs carry a significantly larger battery and therefore have a much longer range. After the new "Worldwide harmonized Light-duty vehicles Test Procedure" (WLTP) [WLTP 2018], which was introduced to give more realistic test results following the diesel scandal, most EVs have a driving range in order of 400 km – 500 km on a single charge, with a realistic achievable range of 300 km+, depending on vehicle and battery size, use of air-conditioning/heating and driving style.

Major improvements have also occurred on the charging side. DC charging has replaced AC charging as the preferred method for public charging stations for all new generation EVs. While most new generation EVs in 2018 can charge at a maximum level of 150 kW, there are official statements that the 2020 Porsche Taycan and Audi e-tron will be able to charge at 350 kW [Porsche 2018], [Autoblog 2018], as well as confidential communication from several major OEMs that their EVs will be able to charge at 350 kW from 2019/2020. Combined with news of a major roll-out of 350 kW stations by Ionity in Europe [Ionity 2018] and Australia through Chargefox [Chargefox 2018] and Fast Cities [St Baker 2018], it is safe to assume that most EVs after the year 2020 will be able to accept 350 kW fast-charging.

Tesla vehicles play a special role in this, as Tesla Motors uses its own charging standard and it is the only OEM that funds its own roll-out of DC charging stations (currently at 120 kW), for exclusive use by Tesla customers [Tesla 2018]. Tesla uses a modified European IEC 92168-2 AC connector [Jetcharge 2018] in dual purpose mode for DC and AC charging. While EVs from other brands cannot use Tesla's superchargers, Tesla drivers can access CHAdeMO chargers by using an adapter, available from Tesla. Just recently, Tesla announced to change its Model 3 vehicles to the CCS connector for the European market [Electrek 2018] as well as the Australian market and is offering CCS adaptors for its other models, as it has already done previously with the GB/T socket for the Chinese market [Mashable 2018]. This change guarantees that all Australian Tesla drivers will be able to use the proposed CCS DC charging infrastructure.

Given the inevitably long approval and implementation lead time, we are recommending that today's latest charging technology, 350 kW CCS-2 DC stations, be installed at all locations with sufficient grid strength, while locations in weaker grid areas should use 150 kW stations. In off-grid locations, 50 kW stations may be the more economic choice, given that their usage during the first years will be low. In all cases, we recommend installing multiple charging bays per site. While the number of bays will again be dependent on the expected load under the selected EV uptake scenario, the redundancy of multiple chargers at every site will be a prerequisite of being able to offer a reliable service for travellers. If only single chargers were installed in some locations, then the outage of one would break the link – a problem that is currently being experienced quite often at the RAC-funded DC chargers in South-West WA. Our recommendation for the heavily used Perth metro area follows the typical numbers of 6-

8 charging bays per site, as currently being implemented by Ionity [Ionity 2018], Chargefox [Chargefox 2018], Fast Cities [St Baker 2018] and Tesla [Tesla 2018]. For regional and remote areas, we recommend to install 2-4 charging bays per site.

It should be noted that the type (power-level) and the number of charging stations at each particular site for the minimal configuration is determined by the estimated demand. For example, a site with an expected demand of 700 kW at peak time can either be covered by 2 x 350 kW stations (with a better user experience due to shorter charging times), 5 x 150 kW stations or 14 x 50 kW stations (with a considerably higher demand for land area/real-estate).

Some of the proposed charging sites will necessarily be located in areas off-grid. For these locations, it will be more difficult to set up EV charging. Extending the grid to the desired location would usually be prohibitively expensive, meaning that a stand-alone power supply system (SAPS) will have to be used. Ideally, such a system would comprise a sufficiently large solar PV array, in combination with battery storage and a diesel backup generator. However, stationary battery storage would provide an advantage for only infrequently used stations, as otherwise the required battery capacity would be immense. On the other hand, it will be hard to financially justify an expensive battery storage for an infrequently used charging station. So, this leaves only the diesel genset (SAPS) option for supplying the required power for off-grid charging stations, ideally in combination with some solar PV, as most charging event are occurring during daylight hours [Lim *et al.* 2018].

Although it is not ideal to power EVs from a diesel generator (plus solar), this will be more efficient and requires less fuel than powering a typical diesel vehicle directly, as Tesla owners have demonstrated in an experiment between a Tesla P85D, charged from a diesel SAPS, versus a diesel Volvo D4 [Renew Economy, YouTube 2018].

Fig. 6.4 Diesel SAPS powering an off-grid charging DC charging station;
(photo courtesy of David Lloyd)

As under-utilisation (running below 60% nominal load) of diesel gensets (SAPS) can cause problems in terms of glazing and higher than normal wear, we recommend the installation of one genset per station instead of one per site, i.e. two smaller gensets than one larger one. The cost for this setup is only slightly higher, but also increases redundancy or the charging sites.

The EV Council has expressed its support for a nation-wide charging grid, with sites at 75 km – 200 km distance and equipped with stations of no less than 150 kW and ideally 350 kW technology. The Council also recommends that sites be *"future-proofed"* by being extendible to more stations per site and higher power levels of up to 475 kW per station [EV Council 2018].

6.4. Site Selection Criteria

A number of studies of EVs and EV charging stations have focused on or have provided sections on charging infrastructure site selection [US DoE 2012], [Fraser Basin Council 2015], [Lorentzen *et al*. 2017], [Tweed Shire Council 2018], [Economic Development Queensland 2018]. While in some cases the criteria are detailed and include all types of charging stations, pedestrian safety, design, etc., this study considers high level site selection criteria only for fast DC charging stations.

Urban sites

Accessibility	• The site must have free-of-charge access. • Must be accessible 24/7. • Must have space for dedicated EV parking bays. • For fleet vehicles, charge point locations must meet the likely travel needs of employees. • Must comply with relevant Australian Standards and Regulations for OWH&S. • It will be important to have sites designed for disabled access.
High visibility	• The site must be a prominent site. • The site must be easy to reach and easy to find.
Space availability	• There must be adequate space for charging hardware and distribution board cabinet if required.
Land suitability	• The site must be low flood risk.
Security	• There must be adequate lighting and security surveillance as those recharging will need to be and feel safe when charging their EVs. • Lighting should be sufficient to easily read associated signs, instructions, or controls on the EVs, to provide sufficient lighting around the vehicle for all possible EV inlet locations and for charging cable visibility to reduce the risk of trips.
Safety	• The impacts on adding EV charging traffic to local traffic of traffic flows will need to be considered.
Telecommunications	• Telephone or wireless communications must be available at the site as public charging stations contain metering systems that are linked to a network to track usage, bill customers and manage electrical loads.

Electricity supply capacity	• The site needs to have a sufficiently robust electricity supply to avoid the need for high cost electricity supply upgrades.
Site installation costs	• The cost of installing charging infrastructure (costs of trenching, upgrading or replacement of distribution boards, etc.) at the site need to be as low as possible. • To minimise site installation costs, it will be necessary to minimise cable lengths, trenching distances, etc. This will require it to be possible to locate EV chargers adjacent to an existing high power transformer with sufficient capacity, or adjacent to a new transformer if that is required, and to a switchboard cabinet. • A dedicated circuit may be required. This can be added to an existing panel, or planned for in new construction. • The experience from other countries shows that it is useful to consider space requirements to accommodate the option of adding battery energy storage at some point in the future.
Land availability	• There has to be a perceived benefit for the property owner. This could be an additional revenue stream from the sale of electricity, increased patronage, longer customer shopping times. It will be important to understand the host's motivations and goals for installing an EV station.

Non-urban highway sites

As well as the above general criteria, public charging locations on highway routes have a small number of particular criteria. These additional criteria are:

- Need to be close to highways – no more than a five to ten-minute drive from highway.
- Need to have communication (telephone cable) access.
- Need to have amenities, including shaded rest area with picnic tables, restrooms, and refreshments (eateries, cafes or vending machines). Ideally these should be available 24 hours per day, although this is unlikely to be possible at all sites. The types of sites that along highways that are likely to meet these criteria are road-houses, caravan parks and tourist resorts. The owners of those sites will need to perceive some benefit in providing space for EV charging and for supplying power for EV charging if that is the option used.

Table 6.5 provides an overview of the proposed routes and locations along the main roads interconnecting towns throughout Western Australia. In addition, some access roads to major tourist attractions locations were considered. The suggested routes cover a total distance of around 10'000 km.

We have also considered the two towns Collie and Narrogin. Although these towns are not directly located on the proposed routes, they can be reached easily from Bunbury and Williams without the need of recharging inside these towns. Without a detailed traffic analyse proposing, an accurate charge demand and the size and number of DC chargers required inside these towns are difficult to determine.

Table 6.5 The proposed routes and distances along the main roads of Western Australia

Southern Regions	**Northern Regions**
Perth to Albany Route (inland), 415 km	Perth to Lancelin, 126 km
Perth to Albany Route (Coast), 612 km	Overlander Roadhouse to Denham, 129 km
Perth to Esperance Route, 719 km	Perth to Carnarvon, 894 km
Albany to Ravensthorpe, 295 km	Carnarvon to Exmouth, 363 km
Esperance to Eucla, 913 km	Carnarvon to Port Hedland, 858 km
Perth to Kalgoorlie, 593 km	Port Hedland to Broom, 604 km
	Broom to Kununurra, 1044 km
	Warmun to Wyndham, 210 km
	Perth to Kumarina (Gold Mine), 955 km
	Kumarina (Gold Mine) - Port Hedland, 684 km

For this report, it is assumed that modern EVs have a highway drivable range of at least 200 km. Hence the aim was to select suitable charging locations around 200 km apart. For cost effectiveness, the recharging sites were proposed as close as possible to the already available electricity grids. In such locations, it can be expected to also have a certain level of infrastructure, such as phone (data link for chargers), public toilets and shops, and hence increased security.

The longest section between towns with existing infrastructure is between Fitzroy Crossing and Halls Creek, which are 280 km apart. It is assumed that even modern EVs with a relative large range will need to recharge at some point between the two townships. That assumption is based on the fact that EV ranges as stated by manufacturers are based on a new, full recharged battery, energy recovery system being utilized and on vehicle energy consumption as measured in a laboratory environment [Wager *et al.* 2014], [Wager *et al.* 2017].

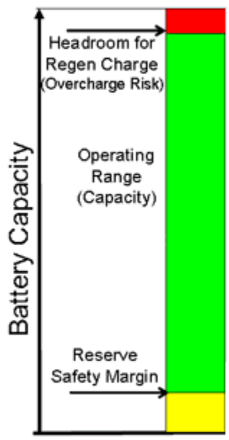

Fig. 6.5 Floor level and headroom to protect the battery from over charge or deep discharge *(Source: adapted from [Electropaedia 2005])*

Cars using fast-DC chargers typically charge up to only 80% of the nominal charge capacity. The vehicle might already have a 10% degraded battery and hence only 90% of the usable battery charge capacity. These two assumptions reduce the manufacturer stated drivable range by 28%. A further reduction in range can be expected by the traction battery safety

margins. This depends on whether the manufacturer's stated battery capacity is the total battery capacity or the 'usable' capacity. Depending on the car manufacturer's battery storage design and strategies, there will always be a "floor level" safety margin of around 10% or more and a possible headroom, as shown in Fig. 6.5. This is to protect the battery from deep discharge and reduces the overcharge risk from the regenerative braking system.
The relative constant high driving speed, heating or air conditioning the passenger cabin, high vehicle loads, headwinds and the absence of frequent available kinetic energy for the energy recovering system increases the energy consumption significantly and hence reduces the range. In a worst-case scenario, an overall range reduction of 50% is realistic [Wager *et al.* 2016]. For some remote locations, the installation of standalone power systems (SAPS) for EVs charging will be required.

6.5. Proposed Rollout

The rollout of the state-wide charging infrastructure does not have to happen all at once. Firstly, there are several years until the 1% EV scenario will arrive. This has been estimated to happen in the year 2025/2026, unless there will be incentives offered or other outside factors, which can significantly accelerate EV uptake.

Secondly, each of the outlined routes can be built out with charging infrastructure independent from the other routes. We have identified eight regional routes in addition to the Perth metro section:

- Perth Metro
- South-West
- South Coast
- Goldfields
- Nullarbor
- Midwest
- Gascoyne/Pilbara
- Kimberley
- Inland

With the exception of the Perth Metro section, which will be more expensive due to the larger number of projected EVs, most routes will cost between $2 and $3 million to complete. The most expensive route will be the South-West route at around $3.4 million with seven grid-connected sites (14 stations at 150 kW–350 kW); the cheapest will be the Nullarbor route at around $420k with four off-grid sites (8 stations at 50 kW).

6.6. Challenges and Coordination

6.6.1. Technical Challenges

(i). Need for shared platforms for payments

The harmonisation of payment systems and protocols (software) around a communication Open Charge Point Protocol (OCPP) is considered to be further behind than for the technical hardware. The problem with subscription services that many public charging companies use is that they lock-in customers and make it difficult for them to use other networks, while unsubscribed EV drivers are required to pay higher rates and instead opt to charge at home

[Rosamond 2018, Spöttle *et al.* 2018]. Open standards, streamlined payment options and transparent and fair pricing would increase use of public charging stations and thereby improve cost recovery

(ii). Home charging – safety

To minimise the need for investment in public charging infrastructure it will be necessary to maximise home and work place charging. It should not be difficult to achieve that outcome as one of the main attractions of owning an EV is the ability to refuel at home. Even if fast charging is essential to prevent range anxiety and is an important incentive when people consider buying an EV, home charging is still the most important attraction and the most effective way to charge an EV on a daily basis. The EV is plugged in at night and the owner starts every day with a full battery. It is cheap and it does not contribute to peaks in the power grid. Private owners of EVs charge their EVs primarily overnight at home and currently have a strong preference for doing this rather than using public or workplace charging [Brook Lynhurst 2015].

Based on the available data, it should be possible for up to 90% of all EV charging events to be undertaken at home or at work, which would mean that public charging stations would be required for around only 10% of the EV charging load. However, encouragement of home charging needs to take into account safety considerations.

The challenge is that residential power supply connections are relatively weak in several countries, including Australia (along with many southern European countries and the U.S.A.). In these countries, standard home-charging electrical cables and sockets overheat with day-after-day use that can exceed the critical temperatures. As a consequence, leading EV manufacturers are urging EV customers to avoid using standard household electrical outlets to charge EVs. It will be necessary to ensure that home charging is undertaken in a reliable and safe way.

(iii). Managing the potential impacts of EV charging on electricity supply systems.

EV charging loads have the potential to impact negatively on peak electricity loads and to stress local distribution systems at locations with high EV adoption rates. They also have the potential to be useful in managing variable renewable energy generation output. This will require network operators to be ready for EV charging loads, to model the potential impacts on distribution systems and to have solutions ready for managing EV charging loads. The challenge is twofold: making sure the electricity system can supply enough energy to quickly charge a large number of EVs, and making sure the distribution system is sufficiently robust to be able to supply electricity to the right EVs at the right time [Massey 2018].

Managing EV charging loads should not be problematical and in fact EVs and EV loads are regarded as potential significant Demand Management (DM) opportunity [Fitzgerald *et al*. 2016]. Increased demand from EVs is set to occur just as there is significant debate in Australia over the potential impacts of increasing penetrations of variable renewable electricity generation (wind and solar PV) on the reliability of electricity supply systems [Massey 2018]. The load created by EV charging could assist by soaking up excess output from solar PV and wind generation if EV charging coincided with maximum solar PV or maximum wind generation output. This means that adding EV demand could avoid the need to curtail the outputs of renewable energy generators.

It is now common for electricity supply companies to manage customer load profiles so as to balance electricity supply and demand by reducing peak loads. The benefits of doing so are a decrease in peak generation capacity requirements, reduced distribution network losses, the deferral of network augmentation investment and improving service quality [Moura and de Almeida 2010]. A common option used for doing is to offer financial incentives by way of time of use tariff structures to encourage electricity users to shift the timing of their loads. The challenge is determining a time of use tariff structure that achieves the optimal balance between reducing peak loads and is economically reasonable [Cossent, Gomez *et al*. 2009]. The clustering of EV chargers behind a single transformer can also create localised problems for the grid if multiple chargers turn on at precisely the same time in response to time-of-use utility rates [Fitzgerald *et al.* 2016].

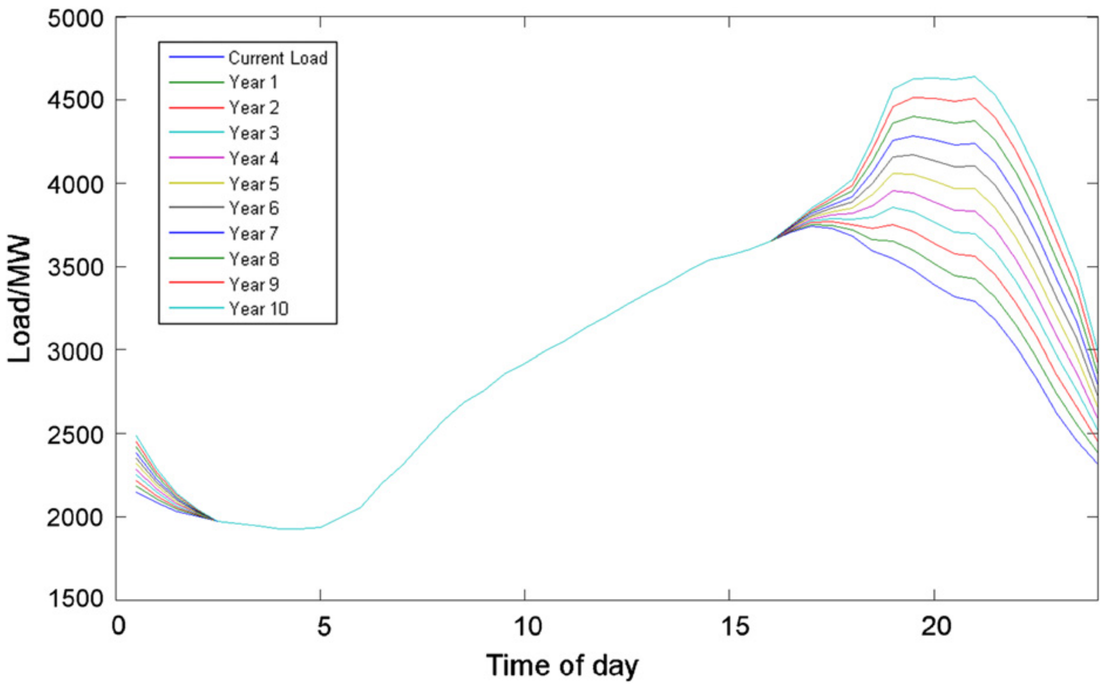

Figure 6.6 Peak-time EV charging, from [Mullan *et al.* 2010]

The impact that EV charging loads would have on the electricity supply system in WA would depend on the number of EVs being charged and on the timing of EV charging [Albrecht *et al.* 2009], [Mullan *et al.* 2011]. Mullan modelled the impact that EV charging would have on the South West Integrated System (SWIS) by superimposing increasing EV charging loads on the then current load on a typical Western Australian summer day (Fig. 6.6) [Mullan *et al.* 2010]. The typical electricity demand curve on such days exhibited a peak at around 17:00 hours. The modelling was undertaken for a worst-case scenario, which was to assume that all new vehicles sold in WA each year of the modelling period would be EVs, which was approximately 10% of the passenger vehicle fleet per year. After 10 years, EVs would therefore make up 100% of the WA passenger vehicle fleet. The modeling results indicated that uncontrolled home EV charging with EVs accounting for just 10% of the WA passenger fleet would increase the magnitude of and extend the duration of the peak load, and that as EV numbers increased these impacts would be amplified. With a 100% EV penetration, the peak load would be increased from the current 3,700 MW to around 4,600 MW and would be extended to around 21:00 hours.

The modelling also included an identical EV adoption scenario with controlled off-peak charging (Fig. 6.7). The results indicated that even with a 100% EV penetration of the fleet, if all EV charging could be controlled so that it occurred during off-peak periods, EV charging would have no impact on peak loads.

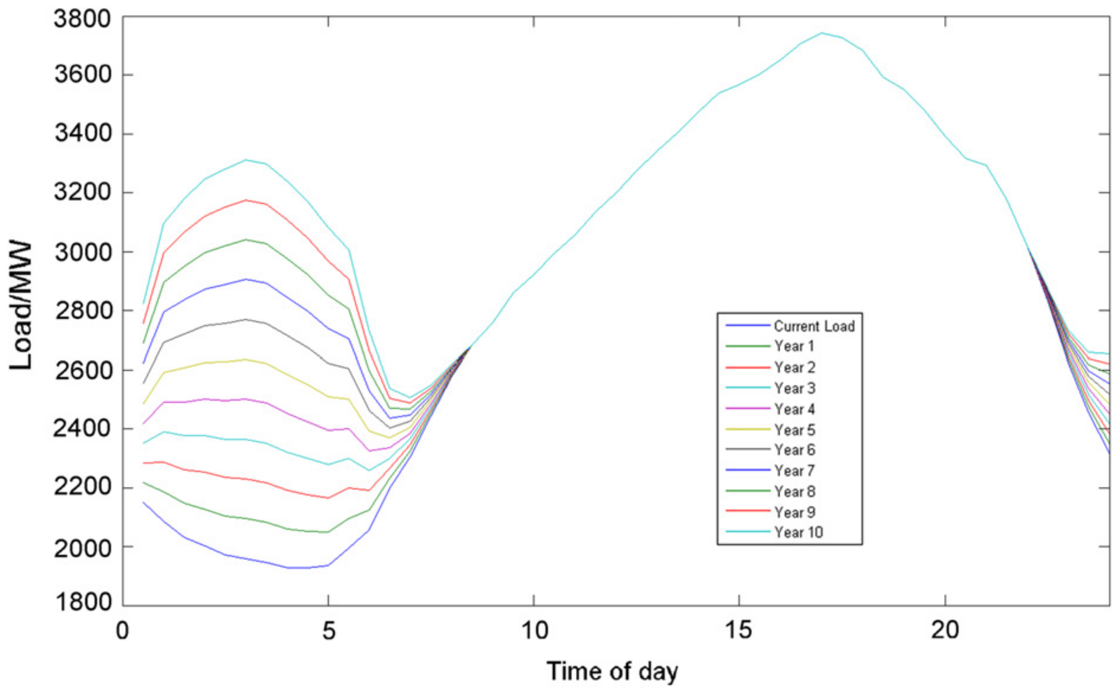

Fig. 6.7 Off-peak-time EV charging, from [Mullan *et al.* 2010]

EV charging at public charging stations would not need to be controlled or managed at the system wide level as this charging tends to occur during the day and to a degree matches the daily solar photovoltaic production curve [Speidel and Bräunl 2014].

EVs are typically plugged into home or workplace chargers for much longer than the minimum required charging time, which generates flexibility for scheduling/optimisation. Immediate EV charging generally involves charging in a single block with termination at full battery capacity to minimise charging time. Controlled charging, on the other hand, makes it possible to ensure that EV charging does not adversely impact on peak loads. However, it requires additional information, including the EV battery state of charge (SoC), the available charging rate, and user preferences. Such preferences may include times of charging, battery SoC, rate of charge, cost of charge, self-produced (home solar PV system) energy consumption maximisation/minimisation, and an increasing number of other options. Depending on the level of dynamic control, these options may involve little or no additional hardware or cost but just adaptations of existing software.

EV owners and manufacturers want to retain control of their vehicle availability and/or flexibility. Depending on who is in 'control' of the EV charging infrastructure (EV owners, EV manufacturers, charging network operators, electricity utilities, etc.), different control solutions would be favoured. For example, electricity utilities would be likely to favour EV charging load shedding during critical load periods. Controlled charging by electricity companies can, however, both enable and disable innovation or flexibility by other parties such as EV OEMs, and there are both pros and cons to these options. The charging process may be assisted by smart charging applications. Manufacturers such as BMW have developed products to automatically optimise home charging to benefit from low electricity rates. These types of products could also be used to optimise usage patterns of other residential appliances that contribute to electricity peak loads, such as air conditioners.

Integrated systems may enable consumers to prioritise appliances, for instance by temporarily reducing air conditioning load to offset additional load from charging an EV during peak load. And direct utility control mechanisms may not be required if time-of-use tariffs and/or automated demand-response mechanisms can be designed that are effective in reducing electricity loads at critical/peak times. Furthermore, automated dynamic time-of-use tariff mechanisms can enable electricity utilities a more precise tool for load shifting without removing customers' rights to opt-in or opt-out.

6.6.2. Non-Technical Challenges

(i). Need for coordination

A common theme in the literature is the need for the planning and installation of EV charging stations to be coordinated [Gilpin 2014, Kettles 2015, Fitzgerald *et al*. 2016, Nelder 2017, Pollution Probe 2017, Hensley *et al*. 2018]. Installing a fast EV charging station involves project development, design, applying for a permit from local government, submitting a connection application to the network operator, negotiating with the land/business owners (if the EV charging station is installed, owned and operated by a third party on private land), and planning for system upgrades [Nelder 2017]. All of that takes both money and time. Kettles [2015] cited a US report that identified 15 'barriers' to EV charging installation, 50% of which were categorised as "Information and coordination', including uncertainty among public planners and private investors about the intensity and demand for public charging stations, and best practices for planning parking sites with public charging stations. Fitzgerald *et al.* [2016] maintain that developing a public EV charging network will require the cooperation of an incredibly diverse group of stakeholders, including electricity businesses, electricity industry regulators, state and local governments, EV OEMs, charging station manufactures and operators, and more. Hensley *et al.* [2018] point out that returns on investment in public charging infrastructure will be poor at the early stages of market development but will be even poorer without careful planning, cooperation and collaboration.

Site selection for fast-charging hubs is regarded to be the biggest challenge [Transport and Environment 2918] and it has been reported that lack of coordination in the early stages in public EV charging infrastructure development resulted in many public charging stations being installed in locations that were not optimal [Giplin 2014]. Local governments will have an important role to play [Fishbone *et al.* 2018] due to their expertise in land use and traffic regulations and planning, which means that they are best placed to ensure that the deployment of charging stations matches the characteristics of the urban traffic patterns and local geography.

EV charging companies have stressed the importance of developing streamlined planning processes and procedures that would make it easier to install fast charging stations. NSW has already moved to do so [Vorrath 2018] and this has already occurred overseas in places, such as California, which has required all cities or counties to adopt improved permitting practices. More than ten other states in the USA and provinces in Canada, including Illinois, Colorado and Ontario, have also legislative exemptions on EV charging infrastructure [IEA 2018].

(ii). Shared apartment buildings
Maximising home charging in order to minimise the need for public charging infrastructure will mean that those living in shared apartment buildings will need to be able to charge EVs parked in their parking bays – with a dynamic effect distribution system, if necessary. In existing buildings, it should be mandatory to allow EV owners to install charging stations on demand. One option will be to require developers of new apartment buildings to install the basic infrastructure for a future 100% EV population [Lorentzen *et al.* 2017, IEA 2018]. Many tenants face huge administrative, time and cost barriers for installing a private charger in multi-occupancy buildings even where they have a parking space. City underground parking also faces similar barriers and strict fire safety measures often prevent installation of chargers [Transport and Environment 2018]. The European Directive on the energy performance of buildings requires builders of new and renovated non-residential buildings (>10 parking spaces) to install at least one charging point and additionally one-out-of-five spaces must have a conduit installed. In new and renovated residential buildings (>10 parking spaces) every parking space must be equipped with a conduit [IEA 2018].

(iii). Workplace charging stations
Minimising the need for public charging will involve maximising the opportunities for work-place charging. This will be particularly important as early take up of EVs is likely to be in company fleets [Transport and Environment 2018] and because work-place charging loads in Western Australia will closely match solar PV output profiles.

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7. Infrastructure Gaps and Commercial Operators

Key findings:

- Shared usage of service stations for EV charging could be an ideal scenario, as service station owners/operators have strategically located sites, the infrastructure and amenities. While future electricity sales may make this model attractive, the current commercial situation may require subsidies to get service stations involved.
- There is evidence that a number of commercial property owners in city and urban areas will invest in pubic charging stations as soon as it becomes profitable for them to do so. Partnering with these companies would bring forward the installation dates.
- Offsetting a 1% EV fleet with renewable energy would require an investment of $7.5 million for solar PV or alternatively $5.2 million for a wind farm.
- Recouping the capital costs of 50 kW and 150 kW DC fast-charging infrastructure within 10 years may only be possible at the highest usage sites during early stages of EV uptake.
- It will be important to minimise the need for public EV charging in urban areas using strategies, such as encouraging and facilitating home and workplace charging.
- There are a number of business case models for investment in urban areas with high EV densities, and there are limited examples of some of these currently being used in Australia.
- The business models and partnerships that will work for investment in non-urban public charging infrastructure are likely to be different from those that will work in urban public charging infrastructure.

7.1. Greenhouse Gas Emissions Associated to EV Charging

From a public policy perspective, one of the primary drivers for the promotion of EVs and investment in EV public charging stations is the need to reduce transport sector GHG emissions. However, a study of the options of using electricity produced from renewable energy sources to supply electricity, or to offset the GHG emissions associated with the electricity used to charge EVs via public charging stations in WA, was not included in the scope of work for this study. In this section, we provide a short, very high level and very approximate estimate of the amount of renewable energy generation capacity that might be required in order to achieve that outcome. A more accurate and more detailed estimate than this would require a separate study to be undertaken.

We estimate from the traffic flow calculations and charging energy demand analysis provided in Chapter 3 that once the penetration of EVs reaches 1% of the WA light vehicle fleet the total amount of electricity that will be required to charge EVs from public charging stations on all regional highways and State roads in WA (i.e. in all public charging stations located in areas outside of the greater Perth metro area), will reach on average 16,370 kWh/day or 5,975 MWh per year. That electricity will be supplied from charging stations supplied from Western Power (the SWIS), Horizon Power, stand-alone power supply systems located at roadhouses, tourist sites or other locations, and from home and commercial roof-top solar PV systems. Furthermore, that electricity will be supplied from a mix of coal-fired power stations, gas-fired power stations, renewable energy generators and diesel generators. That will make the task of calculating the associated GHG emissions complex, but not impossible. The real difficulty in calculating the GHG emissions associated with the electricity used to charge EVs is that at this stage the coal, gas, renewable and diesel generation capacity in the electricity generation mix in WA when EVs account for 1% of the light vehicle fleet is unknown. As a guide, we provide a quick approximate calculation of the size of a renewable energy generator that would be required if all of the electricity that will be used to charge EVs from public charging stations at these sites were to be offset by electricity produced by renewable energy generation.

A solar PV system installed in a location with high solar insolation (e.g. Carnarvon or in the Goldfields region) would produce approximately 1,600 MWh/MWp/year. The size of a solar PV system that would be required to offset the electricity used for charging EVs on regional routes once the penetration of EVs reaches 1% of the light vehicle fleet would therefore be approximately 3.75 MW. The installed costs of a solar PV power station are relatively well established and do not vary significantly from site to site. At an installed cost of $2.2/Watt [ARENA 2016], the total installed (current) cost would be approximately $7.5 million (excluding land purchase or lease costs, and excluding maintenance or insurance costs). If the solar PV system was a tracking solar PV system, the size (MW) of the solar power station could be scaled down, but the unit installed cost ($/Watt) would be increased.

Alternatively, the electricity could be supplied by a wind farm built at a suitable site (such as coastal locations between Esperance and Geraldton near to a strong connection point on the electricity network). Total installed costs of commercial-scale wind farms vary significantly from site to site and depending on the number of turbines installed the location of the project and other factors. The installed costs of windfarms in Australia range from $1.6 to $3.3/kW [Global CCS Institute 2018]. Assuming a capacity factor of 33%, the size of the wind farm would need to be 2.08 MW. At an installed cost of $2.50/W, the cost of the wind farm would be $5.2 million.

7.2. Gap Analysis

The purpose of a gap analysis of EV charging infrastructure is to assist the planning process by assessing what public EV charging infrastructure is needed to support both plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). That is, to assess the optimal numbers and locations of further EV charging infrastructure required to service not only the existing fleet of EVs in WA, EVs travelling within WA and EVs travelling interstate to and from WA, but also the expected near-term increase in the EV fleet. This study can therefore be viewed as a gap analysis.

A comprehensive gap analysis would be informed by surveys of EV drivers, focus group workshops and interviews with relevant policy, industry stakeholders and potential partners, detailed mapping of the existing EV charging infrastructure in the State, as well as detailed technical information about the capacity of the existing electricity supply network at potential EV charging station locations. However, WA is at a very early stage of EV adoption, which makes the task of undertaking such a comprehensive gap analysis difficult. The existing EV charging network has been built in a relatively piecemeal and ad hoc manner by various players and as a consequence it is not only very limited in extent but is also highly fragmented. This means that the role of this gap analysis has less to do with identifying the gaps in the existing DC fast charging network and is more about starting from scratch and designing the initial stage of a public EV charging network in the State. As such, it has to consider the need for both clusters of public charging stations in the largest population centre, Perth, and the need for DC fast charging stations in regional and rural areas along main travel corridors.

One of the problems associated with undertaking a gap analysis in a state in which the take-up of EVs is at an early stage, as is the case in WA, is that many of the stakeholders or potential partners that will or are likely to be involved are not yet sufficiently engaged to be able to provide significant input into the planning process.

This gap analysis also has to take into account the differences between the needs for public charging infrastructure in WA and what is needed in other states and countries. That means that it is not possible to simply look at what pubic charging infrastructure is being built or planned elsewhere and to use that as a template for a roll out of public charging stations in WA. The Queensland Electric Highway is an example. Queensland has the benefit of a single major coastal highway route that stretches from Cairns to the Gold Coast and that connects a significant number of regional towns and cities with large or relatively large populations. The route also has significant traffic flow volumes and large numbers of tourists. Not only is WA is one of the least densely populated states in the world, but over 80% of WA's population live in Perth and the average population density in the State is 0.89 persons per km^2. The number of tourists arriving in WA each year is 22% of the number of tourists in NSW, 32% of the number in Victoria and 35% of the number in Queensland. The public charging needs are also dictated largely by proportion of BEVs in the local EV fleet. WA's public charging infrastructure requirements are therefore likely to be very different to those in other places!

In undertaking this gap analysis, we have relied on interviews with stakeholders and on information obtained from a literature review, and particularly from reports of similar gap analysis undertaken elsewhere, such as by those undertaken in British Columbia by [Fraser Basin Council 2015] and [Pollution Probe 2017] and in the USA by NREL [Wood *et al*. 2017]. The assessment also uses current data on traffic flow volumes along the main regional routes together with a projection of the likely date at which EVs will make up 1% of the passenger vehicle fleet in WA, to determine the EV charging requirements in each location at that point in time.

The number of EVSE stations that will be required within the Perth metro area and in other urban centres in WA will be determined by a number of factors, some of which are at this stage unknown. What proportion of EVs will be charged at home? What proportion of EVs will be charged at work? What electric driving ranges will PHEVs in the EV fleet have? At this very early stage of EV take-up in WA it is not possible to know the answers to all such questions and informed best guesses have to be used.

Based on the stakeholder interviews and from information obtained from literature review, it is possible to make general statements, which are provide below.

7.3.1 Urban areas

1. Home charging: The need for investment in public charging infrastructure in Perth and other cities and towns will be determined to a very large degree by the proportion of EV owners who charge their vehicles at home or at work. It is considered likely that most of the charging of personal passenger EVs in Western Australia will

in fact occur either at home or at work, but the proportion could be increased with appropriate planning and/or incentives.

2. With home charging, it will be important to ensure that EV owners are aware of all safety requirements, including:
   - Normal adapters (such as an In-Cord Control and Protection Device IC-CPD) cannot be used between the socket outlet and the EVSE;
   - A home or work EV charging station needs to be installed by a registered electrical contractor and needs to comply with the relevant standards;
   - Only charging stations supplied by EV manufacturers or by an electric vehicle supply equipment (EVSE) manufacturer should be used;
   - Presently, most home EVSEs plugs into a normal socket at the home and supply up to 10A and the average power demand to charge most EVs is 3-6 kW, which is approximately equivalent to powering a small residential air conditioning unit. Some models draw up to 19 kW, which is more than the load of most large single-family homes. It will not be possible to fully charge EVs with large batteries, such as a Tesla, overnight if the battery was nearly empty without using a higher-powered EVSE.
   - Depending on the age of the wiring, the wiring may need to be upgraded or new wiring installed as EVSEs are high draw devices, can create heat and can be a fire risk if older wiring is used that is not designed for large currents.

3. The shared use of private chargers has been encouraged in Japan by the government and as a result is very common, being described as the Airbnb equivalent of EV charging [McCurry 2016, Gibson 2018b]. The extent to which this will occur in Australia is unknown, but it is unlikely to be very common due to the reluctance of many homeowners having other EVs parked in their driveways or garages. Surveys in Australia of EV owners in strata residential buildings have found that EV owners prefer private chargers over shared chargers and are not interested in making their private EV chargers available to others [McIntyre 2018].

4. Multi-dwelling residential apartment charging: The installation of EV charging infra-structure at shared (strata) residential sites can be challenging for several reasons. The power supply in strata car parking areas is usually common power supply. Installing individual chargers therefore requires consideration of the by-laws of the Owners' Corporation and the negotiation of how unit holders pay for electricity used for EV charging and the allocation or sharing of the costs of any electrical upgrade required. Installing EV chargers can be challenging and expensive. One option for simplifying the installation process would be to connect EV chargers to the tenant's own apartment meter, but depending on the set-up proposed and the location of the meter rooms this type of set-up can be expensive. It may also be necessary to apply for a revenue grade meter installation from the network operator, which will all require Body Corporate involvement to review and approve each installation. However, in the longer term the lower cost and simpler option is likely to be for the Owners Corporation to effectively manage EV charging [McIntyre 2018]. Current regulations can also restrict what charging infrastructure

can be installed in underground car parks. In order to maximise the amount of charging undertaken at such sites it will be necessary to have appropriate planning framework in place and to develop businesses with the capability to providing services to those types of building owners to facilitate negotiations and installations [Transport and Environment 2018]. This is already occurring in Sydney [McIntyre 2018]. It is commonly advocated that building regulations be amended to require all new buildings to incorporate electrical wiring required for installing EV charging stations [Hall and Lutsey 2017].

5. Workplace charging: Increasing the numbers of EVs being charged at the workplace will be particularly important as a large portion of EVs in the early stages are likely to be fleet vehicles. It will be important to encourage companies to install work place charging units and/or to provide incentives for them to do so. It may also be necessary to look at amending the rules relating to the taxation of fringe benefits relating to the use of work charging for private vehicles.

6. Public charging stations: The four groups of EV owners/users that will have the greatest reliance on public EV fast charging in urban areas will be: (i) EV owners without charging stations at home or access to charging stations at work; (ii) those charging at home or the workplace who need quick top ups; (iii) tourist rental EVs, and those driving light commercial EVs throughout the day (mainly weekdays). Some stakeholders estimate that the last group could account for up to 30% of total EV charging (kWh) during a working week in Perth. At this stage, who may invest in required public charging infrastructure and in which locations or within what time frames is largely unknown. Stakeholder interviews revealed that public electricity businesses do not envisage a viable business case for investing in public charging stations, and even if the regulator permitted them to do so, they would not be permitted to cover costs through their rate base but would have to charge at rates that would make the use of these public recharging stations unattractive. No petrol station operators were willing to be interviewed, but the anecdotal information obtained is that these companies recognise that they have the advantage of owning the strategically located sites but are holding back from investing at this stage while the EV numbers are very small but will be ready to invest in public charging station when there are sufficient numbers of EVs on the road. An interview with a company that manages the electricity supply and metering for a number of large commercial properties, such as large shopping centres, business complexes and airports, indicated that several of its client businesses with sites in the Perth metro area, Albany, Bunbury, Geraldton and Kalgoorlie are assessing the business opportunities for investing in public EV fast charging infrastructure, but that they will not be investing until the volumes of EVs required to make the investment profitable are realised. Relying on those businesses to invest in public EV fast charging infrastructure is therefore likely to result in a lag between the need for public EV fast charging in urban areas and the availability of public EV fast charging infrastructure. It will also mean that the locations of initial public EV fast charging infrastructure in urban areas will be determined by the locations of those commercial properties, which may or may not be optimal and may result in localised traffic flow issues. It is likely that other

businesses operators will follow and will invest in public EV fast charging infrastructure once they are confident that their investments will be commercially viable. That second wave of investment may result in a network of more optimally or strategically located public EV fast charging stations as those second wave investors are likely to include petrol station operators that already have strategically located sites for vehicle refuelling. That may result in much of the investment in the first wave of EV fast charges becoming stranded assets.

7. Electricity supply system in urban areas: At the generation level, there is currently significant surplus generating capacity in the SWIS and the system has the capacity to meet the additional loads that would be created by (public and private) EV charging loads.

8. In the early stages of personal passenger EV adoption, adoption patterns are likely to be geographically clustered, with higher take up rates in higher income areas, and this will require Western Power to closely monitor the capacity of the local distribution feeders in those areas to manage the increased loads created by EV charging.

9. Rental and leasing of EVs are becoming more common interstate and in overseas countries such as NZ and Iceland. It will be necessary to ensure that there are sufficient public EV charging stations and in the appropriate locations to meet rental EV charging load

10 Electricity utility interest in EV loads or preparedness for increases in EV loads understandably tends to be commensurate with the take up rates of EVs in their supply areas and their customer interest in adopting EVs [Fraser Basin Council 2015]. Given the low EV take-up rates of EVs in WA to date it is therefore not surprising to find that while electricity businesses have a generalised interest in EVs and in understanding what the implications (negative and positive) will be for their businesses, most do not see it to be as a priority to undertake EV charging impact assessments. However, they are also aware that EV take up rates could accelerate unexpectedly, as was the case with household solar PV systems and for which the electricity utilities were totally unprepared.

11. Western Power is being proactive and is undertaking an early stage or preliminary assessment of local grid capacity. Synergy's activities, on the other hand, are limited to largely promotional activities – sponsoring the installation of sockets for EV charging in remote and regional areas (outside of its supply area) providing educational materials on its website.

12. Electricity businesses are aware that the timing of EV home charging will need to be managed in order to avoid significant EV charging in early evenings that would exacerbate peak loads. The options for doing so include remote control of home charging loads and incentives for EV owners to shift the timing of their home charging.

13. Electricity businesses recognise that EV charging represents a potential new demand that would be welcomed by generators and retailers in a period of declining electricity demand.

14. Electricity businesses recognise that significant daytime EV charging loads would have the benefit of occurring during periods of high solar PV output and would therefore assist in managing the increasing number of solar PV systems being connected to the network.

15. Electricity businesses recognise the potential for remote management or control of EV charging. This would create a new large controllable load that would have significant benefits for the management of the electricity supply system.

16. While it has not been possible in this study to undertake a detailed analysis of the capacity of the existing electricity supply systems and networks to supply the electricity required by EVSEs, the WP network in most areas of the inner Perth Metro region is sufficiently robust to be able to supply banks of EVSE stations without requiring major network reinforcement. However, engaging with electricity businesses will be of critical importance in determining the locations for public charging stations, and especially banks of public charging stations and fast DC charging stations.

7.3.2 Non-urban areas

1. While there are many unknowns associated with the future need for public charging infrastructure in urban areas, the situation in regard to the need for future public EV charging in regional and remote areas is very clear. The need for EV fast charging in those areas will come primarily from those EV users wishing to travel extended distances. However, stakeholder interviews indicated that all parties understand that traffic flow volumes in those areas will be low and that as a result no party (private investors, local governments or EV OEMs) perceive there to be a business case for investing in EV fast charging infrastructure in those locations. None of the stakeholders interviewed was able to offer a solution to this impasse.

2. Neither any of the State government agencies nor the regional electricity supplier, Horizon Power, consider it to be their responsibility to invest public monies in public EV charging in these areas, or that it is even their role to do so.

3. It is not apparent that any businesses perceive themselves to have an interest in investing in public fast-charging stations in these areas, particularly in the early stages of EV take up.

4. The consensus view is that there is only one solution: if there is to be a State-wide network of EV fast charging infrastructure, government investment/ownership or subsidisation of EV fast charging stations in those regional and remote areas will be required. However, no government agency considers it to be its role to do so.

5. It was suggested by some stakeholders that a possible solution could be to adopt the same approach as is used in the telecommunications industry. That is, to require

private companies investing in public charging infrastructure in profitable locations to adopt a universal coverage policy that would require them to also invest in public charging stations in regional, less profitable or unprofitable locations. Given that there are as yet no profitable locations, and that there may not be any profitable locations for quite some time, such an option would be, at best, a very long term solution to the problem.

6. In some non-urban areas the network is relatively weak. To minimise network costs WP builds the network in these areas to meet existing demand without capacity to meet any significant increase in demand. It is not possible to know what network reinforcement may be required in any particular location or what the cost would be. The logical strategy is to therefore select locations as close to WP substations as possible. However, that may not always possible.

6. In locations where the costs of network reinforcement required to supply EVSE are high or unknown, it may be necessary or prudent to compare those costs with the costs of other electricity options, such as stand-alone power supply systems using diesel generators and/or solar PV with battery storage.

7. It will be necessary to work closely with Western Power and Horizon Power to determine the optimal locations for installing public charging stations and the best electricity supply option for a site. For example, in areas where the network is weak and the supply capacity is limited, the use of diesel generators or hybrid solar PV and battery systems may be better as grid connected systems than as stand-alone systems, as they may be able to provide grid support in addition to supplying EVSEs.

8. The capacity of Horizon Power to supply EVSEs varies from one HP supply to another, and it will be necessary to work closely with Horizon Power to determine feasibilities and obtain accurate costings.

    (i) In larger supply areas with larger populations and larger generation capacities (Port Hedland, Karratha, Newman, Derby) the network should be adequate to supply EVSEs, although depending on the location of the EVSEs localised network upgrades may be required;
    (ii) In many other locations, the capacities of the networks and of the generation to supply EVSEs are limited and network upgrades are likely to be required;
    (iii) In some HP supply areas, it is doubtful that the systems (generation and or network) will have the capacity to supply the required power (kW) or energy (kWh) and the use of using SAPSs to supply the electricity will need to be considered.

9. In off-grid areas (not supplied by either Western Power or Horizon Power) the capacity to rely on existing SAPSs in off-grid areas, such as diesel generators owned and operated by roadhouses, is unknown. The options for supplying the electricity required for EVSEs in these locations will need to be discussed with the roadhouse owners/operators. These negotiations may include an arrangement that involves the use of the roadhouse’s existing diesel generators where it is technically possible to do so, or an arrangement that involves installing a separate diesel generator or SAPS on or near to the roadhouse to supply the EVSEs.

10. A number of concepts for extending the driving ranges of EVs are being developed by companies such as bb7, including the use of potable battery packs for use in emergencies, additional battery packs towed in a trailer and recharging portable service providers that are able to bring a portable charging station to an EV [bb7 2018].

7.3. Time to Recoup Capital Investment

Before discussing the options for commercial investment in public fast charging stations, the possible business models that could be used for doing so and the possibility or potential viability of public-private partnerships, it is necessary to first understand the financial performance of investment in fast charging stations.

The return on investment in a public charging station is determined by a number of factors, the main ones being the capital equipment and installation costs, the annual O&M costs, the annual cost of the electricity used to charge EVs, the life of the charging equipment, the annual amount of electricity (kWh) sold, and the mark up on the electricity sold. This means that there will be very large differences in the financial performances of investment in public charging stations. We have selected two public charging stations from the analysis in Chapter 3 that represent the extremes: one high usage site (Bunbury) and one low usage site (Auski Tourist Village). In both cases, we have assumed that the chargers are installed in the year that EVs reach 1% of the passenger vehicle fleet and a 30% per year compound rate of growth in demand. We have assumed a discount rate of 5%, a loan interest rate of 5% p.a. and a business tax rate of 27%. It was assumed that electricity costs would increase at an average rate of 3% p.a. The charging station equipment costs, installation costs, depreciation constants and life of chargers used information provided in a recent paper by [Lim *et al.* 2018]. Three sizes of DC chargers were used: 50 kW, 150 kW and 350 kW. Annual discounted flows were calculated for various electricity mark-up rates (%). As the life of a charger was taken to be 10 years, the electricity mark-up rates were increased until the upfront capital costs (equipment costs + installation costs) were recouped within 10 years. Electricity mark-up was adjusted until the lowest mark-up for which it was possible for the capital costs to be recouped within 10 years was found. The results for the high usage site (Bunbury) are shown in Table 7.1 and the results for the low usage site (Auski Tourist Village) are shown in Table 7.2.

Table 7.1 Lowest electricity mark-up (%) for which it would be possible to recoup capital costs within 10 years: Bunbury.

Capacity of Charging Station	Mark up on electricity (%)	Year in which capital costs recouped
50 kW	20%	9
150 kW	35%	10
350 kW	200%	8

What can be gleaned from Table 7.1 is that it should be possible to recover the capital costs of a 50 kW DC fast charger at the highest usage sites using an electricity mark up of approximately 20%. However, to make a profit it would be necessary to use a higher mark up. But using a higher mark-up would have the effect of reducing the financial benefits of an EV in terms of operating costs ($/km) and may reduce usage. Recovering the capital costs of a

150 kW charger within 10 years at high usage sites would be possible, but only if a high electricity mark-up of 35% is used. Making a profit would require a higher mark-up, which would not be viable. It will not be possible to recover the capital costs of a 350 kW charger at the highest usage sites until the numbers of EVs are far higher (well over 10% of the passenger vehicle fleet).

Table 7.2 Lowest electricity mark-up (%) for which it would be possible to recoup capital costs within 10 years: Auski Tourist Village

Capacity of Charging Station	Mark up on electricity (%)	Year in which capital costs recouped
50 kW	300	6
150 kW	350	10
350 kW	2700	6

What can be gleaned from Table 7.2 is that it will not be possible to recover the capital costs of any sized charger within ten years at the lowest usage sites and impossible to make a profit. It should be noted that the above calculations have assumed that the chargers are not installed until EVs reach 1% of the passenger vehicle fleet. If the chargers are installed before EVs reach 1% of the vehicle fleet, the mark ups in electricity required to recoup the investment within the life of the chargers (10 years) would be increased dramatically and it is unlikely that the capital cost would be recovered for any type of charger at any type of site.

Secondly, the calculations have assumed that the costs of electricity are based on Synergy's L1 tariff, which is currently 26.7 c/kWh and a supply charge of $1.715/day. If a lower tariff ere used, the financial performances would improve. However, the cost of supplying electricity at some sites such as roadhouses and off-grid tourism sites can be high, which will make the actual cost of the electricity significantly higher than the L1 tariff. For example, at a delivered diesel cost of $2/L and a fuel consumption rate of 3 kWh/L, the fuel cost of electricity alone will be 66.7 c/kWh and the total cost including O&M costs and the diesel generator capital costs would be higher. That means that either the financial performance of the charging stations at those sites will be worse than calculated above, or that the cost of electricity at those sites would need to be subsidised.

The overall implication of the above is that a lack of private investment in public charging stations cannot be simply explained in terms of 'market failure'. In many cases, and particularly during the early stages of EV take up, it is simply not an attractive financial investment.

7.4. Partners for EV Charging Infrastructure

It has been estimated that if electric vehicle uptake in Australia matched that of Norway, it would create an investment opportunity (cost) of around $3.2 billion in EV infrastructure [Ronngard 2018]. That may be a long way off, but it has also been estimated that fast charging is commercially viable in Norway with as few as 115,000 BEVs, which make up only around 3% of the car fleet [Lorentzen *et al.* 2017]. While there is disagreement within the literature at what point investment in EV charging infrastructure will become commercially viable without government subsidies, there is agreement that it is necessary for charging infrastructure to be supported with public funding in the early stages. One of the strategies for minimising the amount of public funding required as the take up of EVs increases will involve partnering with businesses and other organisations.

In discussing which partnerships may be possible and what business models may be best suited in the case of WA, it is useful to distinguish between those business models that would be applicable in urban areas with high EV numbers and those business models that would be applicable to charging networks designed to meet the requirements of non-urban long distance travel.

7.4.1 Business models for urban areas

Both, overseas and in Australia, a number of different types of private and public sector stakeholders and consortia are investing in, or are planning to invest in public EV charging infrastructure [Energeia 2018], [IEA 2018]. As well as differences in ownership, there are also differences in the business models used. However, according to [Fitzgerald and Nelder 2017] at this early stage of EV adoption, it is not possible to predict which of those stakeholders will or should invest in, own and operate public charging infrastructure, or what business models they will use. There is too little data to unequivocally say that one ownership model is better than another, and the question of who should own charging stations has no simple or universal answer.

Even in countries with comparatively high EV take-up rates there have been doubts about if or when investment in public charging infrastructure will be profitable without public funding support. There is some optimism that as more energy companies, automakers, utilities and grid service providers form alliances to develop EV support infrastructure, public funding could be gradually withdrawn from the buildout of public charging, moving towards self-sustaining and business-driven solutions [IEA 2018]. But it was not until 2017 that a functioning public fast charger market began to emerge in Norway, in which governmental support is no longer required and investment in public fast charging stations is based purely on commercial decisions. And even then, the investment is limited to large cites and along main highways and it is still not clear that the market alone will be able to meet the charging infrastructure needed to Norway's target to make all new cars sales zero emission vehicles by 2025 [Lorentzen *et al.* 2017]. Serradilla concluded from their economic modelling that if future EV take-up rates in the UK are sufficient to meet the 60% market share by 2030 target [Serradilla *et al*. 2017], a credible financial business case would exist for investment in further rapid charging infrastructure in the UK, but only if EV drivers are willing to pay a 3.3 or higher mark-up on electricity prices. As residential electricity prices are approximately 18.6 Euro cents/kWh (A$0.3025) [Statistica 2018], this would mean paying A$1.00 per kWh.

To build a business case that will attract capital and convince the private sector to invest in EV charging, total revenues must be greater than the project's total cost, and an acceptable level of profit is necessary. Developing a profitable business case for investment in publicly available EV charging is clearly challenging and risky, even where EV take-up rates are comparatively high. There are several reasons for this:

(i) The initial investment costs are high;
(ii) The near-term demand for charging at publicly available charging station is low and uncertain; and
(iii) Publicly accessible charging stations compete with home and workplace charging.

In Europe, around 80% of EV charging is done at home, if drivers have a place at home to charge. If they have home charging and workplace charging, 96–97% of charging is done at home or work. For people without a charger near their home, being able to charge at work is the next best thing [Fishbone *et al.* 2018]. So what are the options? There are four general ways to improve the financial performance of charging station projects [Nigro and Frades 2015]. One option is to increase revenues. This would require either increasing the number of EVs charging, which may not be possible, or increasing charging fees, which could reduce patronage. Another option would be to decrease capital investment costs by using lower quality equipment, which is generally not a good long-term strategy. The third option would be to decrease operating costs, which usually lowers service reliability and quality. The final option is to decrease the cost of funds for the project, which effectively means grants or low interest loans.

In terms of business models, at one extreme, companies such as *Chargepoint* and *NRG EVGO* are installing independently owned and operated charging stations that their customers can access for a fee. The revenue model varies widely from a flat monthly fee to pay-as-you-go to bundled electricity with home charging. At the other extreme, EV OEMs such as Tesla and independent organisations, such as the RAC WA, are installing charging stations using currently unproven business models [Bansel 2018].

Hall and Lutsey [2018] outline four possible business cases for investment in public EV charging infrastructure. The simplest is to charge a sufficient margin on the electricity to recover the capital costs and to make a profit. The limitation in the applicability of this model is the difference between the operating costs ($/km) of an electric and a petrol or diesel car. Using the Chevy Volt as an example, with a petrol use efficiency of 5.6 L/100 km, an electric use efficiency of 0.2 kWh/km and a petrol price of $1.30/L, the electricity price at which the cost of operating on electricity is the same as the cost when operating on petrol is 36.5 c/kWh. If the electricity tariff is 28 c/kWh, the maximum mark-up possible would be 8.5 c/kWh, or 30%. But in reality the mark up would need to be significantly lower. This business model therefore is applicable to countries or areas in which petrol price are high and electricity prices are low.

The second business model proposed by Hall and Lutsey was the use of public EV charging to increase retail sales. This would be an option for retailers for which investment in public EV charging would attract new customers or increase shopping times. For this option, Level 2 public chargers would be required.

The third business model proposed by Hall and Lutsey was one which was based on increased advertising. This option would be suited to Level 2 chargers at sites with high traffic volumes and high visibility.

The fourth business model cited by Hall and Lutsey was the integration of investment in public EV charging stations with EV OEM sales strategies. They argue that if public EV charging is critical to increasing EV take up rates (and therefore sales), EV OEMs have a vested interest in ensuring that the necessary levels of investment in public charging infrastructure occurs. A number of EV OEMs, including Tesla, Audi, BMW, Porche and Nissan are investing in public charging infrastructure in Australia, but this is primarily infrastructure for use by owners of their own vehicles.

Spöttle *et al.* [2018] identified 7 different types business models in use, the types of stakeholders that used them, summarised the advantages and disadvantages of each, and ranked them (see Table 7.3).

Table 7.3 Business models used for building public EV charging networks (Source: Spöttle *et al.* 2018).

Business Model	Stakeholders	Benefits	Challenges	Ranking	Comments
BM 1	EV charging network operators (e.g. Fastned, NewMotion, ChargePoint)	Direct and indirect revenue generation methods, cost-sharing partnerships.	Path to profitability for charger owner/operator uncertain	1	Some EV charging network companies create partnerships to distribute charging stations, while others own and operate the stations themselves. These networks are expanded if and when the companies sees value in doing so.
BM 2	Mobile Charging Systems (e.g. Ubitricity)	Lower infrastructure costs allow for quick build-up of charging network	Getting smart cables to consumers	1	Not fast charging. Type 2 outlet that can supply up to 32 amps (7.2 kW), Top up only. Low-cost sockets are installed in publicly accessible places (mainly street lamps). Anyone with a SmartCable is able to use it to top off their vehicle's charge.
BM 3	EV OEM providing the subsidy (e.g. Ionity in Washington State).	Business model does not rely solely on direct revenue from EV charging service. Examples of private sector partners include automakers and battery suppliers looking to expand EV networks as a tool to sell more EVs, energy suppliers that wish to expand access to charging in their service territories, and retail/restaurants where on site charging may provide additional sales	Requires public and private subsidies to cover areas of low EV sales, not supplied by OEMs	2	Not directly profitable for the OEM, has to be factored into the EV sales price. OEM's focus is on increasing vehicle sales to obtain profits rather than profiting from the chargers themselves. With government incentives to help offset installation costs, a larger network can be created with the same amount of OEM capital
BM 4	Energy supplier lead planning and installation of public charging infrastructure (e.g. RWE/ Innogy).	Quickly ramps up EV charging infrastructure	Requires public funds	2	Energy suppliers can take a holistic approach to building a charging infrastructure, making sure that all are provided with sufficient charging amenities. In addition, most customers already have an account with an energy supplier. This model could also provide energy suppliers with the opportunity to use public charging stations to aggregate capacity for demand response events.

BM 5	Public Charging Infrastructure funded by grants and public funding (e.g. many governments provide finan-cial support for EV charging).	Quickly ramps up EV charging infrastructure	Low utilisation, low revenue, requires public funds	3	Many charging network companies have started by using public funds to grow charging networks. Grants function as a funding mechanism for building up networks ahead of revenues justifying growth.
BM 6	Auto OEM - Energy supplier - Operator Partnership (e.g. BYD170/ China Southern Power (CSP) grid franchise partnership)	This business model creates charging infrastructure that is directly tied to the sales of EVs, and there is no imme-diate requirement for profitability.	It is unclear if this business model can continue to scale without subsidies provided by the government.	3	HIgh profitability. Charging station installation is subsi-dised by the government/ energy supplier/OEM and operated by a franchise. Subsidies help charging networks reduce capital costs and achieve profitability much faster.
BM 7	EV OEM owned Charging Network	Marketing advantages for OEM	Balancing cost of installing and operating charging network against marketing and consumer touchpoint value	4	Low profitability. The purpose of the auto OEM-owned network such as Tesla's Supercharger Network is to serve as additional opportu-nities for Tesla to interact with and market to its customers and drive additional sales. Tesla has confirmed that its charging network will never be a revenue stream for the company.

In Australia and Western Australia, EV numbers are still very low, but a number of business models as described by Spöttle *et al* are either being used or in planning. These include their BM 7 (Tesla's Supercharger network, Nissan and Jaguar Land Rover stations at distribution centres), a combination of their BM1 and BM3 (Charging station owner investment with public grants) and their BM4 (Electricity supplier owned and operated network) models. There are also networks with no business model, but that have been or are to be built, owned and operated by government to serve as a kick-start for the EV industry (ACT Government and Adelaide City) or by associations largely as promotional exercises (RAC WA, NRMA).

Based on stakeholder interviews undertaken for this report, another business model that could emerge in metropolitan areas in Perth (and possibly other cities and towns in WA) is for commercial property owners that have properties with significant sized car parks and high patronage to invest in their own public charging infrastructure. This will not occur until there is a profitable business case for them to do so and it is clear that there is an expectation or hope that this could be brought forward using public grant funding from a grant bodies such as ARENA. The disadvantage of this model is that while it could result in public charging stations being installed in a significant number of sites, unless there is coordination and an open source payment method, it could be unwieldly. There is also a risk that the site selection will be based on parking space availability and patronage, rather than on criteria that would result in an optimal network. Such stations could become stranded assets if other businesses subsequently installed charging stations at more strategic sites.

Spöttle *et al.*'s first ranked model, investment by EV charging network operators, would include those charging network companies that have been acquired by oil companies, such as BP, Esso and Shell. Those charging network companies have not yet looked to invest in Australia and it is likely that they will be holding off until it is clearer what future EV take-up rates in Australia are likely to look like.

The implications for a fast charging network in the greater Perth region, and possibly in other urban centres in WA, can be summarised as follows:

- A fast charging network will eventually be built, but public funding will be required.
- By whom, within what timeframe and in what locations a public charging network will be built will depend on what public funding is provided to which players.
- Any public funding that is provided to bring that timing forward should be coupled to steering mechanisms for the locations of charging stations.
- While there may be a preference for EV charging network operators to own and operate the fast charging stations, it may be some time before those companies are willing to do so due to the current low numbers of EVs in WA. It may therefore be prudent to investigate whether or not the option of state electricity business ownership would be a viable and better option. In the US and UK, electricity businesses have been prohibited from owning and operating charging infrastructure, but the benefits of allowing electricity companies to do so (a more holistic approach to a roll-out of charging stations, site selection, ease of payments, the ability to incorporate home, work and public charging into an integrated DM scheme) have led some jurisdictions such as California and the UK to amend their regulations, and a numbers of other jurisdictions are now flowing suite [Fitzgerald and Nelder, 2017].

7.4.2 Business models for non-urban areas.

Developing a business case and a business model for investment in public charging infrastructure in the Perth metro area and other urban centres in WA is challenging. In the case of a non-urban fast charging network, developing business models for financially sustainable EV charging networks developing is far more challenging.

In the light of the limited business opportunities available, the first guiding principle should be to keep the public fast charging infrastructure to a minimum [Kley *et al.* 2011].

The second guiding principle should be that while dependency on subsidies should be avoided, incentives will be needed to develop a comprehensive network of recharging to cover less heavily trafficked and populated areas – just as is necessary for the privately owned mobile phone network [Transport and Environment 2018]. But to minimise public subsidies, it will be necessary to form public-private partnerships and to find a business model that does not rely solely on direct revenue from EV charging services. This will involve forming partnerships with one or more companies or organisations that are willing to contribute toward financing the charging infrastructure, in order to obtain some non-monetary value from the development of such networks. A study by [Negro and Frades 2015] examines which business models are available for a fast charging network on a highway in Canada. One promising opportunity to improve the financial performance of charging station investments was to develop business models that, through private partnerships and joint investment strategies, captured other types of business value in addition to selling electricity. The potential opportunities included tourist revenue for retailers and tourism businesses that would get more sales from EV drivers when located near EV charging stations; EV OEMs selling more EVs; and businesses attracted to "clean energy" marketing and brand-strengthening opportunities visibly involved in EV charging deployment projects.

This study identified three business models aimed at capturing these sources of value, and analysed the financial viability of each business model by applying them to address an infra-structure gap in British Columbia. The three business models assessed were:

1. Partnering with a large business, such as an EV OEM, a battery supplier, a retail chain or a restaurant chain) willing to contribute toward a DC fast charging network in regional high-ways. The modelling assumed that the EV OEM provided an upfront amount of $7,000 to charging owner-operator for each DC fast charging station.

2. Partnering with a consortium of local businesses that would be willing to make annual contributions toward the cost of a charging network in regional areas. Possible businesses included tourism businesses and retailers aiming to sell products and services to EV drivers. The modelling assumed that these local businesses would share 10% of the revenue from new business that they gained from EV charging use each year for 10 years with the charging owner-operator.

3. Partnering with a combination of a large business and a funding pool financed by local businesses. The modelling assumed that these stations could be hosted by local businesses that would contribute 10% of their new revenue gained EV tourism each year for 10 years, the EV OEM provided an upfront cash transfer to the charging owner-operator in the amount of $7,000 for each DC fast charging station and $500 for each Level 2 charging station.

The study found, unsurprisingly, that all of the business models would materially improve the financial performance of EV charging projects by capturing the value of EV charging services to other businesses, thereby increasing private sector investment in the EV charging network. However, the analyses also show that it is unlikely that the private sector would be willing to implement any of these business models in the near-term as they would be per-ceived as unfavourable investments under the then current market conditions. In summary, none of the three business models were found to be financially viable without public interventions.

The study also addressed the possible rationales or justifications for public intervention. These were:

- Local economic development (e.g., from retail sales);
- EV driver safety (ensuring a sufficiently dense network that keeps EV drivers from getting stranded);
- Promoting the use of 'clean energy' (almost 100% of the electricity in BC is produced from renewable energy sources) ; and
- Reducing transportation emissions.

The study concluded that both private and public sector participation would be required to ensure the sustained development of EV infrastructure in regional areas of British Columbia, but that with sustained EV market development, public sector interventions may no longer be needed to attract private investment in charging stations after five years. The study also concluded that there was growing evidence that diverse businesses could be willing to contribute toward the cost of a fast charging network because of the indirect benefits that they receive.

7.5. Transitioning to Commercial Operators

All public charging infrastructure built to date in all countries has been government subsidised [Energeia 2018]. While there are signs that the point is approaching in some countries where the need for public subsidisation is nearing an end, those cases are in countries with high EV numbers on the road. How long it will take for that point to be reached in Australia and Western Australia is difficult to predict, but it is not likely to be very soon. Because of this, it will be necessary to build and to maintain a network of publicly accessible charging infrastructure across the entire road network, and traffic flows on some routes will always be low, full cost recovery may never be possible [IEA 2018]. The transitioning of government-funded infrastructure to commercial operators will in some cases take longer than in others. How long it will take for any situation is impossible to determine at this stage. It will be important to determine which business models are the most likely to succeed and within the shortest timeframes, and to test the waters.

One option would be for the Government to call for private sector partners to apply for grants or low-interest loans to lower the cost of funds for fast charging projects. Applicants would be required to demonstrate that their proposed project addresses a specific charging infrastructure gap in WA. The project could address a particular route to a specific location, such as a tourist destination, routes within a particular area, or a combination of both. Applications would be expected to present a clear case for the value proposition of filling the charging gap and provide evidence that the project would be profitable and sustainable for the charging network owner-operator and any private sector partner. This approach would require applicants to form the proposed partnerships with local business, EV OEMs, and others, with any assistance required provided by bodies such as business associations, local governments and regional commissions.

7.6. References

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Appendix A. Electric Vehicle Support Benchmarking

A brief EV charging infrastructure benchmarking analysis is provided in Chapter 5 of this report. As explained in that chapter, the purpose of EV benchmarking analyses is to provide policy makers and planners in making decisions regarding the number, the best mix (Level 2, Level 3 and DC fast charging) and locations public EV charging stations. To that end, a number of international EV charging benchmarking analyses have been undertaken. However, as also explained in Chapter 5, unless a benchmarking analysis is sufficiently comprehensive and complete its ability to inform and assist policy makers by providing answers to those questions is, at best, highly questionable. This is not only because bench-marking analyses indicate that the difference between countries in metrics such as the number of publicly accessible charging stations per 100 EVs in the passenger vehicle fleet are very large, but if they fail to explain the reasons for those large differences their power to explain and inform is severely limited. For example, a recent Australian study on electric vehicle uptake rates [Energeia 2018] used benchmarking in order to compare the effectiveness of different incentives used to encourage increased EV uptake rates and the correlation between EV uptake rates and the numbers of charge points installed. It has been pointed out, however, that the value of such benchmarking is limited if the benchmarking is based on comparing EV uptake rates with the *types* of incentive used, but not the incentive *amounts* involved [German *et al*. 2018]. While including the incentive amounts is necessary to compare the differences in the effectiveness of different incentives, it is also necessary for benchmarking analyses to understand the reasons that those incentives have been or are being provided by governments.

This EV charging infrastructure benchmarking analysis provided in this Appendix is therefore more comprehensive. It compares not only the number of EV charging stations that have been installed in Western Australia with the number of EV charging stations that have been installed in other Australian states and in a number of selected countries, but also provides information on the incentives and programs that have underpinned the roll out of EV charging infrastructure, and the policy objectives or drivers that have resulted in those incentives being offered. It is particularly important to provide such comment if, as is the case in most EV charging infrastructure benchmarking analyses, the countries selected for comparison are countries that have the highest EV uptake rates and the highest numbers of EV charge points installed, but which fail to point out that these are atypical. For example, just ten countries (China, the United States, Japan, Canada, Norway, the United Kingdom, France, Germany, the Netherlands and Sweden) account for 95% of global EV sales [Gotis 2018], just 20 cities in the world account for about 40% of the world's electric vehicles [ICCT 2018], and 76% of all charging stations in Europe are located in 4 countries (Netherlands, Germany, France, and UK) [Transport & Environment, 2018]. Using countries for benchmarking that are atypical in terms EV uptake rates and the numbers of charge points installed are also likely to be characterised by differences in policy drivers and incentive programs that have resulted in those atypical EV uptake rates and large numbers of charge points. They are also likely to differ with respect to many other metrics, such as GDP/capita rates [European Automobile Manufacturers' Association, 2018], the carbon intensity of electricity, home ownership vs home rental statistics, percentages of the population that live in apartments and do not have access to off-street parking, etc. [Fishbone *et al*. 2018]. Therefore, there are many factors that would need to be considered to provide a complete explanation of the differences in EV uptake rates and numbers of EV charging stations installed.

In this appendix, the countries selected for comparison include not only the countries with high EV uptake rates and large numbers of charge points installed, but also a small number of countries with lower EV uptake rates and smaller numbers charge points installed. The data used in this chapter includes data from the IEA [2018], the European Alternative Fuels Observatory, and country national vehicle statistics.

One of the metrics used is the projected date by which EVs will reach 1% of the passenger vehicle stock for each country. The method used to project the dates was to use statistical data on EVs from sources such as the European Alternative Fuels Observatory and IEA publications, together with statistical data on passenger and light vehicle numbers from on-line government sites with country statistics on transport data with historical percentages of EVs in the passenger vehicle fleet. That information was used to plot the historical percentages, and to then find the equation of the line of best fit. The equation was then used to extrapolate to the year in which the percentage of EVs in the passenger vehicle fleet would reach 1%. An example using EVs as a percentage of the Portuguese passenger vehicle fleet is shown in Fig. A.1, for which the projected date for EVs reaching 1% of the passenger vehicle fleet was found to be mid-2023.

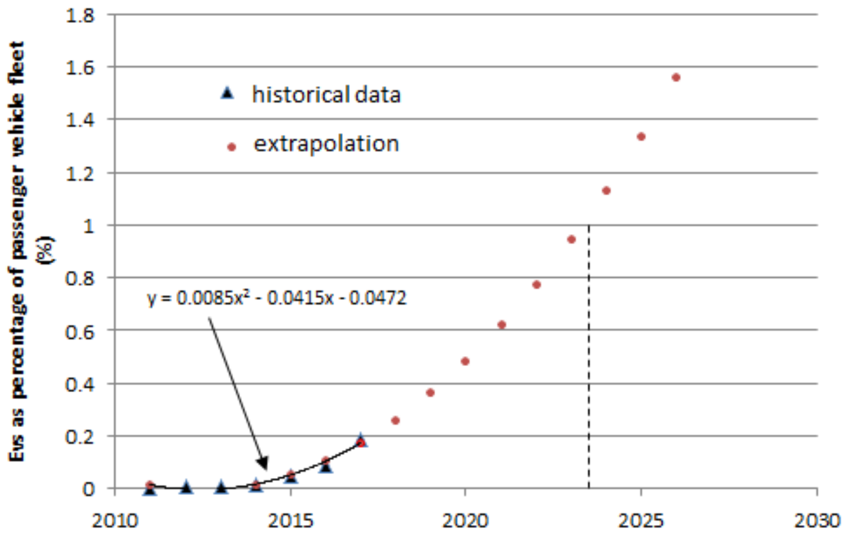

Fig. A.1. Historic EV data (Portugal) on EVs percentage of passenger vehicle feet and using line of best fit to project date when EVs will reach 1% of passenger vehicle fleet.

A.1. Australia

The total number of EVs in Australia's passenger vehicle stock by the end of 2017 was 7,340, which represented 0.05% of the passenger vehicle stock. BEVs accounted for just under half of the number of EVs on Australian roads in 2017. The number of EVs per 1000 population is 3.4.

Based on Energeia's [2018] modelling, assuming no change in Australian Federal or State Government EV policies ('no intervention' scenario), EVs are projected to reach 1% of the Australian passenger vehicle fleet at around 2023. This appears to be slightly optimistic, as using our line-of-best-fit method, the earliest date by which EVs would reach 1% of the Australian passenger vehicle stock under a 'no intervention scenario' is 2026 (Table A.1).

Table A.1 EV statistics - Australia

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
7,340	0.05%	3,420	46%	2026

(Sources: IEA 2018, Energeia 2018, Charting Transport 2018).

Charging Infrastructure

There are inconsistencies in the available data on charging infrastructure in Australia, which stems in part from differences in terminology, such as low power vs high power, slow versus fast, and what types and sizes (kW) are included or are not included in those terms. According to the [IEA 2018], the number of publicly accessible charging stations that had been installed in Australia by the end of 2017 was 476, of which 436 were fast chargers. According to [PlugShare 2018], however, the number of high power EV charging sites in Australia is currently 250 and the total number of publicly accessible fast-DC charge points that have been installed in Australia to date is 82. Most of these have been installed on the Eastern seaboard in QLD, NSW, the ACT and Victoria. Of the 79 DC-fast charge points installed, 57 are general usage sites and the other 22 are Tesla superchargers.

Table A.2 EV charging infrastructure statistics - Australia

No of public charge points (PCP)	No of EVs per PCP	No of high power charge sites	No of DC fast charge sites	No of BEVs per DC charging site
476	15.4	250	79	43.3

(Sources: IEA 2018, PlugShare 2018).

A number of governments, organisations, businesses, and consortia have mooted plans to install additional fast DC charging stations. For example, the Fast Cities consortium has announced plans to install DC fast charging stations at 7 sites, with a minimum of 2 x 350kW per site [Vorrath 2018]. The motoring association, NRMA, announced in 2017 that it was planning to invest $10 million to install 40 DC fast charging stations at 10 sites on highways in NSW [NRMA 2017]. Similarly, Jaguar Land Rover has announced that it will invest $4 million to install charging stations at its distribution sites. The Victorian Government has committed $1 million to building two ultrafast charging stations in locations that will assist EV drivers travelling interstate to NSW and the ACT [Victorian Government 2018]. Almost all of these additional fast DC chargers will be installed in the Eastern States.

Western Australia

There are only 13 fast-DC charge sites in Western Australia, all of which are equipped with a single 50 kW charger. One is located at The University of Western Australia, another is located at the City of Swan, 11 RAC charge points are located at sites in SW of Western Australia between Perth and Augusta. In addition, there is a Tesla supercharging site with 6 x 125 kW stations. All of these stations are located in the Perth Metro and South-West WA region.

Charging infrastructure policy and incentives

- No Federal Government incentives are offered for EV charging infrastructure.
- The ACT government has announced plans to build 50 'standard' charging stations at ACT government sites in the ACT at a cost of $454,000 [Black 2018], and offers stamp duty exemption under its Green Vehicles Scheme
- The Qld government has invested in 'the Queensland Electric Super Highway' with fast DC chargers at sites in 15 coastal towns and cities along the Queensland coast. Charging will remain free until December 2018 [Queensland Government 2018].
- Adelaide City installed a network of charging stations (Type 2 22 kW and two 50 kW chargers around the City. After an initial stage with free electricity, the fees for the 22 kW stations was increased to 20c/kWh during peak and 10c/kWh during off-peak periods, while the fee for the 50 kW charging stations is 30 c/kWh [Adelaide City 2018].
- The City of Adelaide offers a grant for installing EV charging stations at business or residential sites ($1,000 for Level 2 chargers and up to $5,000 for fast DC chargers)
- Investment in other public charging stations in Australia has been undertaken by a mixture of electricity utilities, EV OEMS, motoring associations and EV charging OEM, and in most cases, free charging is being gradually phased out in favour of a user-pays (e.g. ChargeFox, ChargePoint, Adelaide City, and Everty) or 'embedded' revenue model (NRMA/RAC and Tesla) [Energeia 2018].

EV policies and incentives

- The ACT offers the strongest incentives for EVs. The ACT Government plans to convert its own leased fleet to 100% EVs by 2020 [Whyte 2018], exempts those buying an EV from stamp duty ($3 per $100 value of the vehicle's value), offers a 20% reduction in annual registration fees, and free parking [ACT Government 2018].
- The previous South Australian Labor government promised to exempt EVs from stamp duty and from annual registration fees for the first 5 years, with the total savings over 5 years ranging from $2,155 to $3,755. However, the scheme was never implemented as the Labor Government was not returned to office [Vorrath 2108].

Policy drivers

- The Australian governments' support for EVs has been described as 'measured' [NSW Government 2018]. Rather than looking at the EV policy drivers, the situation in Australia's case is reversed and it is necessary to explain the lack of a national EV policy in terms of a lack of policy drivers. Some of the possible reasons behind the lack of an Australian EV policy are:
  (i) GHG emissions: Light vehicles and passenger vehicles account for 10% of Australia's GHG emissions [Climate Change Authority n.d.]. Australia's emission reduction targets are a 5% reduction on 2000 levels by 2020, and a 26%-28% reduction on 2005 levels by 2030. According to the Australian Government, Australia is already on track to meet those targets with the initiatives that have already been put in place, such the $2.55 billion Emission Reduction Fund and higher vehicle emission standards [Australian Government 2017a].
  (ii) Electricity carbon intensity: The average emissions intensity of electricity in Australia of approximately 750 kg $CO_{2\text{-}e}$/MWh is approximately 6 per cent higher

than in China and 60 per cent higher than in the US [Vivid Economics 2013]. The carbon intensities of electricity in the largest states are relatively high, Victoria being the highest at (1070 kg CO_2/MWh Victoria, followed by 820 kg CO_2/MWh in NSW and 800 kg CO_2/MWh in Queensland) [Australian Government 2017b]. These high carbon electricity intensities reduce the ability to use electrification of the vehicle fleet to reduce GHG emissions, especially in Victoria [Victorian Parliament 2018].

(iii) The lack of a car manufacturing industry: this reduces the potential economic and employment benefits that could be obtained from strong EV policy [Victorian Parliament 2018].

(iv) Impact on government revenue: The value of Federal Government revenue from fuel excise is over $12.4 billion per year. Annual revenue has fallen over time as a consequence of the shift to smaller and more fuel efficient vehicles and there are concerns over the impact that a rapid uptake of EVs would have [Bradley 2018, Mortimore 2018].

A.2. New Zealand

The total number of EVs in NZ's passenger vehicle stock by the end of 2017 was 6,108, which represented 0.16% of the passenger vehicle stock. The projected date by which EVs will reach 1% of the NZ passenger vehicle stock is 2021 to 2022 (Table A.3).

Table A.3 New Zealand EV statistics

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
6,108	0.16%	4,478	73%	2021/22

(Source: Adapted using data from NZ Ministry of Transport. Vehicle statistics https://www.transport.govt.nz/resources/vehicle-fleet-statistics/).

Charging Infrastructure

There are currently 249 public charging sites in NZ, including 169 fast-DC charging sites and 6 Tesla supercharger sites (Table A.4) [Plugshare 2018].

Table A.4 New Zealand EV statistics

No of public charge points (PCP)	No EVs per PCP	No of DC fast charge sites	No of BEVs per DC charging site
249	24.5	175	25.6

(Source: Adapted using data from NZ Ministry of Transport. Vehicle statistics https://www.transport.govt.nz/resources/vehicle-fleet-statistics/).

Charging infrastructure policy and incentives

- There is coordination between government agencies on activities to support the development and roll-out of public charging infrastructure, including providing information and guidance. The government has committed NZ$1 million per year for a nation-wide electric vehicle information and promotion campaign over five years [Bridges, 2016, Beijing Capital Energy Technology Co. Ltd 2017].

EV policies and incentives

- Light electric vehicles are exempted from road user charges. The NZ government has announced that the exemption will remain in place until EVs make up two percent of the light vehicle fleet, and will be extended to heavy electric vehicles [Bridges, 2016].
- The NZ government has set a target of 33% of EVs for the government vehicle fleet [Energeia, 2018]. The target date is 2021 [Bennett and Bridges 2017].
- The government has established an electric vehicles leadership group across business, local and central government, and is establishing an electric vehicles leadership group across business, local and central government. It is also working with the private sector to investigate the bulk purchase of EVs for public and private vehicle fleets [Bridges, 2016].
- The government has established a competitive fund of up to NZ$6 million per year to encourage and support innovative low emission vehicle projects [Bridges, 2016].
- EVs have access to bus lanes and high-occupancy vehicle lanes on the state highway network and local roads [Bridges, 2016].
- The NZ government is reviewing of tax depreciation rates and the method for calculating fringe benefit tax to ensure that EVs are not being unfairly disadvantaged [Bridges, 2016].
- The NZ government removed restrictions on third party car imports the late 1980s, and more than two-thirds of the cars now sold are "grey market" vehicles imported by brokers and the majority of imports by third-party are near-new, second-hand vehicles [Energeia, 2018].

Policy drivers

- The NZ government's EV policy is a part of its strategy for reducing GHGs and reducing the country's reliance on oil imports. The government has set a target of 64,000 EVs by 2021, which would be approximately 1.7% of the passenger vehicle fleet [Bridges 2016, Beijing Capital Energy Technology Co. Ltd 2017].

Other contributing factors to EV uptake rate

- Car ownership in NZ is relatively high (almost 800 vehicles per 1000 population)
- Petrol prices in NZ are relatively high (A$2/L in 2017)
- NZ's electricity GHG emission intensity is relatively low (approx. 100 g/kWh)
- GDP per capita in NZ is relatively low (A$59,228 in 2017) and is one of the reasons that many second hand cars are imported into NZ (According to Ministry of Transport, almost 50% of light passenger vehicles were imported second-hand.

A.3. Europe

A.3.1 Non-EU Member Countries

Neither of the two European countries with the highest percentage of EV in new car sales in 2017, Norway and Iceland, are members of the EU. Switzerland, another non-EU member, had the sixth highest percentage of EV in new car sales in 2017. These countries need to be grouped separately from EU member countries as they do not share policies with each other or with the EU member countries, and so the policy drivers for their high EV uptake rates are very different in many respects.

A.3.1.1 Norway

In terms of both the percentage of new passenger car sales that are EVs, and the percentage of vehicles in the passenger vehicle fleet that are EVs, Norway is the outlier. Although the country has a population of only 5.35 million, it is the third-largest market for electric vehicles in the world after China and the USA, and in 2013 became the first country in which EVs reached 1% of the passenger vehicle fleet. By the end of 2017 the number of passenger EVs reached 176,310 vehicles, equating to 33.9 EVs per 1000 population. According to Bradley *et al.* [2018], Norway is the only country in the third stage of EV market penetration as developed by [Hertzke *et al*. 2018], only two other countries, China and Sweden, are in the second stage, and all other countries are still in the first stage.

Table A.5 EV statistics – Norway

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
176,310	7%	116,130	66%	2013

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure

By September 2018, a total of 11,535 public EV charging stations had been installed, 2,535 of which were high power charging stations (>23 kW), which included 59 superchargers.

Table A.6 EV charging statistics - Norway

No of public charging points (PCP)	Number of high power charging sites	No of DC fast charging sites	No of EVs per PCP	No of BEVs per high power PCP	No of BEVs per DC fast charging site
11,535	2,535	173	24.5	45.8	671

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure policy and incentives

- Norway's EV policy has focused primarily on the incentives for the vehicle with the expectation that "infrastructure follows vehicles", i.e. if there are more electric vehicles on the road, a market for EVSE (Electric vehicle service equipment) will be created as EV users grow [European Commission, 2016].
- In addition to the EV incentives the Norwegian government also supported the installation of basic charging infrastructure. The scheme for public charging infrastructure took place in 2009-2010 as part of a financial stimulus package after the 2008 fiscal crisis. Under the scheme, 100 % of the installation cost for normal chargers and up to A$4,800 per charging point was provided The total support amounted to A$8 million and around 1800 Schuko-points (household sockets) were installed [Lorentzen *et al.* 2017].
- In 2010 the government opened its first round of funding support for fast charging stations. Several charging operators that applied for funding originated from local electricity utility companies [Lorentzen *et al.* 2017].
- In 2015 the public electricity company Enova introduced a funding support scheme for fast charging stations with aims of having fast charging stations installed every

50 km on the Norwegian 7,500 km main road network, with at least two stations per site [Lorentzen *et al.* 2017].

- All of the fast charging stations in Norway are owned and/or operated by charging operators. Under the payment model used by the two national charging operators, Fortum Charge & Drive and Grønn Kontakt, customers pay per minute of charging. This translates into a price of approximately A$0.48/kWh to A$0.80/kWh, depending on actual charging speed, which is three times more than EV drivers pay for the electricity that they use at home.
- It has been estimated that fast charging is commercial in Norway with as few as 115,000 BEVs, around 3% of the car fleet [Lorentzen *et al.* 2017].

EV policies and incentives

- The high EV uptake rate in Norway has been attributed to the number of strong acquisition recurring incentives that have been offered over a long period [Energeia, 2018] and the use of strong 'acquisition incentives' that reduce the purchase price of EVs to achieve pricing parity with petrol and diesel conventional ICEVs [Bjerkan *et al*., 2016, Haugneland *et al.,* 2016, Lorentzen *et al*., 2017].
- In 1990, BEVs were exempted from import taxes, which averaged 5-figures [HEV TCP [2018]. In 1996 annual registration fees were reduced for BEVs. In 1997 BEVs were exempted from road toll fees. In 1999 special 'EL', 'EV' and 'EK' number plates were introduced and BEVs were exempted from municipal parking fees.
- In 2000, the company car tax was halved and in 2001 BEVs purchased as company cars were exempted from VAT (25% of sale price).
- In 2003, BEVs were permitted to use bus lanes in Oslo, and in 2005 the access to bus lanes was made permanent and extended nationwide. In 2009, BEVs were exempted from ferry fees.
- Since late 2013, PHEVs received favourable fiscal treatment, including a reduction of up to 10,000 Euros for purchase tax. The Norwegian tax system levies higher taxes on heavier vehicles, making plug-in hybrids more expensive than equivalent gasoline and diesel-powered cars due to the extra weight of the battery pack and its additional electric components. PHEVs were therefore given a 10% weight deduction. In 2013, the weight deduction was increased to 15%, and in 2015 was increased again to 26%. As a result, sales figures of PHEVs have increased while those of BEVs have stabilised, the popularity of PHEVs most likely linked to the fact that the average distance travelled per year for cars in Norway (15,000 vehicle km /capita) is the second highest in Europe (after Luxembourg). In 2015, leasing EVs was exempted from 25% VAT.

Policy drivers

- The policy drivers behind the incentives offered to encourage the uptake of EVs have been described as unclear [Holtsmark and Skonhoft 2014]. The country has no car manufacturing industry to protect. The country is an oil and gas producer and the export of oil and gas is the country's largest export earner. Norway is not a member of the EU and so is not committed to EU policies related to reducing vehicle emissions or reducing greenhouse gas emissions. The most likely main drivers is considered to be linked to the goal of reducing GHG emissions, as almost 17% of the country's GHG emissions are from the transport sector and 85% of Norway's electricity is produced from renewable energy sources.

- The Norwegian EV policy did result in the establishment of an EV manufacturing industry. One domestic electric vehicle manufacturing company, PIVCO (later renamed *Think*) started up in 1994, and in 1999 Kewit (later renamed *Buddy*) was purchased by a Norwegian company. However, both went bankrupt in 2011.
- The Norwegian government has announced a plan for all new private cars, city buses and light vans to be zero-emission vehicles by 2025 [PwC 2018].

Other contributing factors to EV uptake rate

- It is likely that the high uptake rates are also partially explained by Norway's high GDP per capita (the highest in Europe other than Luxembourg) and high petrol prices (A$2/L in 2017), which are the highest in Europe
- A portion of the EVs in Norway are second hand EVs imported from other countries, particularly Sweden and France [Amiot 2013, Elec Trans 2018].
- The Norwegian electricity system is robust and has been able to accommodate the increased loads created by EV charging.
- Due to the cold weather in Scandinavian countries, ICEV engines are preheated using electricity and the pre-heater electricity cabling is suitable for EV charging.

A.3.1.2 Iceland

In absolute numbers, everything related to Iceland is small. The total passenger vehicle fleet in 2017 was only 236,000 (many of which are rental vehicles for tourism), but the number of EVs in the fleet was almost 3,000, equating to 15.3 EVs per 1000 population. The proportion of EVs in the passenger vehicle fleet is the second highest in the world. EVs accounted for 14% of new cars sales in 2017 (28.5% of which were BEVs), and by the end of that year 2.14% of all cars in Iceland were EVs, two thirds of which were EVs. EVs reached 1% of the vehicle fleet in 2015.

Table A.7 EV statistics – Iceland

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
2,990	2.14%	1,097	65.9%	2015

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018)

Charging infrastructure

- There are 127 publicly available charging sites in Iceland, 87 of which are high power charging sites, and 35 of which are DC fast charging sites. The high number of EVs per charging station can be explained by the reduced need for public charging infrastructure due to short driving distances and high levels of home charging.

Table A.8 EV charging statistics - Iceland

No of public charging points (PCP)	Number of high power charging sites	No of DC fast charging sites	No of EVs per PCP	No of BEVs per high power PCP	No of BEVs per DC fast charging site
127	87	35	23.5	21.9	54.5

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure policy and incentives

- In 2014, there were only eleven public charging stations in Iceland, six in the capital city, Reykjavik, and the other two in Akureyri. The government's aim was to have more than 25 public charging stations installed, and so offered grants with a total value of 200 million Icelandic Kroner (approx. A$2.3 million) for public charging stations.

EV policies and incentives

- Acquisition incentives (zero purchase/import tax and VAT for BEVs) and recurring financial incentives. Vehicles emitting 80 g CO_2/km or less are exempted from import excise duties, which can be up to 65% of the vehicle's customs value if emissions exceed 250 g CO_2/km. In combination, these reduce the purchase costs of EVs to that of comparable ICEVs.
- BEVs are exempt from annual registration fees
- The Icelandic government is currently developing amendments to building codes to require charging outlets for EVs in new and renovated buildings.
- The Reykjavik City Council has converted its own car fleet to electric and offers its employees travelling to and from work by a means other than a diesel car a 72,000 ISK (A$824.50) annual stipend. The City also offers free parking for low emission vehicles
- A number of companies offer free EV charging for their employees and/or their customers.
- The Icelandic government's goal is to have 30,000 EVs by 2026 (approx. 12% of the passenger car fleet).

Policy drivers

- The drivers behind the Iceland government's EV policies are to reduce the country's reliance on imported oil and to reduce GHGs. Under the Paris Agreement, Iceland, Norway, and the EU are required collectively to decrease GHGs by 40 percent from 1990 levels by 2030. Most of the country's emissions are from aluminium production and second most are from the transport sector. However, because Iceland is not required to reduce emissions from the production of aluminium or ferrosilicon, international aviation or from a number of other sectors, transport is left as the primary sector from which emission reductions can be achieved to meet the country's emission reduction commitments.
- Electrification of the vehicle fleet will reduce GHG emissions as all of the electricity is produced from renewable energy. Biofuels and electricity accounted for 6% of transport energy use in 2017, and the government's aim is for this to be increased to 10% by 2020, and to 40% by 2030, and to have 30,000 EVs in Iceland by 2026. The target is ambitious but surveys of prospective car buyers in Iceland have found that almost half are planning to purchase an EV [Wapppelhorst and Tietge 2018].

Other contributing factors to EV uptake rate

- The high cost of petrol (A$1.91 in 2017) in Iceland provides a strong incentive to purchase an EV.

A.3.1.3 Switzerland

In 2017, 2.66% of new car sales in Switzerland were EVs, of which BEVs accounted for 57%. By the end of 2017 there were 13,800 EVs registered, making up 0.32% of the passenger vehicle fleet, and there were 1.7 EVs per 1000 population.

Table A.9 EV statistics – Switzerland

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
13,800	0.32%	8,023	58%	2022

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure

- By September 2018, there were 4,259 normal and 638 high power public charging sites in Switzerland, of which 17 are supercharger sites.

Table A.10 EV charging statistics - Switzerland

No of public charging points (PCP)	Number of high power charging sites	No of DC fast charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
4,259	638	638	3.24	12.57

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure policy and incentives

- The Swiss government does not provide financial incentives for EV charging infrastructure. That has resulted in the electricity utilities taking the lead in installing public charge points and promoting EVs. EV owners are not charged for the electricity used for public charging, and the electricity network is incrementally extended to match the demand.
- For charging on long distance trips, a private company, TEXX began installing public charge points at petrol stations on freeways. The Electric Vehicle Club of Switzerland promotes public charging infrastructure. Some of the charging stations include 32 Amp 230-400 V outlets, while the owners of many private charge points make these available to others.
- Swisscom and Energie Service Biel/Bienne are two of the private EV charge point operators in Switzerland, and use the same Hubject GmbH platform as many other charge point operators in Europe.

EV policies and incentives

- The Swiss government has not provided acquisition incentives for EVs, but has exempted BEVs from import taxes.
- Registration fees are set and collected by local governments (Cantons) in a similar way to the Australian states and territories set and collect car registration fees. Several Swiss cantons offer reduced registration fees or exempt registration fees for BEVs and PHEVs.

Policy drivers

- The Swiss government has been hesitant to play a leading role in promoting EVs or to provide incentives to encourage the adoption of EVs. This reluctance has been based on a belief that the push for accelerated EV uptake rates should be left to market forces. Despite this, the Swiss government has recently set an ambition of EVs reaching 15% of new car sales in Switzerland by 2022.
- The Swiss lack of an EV policy is somewhat surprising given that the Swiss government has set a GHG emission reduction target of at least 20% below 1990 levels by 2020, and emissions from the transport sector are higher than any other sector, and most of the electricity is generated from renewable energy resources. The government's EV policy is instead focused on developing the framework conditions for EV and EV charging infrastructure, which it maintains is technology neutral and does not favour any specific technology [HEC TCP 2018]. In 2012, the Swiss government adopted vehicle emission standards (g CO_2/km) in line with the EU standards for new passenger vehicles, and the penalties on car importers surpassing the emission limit provides an incentive to car retailers to import more EVs, to offset vehicles imported that do not meet the emission levels. In 2008, the government imposed a carbon levy (tax) on fossil fuels such as oil and natural gas.
- The lack of federal government incentives for EVs or charging infrastructure means that the promotion of EVs in Switzerland is being driven largely by non-government organisations, and in particular by the electricity utilities, EV importers, and non-government agencies such as Eco Mobile and the Electric Vehicle Club of Switzerland

Other contributing factors to EV uptake rate

- The high uptake rates of EVs in Switzerland despite the lack of strong government incentives may be partially explained by the fact that GDP per capita in Switzerland (A$135,000) is the 4th highest in Europe.

A.3.2 Europe – EU Member Countries

A small number of the wealthier EU member countries have long been among the leaders in EV uptake rates due to their robust EV policies. It is not possible to explain EV uptake rates and numbers of public charge points installed in these countries in isolation, simply because EU countries share policies and targets related to GHG emission reductions, renewable energy targets, vehicle emission reductions, EV penetration rate targets, as well as programmes to accelerate EV uptake rates and to support the installation of public charging stations. For example, the European Commission has requested its member governments set deployment public EV charging infrastructure targets for 2020, 2025, and 2030 in order to match the level of infrastructure required by the AFI Directive [EC 2014]. Furthermore, many companies that invest in and operate public EV charging networks in Europe do so not in just one EU country, but also in neighbouring countries and cross-border projects. The countries are therefore grouped together, but in terms of EV uptake rates and numbers of public charge points installed, each EU country has been placed in one of three sub-groups: 'Front Runners', 'Followers', and 'Slow Starters' [Transport and Environment 2018].

The EU has had strong overall GHG reduction target commitments that have been progressively made stronger (Table A.11), and member states individually have GHG emission reduction commitments through EU legislation and international obligations. Because the transport sector accounts for around 25% of total EU-28 GHG emissions and is the only sector in the EU for which GHG emissions are still increasing, there is strong EU emphasis on reducing GHG emissions from this sector. Passenger cars are responsible for 44% of transport emissions in the EU, and are therefore regarded as an important target for emission reduction policies [EEA 2017]. However, the 2020 GHG emission reduction commitments of the EU member states vary between members and have been set on the basis of each member state's relative wealth (GDP per capita). At one extreme, the least wealthy states are permitted to increase their emissions in 2020 by 20% above 2005 levels, while at the other extreme the wealthiest member states are required to reduce their emissions in 2020 by 20% below 2015 levels [Amsterdam Roundtable Foundation, McKinsey & Co. 2014].

Table A.11 EU GHG emission reduction commitments 1990 to 2018

Year commitment made	Target year	Target
1990	2000	stabilise at 1990 levels
1997	2008-2010	8% below 1990 levels
2007	2020	20% below 1990 levels
2014	2030	40% below 1990 levels
2018	2050	80-95% below 1990 levels

A key mechanism for reducing GHG emissions from cars in the EU is Regulation (EC) No 443/2009, which places an obligation on vehicle manufacturers to achieve an average CO_2 emission performance for the vehicles they produce, and sets an EU-level target of 130g CO_2/km to be met by 2015, and a further target of 95g CO_2/km to be met by 2021 (phased in from 2020) [German *et al.* 2018].

The EU also has long been concerned about the negative impacts of ICE vehicles on urban air quality and noise, and the high percentage of those living in the EU exposed to harmful particulates higher than acceptable levels. In 2008 the EU Air Quality Directive was introduced to regulate permissible NOx emissions. The regulations have been and continue to be gradually tightened. Cities, the major areas with local air quality issues, are fined if they do not meet the regulated standards. In response, several cities in the EU are actively promoting the uptake of EVs. An EU white paper released in 2011 proposed that limits be imposed on the number of petrol and diesel ICE vehicles in the EU by 2030 and that they be completely phased out by 2050 [URBACT 2012]. EU Directive 2014/94 on alternative fuels for sustainable mobility obliges member states to develop national policies in this area. Member states must submit to the Commission national policy frameworks and deploy a minimum level of infrastructure, such as refuelling and recharging points for alternative fuels (electricity, hydrogen, and natural gas) [European Commission 2016]. As a result, there has been some level of investment in public charging infrastructure at the local and national levels in even EU member states with low EV uptake rates, such as Croatia, Czechia, Hungary, Latvia, Lithuania, Macedonia, Serbia, Poland, Romania, Slovakia, and Slovenia [Fishbone *et al.* 2017]. The charging points operated by several countries across Europe, including Fortum, Grønn Kontakt, VIRTA and CleanCharge, the Swiss companies Swisscom and Energie Service Biel/Bienne, and the French operator Freshmile, all use the Hubject platform. The approaches currently being pursued by EU member states to meet the EU directive on vehicle emissions vary, some focusing on electrification of vehicle fleets (Austria, Bulgaria, Denmark, Finland, France, Germany, Ireland, Luxembourg, the Netherlands, the UK and France), some on natural gas (Czechia, Hungary and Italy), while Belgium is focusing on both electrification and natural gas, and others have adopted either low emission reduction targets or no emission targets [Electro-Mobility Platform 2018].

Over recent years an increasing number of EU member countries such as the UK have announced target dates for completely phasing out the production of new petrol and diesel ICE vehicles due to the negative impacts of their emissions on both human health and the global climate. A number of cities, including London, Oslo, Rome, Paris, Madrid, and Athens, have announced plans to ban diesel cars and vans from their roads by 2025 [URBACT 2012].

The EU also imports more than half of all of the energy that it consumes. Its import dependency is particularly high for crude oil (90%) and natural gas (69%), and the total cost of energy imports is more than €1 billion (A$1.8 billion) per day. Many EU countries are also heavily reliant on a single supplier, including some that rely entirely on Russia for their natural gas. This dependence leaves them vulnerable to supply disruptions, whether caused by political or commercial disputes, or infrastructure failure. For instance, a 2009 gas dispute between Russia and transit country Ukraine left many EU countries with severe shortages. In response to these concerns, in 2014 the European Commission released its Energy Security Strategy that aimed to ensure a stable and abundant supply of energy. The long-term measures contained in the strategy included increasing energy efficiency, reaching the proposed 2030 energy and climate goals, increasing EU energy production, and diversifying supplier countries and routes [European Commission 2014].

The EU accounts for approximately 21% of world car manufacturing production, the member states with the largest car manufacturing sectors being Germany, Spain, France and the UK, respectively. The rapid growth of EV manufacturing has led the EU to support the uptake of EVs as a means of maintaining world car manufacturing market share. Many EU member countries also participate in joint programs, such as the European Green Cars Initiative that aim to create the conditions needed for a transition to e-mobility by 2025, including funding contribution. The EU's European Clean Power for Transport recommends one public available charging point for every 10 EVs by 2020.

A.3.2.1 The Netherlands

The Netherlands has the highest penetration of EVs in the passenger vehicle fleet of any EU member country, EVs accounting for 1.51% of all cars on the road by the end of 2017, and taking the number of EVs per 1000 population to 7.1. In that year, EVs made up 2.2% of all new cars sales, 87% of which were BEVs.

Table A.12 EV statistics – The Netherlands

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
120,457	2.2%	8,023	87%	2022

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure
The Netherlands has the highest rate of public charging infrastructure in the world. By September 2018, the number of normal public charging stations and the number of high power public charging stations that had been installed was 36,010 and 952, respectively.

Table A.13 EV charging infrastructure statistics - The Netherlands

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
36,100	952	3.3	8.4

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure policy and incentives

- A consortium of electricity grid operators, E-laad, was established in 2010 to roll out 10,000 public charging points, with the electricity grid companies bearing the full cost of the installations. The majority (8,000) of the charge point locations were determined by EV drivers and the other 2,000 by municipalities. E-laad also assists communities in developing their own local e-mobility plans. As well as E-laad, some provinces also provide funding to support the development of e-mobility in their regions [HEC TCP 2018, EAFA 2018].
- The reason for the large numbers of normal charging stations relative to the number of high power charging stations relates to the small vehicle travel distances in the Netherlands (the average one way trip is less than 20 km).
- All parties involved in the EV charging infrastructure rollout agreed early on to use the same identification and communication systems for charging stations based on open-source protocols, so that inter-operability at a national level would be ensured.
- The tax rate for companies installing/operating public charging points was reduced in 2017 [Hamer 2017].
- Investment in fast charging stations in the Netherlands is now creating competition and legal challenges over rights. In 2012, Fastned was granted the right to build 201 EV charging stations along Dutch highways and to operate them for 15 years. Sixty three stations so far have been built at a cost of 30 million Euro and 30 more will be built in 2018. MisterGreen has installed another 20 public charging stations under similar concession, and ANWB another 38 stations. In October 2017 Shell bought EV charging company, NewMotion which operates Europe's largest public EV charging station network of 50.000 charge points, and Esso is planning to install fast charge points at its 25 largest fuel stations in the Netherlands, resulting in legal challenges between the companies [van Roy 2018].
- Nuon-Heijmans is planning to install 2,480 points in the provinces of Noord-Brabant and Limburg in the south of Netherlands without financial contribution from the government subsidy [Hammer 2018].
- The Dutch fast charging point operator, Fastned, has stated that its business will be profitable once the number of BEVs in the Dutch passenger vehicle fleet reaches 0.6% to 1.3% (approx. 50,000 to 100,000) [Transport and Environment 2018].

EV policies and incentives

- Zero emission vehicles are exempt from sales tax, and the sales tax for other cars increases in 5 increments from 6 Euros for cars emitting 1 to 79 g CO_2/km (PHEVs) to 476 Euro for cars emitting 174 g CO_2/km or more.
- Since 2006 the registration vehicle fees have been based on the vehicle's CO_2 emissions. The incentives for EVs in the Netherlands were increased in 2015 and again in 2017, and will be further increased in the period to 2020. The financial incentives for plug-in hybrid vehicles have been reduced and the anticipation of a reduction in the financial incentives for PHEVs led to a large spike in PHEV sales before the reductions came into effect. The financial incentives for PHEVs are to be reduced further over time and to eventually be phased out altogether. This explains the dominance of BEVs in new electric car sales in the Netherlands after 2016.
- Zero emission vehicles are also exempted from paying annual registration fees, while the registration fee for PHEVs is reduced by 50%.
- The purchase of a zero emission company cars and cost of work place charging stations are tax deductible company expenditures.
- The fringe benefit tax for use of a company vehicle is 4% for a zero emission car, 15% for a PHEV, and up to 25% for other cars.
- In addition, various regional governments subsidise electric or zero emission cars (passenger cars, commercial cars, trucks and/or scooters) and/or the installation of charging points.
- In some urban areas, 'environmental zones' have been created with entry rules on the basis of vehicle emissions.

Policy drivers

- The Netherland's EV policy began in 2009 with the launch of a National Plan for Electric Driving. The national government committed 65 million euros to the Plan, as well as 500 million euros to support the development of e-mobility by local and regional governments, social organisations, and private companies.
- The drivers behind the Netherland government's EV policy were subsequently explicitly enunciated in the National Energy Agreement for Sustainable Growth, which includes a chapter on transport and transport sector GHG emission reduction targets (a 17% reduction by 2030 and a 60% by 2050). The Agreement also contains a vision statement that all new vehicles sold in 2035 will be capable of driving emission free.
- Reducing GHG emissions is a national policy priority. The Netherlands has the highest per capita GHG emissions of any European country and there is a strong perceived need for GHG emissions to be reduced. The five remaining coal-fired power stations are scheduled to be closed by 2030. The electrification of transport is considered to be another important means of meeting climate policy objectives, improving urban air quality, and the quality of life in cities. It is also regarded as having industry development benefits and employment growth opportunities [EAFO 2018].
- According to the IEA's Hybrid and Electric Vehicle Technology Collaboration Program [HEV TCP 2018] the policy objectives that lie behind and drive the Netherland's EV policy are broad, and include objectives relating to economic growth, social well-being, local environmental (air quality, noise, etc.), and global climate change.

- The Netherlands government's goal is for all new passenger vehicles sold by 2030 to be zero-emission [IEA 2018b].

Other contributing factors to EV uptake rate

- Fuel prices in the Netherlands are relatively high (A$1.87/L in 2017) and electricity prices relatively low (A$0.25/kWh).

A.3.2.2 Sweden

In 2017, EVs made up 5.3% of new passenger car sales and 1.1% of the passenger vehicle fleet, 85% of which were PHEVs, the total number of EVs on the road by the end of 2017 reaching 49,295, taking the number of EVs per 1000 population to 5.

Table A.14 EV statistics - Sweden

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
49,295	1.1%	7,162	14%	2017

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure

- In September 2018, 5,869 public charging stations had been installed in Sweden, 2807 of which were high power (23 kW or greater) charging stations.

Table A.15 EV charging infrastructure statistics - Sweden

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
5,869	2,807	8.4	2.1

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure policy and incentives

- In 2015 the Swedish government introduced a competitive grant scheme '*Climate Leap*' with a budget of 355 million kr (A$54 million) for 2015-2020 to support investment in measures that would achieve long term GHG emission reductions. By July 2017, 8,800 charge points had been installed with funding support from the program, two thirds of which were 'normal' (< 22 kW) charging points, half of which were private and the other half public. The other one third was high power charge points, and was predominantly public charge points. The program specifically encourages investment in EV charging infrastructure for passenger vehicles.
- There is both private and public investment in low power public charging. The first rounds of support for fast charging stations resulted in a several charging operators applying for funding. Many of the operators originated from local utility companies. In 2015 a Danish EV charging company, Clever, owned by five Danish utilities, started a subsidiary in Sweden, with the Swedish energy company Öresundskraft as the majority shareholder, and with cooperation agreements with BMW, Nissan, Volkswagen, Renault, and Tesla.

- Installing low power charging stations is relatively straight forward as the electricity grid is very robust and large electrical ‘block’ heaters are in common use which can be easily disconnected and the connection used for an EV charger [HEV TCP 2017].
- Sweden has also built the first smart road that will allow EVs to charge as they drive. The eRoadArlanda pilot scheme covers two kilometres of road outside Stockholm

EV policies and incentives

- In 2012, the Swedish government started a Kr 200 million program (approx. A$30 million) to provide a subsidy of 40,000 kr per car (A$6,120) for the purchase of 5,000 EVs and other "super green cars" with ultra-low carbon emissions, defined as those with emissions below 50 grams of CO_2 per km. EV owners were also exempted from paying annual registration fees for the first 5 years for EVs with an energy consumption of 37 kWh per 100 km or less, and hybrid vehicles with CO_2 emissions of 120 g/km or less. However, annual registration fees are very low (A$10 – A$60 per year), so the value of the exemption for 5 years was A$50 to A$280. The fringe benefits tax for use of a company car was reduced by 40% compared with the corresponding or comparable gasoline or diesel-powered car, capped at a maximum reduction of Kr 16,000 per year (approx. A$2,500).
- The super green car rebate was increased by Kr 132 million for 2015 and by Kr 94 million for 2016, but starting in 2016 only BEVs (zero emissions cars) were eligible for the full Kr 40,000 premium, while PHEVs received Kr 20,000 . In 2016, the government also allocated Kr 50 million for 2016 and Kr 100 million per year between 2017 and 2019 to introduce a similar premium for electric buses.
- In 2018, the government announced the introduction of a bonus-malus system for new light vehicles to increase the proportion of vehicles in the fleet with lower CO_2 emissions, complemented by increased fuel taxes and help reduce the transport sector’s oil dependence and climate impact. The malus was an increase in taxes for petrol and diesel vehicles that amounted to Kr 3,000–7,000 (A$460 – A$1,070). The five-year exemption from vehicle tax for EVs was removed and the super-green car premium was replaced by a bonus of Kr 60,000 (approx. A$6,700) for cars with zero emissions, and of Kr 10,000 (A$1,100) for low emission vehicles with emissions of 60 g/km (PHEVs and LNG vehicles). The new tax scheme resulted in a collapse of new car sales, especially diesel cars, which decreased to 23% of the market (from 48% in the previous year), while sales of EVs increased dramatically. Sales of new EVs in 2018 to September accounted for 7.2% of new car sales (80% of which were PHEVs), up from 5.3% in 2017.
- The Swedish government also offers a rebate for new electric bike, quadricycle, or tricycle equivalent to 25% of the cost.

Policy drivers

- Sweden has had a long-standing commitment to reducing reliance on imported fossil fuels, reducing GHG emissions and improving urban air quality. Almost half of the electricity produced in the country is generated from renewable energy sources, and another 45% is produced from low emission sources (mainly nuclear power). The carbon intensity of electricity (43 kg/MWh) means that encouraging the adoption of EVs is a logical strategy for reducing GHG emissions and the other two policy goals. In 2017 Sweden’s commitment to GHG reductions was strengthened with legislation binding all future governments to net zero emissions by 2045. As a part of this commitment the Swedish government has set a target of a 70% reduction of GHG emissions from the transportation sector by 2045, which essentially will mean a 100% fossil fuel-free vehicle fleet.

- There is no question that Swedish EV policies have been successful, but they have also been described as inconsistent and to have resulted in an EV uptake roller-coaster [Tietge 2017]. The main EV policy problem was that “Super green car rebate” (S*upermiljöbilspremie*) scheme introduced in 2012 was designed to achieve a uptake of 5,000 low-carbon vehicles, a target that was reached in mid-2014. In each year 2014, 2015, 2016 and 2017, the Swedish government therefore budgeted further amounts to extend the program, and in each year the budget was exhausted before the program was extended, causing delays in rebate payments. A second problem was that EV buyers did not receive the rebate at the point of sale but were sent paperwork from the Swedish Transport Agency, and EV owners received payment once they had completed and submitted the paperwork. It was these problems that eventually led the Swedish government to abandon the rebate scheme in 2018 and to replace it with the bonus-malus (feebate) scheme, which used the money raised from taxes on high emission vehicles (malus) to fund the rebates (bonus) for low emission vehicles.
- Unlike some other countries with significant car manufacturing industries which have not adopted strong EV policies, the Swedish government appears to have placed a priority on environmental policies and has left it to car manufacturers to face the challenge. Some Swedish car manufacturers, most notably Volvo, have done so (Volvo has announced that by 2019 all of its models will be either BEVs or PHEVs) and one new EV manufacturer start-up has emerged. Uniti is building a compact, lightweight, high tech electric city car made of bio-composites and carbon fibres with a steer-by-wire system, and a range of 300 km.
- In June 2017, Sweden adopted a climate law that aims to reduce road transport emissions by 70 percent by 2030, compared with 2010, and for the transport sector to be completely fossil-free by 2045.
- In July 2018, Sweden introduced a cost-neutral bonus/malus system, replacing a plug-in EV purchase rebate scheme, which for example increases the maximum support for BEVs from 4000 Euro to 6000 Euro. Simultaneously, an increased vehicle tax is applied to petrol and diesel vehicles. The policy framework promotes the use of plug-in EVs among company cars and vans. Electric buses have since 2017 been granted a purchase rebate. During spring 2018, the Swedish government also enabled for municipalities to introduce new levels of environmental zones. Since 2015, public support has been granted for the deployment of charging infrastructure (both publicly accessible and private charging infrastructure), and on 1 January 2018, a specific home-charger scheme was introduced. In 2015 the Swedish government appointed the Swedish Energy Agency to coordinate the public charging infrastructure deployment efforts. The R&D funding on e-mobility is continually substantial, and has for example enabled demonstrations of electric road systems on public roads, a pilot production line for sustainable battery production and the on-going establishment of a 100 million Euro testbed for electric drivetrains

Other contributing factors to EV uptake rate

- Swedes are renowned for being early adopters of new technologies and to have high environmental awareness. The combination of those traits with a relatively high GDP/capita (A$92,098) provides a good environment for EV adoption.
- Fuel prices are also high relatively high (A$1.71/L for petrol in 2017), which provides an additional incentive to purchase an EV.
- The nature of the electricity grid also helps. The Swedish electricity system and grids are robust as they have been built to meet peak demand on cold winter days, and a large scale introduction of EVs is not considered likely to have a significant impact on electricity networks, especially since most EV charging occurs at during off-peak hours. Furthermore, approximately 65 percent of Swedish households have off street parking and charging at work is common. At home, the electrical wiring of most houses includes wiring for vehicle engine preheaters that is suitable for EV chargers.

A.3.2.3 Finland

There were 6,107 EVs on Finland's roads by the end of 2017, equivalent to 0.19% of the vehicle stock, taking the number of EVs per 1000 population to just over 1. BEVs made up only 12.1% of the EV stock. EVs accounted for 2.57% of new car sales in that year.

Table A.16 EV statistics – Finland

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
6017	0.19%	727	12.1	2023

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure

- By the end of 2017 just under 1000 public charging stations had been installed, more than 700 of which were high power charging stations, including 7 super-charging stations.

Table A.17 EV charging infrastructure statistics - Finland

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
947	706	6.4	1.03

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure incentives

- A subsidy is offered for investing in a public charging station in buildings over 11 kW, the subsidy amount being 30% of the installed cost.
- A subsidy is offered for investing in a public charging station over 22 kW, the subsidy amount being 35% of the installed cost.
- A number of Finnish companies manufacture hardware for charging equipment [IEA 2018b].

EV policies and incentives

- A subsidy of €2000 is offered for the purchase of a BEV with a maximum sale value of €50,000.
- The sales/import tax on a BEV is 5% of the standard passenger vehicle import tax
- Owners of EVs pay the lowest annual registration fee (5% of the highest rate), which is based on the vehicle CO_2 emissions.

Policy drivers

- The Finnish energy and climate strategy for 2030, launched in November 2016, calls for a 50% reduction in transport related GHG emissions by 2030 (reference year 2005). To achieve this goal, the strategy set a target of 250,000 EVs by 2030. Finland is a member of the IEA's 30EV@30 Campaign, which has a target of EVs reaching 30% of the vehicle fleet by 2030. According to the IEA, Finland would meet that target if there were 250,000 EVs in Finland by that date [IEA 2018b].

A.3.2.4 The United Kingdom

The UK has the second highest penetration of EVs in its passenger vehicle fleet of any EU member state other than the Netherlands. EVs accounted for 0.48 of the passenger vehicle fleet by the end of 2017, two thirds of which were PHEVs. In that year BEVs made up 0.54 % of new cars sales, while PHEVs made up 1.36%. Over 48,000 EVs were registered in the UK at the end of 2017, and the number of EVs per 1000 population to 2.1.

Table A.18 EV statistics – The UK

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
137,642	0.48%	45,581	33%	2020

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure

- By the end of 2017, over 14,000 public charge points had been installed, the majority (78%) of which were normal charge points.

Table A.19 EV charging infrastructure statistics – The UK

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
14,256	2,759	9.7	16.5

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure incentives

- Electricity distribution companies are not allowed to own or operate charging infrastructure in the UK [ICCT 2017].
- The UK government adopted a position that the first stage in the uptake of EVs would be for fleets, and that the majority of charging would therefore occur either at the home or "back at base" for fleets. That meant that public charging infrastructure would be needed only at a limited number of key locations, and that as the number

of EVs increased, businesses would develop commercial business models for their own investment in public charging infrastructure.

- The UK government therefore developed its 'Plugged-In Places' program, which funded an initial investment in public charging stations.
- From 2013 to 2015 the UK The Government made £9 million (A$16.2 million) of funding available to train companies in England to cover up to 75% of the costs of obtaining and installing plug-in vehicle charging infrastructure at train stations, up to a maximum of £7,500 (A$13,500) per installation [Butcher *et al.* 2018].
- There are today at least 20 different companies and organisations installing and running nationwide or regional electric car charging networks in the UK. Most of the EV charging networks in the UK are operated by either electricity utilities, petrol station operators, local authorities, or third party companies wanting to enter the EV car charging business [Rosamond 2018].
- In June 2018, BP purchased Chargemaster, the company that operates the largest public network of EV charging points (over 6,500) in the UK and also designs, builds, sells and maintains public and home EV charging units. [BP 2018].
- Shell has also installed 50 kW DC fast chargers (Shell Recharge) at a number of its sites in the UK, concentrated primarily in the greater London area, with partner Allego managing the operations of the charge points [Shell UK 2018].
- Pivot Power has announced a A$2.88 billion program to build 2 GW of battery storage connected to the UK high voltage grid at 45 sites to provide grid stability, and will install 100 high powered EV fast charging stations at the sites [Pivot Power 2018].
- Instavolt has announced that it will install 200 ChargePoint rapid chargers across the UK [Instavolt 2018].
- The Dutch owned fast EV charging company, Fastned, has announced plans to invest in fast charging stations in the UK [Topolov 2018].
- One of Europe's largest energy companies, E.ON is partnering with a EV charging station company, CLEVER, to install 180 fast EV charging stations in seven European countries, the majority being in Germany France, Norway, Sweden, UK, Italy and Denmark [E.ON 2017].

EV policies and incentives

- A Plug-in Car Grant (PICG) programme was established in 2011. Under the programme, the up-front cost of eligible cars was initially reduced by providing a 25% grant towards the cost of new plug-in cars, with a grant cap of £5,000. The programme was extended in 2012 to include plug-in vans. Van buyers receive 20% off the cost of a plug-in van, with a maximum grant capped at £8,000. The programme was extended until March 2018, the maximum grant was reduced to £4,500, and the amount granted varied according to emission levels. The current purchase subsidy is approximately A$9,500 for vehicles with a zero emission range of at least 70 km. The subsidy for PHEVs costing under A$123,000 is approx. A$5,250. The subsidy for motorcycles with CO_2 emissions of 0g/km and an electric range of at least 31 km is up to approx. A$2,700.
- In 2017, zero emission vehicles with a value of approx. A$72,500 or less were exempted from sales tax and from annual registration fees, while the sales tax on low emission vehicles (PHEVs) was reduced.

- Early purchasers of EVs are expected to be fleet or business users, and the tax on EVs purchased by companies is reduced and companies are given a 100% tax allowance for the first year for the expenditure incurred on EV charge point equipment.
- EVs exempt from the London congestion zone charge and many cities offer free parking for EVs.
- A £500 (approx. A$900) incentive is provided for installing a dedicated home charging station and grants of up to 75%, capped at £7500 (approx. A$13,600) are provided towards the cost of installing an on-street residential charge point in areas without off-street parking.
- The UK government established a £400m (A$720 million) charging infrastructure fund in partnership with industry. Highways England has also committed funding to ensure that a charging point is available at least every 20 miles (approx. 32 km) across 95% of the network [Butcher et al. 2018].

Policy drivers

- The UK's stated objectives of its EV policies are the need to reduce GHG emissions, to improve urban air quality, and the desire to maximise UK business opportunity in the ultra-low emission vehicle [Seradilla *et al.* 2017, Butcher *et al*. 2018].
- While the current UK policies are in line with EU directives and the Paris Agreement on Climate Change, the UK has had a long standing commitment to reducing vehicle emissions. In 2009, road transport accounted for almost 24% of the UK's GHG emissions and an Office for Low Emission Vehicles (OLEV) was established to develop and implement programs and regulations required to decarbonise road transport in the UK. In October 2010 the UK government announced a $400 million package to promote low emission vehicles.
- The UK Government's EV policy also aims to stimulate growth in the manufacturing and uptake of EVs.
- The UK government has announced a plan or target for every new car and van sold in the UK in 2040 to be effectively zero emissions.
- The UK government's aim is to put the UK at the forefront of the design, manufacture and use of zero emission vehicles [IEA 2018b]. A 'Road to Zero' plan has been adopted which includes ending the sale of new conventional ICE cars and vans by 2040, and for almost every car and van in the UK to be zero emission by 2050. By 2030 the UK government wants at least half of new cars sold and as many as 70%, to be ultra-low emission, alongside up to 40% of new vans. To achieve this, the government is investing nearly A$2.7 billion in a comprehensive package of support for the transition to zero emission vehicles with grants available for plug in vehicles and schemes to support charging infrastructure [IEA 2018b].

A.3.2.5 France

By the end of 2017 EVs made up 0.37% of France's passenger vehicle fleet, just over three quarters of which were BEVs. BEVs and PHEVs accounted for 1.2% and 0.55%, respectively, of new cars sales in 2017. The number of EVs per 1000 population was 1.8.

Table A.20 EV statistics – France

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
120,113	0.29%	91,951	76.6%	2021

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure

- By September 2018, almost 25,000 public charging stations had been installed in France, just over 90% of which were normal charging stations.

Table A.21 EV charging infrastructure statistics - France

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
20,439	1,819	5.9	50.6

(Sources: European Alternative Fuels Observatory, http://www.eafo.eu/ and IEA 2018).

Charging infrastructure incentives

- Around 80% of homes in France have a single-phase x 32 A (7.4 kW) electricity connection that are able to power only a level-2 medium-fast EV charger with no concurrent electricity load. This increases the need for public charging.
- Investment in public charging stations has been driven by a long-term commitment and a national installation strategy. In 2010, the government formed a charging infrastructure working group to coordinate installation of a standardised national charging network for PHEVs and BEVs. Legislation was introduced that:
  - enabled local governments to install public charging infrastructure, a quota of parking areas in work places and shopping areas was reserved for EVs and charging spots
  - developers/builders of apartment residences were required to install charging facilities at parking places upon request of the inhabitants
  - required local governments to install public-parking areas with charging facilities.
  - allocated a budget to support investment in public infrastructure for an estimated one million public and private charging stations to be built by 2015.
- The French strategic electric mobility roadmap included the development of standards for EV charging, strategies for matching charging infrastructure (level, type, numbers, locations) with demand, and the development of long-term business models for investment in charging infrastructure. The last of the three objectives was considered necessary as no charging point network operator was considered able to develop an economically profitable charging business model in France or anywhere else. The Roadmap adopted a view that a strong commitment from the national government would be required until 2020, but that after 2020 viable business models must be developed and implemented by the private sector and take over without government intervention.
- Business models have been developed by the private sector, and the EV charging infrastructure market in France is now crowded. Sodetrel, a subsidiary of the French government owned electricity utility, EDF, operates 5,000 charging stations in France

and provides access to another 60,000 charging points in Europe. The company is seeking to be the dominant player in the market and has set a target of a 30 percent market share in EV charging in France, Belgium, Italy, and the UK, aiming to supply power for 600,000 EVs by 2022 from 75,000 EV charging stations and to give its European customers access to 250,000 terminals operated by other providers [De Clercq 2018].

- The current French objective is to reach 7 million charging points for plug-in hybrid and EVs by 2030 [EIA 2018b].

EV policies and incentives

- France was the first country (2008) to use a bonus-malus scheme for vehicle emissions. The bonus-malus scheme was designed to be revenue neutral, with revenue from penalties balancing expenditure on subsidies. In 2009 the bonus amount was set at €5,000 for new cars and light commercial vehicles emitting less than 60 g CO_2/km. In 2009 the amount was increased to €6,000 for the first 100,000 low-carbon vehicles purchased. Vehicles emitting 20 g CO_2/km or less are eligible for a bonus of €6,000 (approx. A$10,800) under a bonus-malus scheme. For vehicles emitting between 21 and 60 g CO_2/km, the premium is €1,000 (A$1,800).
- In 2015, the owners of diesel cars switching from a diesel car 11 years old or older for a new BEV received an additional 'scrappage' grant of €4,000, (A$7,200) and if swapping for a PHEV receive an additional €2,500 (A$4,500). The subsidy for motorbikes with electric range (lead acid batteries are excluded) is €250 (A$450) per kWh of battery capacity to a maximum grant amount of€ 1,000 (A$1,800) or 27% of purchase price. BEVs are also exempt from road taxes, annual registration fees, while PHEVs emitting less than 10 g CO_2/km are exempted from annual registration for 2 years. Many provincial governments also offer subsidies.
- In 2015 France adopted a target of a minimum of 50% low emission vehicles for fleet renewals at the national level, and 20% for local authorities, as well as a target of full electrification of new buses by 2025 [IEA 2018].

Policy drivers

- France is committed to electrification of the vehicle fleet as a part of its effort to tackle both global climate change and air pollution [IEA 2018b].
- Under the French Climate Plan 2017, the French government set a goal of ending the sale of GHG-emitting passenger cars by 2040. To foster the deployment of charging infrastructure for EVs, French local authorities benefit from the Investments for the Future programme (PIA), which was launched in 2009 by the French government to boost strategic initiatives on electric mobility. More than 20,000 charging points for EVs have already been funded by PIA, representing an investment of €61 million. France is committed to enhancing its market share of EVs, and has designed incentives so that the number of new EVs sold in 2022 is 5 times higher than in 2017. In particular, a bonus-malus scheme rewards or penalizes the purchase of cars depending on their CO_2 emissions level, and since the beginning of 2018 the bonus is exclusively dedicated to EVs. A vehicle conversion premium is also in place, supporting the replacement of an old GHG-emitting vehicle with a cleaner one. In May 2018, the French government and the French automotive sector signed an agreement in order to achieve this target. Moreover, France will continue to support

the installation of charging points available to the public. A national scheme will be issued by 2020 to encourage French local authorities to do so. The number of charging points is expected to reach 100,000 by 2022. Since February 2016, the ADVENIR program (in the context of energy savings certificates) has eased the installation of 12,000 charging stations on car parks (shops or businesses) and in collective habitats.

- Another primary driver behind France's EV policies is the development of an EV manufacturing sector. France has the second largest car manufacturing industry after Germany, and the French car manufacturers have moved to maintain market share as industry shifts to electrification. The Renault Zoe is the highest selling BEV in France, while the Renault Kangoo Z.E. is the top selling electric utility van.

A.3.2.6 Germany

In terms of the absolute numbers of EVs sold, Germany is rapidly catching up to the other European leaders. The total number of EVs sold in 2017 was 53,562, taking the total number of EVs on the road by the end of 2017 to just fewer than 127,000. In 2017, EVs accounted for 1.56% % of new cars sales, while BEVs accounted for 0.71%. The number of EVs per 1,000 population was 1.6.

Table A.22 EV statistics – Germany

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
126,695	0.29	65,788	51.9	2022

(Sources: European Alternative Fuels Observatory http://www.eafo.eu/ and IEA 2018).

Charging infrastructure

- By the end of 2017, 0ver 25,200 public charging stations had been installed, of which just over 3,000 were high power charging stations, and over 530 were DC fast charging stations [Germany Trade and Invest 2018].

Table A.23 EV charging infrastructure statistics - Germany

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
25,250	3,027	5	21.7

(Sources: European Alternative Fuels Observatory http://www.eafo.eu/ and IEA 2018).

Charging infrastructure incentives

- In Germany, electricity distribution companies are not allowed to operate charging infrastructure [ICCT 2017].
- Most homes in Germany have a three-phase x 63 A (43.5 kW) electricity connection, although a study found around less than half of households in Berlin suitable for EV charging. This increases the need for public charging.
- The German government established a charging infrastructure stimulation program in 2017 to stimulate charging companies to invest approx. A$520 million in fast

charging infrastructure over 3 years (A$360 million for DC charging, which can fully charge vehicles within minutes, and A$180 million for slightly slower AC charging stations). The subsidy covers around 40% of capital expenditures related to the construction of the stations [Morris 2017]. The program is expected to increase the number of AC charging points in Germany from 7,100 to 70,000 by 2020, and to increase the number of DC charging stations to around 7,000 over the same period [Kaufung 2018].

- The Dutch charging company, Fastned, won the first tender to invest ahead of the market and have charging infrastructure in place before large numbers of EVs hit the roads.
- Plugs and sockets for EVs are also being standardized, which will keep consumer costs down [Kaufung 2018].

EV incentives

- Those purchasing a BEV receive a grant of €4,000 (A$7,200) and those purchasing a PHEV receive a grant of €3,000(A$5,400). In both cases the grant is restricted to cars with a list price of a maximum of €60,000(A$108,000). The grant scheme is open for the first 400,000 cars and ends in 2020. The federal government contributes a total of €600 million (A$1,080 million) to the grant scheme, which is matched by €600 million from car manufacturers. The €60,000 upper limit in car value meant that Tesla vehicles were not eligible for the subsidy. Tesla responded by offering a Model S without many standard features (navigation, reversing camera, internet radio, blind spot assist, etc.) to reduce the base price to €60,000. Tesla has since been excluded from the list of cars that are eligible for the subsidy and Tesla buyers who received the subsidy are required to repay the grant amount [Lambert 2017].
- EVs are exempted from annual registration fees for the first 5 years.
- Companies receive tax deductions for purchasing EVs as company cars.
- Transport companies pay reduced electricity tax, from €20.5 (A$36.9/MWh)/MWh to €11.42 per MWh (A$20.16/MWh) when operating electric or hybrid buses.
- In 2015, the German parliament passed the *Electric Mobility Act* that gave local governments the authority to allow these vehicles into bus lanes, and to offer free parking and reserved parking spaces in locations with charging points for cars with emissions of no more than 50 g CO_2/km, or an all-electric range of over 30 km, and special licence plates to identify EVs. The range criterion was increased to 40 km in 2018. Twelve local governments also offer incentives for BEVs, including free parking, reserved parking, and access to bus lanes.

EV policies and incentives

- In 2010, the German government set the goal under its National Platform for Electric Mobility to have one million EVs on German roads by 2020, but announced that it would not provide subsidies for the sales of plug-in electric cars as the push for EVs should be market driven, but would instead would fund R&D.
- By 2016 it was clear that the market forces alone were not going to be sufficient to achieve the EV uptake rate targets and the purchase subsidy for green car buyers worth up to €5,000 was introduced to boost sales of electric and plug-in hybrid cars. The subsidy was funded 50% by government and 50% by car manufacturers.

- Germany's Federal Office of Economics and Export Control (BAFA) has recently revealed that the subsidy is not being taken to the extent expected and that a total of 46,897 EV buyers have submitted applications for the subsidy by September 2018 [Morris 2018a].

Policy drivers

- The drivers for Germany's EV policies are the same as those of other EU countries – reduction in GHG emissions, improved urban air quality, and reduced reliance on imported petroleum. However, Germany has by far the largest car manufacturing industry in Europe and German car manufacturers were initially uncertain how the market for EVs would evolve. Given that there is a five-year lead time to developing capacity to manufacture new products, the German manufacturing industry until recently has been hesitant to invest heavily in EV production [Morris 2018b]. The German government's strategies for meeting the EU vehicle emission standards therefore focused in the early years on improving the efficiencies of and reducing emissions from ICEVs and on alternative fuels, including CNG [Electro-Mobility Platform 2018].
- Today, the German government sees electric mobility as playing a key role in its future energy system. As the share of renewable energy generation in Germany increases (currently 35%), it will enable a greater share of the country's transport energy needs to be met by renewable energy
- Germany has now set a goal of becoming the leading EV supplier by 2020 as a part of its long-term zero-emission transport vision [Kaufung 2018].

A.3.2.7 Portugal

Portugal is included in this benchmarking chapter as it has been labelled as one of the three European 'Followers', along with Italy and Spain [Transport and Environment 2018]. EVs made up 1.81% of new cars sales in 2017. By the end of that year there were over 8,000 EVs in the passenger vehicle fleet, almost a half of which were BEVs. EVs accounted for 0.19% of the passenger vehicle stock and the number of EVs per 1,000 people is 0.78. Despite being labelled a 'Follower', the projected date by which EVs will make up 1% of the passenger vehicle fleet is 2024.

Table A.24 EV statistics – Portugal

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
8,064	0.19%	3,843	0.09%	2024

(Sources: European Alternative Fuels Observatory http://www.eafo.eu/ and IEA 2018).

Charging infrastructure

- By the end of 2017 just over 1,500 public charging stations had been installed, 223 of which were high power charging stations, including 4 supercharging stations.

Table A.25 EV charging infrastructure statistics – Portugal

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
1,545	223	5.2	17.2

(Sources: European Alternative Fuels Observatory http://www.eafo.eu/ and IEA 2018).

Charging infrastructure incentives

- No subsidies are offered for public charging infrastructure.

EV policies and incentives

- A subsidy of €2,250 (approx. A$4,000) is offered for the purchase of a BEV, and a subsidy of €2,125 (approx. A$2,000) for a PHEV.
- Owners of EVs pay reduced annual registration fees, which are based on the vehicle's CO_2 emissions.
- Local governments offer free parking in Lisbon.
- One electricity utility company offers 1 year discount in electricity for BEV buyers.
- Companies are permitted to treat VAT on EVs valued at less than of €50,000 as a company tax deduction.

Other contributing factors to EV uptake rate

- The transport sector in Portugal accounts for 25% of GHG emissions, 96% of which is from road transport. Electrification of the transport fleet would therefore be an effective strategy for reducing GHG emissions as 64% of the electricity generated in the country is produced from renewable energy, and the carbon intensity of electricity is relatively low (250 kg CO_2/MWh). However, Portugal has a GDP/capita of A$35,340 and the country is not required under the EU GHG emission reduction sharing to achieve a reduction in GHG emissions in 2020 relative to 2005 levels.

A.3.2.8 Poland

Poland is included in this benchmarking chapter as it has been labelled as one of the three European 'Slow Starters' along with all other eastern European countries and Greece. EVs made up 0.12% of new cars sales in 2017. By the end of that year there were over just over 2,300 EVs in the passenger vehicle fleet, just over one third of which were BEVs. EVs accounted for 0.011% of the passenger vehicle stock and the number of EVs per 1,000 population was 0.06. The date by which EVs are projected to make up 1% of the passenger vehicle fleet is 2026.

Table A.26 EV statistics – Poland

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
2,313	0.019%	848	0.004%	2026

(Sources: European Alternative Fuels Observatory http://www.eafo.eu/ and IEA 2018).

Charging infrastructure

- By the end of 2017 just over 550 public charging stations had been installed, 142 of which were high power charging stations, including 4 supercharging stations.

Table A.27 EV charging infrastructure statistics – Poland

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
410	142	5.6	6

(Sources: European Alternative Fuels Observatory http://www.eafo.eu/ and IEA 2018).

Charging infrastructure incentives

- No subsidies are offered for public charging infrastructure.

EV policies and incentives

- No incentives are offered for EVs.

A.4. USA

The USA has the second highest number of EVs sold in 2017 after China [IEA 2018]. In 2017, the number of new EVs sold was 198,350, or 0.52% of new passenger vehicle sales. However, there were very large variations in the percentages of EVs in new car sales across the states, from a low of 0.12% (North Dakota) to 5.02% (California), with almost 50% of new EV sales in the USA in California [EV Adaption 2018]. By the end of 2017 the stock of EVs reached 762,060 or 0.42% of the light and passenger vehicle stock, of which BEVs accounted for 52.7%. By the end of the year, the number of EVs in stock per 1,000 population was 2.3.

Table A.28 EV statistics – USA

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
762,060	0.42%	401,550	52.7%	2022

(Source: IEA 2018)

Charging infrastructure

- By the end of 2017, the number of public charging stations that had been installed in the USA was 45,868, of which 39,601 were slow chargers and 6,267 were fast chargers [IEA 2018], including 548 superchargers [PlugShare 2018]. California, Colorado, Connecticut, Hawaii, Maryland, Nevada, Oregon, Vermont, and Washington State had the highest numbers of EV public Level 2 and DC fast charging stations [Cattaneo 2018].

Table A.29 EV charging infrastructure statistics - USA

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
45,868	6,267	16.6	64.1

(Sources: IEA 2018)

Charging infrastructure incentives

- The regulatory framework for electricity retailers in the USA does not permit them to own or operate EV charging stations [ICCT 2017]. California has been proactive to change the definition of 'a public utility' to exclude charging stations and a number of other states are reviewing their regulations [Bloomberg 2018].
- A number of states in the USA provide a variety of financial incentives for charging infrastructure in the form of grants, tax credits, and rebates. Seventeen states have financial incentives that lower the cost of public Level 2 and DC fast chargers. The range in the incentives is very large. New York, for example, has committed $250 million to charging infrastructure to 2025, while Washington's incentive is limited to exempting those installing charging stations from stamp duty [Cattaneo 2018].
- Current and future funding for charging infrastructure over the next 10 years will come from the 'VW settlement funds', funds from the settlement agreed by the Volkswagen Group to resolve the US Government's claims over NOx emissions standards. Of the fund, A$3.8 billion will be used to establish an Environmental Mitigation Trust that states and territories will be able to access over the next 10 years to invest in projects to reduce NOx emissions from the transport sector starting in January 2017. States have been permitted to use 15% of those funds to build EV charging infrastructure. Seven states have committed to spend their full 15% on charging infrastructure and another 12 states are proposing to use their full 15% on charging infrastructure. The total amount of the fund spent on charging infrastructure will be A$190 million to A$260 million. A further A$2.8 billion will be spend by Electrify America, an organisation established by VW, on charging infrastructure and the promotion of zero-emission vehicles, of which A$1,100 million will be spent in California [Cattaneo 2018].
- The U.S. Department of Energy (DOE) has developed a new tool—EVI-Pro Lite—that uses data on personal vehicle travel patterns, EV attributes, and charging station characteristics to estimate the quantity and type of charging infrastructure necessary to support regional adoption of EVs [US DoE 2018].
- In 2016 California increased its public EV charging station target for 2025, along with its 2030 target of 5 million EVs. California's ZEV action plan includes an investment of A$1,260 million to install 250,000 charging stations by 2025, of which around 10,000 outlets will be DC fast chargers [Electrify America 2018, State of California 2018).

EV Policies and incentives

- A federal Internal Revenue Service (IRS) tax credit is offered of $2,500 to $7,500 per new EV purchased for use in the USA [US DoE 2018]. The size of the tax credit depends on the size of the vehicle and its battery capacity. The tax credit is available to manufacturers until they achieve sales of 200,000 EVs in the USA, at which point the credit is phased in increments out for that manufacturer. Currently, no manufacturers have been phased out yet. [US DoE 2018].
- The majority of states also offer a range of incentives. Seven states offer a purchase rebate, another seven states offer tax credits, three states offer reduced or exempt sales tax, and one state offers low interest loans. For example, California offers an EV purchase rebate of A$4,200 under its Drive Clean Program for residents and businesses in the San Joaquin Valley district, and a means (income) tested rebate under its Clean Vehicle rebate project. Four electricity utilities offer reduced

electricity tariffs for customers who buy EVs, and one electricity utility offers a US$500 EV purchase rebate.

- The strongest policy instruments used are zero emission vehicle (ZEV) mandates, first introduced by California in 1990. Under the ZEV program, each manufacturer is assigned "ZEV credits" and required to maintain ZEV credits equal to a set percentage of non-electric sales. Each car sold earns a number of credits based on the type of ZEV and its battery range. The credit requirement is 4.5% in 2018, which will require about 2.5% of sales to be ZEVs. The credit requirement rises to 22% in 2025, which will require about 8% of sales to be ZEVs [Union of Concerned Scientists, 2016]. California is the only state that is able to issue stricter emission standards than those set by the federal government, but the 49 states have the choice of following either the California Air Resources Board (CARB) standards or the federal standards. Currently, twelve others states have adopted the standards set by California [Malone 2018]. Of the total number of new EVs sold in the USA in 2017, almost 60% were sold in the 13 states with EV mandates [Malone 2018]. All of the 13 states with ZEV mandates are among the 20 states with the highest uptake rates of EVs.

EV policy drivers

- The primary EV policy driver in the USA has historically been improvement in urban air quality, and has been led by California.
- Reducing GHG emissions has been a policy priority for some States, most notably California. The California Air Resources Board (CARB), which was established to regulate emissions impacting on urban air quality, in the early 2000s it turned its attention to climate change and requested authority from the federal Environmental Protection Agency to enforce more stringent regulations on auto manufacturers than were contained in the federal Clean Air Act in order to reduce GHG emissions [Given 2018]. California was granted a waiver by the EPA to implement its GHG emission standards in 2009, and reducing GHG emissions is now one of the drivers behind California's Zero Emission Vehicle mandate.
- The relevance that reducing GHG gas emissions has on EV policy is demonstrated by the fact that states with high energy carbon intensities (Mt CO_2/million dollars of GDP) and low percentages of electricity produced from renewable energy resources and nuclear power(such as North Dakota), tend to have the lowest EV uptake rates. States with low energy carbon intensities and high percentages of electricity produced from renewable energy sources and nuclear power (such as California), tend to have the highest EV uptake rates [US EIA 2018]. This might be explained by the fact that electrification of the vehicle fleet would have lower potential to reduce GHG emissions in states with high energy carbon intensities.
- Economic development opportunities also now drive EV policy in the USA as states such as California and Michigan strive to gain global EV market share.

A.5. Canada

In 2017, the number of new EVs sold in Canada was 16,680, which was 1.1% of new passenger vehicle sales. The number of BEVs sold was 8,710, which accounted for 0.6% of new car sales. By the end of 2017 the stock of EVs reached 45,950 or 0.2% of the light and passenger vehicle stock, of which BEVs accounted for just over half. Almost all (96.6%) of the EVs sold in Canada were sold in three provinces, Quebec, Ontario, and British Columbia [Schmidt, 2018]. By the end of the year the number of EVs in stock per 1,000 population was 1.25.

Table A.30 EV statistics – Canada

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
45,950	0.2%	23,620	51.4%	2024/25

(Source: IEA 2018)

Charging infrastructure

- By the end of 2017, the number of public charging stations that had been installed in in Canada was 5,841, of which 673 (11.1%) were fast chargers, including 52 superchargers [PlugShare 2018].

Table A.31 EV charging infrastructure statistics - Canada

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
5,841	637	7.9	37.1

(Sources: IEA 2018)

Charging infrastructure incentives

- The Canadian government does not provide rebates of incentives for public charging infrastructure. Three provinces, British Columbia and Quebec, provide incentives for private and/or public charging infrastructure [CAA 2018].
- British Columbia introduced the CEV Program in 2011 with an expenditure to date of CAN$71 million, and a further CAN$40 million is committed. The program includes investment in charging infrastructure and over 1,300 residential and public charging stations were installed under the CEV Program. A gap analysis was used to identify high priority gaps in the DC fast-charging network and in charging infrastructure in multi-unit residential buildings [Fraser Basin Council 2015]. A DC Fast Charger Program was established to support the adoption of EVs by providing increased charging options within regions with high EV adoption while providing mobility across the province. Through a partnership between BC Hydro, the Province of British Columbia, Natural Resources Canada, local governments, and academic institutions, 30 DC fast chargers were installed in the first phase along major highway corridors. Further DVC fast chargers are planned. A Multi-Unit Residential Building Charging Program was also launched. [Government of British Columbia 2018].
- Quebec offers a rebate up to a maximum of CAN$600 is provided for the purchase and installation of a 240 volt home charging station at your home [CAA 2018].
- The Government of Ontario provides up to $1,000 of the price of a home charging station [Gibson 2018a].

EV policies and incentives

- Three provinces, British Columbia, Quebec and Ontario, have provided rebates and incentives for EVs. Ontario’s program ended in September 2018 [CAA 2018]

- British Columbia provides point-of-sale incentives on eligible vehicles of up to A$5,000 for the purchase or lease of a new BEV, and A$2,500 – A$5,000 for the purchase or lease of a PHEV [Government of British Columbia 2018].
- The Québec government offers individuals, businesses, organisations and municipalities a rebate of A$8,000 on the purchase or lease of a new EV with a sale price less than A$75,000, and A$3,000 if the sale value is between A75,000 and A$125,000. The rebate for PHEVs is offered only for PHEVs with a sale price less than A$75,000. The rebate amount depends on the battery size and ranges from A$500 to A$8,000 [Government of Quebec 2018].
- The Ontario government offered individuals, businesses, and organisations that purchase or lease a new PHEV or BEV a rebate of up to A$14,000. BEVs with a battery capacity from 5 to 16 kWh were eligible for incentives ranging from $6,000 to $10,000, based upon the battery size. BEVs with a battery capacity of larger than 16 kWh were also eligible for an additional $3,000 incentive. PHEVs with a sale price $75,000 to $150,000 were eligible for a maximum incentive value of $3,000. EVs with a sale price over $150,000 were not eligible for an incentive. BEVs with a 12 month lease term received 33% of the incentive, 24 month lease term received 66% of the incentive, and leased vehicles with a 36 month or longer term received the full incentive. The program ended in September 2018. [CAA 2018, Gibson 2018a].

EV policy drivers

- As with all countries, electrification of road transport is considered a means of addressing urban air pollution. However, in Canada, the main driver for EV policy appears to be a reduction in GHG emissions. The transport sector in Canada accounts for approximately 25% of all GHG emissions in Canada in 2016 [Government of Canada 2018a]. Light and passenger road vehicles account for approximately half of the GHG emissions from the transport sector [Pollution Probe 2017]. The degree to which electrification of the road vehicles could reduce GHG emissions varies from province to province. In both British Columbia and Quebec electricity is produced almost entirely from renewable energy sources, while in Ontario, 33% of the electricity is produced from renewable energy resources and another 58% from low emission sources (nuclear). These three provinces, but particularly in the cases of British Columbia and Quebec, have been the Canadian leaders in electrification of the transport fleet as electrification of transport has the highest potential to reduce GHG emissions in those provinces.
- However, EV policy is set to be strengthened for the country as a whole. The Canadian Government's Clean Growth and Climate Change Plan is component of a national strategy aimed at reducing Canada's GHG emissions in 2030 to 21% below 2005 levels. In the case of the transport sector the strategy includes more stringent vehicle emission standards, increased use of public transport, increased investment in zero emission vehicles and increased investment in EV charging infrastructure [Government of Canada 2018b, Gibson 2018b].
- British Columbia and Quebec border states in the USA that have EV penetration rates and the fact that these two provinces have the two largest networks of superchargers [PlugShare 2018] may be connected to tourism from the USA.

A.6. China

China produces and has more EVs on the road than any other country. The number of EVs sold in 2017 was almost 580,000 (2.2% of new cars sold), and the number of BEVs sold was almost 470,000 (1.8% of new car sales). This was over half of the EVs sold in the world that year. By the end of the year there were almost 1.25 million EVs on the road, over 75% of which were BEVs. However, a small number of large cities (Beijing, Hangzhou, Shanghai, Shenzhen, and Tianjin) account for a majority of EV sales [Hertzke *et al.* 2018]. The number of EVs per 1,000 population was 0.89.

Table A.32 EV statistics – China

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
1,227,770	0.57	942,500	77%	2019

(Source: IEA 2018)

Charging infrastructure

- By the end of 2017 over 200,000 public charging stations had been installed, of which over 83,000 were high power charging stations [IEA 2018a]. Of the high power stations, over 354 were DC fast charging stations [PlugShare 2018].There were also another 240,000 privately owned units [Yuanyuan 2018].

Table A.33 EV charging infrastructure statistics - China

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
213,903	83,395	5.7	11.3

(Sources: IEA 2018)

Charging infrastructure incentives

- China plans to have 4.3 million private EVSE outlets and 500,000 publicly accessible chargers by 2020 [IEA 2018].
- In China, the electricity generation and supply companies are state-owned vertically integrated monopolies. It is these utilities that have driven the expansion of charging infrastructure (ICCT 2017). Private companies have entered the charging business especially in urban areas, in which the National Development and Reform Commission (NDRC) issues operating licences, and the local administration regulates prices.
- Although subsidies have not been provided for investment in public charging stations, there are more than 100 charging station operators in China, the top four being state-owned and account for 86% of installed chargers. However, it has been reported that all are operating at a loss due to the long cost recovery periods due to low utilisation rates, with 75% of the units unused after being installed and others are being used for around four uses per day [Yuanyuan 2018].
- The Chinese government plans to build a network of 12,000 charging stations to meet the power demands of 5 million EVs by 2020. In addition, 4.8 million distributed power stations, including 500,000 for public use, will be built during the same period [Yuanyuan 2018].

- In 2014, the Chinese government allocated the equivalent of A$19.6 billion towards the development of rapidly increasing EV charging infrastructure in China [Hertzke *et al.* 2018].

EV policies and incentives

- China's national and local subsidies for EVs are among the highest in the world. The level of subsidy is based on the vehicle range, energy efficiency, and the energy density of the battery. The Chinese central government provides a subsidy that is removed from the list price of the vehicle. In 2018, to reduce the costs of the national subsidy scheme, the subsidy was reduced for PHEVs and low-range BEVs (< 300 km) to 22,000 renminbi (A$4,400), and increased for long-range BEVs (>300 km) to 50,000 renminbi ($10,000) [IEA 2018a].
- EVs from selected EV OEMs are exempt from import tax [Hertzke *et al.* 2018].
- The Chinese central government provides an incentive that exempts all EVs, regardless of where they are built, from the 10% sales tax [Hertzke *et al.* 2018].
- EVs are exempt from license-plate lotteries and auctions in some Chinese cities. The license plate lottery system operated in Beijing is capped to 18,000 per month for ICE vehicle, and the probability of success is approximately 1%. The average value of the incentive is A$18,200, while the value of the incentive in Beijing is up to A$46,200 [Hertzke *et al.* 2018].
- On top of the central governments incentives, the local government of Beijing offers an additional subsidy equivalent to A$13,720 for pure EVs, and A$7,980 for PHEVs. Hangzhou also offers subsidies worth nearly A$28,000 for BEVs [Hertzke *et al.* 2018].
- In 2017 the Chinese government introduced green license plates for new energy vehicles (NEVs) across China. Car owners with these license plates are eligible for preferential treatment.
- The Chinese central government has offered tax break incentives for non-domestic automotive OEMs that have formed joint ventures with Chinese OEMs [Hertzke *et al.* 2018].
- EVs are exempt from congestion charges.
- The government introduced a new energy vehicle (NEV) credit mandate in 2017 that set a minimum target for the production of new energy vehicles (PHEVs, BEVs and FCEVs) by Chinese car manufacturers of 10% of the passenger car market in 2019 and 12% in 2020. The number of NEV credits is based on the vehicle's range and energy efficiency level [MIIT 2017].
- The Chinese government has flagged that petrol and diesel ICE cars may ultimately be banned [IEA 2018b].
- The Chinese government offers further incentives for EVs in EV pilot cities program, which include free electricity for the first three years after the purchase of the EV, or a 60,000 km distance, whichever comes first [Hertzke *et al.* 2018].
- The Chinese government supports the deployment of EVs including buses, sanitation trucks, and urban logistics vehicles in main cities and regions [IEA 2018b].
- Starting in 2009, electric bus are subsidised [IEA 2018a].

Policy drivers

- One of the primary drivers of China's EV policy is the need to improve urban air quality. The range in annual average concentrations of $PM_{2.5}$ in 388 cities in 2015 was 11–125 μg·m^{-3} with an average value of 50 μg·m^{-3} and an average of 86 μg·m^{-3}, while the WHO recommends avoiding values above 10. The $PM_{2.5}$ value cities like Beijing occasionally exceed 400 [Lin *et al.* 2018].

- A second policy driver is the economic development opportunities associated with developing an EV vehicle manufacturing industry. Over 98% of new EVs sold are manufactured in China [Hertzke *et al.* 2018]. China perceives New Energy Vehicles (BEVs, PHEVs and FCEVs), as the main solution to the energy and environment challenge [IEA 2018b].
- The third policy driver is the need to reduce GHG emissions [IEA 2018b]

A.7. Japan

Japan was one of the first countries in the world to embrace EVs, and at the end of 2017 Japan had the third largest fleet of EVs worldwide. The number of new EVs sold was 54,100, which was 1% of new passenger vehicle sales. The number of BEVs sold was 36,000, which accounted for 0.3 % of new car sales. By the end of 2017 the stock of EVs reached 205,350, or 0.2% of the light and passenger vehicle stock, of which BEVs accounted for half. By the end of the year the number of EVs in stock per 1,000 population was 1.25.

Table A.34 EV statistics – Japan

Total number of EVs in passenger fleet 2017	EVs as % of light and passenger vehicles fleet 2017	Total number of BEVs in passenger fleet 2017	BEVs as % EVs in fleet 2017	Year that EVs are projected to reach 1% of passenger vehicle fleet
205,350	0.2%	104,490	0.1%	2024

(Source: IEA 2018, Japanese Automobile Manufacturers Association (JAMA) 2018)

Charging infrastructure

By the end of 2017 there were almost 7,500 fast charging stations in Japan, most of which were CHAdeMO chargers (mostly around 50 kW) installed at car dealerships (2,300), convenience stores (1,000), shopping centres (400), and highways (nearly 400) [Kane, 2018]. By the end of 2017, a total of over 28,000 public charging stations had been installed, over a quarter of which were fast chargers [IEA 2018a, Brasor and Tsubuku 2018]. Of the fast chargers, 20 were superchargers [PlugShare 2018]. As well as the 7,327 fast chargers (40% of the global total), there were more than 20,000 AC Level 2 charging stations. While most of the slow chargers are private charging stations, the Japanese government has encouraged owners of private charging stations to offer them for use to other EV stations [McCurry 2016, Gibson 2018b]

Table A.35 EV charging infrastructure statistics - Japan

No of public charging points (PCP)	Number of high power charging sites	No of EVs per PCP	No of BEVs per DC fast charging site
28,834	7,327	7.1	14.3

(Sources: IEA 2018)

EV charging infrastructure incentives

- Japanese government support for public charging stations began early. In 1993, the ECO-Station Project was initiated to build approximately 1,000 charging stations,

including fast charging stations with energy storage to be used for load levelling [Beijing Capital Energy Technology Co. Ltd. 2017].
- In 2013, a partnership was formed between the Japanese Government and four Japanese car manufacturing companies, Nissan, Honda, Mazda and Mitsubishi, to invest nearly A$142.5 million in EV charging infrastructure in key locations across the country. As a result, the number of charging stations increased from 4,700 chargers in 2013 to 40,000 charging points in 2016 (compared to 34,000 petrol stations) stations [McCurry 2016, Gibson 2018b]. The current aim is to install 5,000 CHAdeMO chargers by 2020 [Business Wire 2018], with one fast charger every 15 km or within every 30 km radius. The Government offers subsidies of A$60,000 per charger, and up to A$ million ($540,000) for construction costs [Kane 2018] to EV changing station operators such as Nippon Charge Service. Nippon Charge Service operates charging stations throughout Japan on behalf of four car makers, and also offers several plans that combine monthly fees (A$45.60 for high-speed, A$16.80 for regular) with per-use fees A$0.18/minute for high-speed and A0.03/minute for regular) [Brasor and Tsubuku 2018].
- The Japanese government is currently co funding a A$1.4 billion Next Generation Vehicle Charging Infrastructure Deployment Promotion Project through a partnership between the Government, Nippon Charge Service, and EV OEMs that provides grants to local governments and highway operators, and invests in public charging infrastructure in public-private partnerships [Hall and Luskey 2017].

EV Purchase subsidies

- In 2009 the Japanese government established a program to support the adoption of both EVs and hybrids. Those buying a new EV or hybrid and scrapping their petrol or diesel ICEV received grants of A$775, or A$5,250 if the existing car was over 13 years old. EVs and hybrids were also exempt from 'tonnage taxes' and annual registration fees were reduced by 50%.
- A new subsidy scheme introduced in 2016 increased the purchase subsidy in line with increases in battery capacity and driving range. The subsidy for a car with a 30-kWh battery is A$4,200, and the maximum subsidy is A$10,780 [Gibson, 2018a].

Policy drivers

- Many state that the primary driver behind the Japanese government's EV policy is to reduce GHG emissions [Gibson 2018b, IEA 2018b]. Japan is aiming to reduce its GHG emissions by 2050 to 80% below 2005 levels. As a part of its strategy to meet its Paris Agreement commitment, the Japanese Government has adopted a goal of increasing the share of EVs to between 20% and 30%, and also the share of fuel cell vehicles up to 3% among total new passenger vehicle sales by 2030, and a goal of all passenger vehicles being electric or hybrids by 2050 [Beijing Capital Energy Technology Co. Ltd. 2017].
- Another important driver behind Japan's EV policy is to capture a large share of the global EV manufacturing market.
- Japan also has limited indigenous energy resources, and reducing oil imports has long been a Japanese Government policy priority, and was one of the reasons that Nissan built its first EV, the Nissan Tama, as early as 1947.

Other contributing factors to EV uptake rate

- The relatively low uptake rate of EVs in Japan despite Japanese car manufacturers, Nissan and Mitsubishi being two of the largest EV manufacturers in the world can be explained by the high numbers of non-plugin hybrids sold in Japan. Japanese R&D supported with funding from the Japanese government was used to develop the electric drivetrain with the intention of developing EVs. However, once developed the electric drivetrain was used by the country's largest car manufacturer and the second largest car manufacturer in the world, Toyota, to invest heavily in hybrid [Ahman 2006]. Today more hybrids are sold in Japan than in any other country, and in 2017 the number of new hybrids sold in Japan was over 16 times the number of EVs sold [Schreffler 2018]. For many years, Toyota did not invest in EVs and has only recently announced that it plans to have an EV on the market by 2022.
- A second explanation for the relatively low EV uptake rates in Japan despite the EV acquisition subsidies offered by the government (which have also been offered for hybrid cars), is the relatively small portion of electricity generated in the country from renewable energy sources, and the very limited opportunities for increasing the share of renewable energy generation in the mix [Sasamata, n.d.].

A.8. Summary and Discussion.

One of the uses of a benchmarking study is to assist in answering the question of what investment in public charging infrastructure will be required to overcome the 'chicken-and-egg problem' that results in insufficient investment in public charging infrastructure. A number of previous benchmarking studies have concluded that the number of fast and slow charging stations across countries and the number of EVs is correlated [Hall and Lutsey 2017, Energia 2018]. Hall and Lutsey [2017], for example concluded that 'both Level 2 and DC fast charging infrastructure are linked with electric vehicle uptake'. However, they do not provide a correlation coefficient that would indicate how strong or weak the correlation is. In fact the plots of their own data indicate that the correlation is not that strong (Fig.A.2 and A.3). As these authors noted, if there was a strong correlation between the two parameters, the points on the graph in Fig. A.3 would have been close to a single diagonal line. The authors in fact acknowledged that the correlation is not strong when they added that:

> '*[there are] major differences across the electric vehicle markets regarding the role of public charging … there is no universal benchmark for the number of electric vehicles per public charge point … data demonstrate that there are some rough apparent patterns between electric vehicle uptake and charging infrastructure availability*'.

Using the term "PEV" (plug-in EV), synonymous with "EV" in this report, [Spöttle *et al*. 2018] concluded that the correlation is not strong and that the density of charging infrastructure …

> '*generally correlates positively with PEV adoption ...* [but] … *the influence of charging infrastructure as a variable differs depending on the national context. Furthermore, there is a range of other factors that are proven or suspected to be correlated with PEV uptake, such as model availability, financial incentives, urban density, etc. ... it can be concluded that charging infrastructure is necessary, but not sufficient for PEV adoption in any given market*'.

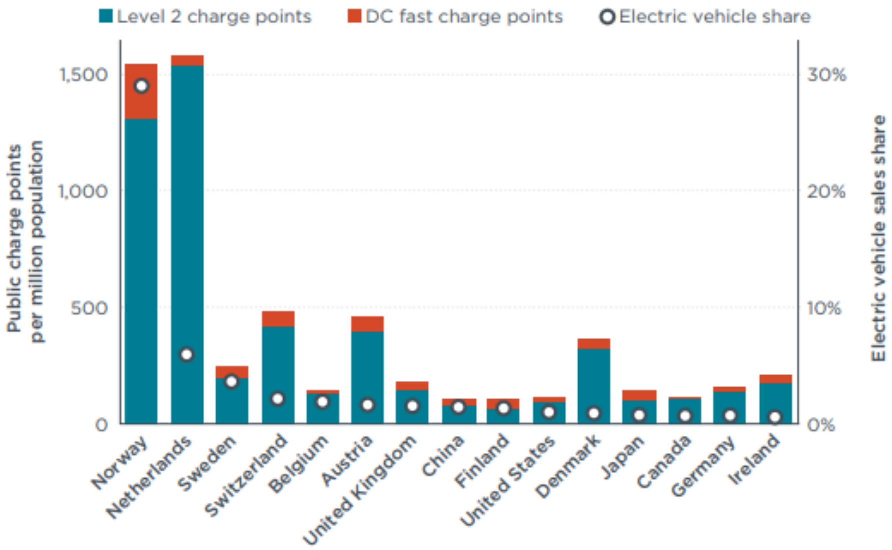

Fig. A.2 EV sales share and public charge points per million persons in major national markets (Source: Hall and Lutsey 2017).

It can be concluded that to simply look at what is being done elsewhere and to take that as a guide for what needs to be done, is fraught with problems. The reality is that there many differences between countries in terms of the incentives offered for public charging infrastructure, in the ratios of BEVs to PHEVs in the EV fleets, in regulations around whether or not electricity companies are permitted to invest in public charging infrastructure, in the proportion of the population that has access to off street parking and charging at work, or the ease with which home charging units can be installed, etc. Separating out and accurately quantifying the impact of public incentives is not possible, and is always likely to prove challenging. This is true not only for charging infrastructure, but for incentives for EVs and the uptake rate of EVs. While international comparisons suggest a positive relationship between financial incentives and EV uptake, there are confounding examples (of countries with high incentives, but low EV uptake and, conversely, countries with low incentives and high EV uptake rates). Most benchmarking studies that have attempted to address the questions of how much more public infrastructure will be needed in the future and where the additional infrastructure should be located in order to maximise its impact have failed convincingly to do so [Brook Lyndhurst 2015].

What the EV infrastructure benchmarking provided in this appendix does reveal is that a large number of factors determine EV uptake rates and the numbers and types of EV charging infrastructure installed in any particular country. It shows that the uptake rates and EV the levels of EV infrastructure installed are influenced by the incentives provided by governments or by the direct investment that governments themselves make in EV charging infrastructure. But that leads to the question of what has motivated governments in some countries or states to provide those incentives and investments, while governments in other countries and states have not. Nor is it governments alone that determine EV uptake rates. Car manufacturers, EV charging equipment manufacturers and operators, electricity utilities, petrol station operators and other actors are also involved. And then there are the car buyers themselves who differ from one country to another in terms of average disposable incomes, in their levels of environmental concern, in the types of cars they use and how far they drive them per year. And those factors are, in turn, determined by, among other things, the cost of buying and driving a car in that country and the price of fuel. What this benchmarking highlights is the complexity behind the numbers that makes it difficult to attribute EV uptake rates to the numbers of charging stations installed or anything else.

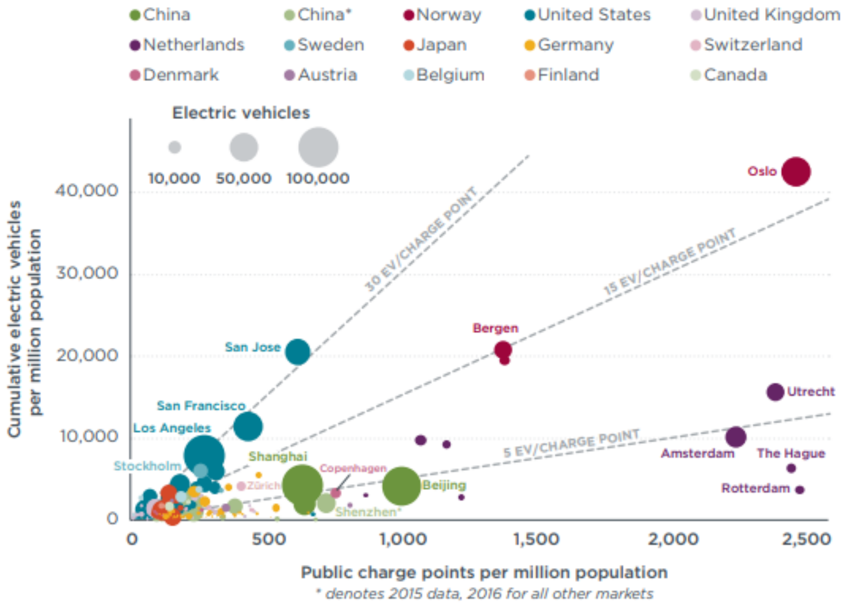

Fig. A.3 The number of EVs in fleets vs public charging stations per 1 million people for various countries (Source: Hall and Lutsey 2017).

Hall and Lutsey [2017] concluded their EV infrastructure benchmarking analysis with the following four high level comments:

1. EV charging infrastructure is a key factor in increasing EV take up rates. The number of public Level 2 and DC fast charging stations in metropolitan areas is correlated with EV take up rates and EV take up rates and public EV charging infrastructure need to be increased in unison. However, there are major differences in the role of public EV charging infrastructure.

2. There is no universal benchmark in the number of EV charging stations per 100 EVs as there are many variables that determine the optimal ratio of EVs to EV charging stations in a particular location. The ratio of public charging stations to EVs needs to be higher in places in which private parking is rare (such as The Netherlands) than in places in which home and work place parking is the norm (such as California).

3. Governments (national, regional, state and local) have used various strategies to facilitate investment in EV charging infrastructure. The strategies employed by the most successful programs have included transparent stakeholder engagement, EV driver feedback, public funding, public-private partnerships and participation by electricity utilities.

4. There are inconsistencies in the available data on public charging infrastructure, and there is a lack of consistent standards for EV charging equipment.

As well as the general, high level conclusion that Hall and Lutsey have made, we would add the following observations drawn from the analysis presented in this appendix:

5. It is possible to use EV charging infrastructure benchmarking analyses to help answer questions about how many, what type and in what locations publicly accessible charging infrastructure will need to be installed in order to support the development of the EV market in a particular context. However, this comes with the caveat that in order to be useful the analysis needs to include sufficient information to be able to compare like with like in terms of the policy drivers, the electricity supply infrastructure, GDP per capita, and a large number of other variables.

6. Most of the countries with the highest levels of EV uptake rates as measured by the percentage of EVs in the passenger vehicle stock are relatively wealthy countries with the high a GDP/capita. The anomalies are China (and India is likely to be another) and Australia. China has the highest number of EVs in its passenger vehicle fleet and yet has a low GDP per capita, which can be explained by the large population, the high levels of subsidies offered and the strong regulations in place. Australia, on the other hand, has a relatively high GDP per capita, but a low portion of EVs in its passenger vehicle fleet compared to countries with similar GDP/capita. This can be explained by a number of factors, including the lack of a car manufacturing industry, a relatively low proportion of renewable or low carbon intensity generation in the electricity generation mix, and a reliance on other measures to achieve national GHG reduction targets.

7. Government (national or state) wiliness to provide strong incentives for EVs, such as high acquisition or purchase rebates in most cases is higher if one or more of the following conditions are met: (i) Improving urban air quality is an urgent or important national, regional or local policy priority; (ii) There is a strong national or state commitment to reducing GHG emissions; (iv) There is a domestic or local EV manufacturing industry; (iv) The carbon intensity of electricity is relatively low.

8. In countries in which EV policy has been left to the states or provinces, the differences in EV uptake rates and in the charging infrastructure installed can be very large. This is the case in Canada, the USA and Australia.

9. The need for DC fast charging is determined not just by the number of EVs but by the number of BEVs in the EV fleet, and there is a large range in the ratio of BEVs to PHEVs in the EV stock of any country. In Finland, which has a relatively low population, a low population density and a large land area, PHEVs make up 88% of the EV stock. In Sweden, with similar geography and population, PHEVs make up 85% of the EV stock. In Australia PHEVs currently make up 53% of the EV fleet, but the number of EVs is low and the ratio of the number of PHEVs to the number of BEVs sold per year has fluctuated widely from 2013 to 2017 (from a minimum of 0.34 to a maximum of 0.72).

10. There are large differences between countries in terms of the number of EVs per publicly accessible charging station. The country included in this study that had the lowest number of EVs per charging station was Switzerland (3.3 EVs/PCP), and the counties with the highest number of EVs per publicly accessible charging station were New Zealand (24.5) and Norway (24.5). The country with the lowest number of BEVs per publicly accessible high power charging station was Finland (1.03) while the country

with the highest number of BEVs per publicly accessible high power charging station was Norway (671), followed by the USA (64.1). These differences, however, cannot be explained simply by good or poor government policy. Norway, for example, has the highest EV penetration rate of energy country and yet has the highest number of EVs/per publicly available charging station and the highest number of BEVs per publicly available high power charging station. That can be explain in part by the fact that the Norwegian Government adopted a view that if it provided strong incentives to encourage the uptake of EVs, others would follow and invest in the necessary public charging infrastructure. But the actual need for public charging stations and for publicly available high power charging stations is also determined by a large number of other factors. While BEVs make up two thirds of the EV fleet in Norway, the evidence is that most are bought as second cars. A very high proportion of Norwegian houses have off street parking. Installing a home charger in Norway is made easy as the wiring used to supply the electricity for heaters used to pre-heat ICEs can be used to supply a home charging station. Large numbers of workplaces have EV chargers. Although the Norwegian EV Association has provided a universal charging tag to all of its members, 60% of its members do not use public charging stations as their charging requirements are met by their home and work chargers [Lorentzen *et al.* 2017]. What this means is that it is not possible to readily gauge the public charging requirements in a country simply by looking at what public charging infrastructure has been installed in other countries. This is an accord with a study undertaken by PwC [2018] which concluded that the international experience indicates that there is no consistent ratio of charging stations to EVs for benchmarking purposes.

11. It is not surprising to find that the uptake rate of EVs in highest in countries in which strong financial (acquisition and recurrent) and non-financial incentives are offered. What is less expected and more surprising is how quickly EV uptake rates are projected to follow in countries in which incentives are weak or non-existent. The proportion of EVs in the passenger fleets of countries with in which the strongest incentives have been offered over a number of years has already exceeded 1% (Norway, Iceland and Sweden). The proportion of EVs in the fleets is projected to reach 1% in 2 to 3 years in a number of other countries that have offered strong incentives for shorter periods, such as the UK (2020), France (2021) and The Netherlands (2022). But the projected date at which countries in which weaker incentives are offered is not that much further away. EVs are projected to make up 1% of the passenger vehicle fleet in the ‘followers’ such as Portugal by mid-2023. Even more surprisingly, EVs are projected to make up 1% of the passenger vehicle fleet in ‘the slow starters’ such as Poland and Australia by 2026. This is in line with the finding by Transport and Environment [2018] report that EVs are expected to make up 5 to 7% of new car sales in the ‘Leaders’ such as the UK and France by around 2022 and in the ‘Followers’ about 5 years later. This strongly suggests that despite the current low numbers of EV is Australia and in Western Australia, EV uptake rates will increase rapidly.

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Appendix B. EVSE Signage

There is often some confusion in relation to details of EV charging stations. A 'charging station' (electric vehicle supply equipment – EVSE) can have one or multiple charging outlets, support more than one charging standard (different charging connectors), and possibly have different power ratings for different connectors. Some signage or online listings for EV charging stations may not indicate how many chargers have been installed at the site, their power level and technical specifications, or even the charging standards that they are compatible with.

There are many different designs for EVSE signage worldwide, albeit similar in nature. Some countries have adopted other countries' signage, and many countries have developed their own means to communicate details of available EV charging stations. Charging station signage falls into two categories: way-finding signage and station signage. The former simply enables drivers to find charging stations from further away locations. The latter identifies details of charging stations, and communicates/enforces regulations related to the use of the EVSE and associated parking spaces [Kettle, 2015].

Consistency of state-wide and nationwide EV charging and parking signage is essential for way-finding and usage of a charging station matching a user's vehicle. The different technical elements of charging stations will ideally give essential information to users, as well as reassurance for potential new EV customers.

Digital signage should include all relevant details:

- Distance to charging site (e.g. 5km)
- Number of charging outlets (e.g. 2)
- Supported charging type (e.g. DC or AC)
- Connector type in text and symbols (e.g. CCS2 + CHAdeMO)
- Power level (e.g. 350kW)
- Energy pricing per kWh (e.g. $0.30 / kWh)
- Amenities on site, if any (e.g. food + drinks)
- Regulations, e.g. time limitations (e.g. max 30 min.)

As we expect existing service stations to play a major role in rural and remote EV charging, we believe that EV charging signage is likely to become integrated into the existing fuel type and price information presented at each service station, which will offer EV charging as an additional service.

Fig. B.1. Road marking signage from New Zealand *and* Germany (general), and U.S. and Germany with time limitations *(images [NZTA 2018], Medienkraftwerk, Pluginsites, Hamburger Morgenpost*)

MainRoads WA is currently using three EV parking/charging signs, two exemption signs and one permission sign (See Fig. B.2).

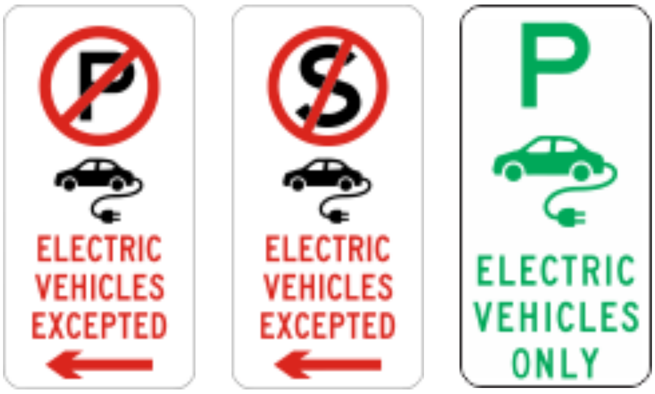

Fig. B.2. Mainroads WA EV signs [MainRoads 2018]

Digital signage / digital applications offer many alternative benefits to conventional ‘hard’ or ‘physical’ signage. Such ‘software signage’ and mobile phone apps can provide real-time data and a much greater level of technical and geographical information to EV drivers. In contrast to conventional signage, in a rapidly changing market it is easier to modify digital information rather than change a number of physical signs. The limitations of conventional signage are largely the reason why EV charging information is already available digitally. Applications like PlugShare [PlugShare 2018] and similar are largely making conventional charging station signage redundant, and in particular way-finding signage. However, prominently placed EV charging signage enhances the visibility of EV charging infrastructure, and therefore has a significantly positive effect on public perception and recognition of EV infrastructure, convincing more potential buyers to make a decision for an EV.

Fig. B.3 Example NZTA way-finding signage *(images from [NZTA, 2018])*

The New Zealand Transport Agency (NZTA) recommends roadside signs to be placed on major roads to identify upcoming public charging stations over 43kW [NZTA, 2018]. Roadside and road marking signage are shown in Fig. B.1, while way-finding signage is shown in Fig. B.3. However, we recommend that Australian EV signage should include additional information to what is currently used in other countries.

Physical signage should include information on:

- Number of charging outlets (e.g. 4 stations)
- Connector type in text and symbols (e.g. CCS2)
- Power level (e.g. 350kW)
- Distance to charging site (e.g. 3km)

The first three items can be combined to a single text line plus one connector symbol. So, a complete sign with full information could look like the one in Figure 3.8.

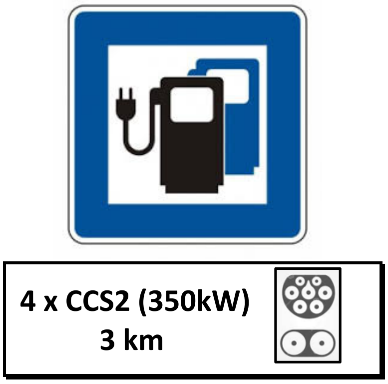

Fig. B.4 Proposed Australian EV way-finding signage with all relevant user information

In addition to EVSE signage, state-wide and nationwide unique stickers for EVs themselves should also be considered, in order to indicate the vehicle type to emergency services**.**

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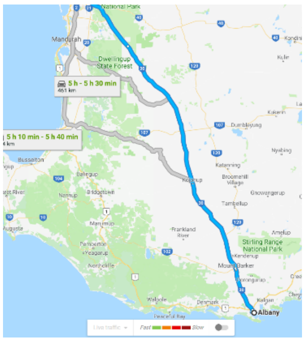
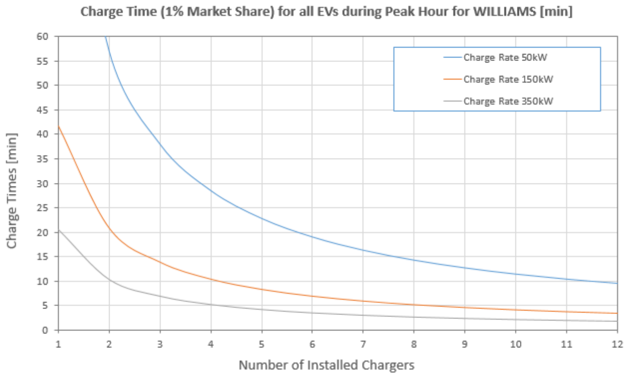
Appendix C. Regional and Remote Traffic Analysis

PERTH to ALBANY ROUTE (INLAND)





Peak traffic

PERTH to ALBANY ROUTE (INLAND)

DATA FOR [YEARS 20xx]	ALBANY ROUTE (INLAND)	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	PERTH										
13-14	WILLIAMS	165	3248	86.3	2803	13.7	445	293	253	Mo - Fr	11
16-17	KOJONUP	95	2255	88.2	1989	11.8	266	240	212	Sat - Sun	12
17-18	ALBANY	156	3680	88.8	3268	11.2	412	327	290	Mo - Fr	16

EV SHARE (NUMBER OF CARS) WITHIN THE PEAK HOUR

EV SHARE [%]	WILLIAMS	KOJONUP	ALBANY
1	3	2	3
5	13	11	15
10	25	21	29
20	51	42	58
50	126	106	145
100	253	212	290

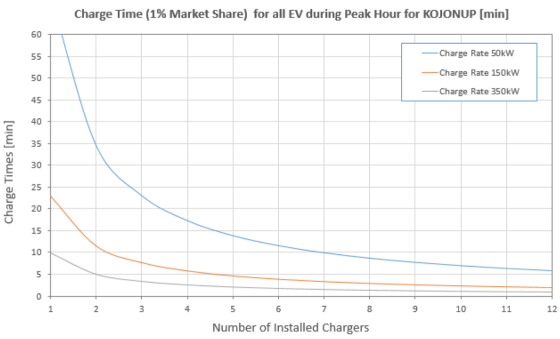
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

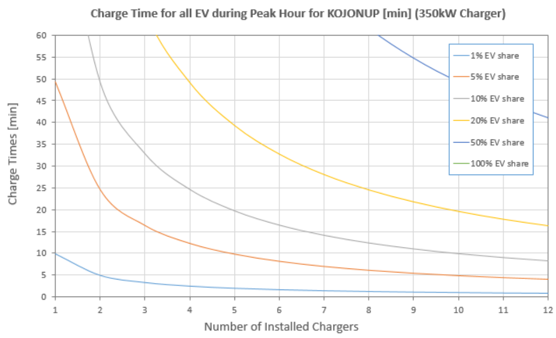
EV SHARE [%]	WILLIAMS	KOJONUP	ALBANY
1	925	378	1020
5	4625	1889	5098
10	9250	3779	10196
20	18500	7558	20391
50	46250	18895	50978
100	92500	37789	101957

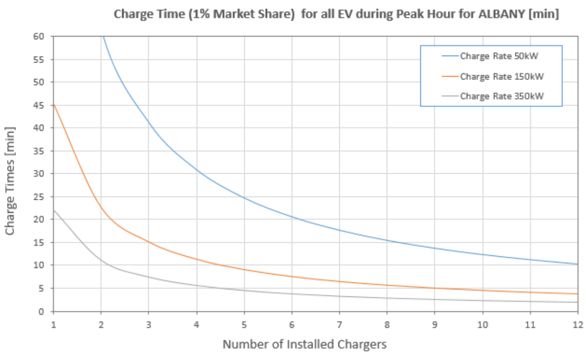
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

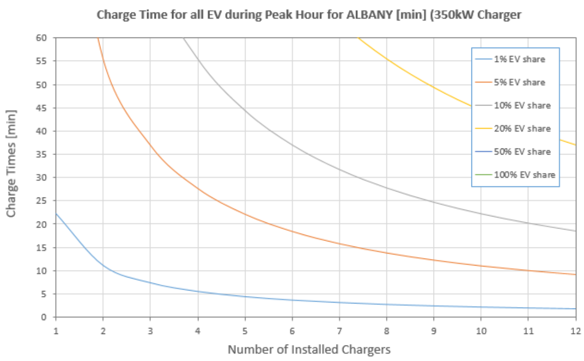
EV SHARE [%]	WILLIAMS	KOJONUP	ALBANY
1	83	40	91
5	417	201	453
10	834	402	906
20	1669	804	1812
50	4172	2011	4530
100	8344	4022	9060

Market share (See Footnote [1])





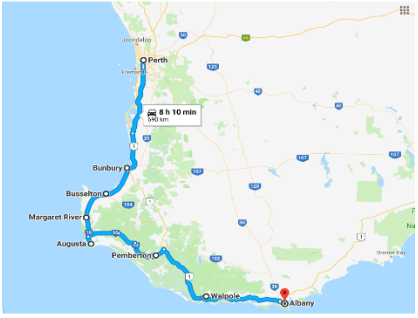


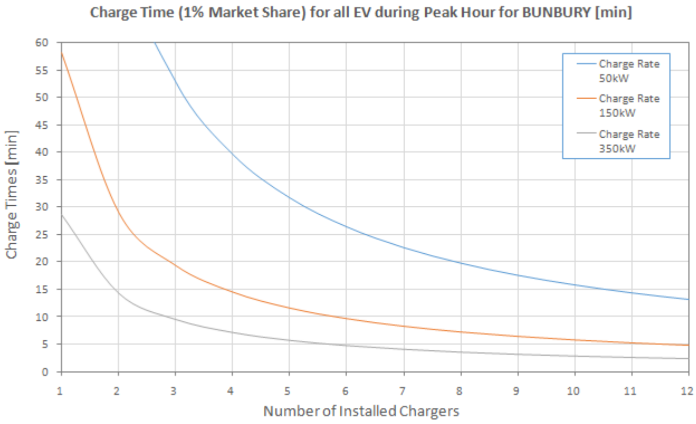


The full data set is available at: http://REVproject.com/traffic/regional.xlsx

[1] EV Market share [%] refers to the share of passenger vehicle fleet

PERTH to ALBANY ROUTE (COAST)





Peak traffic

PERTH to ALBANY ROUTE (COAST)

DATA FOR [YEARS 20xx]	ALBANY ROUTE (COAST)	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	PERTH										
16-17	BUNBURY	169	4257	85.3	3631	14.7	626	404	345	Mo - Fr	16
17-18	MARGARET RIVER	100	2115	86.3	1825	13.7	290	225	194	Sat - Sun	11
17-18	PEMBERTON	135	1052	81.3	855	18.7	197	121	98	Sat - Sun	11
17-18	WALPOLE	125	683	91.2	623	8.8	60	79	72	Mo - Fr	11
17-18	ALBANY	120	2359	91.8	2166	8.2	193	251	230	Mo - Fr	8

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

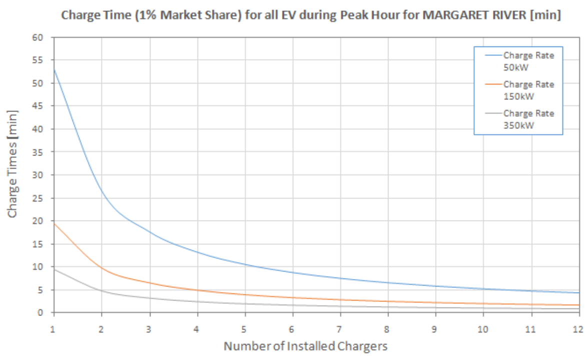
EV SHARE [%]	BUNBURY	MARGARET RIVEI	PEMBERTON	WALPOLE	ALBANY
1	3	2	1	1	2
5	17	10	5	4	12
10	34	19	10	7	23
20	69	39	20	14	46
50	172	97	49	36	115
100	345	194	98	72	230

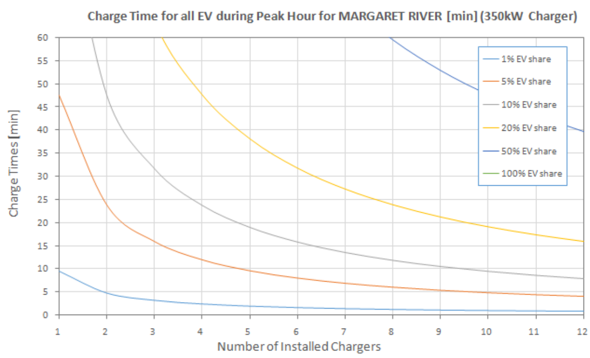
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

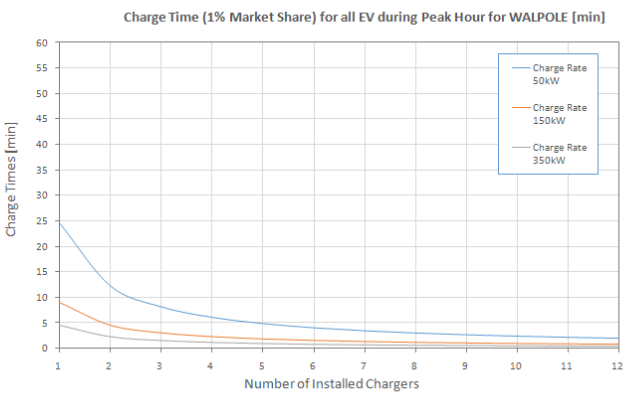
EV SHARE [%]	BUNBURY	MARGARET RIVEI	PEMBERTON	WALPOLE	ALBANY
1	1227	365	231	156	520
5	6137	1825	1155	779	2599
10	12274	3650	2309	1557	5197
20	24547	7301	4618	3114	10395
50	61368	18252	11546	7786	25987
100	122735	36505	23092	15572	51973

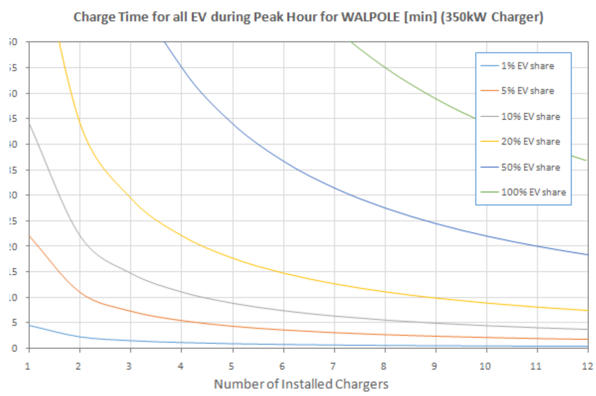
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	BUNBURY	MARGARET RIVEI	PEMBERTON	WALPOLE	ALBANY
1	116	39	27	18	55
5	582	194	133	90	277
10	1165	388	266	180	553
20	2330	777	531	360	1106
50	5824	1942	1328	901	2765
100	11648	3884	2656	1801	5530





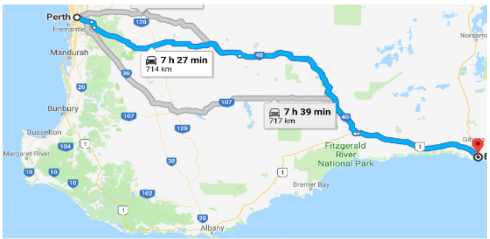


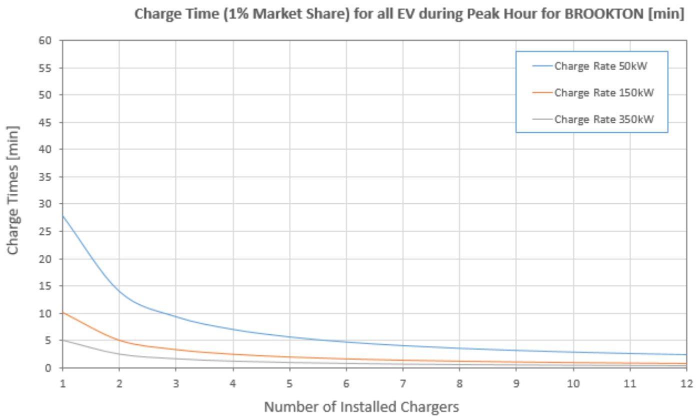


The full data set is available at: http://REVproject.com/traffic/regional.xlsx

 [1] EV Market share [%] refers to the share of passenger vehicle fleet

PERTH to ESPERANCE ROUTE





Peak traffic

PERTH to ESPERANCE ROUTE

DATA FOR [YEARS 20xx]	PERTH - ESPERANCE ROUTE	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	PERTH										
17-18	BROOKTON	134	1046	76.7	802	23.3	244	99	76	Sat - Sun	11
17-18	HYDEN	198	532	75.9	404	24.1	128	55	42	Sat - Sun	12
17-18	RAVENSTHORPE	195	890	79.7	709	20.3	181	77	61	Mo - Fr	18
17-18	ESPERANCE	187	1270	66.8	848	33.2	422	112	75	Mo - Fr	9

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

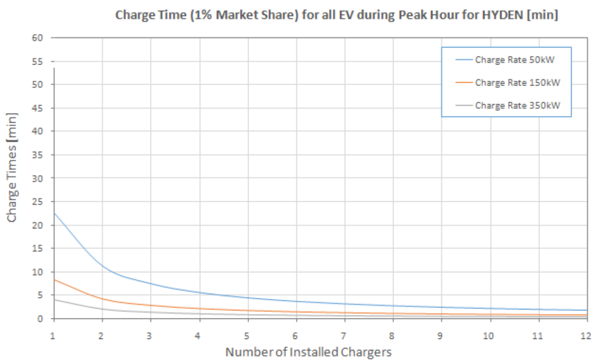
EV SHARE [%]	BROOKTON	HYDEN	RAVENSTHORPE	ESPERANCE
1	1	0	1	1
5	4	2	3	4
10	8	4	6	7
20	15	8	12	15
50	38	21	31	37
100	76	42	61	75

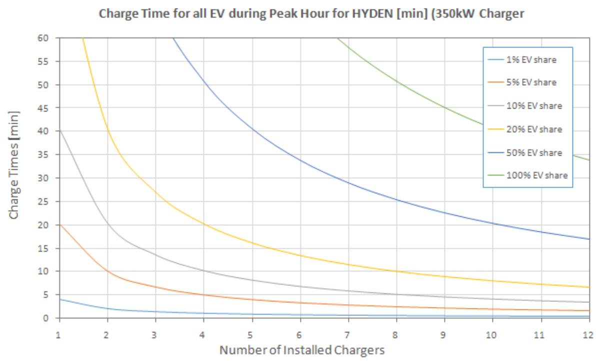
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

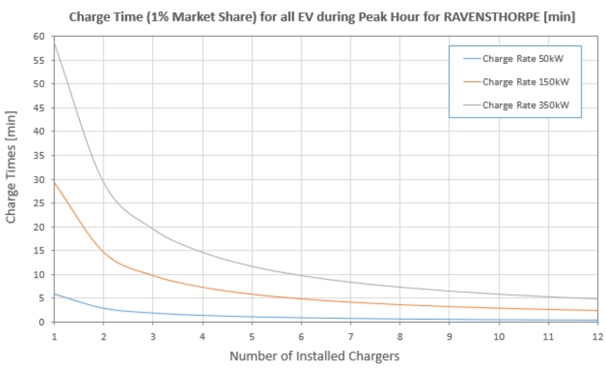
EV SHARE [%]	BROOKTON	HYDEN	RAVENSTHORPE	ESPERANCE
1	215	160	277	317
5	1075	800	1383	1586
10	2150	1599	2766	3173
20	4300	3198	5533	6346
50	10751	7995	13832	15864
100	21501	15990	27664	31729

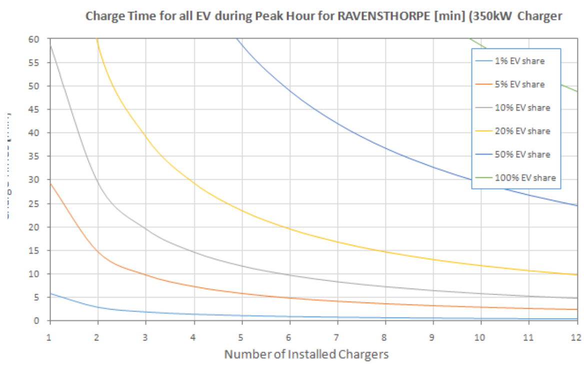
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	BROOKTON	HYDEN	RAVENSTHORPE	ESPERANCE
1	20	17	24	28
5	102	83	120	140
10	204	165	239	280
20	407	331	479	560
50	1018	827	1197	1399
100	2035	1653	2393	2798









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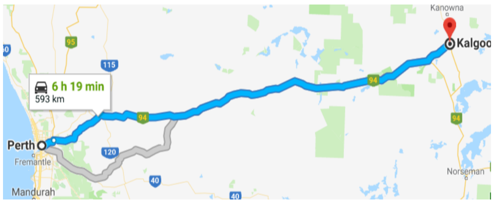
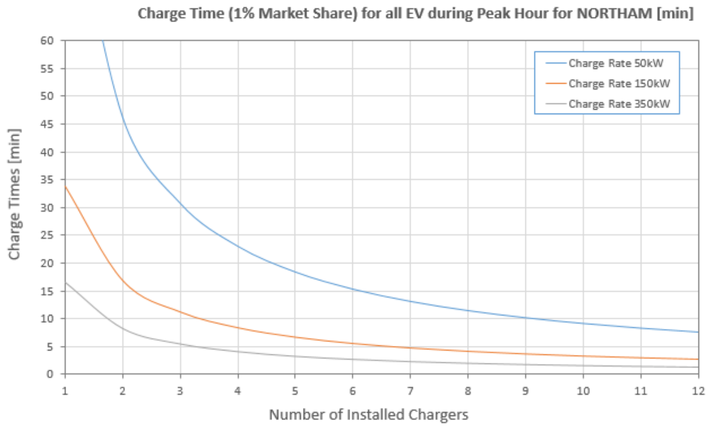
[1] EV Market share [%] refers to the share of passenger vehicle fleet

PERTH to KALGOORLIE





Peak traffic

PERTH to KALGOORLIE

DATA FOR [YEARS 20xx]	PERTH - KALGOORLIE	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	PERTH										
16-17	NORTHAM	96	5200	78.5	4082	21.5	1118	449	352	Mo-Fri	16
1516	MERREDIN	163	1417	59.1	837	40.9	580	128	76	Mo-Fri	12
14-15	SOUTHERN CROSS	109	1119	63.1	706	36.9	413	97	61	Weekend	13
17-18	COOLGARDIE	187	1144	58.4	668	41.6	476	83	48	Mo-Fri	15
1516	KALGOORLIE	39	1675	80.5	1348	19.5	327	143	115	Mo-Fri	16

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

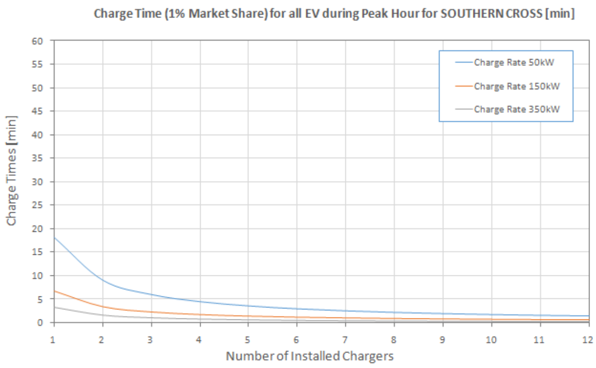
EV SHARE [%]	NORTHAM	MERREDIN	SOUTHERN CROSS	COOLGARDIE	KALGOORLIE
1	4	1	1	0	1
5	18	4	3	2	6
10	35	8	6	5	12
20	70	15	12	10	23
50	176	38	31	24	58
100	352	76	61	48	115

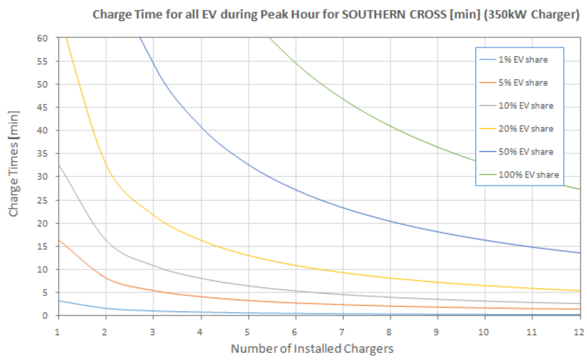
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

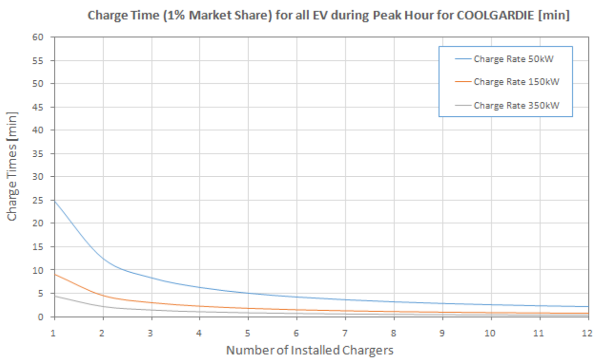
EV SHARE [%]	NORTHAM	MERREDIN	SOUTHERN CROSS	COOLGARDIE	KALGOORLIE
1	784	273	154	250	105
5	3919	1365	770	1249	526
10	7837	2730	1539	2499	1052
20	15675	5460	3079	4997	2103
50	39187	13650	7696	12493	5259
100	78374	27301	15393	24987	10517

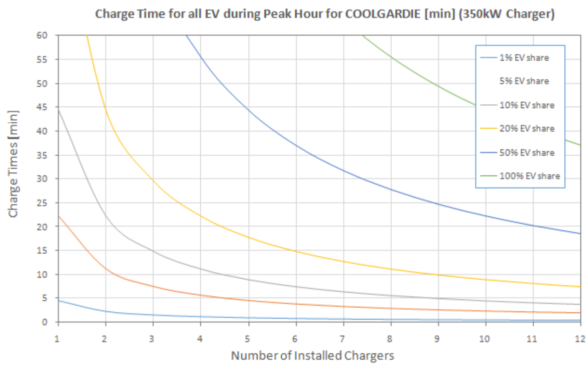
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	NORTHAM	MERREDIN	SOUTHERN CROSS	COOLGARDIE	KALGOORLIE
1	68	25	13	18	9
5	338	123	67	91	45
10	677	247	133	181	90
20	1353	493	267	363	180
50	3384	1233	667	906	449
100	6767	2466	1334	1813	898









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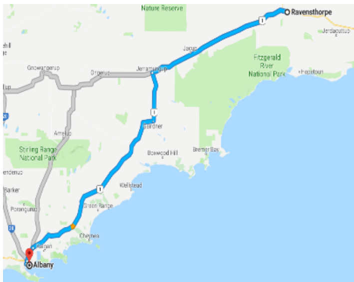
 [1] EV Market share [%] refers to the share of passenger vehicle fleet

ALBANY to RAVENSTHORPE



Peak traffic

ALBANY to RAVENSTHORPE

DATA FOR [YEARS 20xx]	ALBANY to RAVENSTHORPE	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	ALBANY										
17-18	JERRAMUNGUP	181	293	76.7	225	23.3	68	34	26	Mo - Fr	12
17-18	RAVENSTHORPE	116	455	81.3	370	18.7	85	53	43	Mo - Fr	12

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

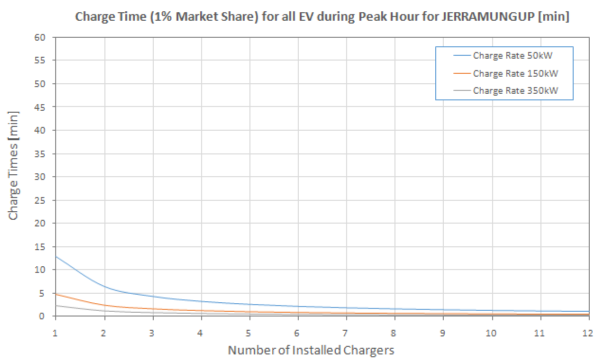
EV SHARE [%]	JERRAMUNGUP	RAVENSTHORPE
1	0	0
5	1	2
10	3	4
20	5	9
50	13	22
100	26	43

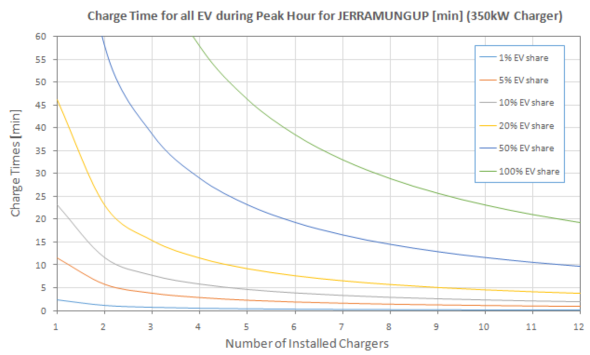
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

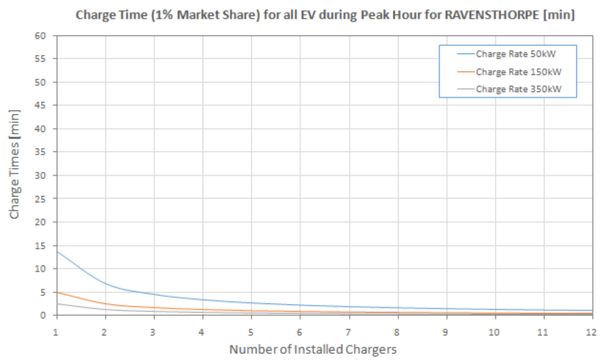
EV SHARE [%]	JERRAMUNGUP	RAVENSTHORPE
1	81	86
5	407	429
10	814	858
20	1627	1716
50	4068	4291
100	8135	8582

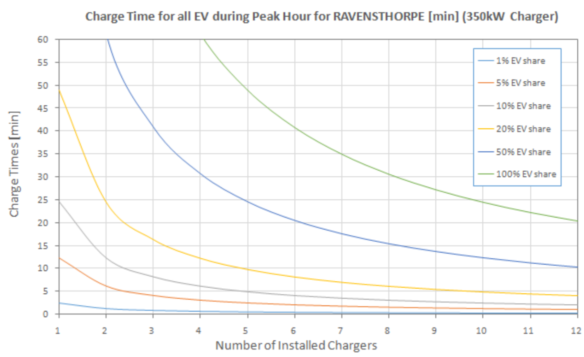
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	JERRAMUNGUP	RAVENSTHORPE
1	9	10
5	47	50
10	94	100
20	189	200
50	472	500
100	944	1000









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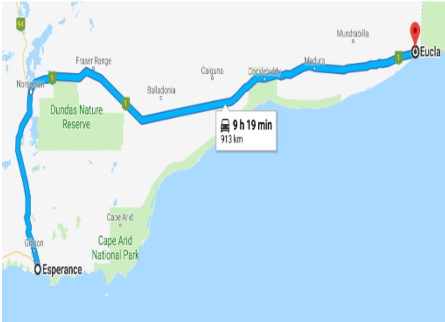
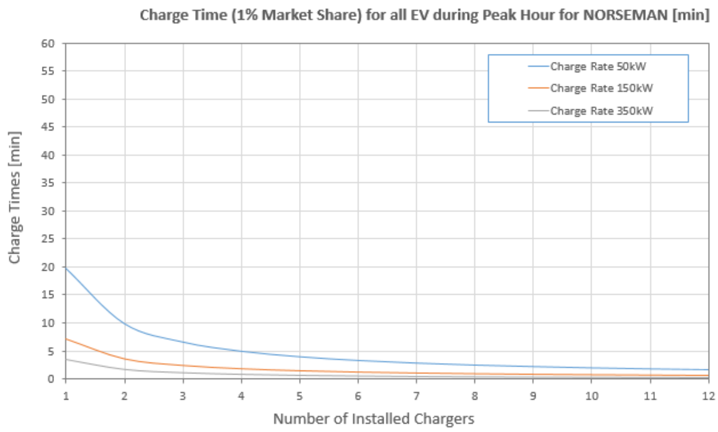
[1] EV Market share [%] refers to the share of passenger vehicle fleet

ESPERANCE to EUCLA





Peak traffic

ESPERANCE to EUCLA

DATA FOR [YEARS 20xx]	ESPERANCE - EUCLA	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	ESPERANCE										
16-17	NORSEMAN	204	548	68.1	373	31.9	175	52	35	Mo - Fr	11
15-16	BALLADONIA HOTEL	191	440	53.9	237	46.1	203	51	27	Sat - Sun	10
17-18	CAIGUNA ROADHOUSE	181	587	61	358	39	229	65	40	Sat - Sun	11
17-18	MADURA ROADHOUSE	158	476	60.1	286	39.9	190	53	32	Mo - Sun and Sat - Sun	10 and 11
17-18	EUCLA	183	541	63.9	346	36.1	195	54	35	Sat - Sun	9

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

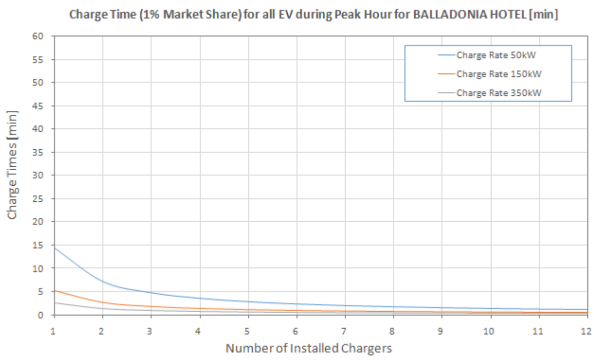
EV SHARE [%]	NORSEMAN	BALLADONIA HOTEL	CAIGUNA ROADHOUSE	MADURA ROADHOUSE	EUCLA
1	0	0	0	0	0
5	2	1	2	2	2
10	4	3	4	3	3
20	7	5	8	6	7
50	18	14	20	16	17
100	35	27	40	32	35

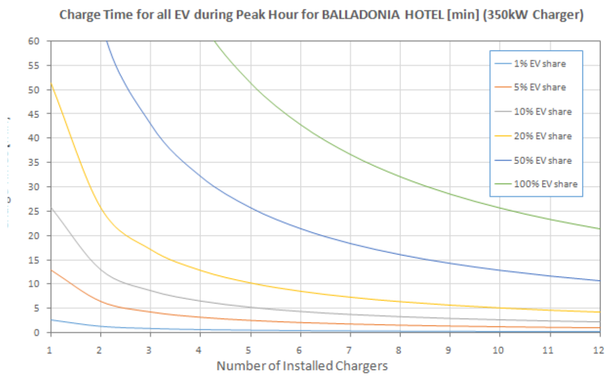
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

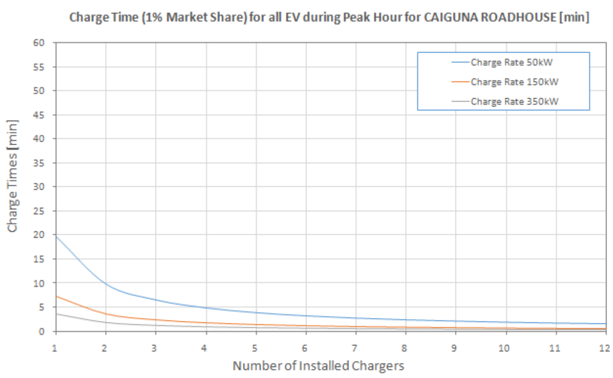
EV SHARE [%]	NORSEMAN	BALLADONIA HOTEL	CAIGUNA ROADHOUSE	MADURA ROADHOUSE	EUCLA
1	152	91	130	90	127
5	761	453	648	452	633
10	1523	906	1296	904	1265
20	3045	1812	2592	1808	2531
50	7613	4530	6481	4520	6326
100	15226	9060	12962	9040	12653

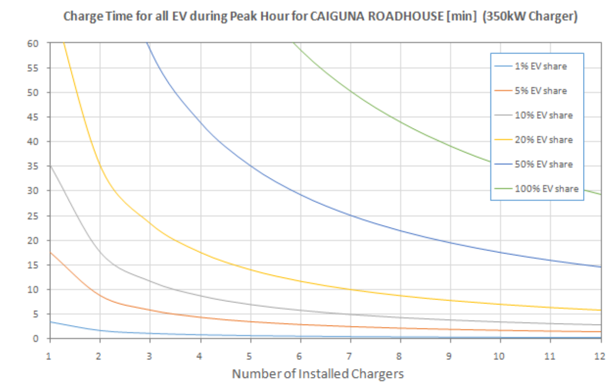
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	NORSEMAN	BALLADONIA HOTEL	CAIGUNA ROADHOUSE	MADURA ROADHOUSE	EUCLA
1	14	11	14	10	13
5	72	53	72	50	63
10	144	105	144	101	126
20	289	210	287	201	253
50	722	525	718	503	631
100	1445	1050	1435	1007	1263









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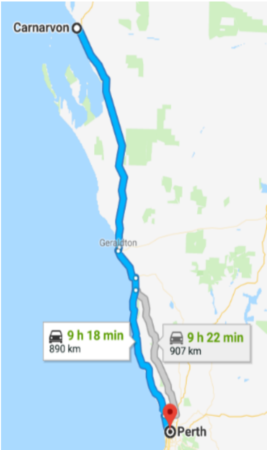
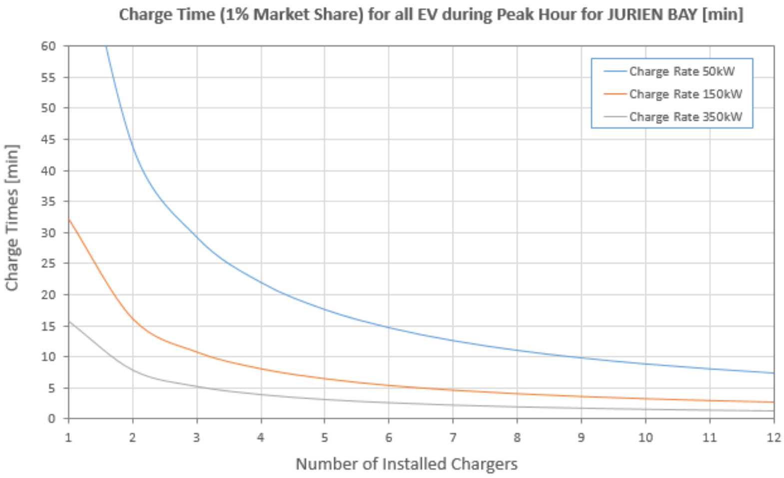
 [1] EV Market share [%] refers to the share of passenger vehicle fleet

PERTH to CARNAVON





Peak traffic

PERTH to CARNAVON

DATA FOR [YEARS 20xx]	PERTH - CARNAVON	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC (CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	PERTH										
16-17	JURIEN BAY	220	1373	82.9	1138	17.1	235	176	146	Sat - Sun	12
17-18	GERALDTON	196	2957	75.2	2224	24.8	733	260	196	Sat - Sun	11
16-17	KALBARRI	154	370	86.5	320	13.5	50	39	34	Sat - Sun	10
17-18	BILLABONG ROADHOUSE	200	749	74.2	556	25.8	193	91	68	Sat - Sun	11
17-18	OVERLANDER ROADHOUSE	48	749	74.2	556	25.8	193	91	68	Sat - Sun	11
16-17	CARNAVON	196	675	70.7	477	29.3	198	63	45	Mon - Fri	13

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

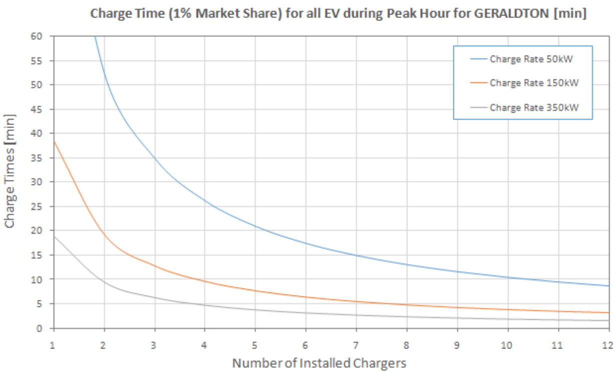
EV SHARE [%]	JURIEN BAY	GERALDTON	KALBARRI	BILLABONG ROADHOUSE	/ERLANDER ROADHOU:	CARNAVON
1	1	2	0	1	1	0
5	7	10	2	3	3	2
10	15	20	3	7	7	4
20	29	39	7	14	14	9
50	73	98	17	34	34	22
100	146	196	34	68	68	45

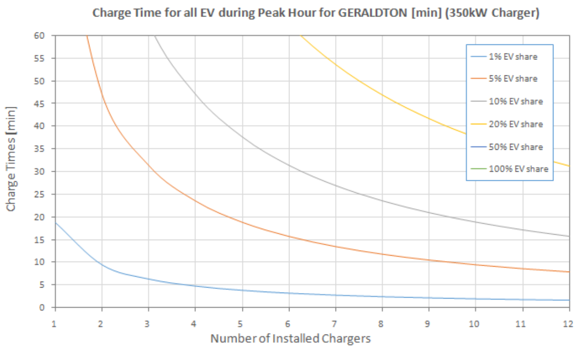
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

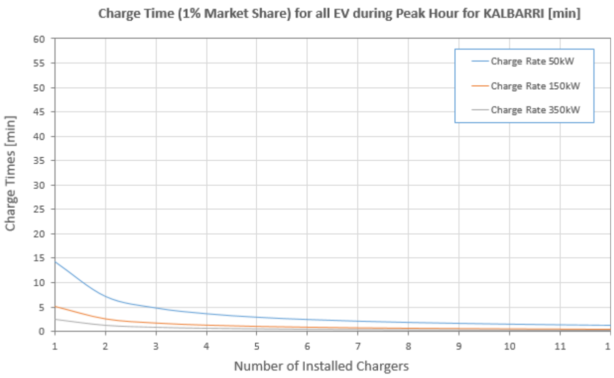
EV SHARE [%]	JURIEN BAY	GERALDTON	KALBARRI	BILLABONG ROADHOUSE	/ERLANDER ROADHOU:	CARNAVON
1	501	872	99	222	53	187
5	2504	4358	493	1112	267	935
10	5008	8717	986	2223	534	1871
20	10016	17434	1972	4446	1067	3741
50	25041	43584	4929	11115	2668	9354
100	50082	87168	9858	22230	5335	18707

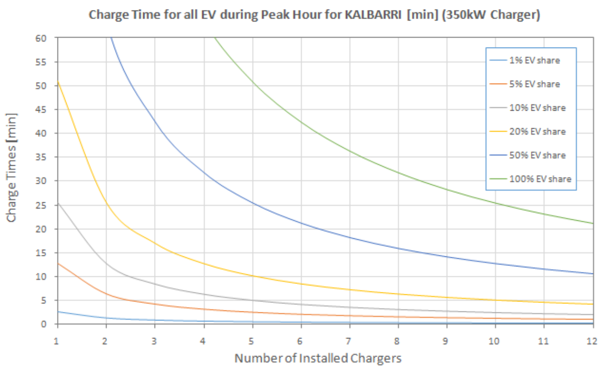
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	JURIEN BAY	GERALDTON	KALBARRI	BILLABONG ROADHOUSE	/ERLANDER ROADHOU:	CARNAVON
1	64	77	10	27	6	17
5	321	383	52	135	32	87
10	642	766	104	270	65	175
20	1284	1533	208	540	130	349
50	3210	3832	520	1350	324	873
100	6420	7664	1039	2701	648	1746









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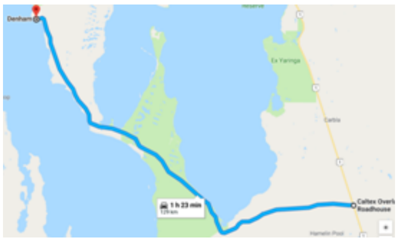
[1] EV Market share [%] refers to the share of passenger vehicle fleet

OVERLANDER ROADHOUSE to DENHAM



Peak traffic

OVERLANDER ROADHOUSE to DENHAM

DATA FOR [YEARS 20xx]	OVERLANDER ROADHOUSE - DENHAM	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
16-17	OVERLANDER ROADHOUSE DENHAM	129	406	79.8	324	20.2	82	51	41	Weekend	14

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

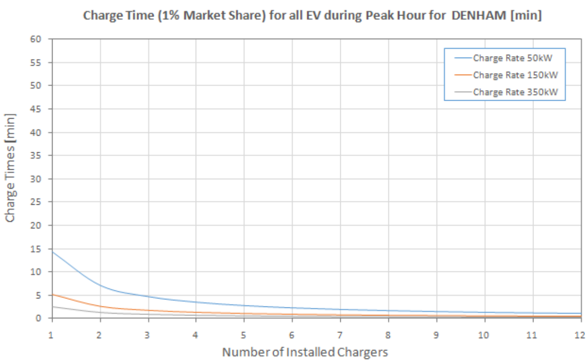
EV SHARE [%]	DENHAM
1	0
5	2
10	4
20	8
50	20
100	41

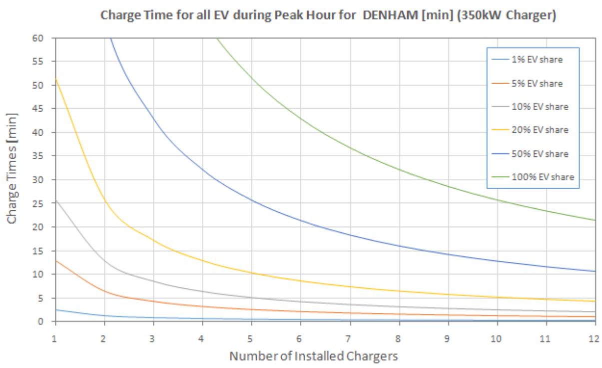
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

EV SHARE [%]	DENHAM
1	84
5	418
10	836
20	1672
50	4179
100	8359

ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	DENHAM
1	11
5	53
10	105
20	210
50	525
100	1050





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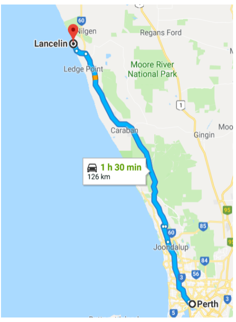
174 [1] EV Market share [%] refers to the share of passenger vehicle fleet

PERTH to LANCELIN



Peak traffic

PERTH to LANCELIN

DATA FOR [YEARS 20xx]	PERTH - LANCELIN	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC (CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
2017/2018	PERTH LANCELIN	125	2103	79.3	1668	20.7	435	257	204	Sat - Sun	11

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

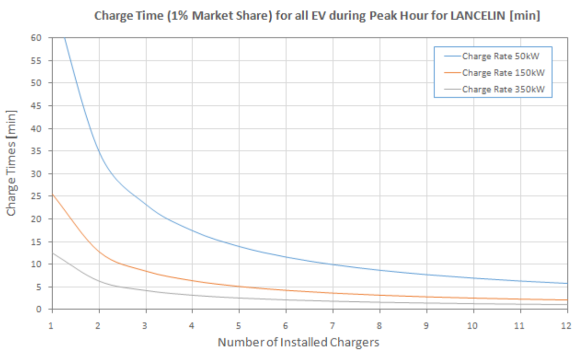
EV SHARE [%]	LANCELIN
1	2
5	10
10	20
20	41
50	102
100	204

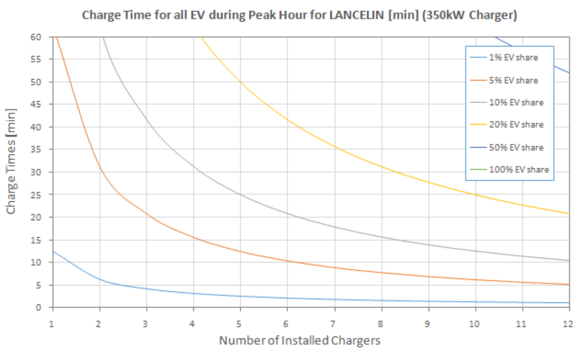
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

EV SHARE [%]	LANCELIN
1	417
5	2085
10	4169
20	8338
50	20846
100	41692

ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	LANCELIN
1	51
5	255
10	510
20	1019
50	2548
100	5095





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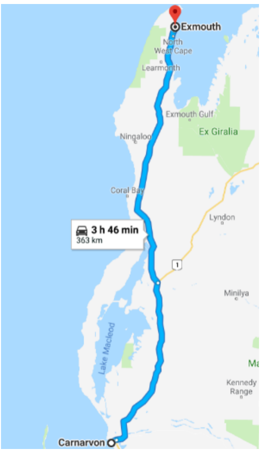
[1] EV Market share [%] refers to the share of passenger vehicle fleet

CARNAVON to EXMOUTH



Peak traffic

CARNAVON to EXMOUTH

DATA FOR [YEARS 20xx]	CARNAVON - EXMOUTH	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	CARNAVON										
16-17	MINILYA BRIDGE ROAD HOUSE	140	452	67.5	305	32.5	147	44	30	Sat - Sun	10
17-18	EXMOUTH	224	395	82.3	325	17.7	70	53	44	Mon - Sun	10

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

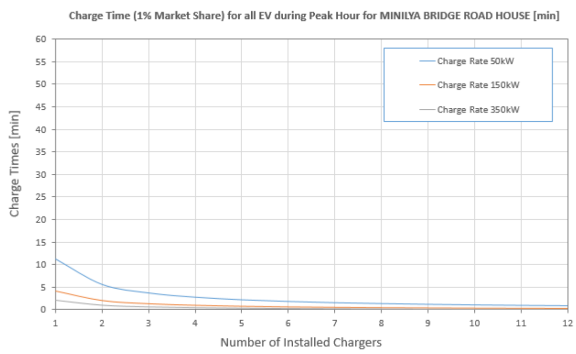
EV SHARE [%]	MINILYA BRIDGE ROAD HOUSE	EXMOUTH
1	0	0
5	1	2
10	3	4
20	6	9
50	15	22
100	30	44

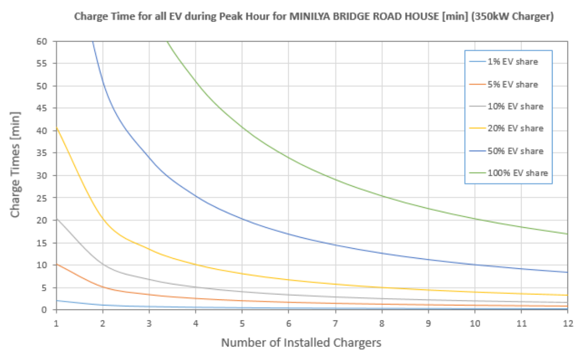
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

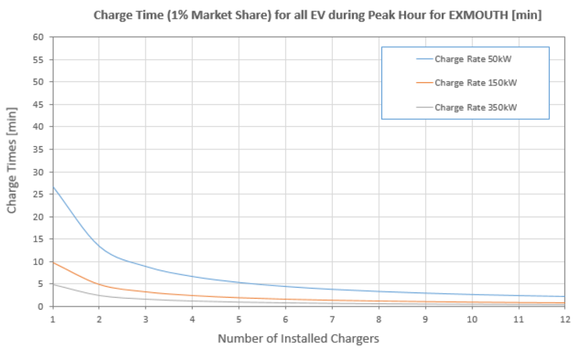
EV SHARE [%]	MINILYA BRIDGE ROAD HOUSE	EXMOUTH
1	85	146
5	427	728
10	854	1456
20	1709	2913
50	4271	7282
100	8543	14564

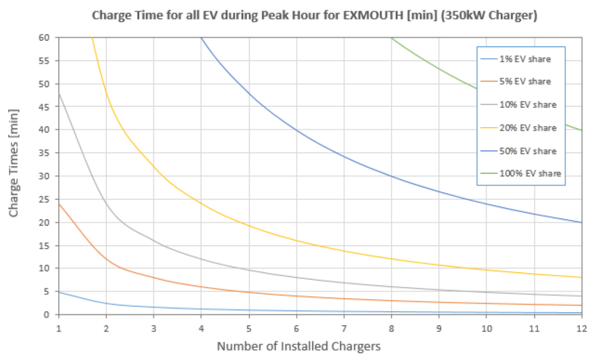
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	MINILYA BRIDGE ROAD HOUSE	EXMOUTH
1	8	20
5	42	98
10	83	195
20	166	391
50	416	977
100	832	1954









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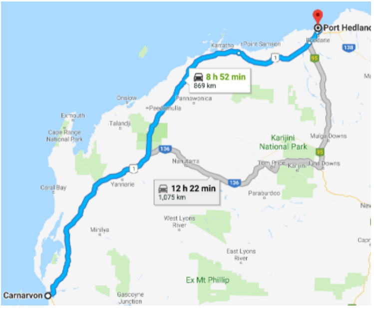
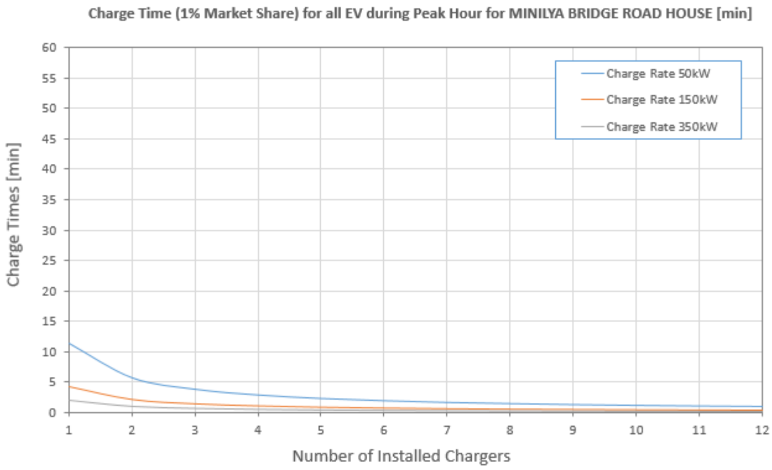
CARNAVON to PORT HEDLAND





Peak traffic

CARNAVON to PORT HEDLAND

DATA FOR [YEARS 20xx]	CARNAVON - PORT HEDLAND	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	CARNAVON										
16-17	MINILYA BRIDGE ROAD HOUSE	140	452	67.5	305	32.5	147	44	30	Sat - Sun	10
16-17	NANUTARRA ROADHOUSE	228	357	61.9	221	38.1	136	42	26	Sat - Sun	10
16-17	FORTESCUE RIVER ROAD HOUSE	163	613	64.4	395	35.6	218	75	48	Sat - Sun	11
16-17	KARRATHA	106	769	70.4	541	29.6	228	73	51	Mon - Fri	15
17-18	WHIM CREEK	127	492	70.1	345	29.9	147	55	39	Sat - Sun	13
16-17	PORT HEDLAND	122	545	67.7	369	32.3	176	54	37	Sat - Sun	11

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

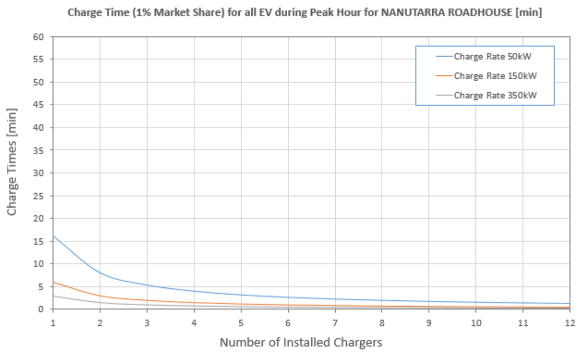
EV SHARE [%]	MINILYA BRIDGE ROAD HOUSE	NANUTARRA ROADHOUSE	FORTESCUE RIVER ROAD HO	KARRATHA	WHIM CREEK	PORT HEDLAND
1	0	0	0	1	0	0
5	1	1	2	3	2	2
10	3	3	5	5	4	4
20	6	5	10	10	8	7
50	15	13	24	26	19	18
100	30	26	48	51	39	37

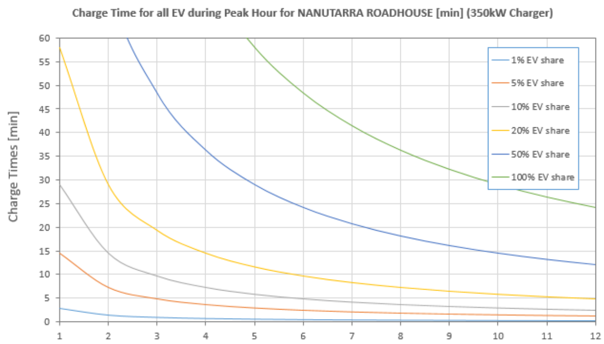
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

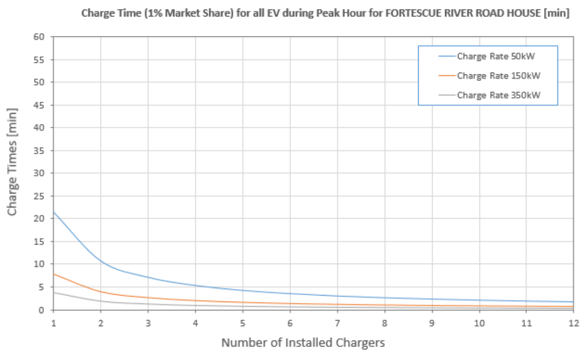
EV SHARE [%]	MINILYA BRIDGE ROAD HOUSE	NANUTARRA ROADHOUSE	FORTESCUE RIVER ROAD HO	KARRATHA	WHIM CREEK	PORT HEDLAND
1	85	101	129	115	88	90
5	427	504	643	574	438	450
10	854	1008	1287	1148	876	900
20	1709	2015	2574	2295	1752	1801
50	4271	5038	6435	5739	4380	4501
100	8543	10077	12870	11477	8760	9003

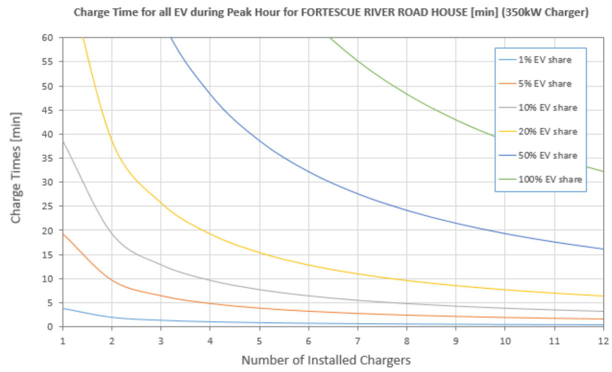
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	MINILYA BRIDGE ROAD HOUSE	NANUTARRA ROADHOUSE	FORTESCUE RIVER ROAD HO	KARRATHA	WHIM CREEK	PORT HEDLAND
1	8	12	16	11	10	9
5	42	59	79	54	49	45
10	83	119	157	109	98	89
20	166	237	315	218	196	178
50	416	593	787	545	490	446
100	832	1186	1575	1090	979	892





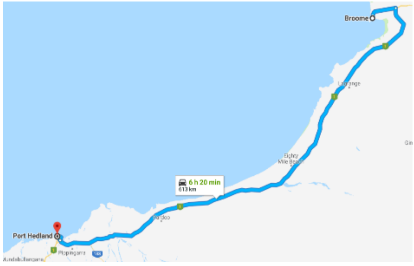


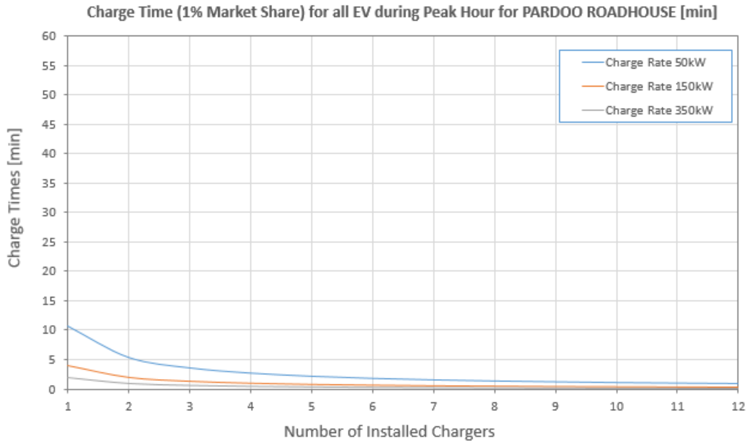


The full data set is available at: http://REVproject.com/traffic/regional.xlsx

[1] EV Market share [%] refers to the share of passenger vehicle fleet

PORT HEDLAND to BROOME





Peak traffic

PORT HEDLAND to BROOM

DATA FOR [YEARS 20xx]	PORT HEDLAND - BROOME	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC) WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	PORT HEDLAND										
14-15	PARDOO ROADHOUSE	152	344	70.1	241	29.9	103	37	26	Mon-Sun	10
N/A, Assumed as abobe	SANDFIRE ROADHOUSE	138	344	70.1	241	29.9	103	37	26	Mon-Sun	10
N/A, Assumed as abobe	ECO BEACH	211	344	70.1	241	29.9	103	37	26	Mon-Sun	10
15-16	BROOME	133	442	70.6	312	29.4	130	47	33	Mo-Fri	9

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

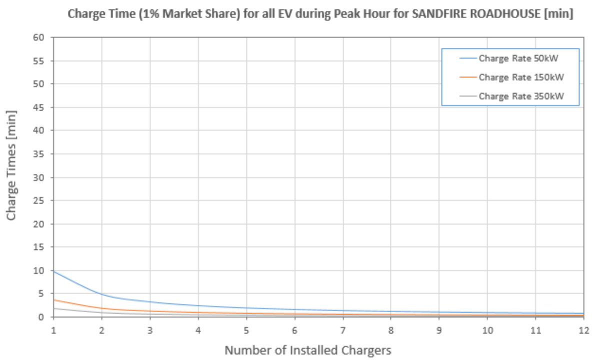
EV SHARE [%]	PARDOO ROADHOUSE	SANDFIRE ROADHOUSE	ECO BEACH	BROOME
1	0	0	0	0
5	1	1	1	2
10	3	3	3	3
20	5	5	5	7
50	13	13	13	17
100	26	26	26	33

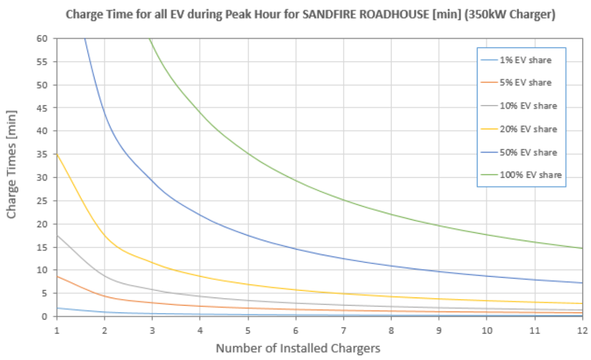
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

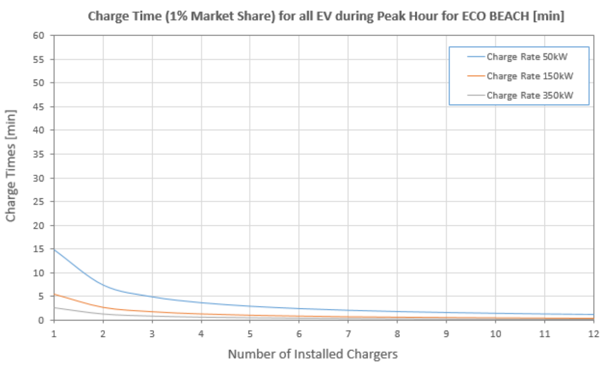
EV SHARE [%]	PARDOO ROADHOUSE	SANDFIRE ROADHOUSE	ECO BEACH	BROOME
1	73	67	102	83
5	367	333	509	415
10	733	666	1018	830
20	1466	1331	2035	1660
50	3665	3328	5088	4150
100	7331	6656	10176	8301

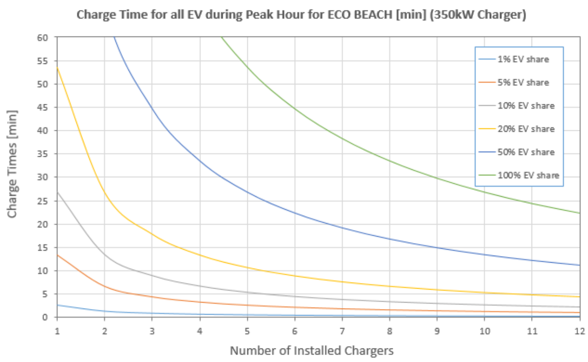
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	PARDOO ROADHOUSE	SANDFIRE ROADHOUSE	ECO BEACH	BROOME
1	8	7	11	9
5	39	36	55	44
10	79	72	109	88
20	158	143	219	177
50	394	358	547	441
100	788	716	1095	883





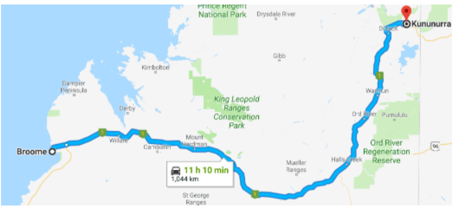


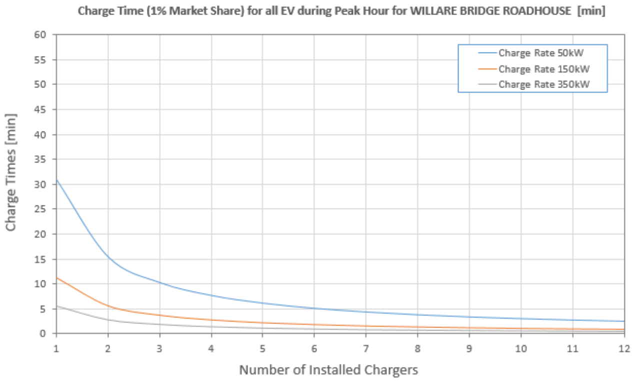


The full data set is available at: http://REVproject.com/traffic/regional.xlsx

 [1] EV Market share [%] refers to the share of passenger vehicle fleet

BROOME to KUNUNURRA





Peak traffic

BROOM to KUNUNURRA

DATA FOR [YEARS 20xx]	BROOME - KUNUNURRA	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC TOTAL WITHIN ONE HOUR	PEAK TRAFFIC (CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	BROOME										
18-19	WILLARE BRIDGE ROADHOUSE	167	758	79.8	605	20.2	153	85	68	Mon - Fri	10
17-18	FITZROY CROSSING	257	380	80.5	306	19.5	74	38	31	Mon - Fri	9
N/A, assumed same as abov	MARY POOL CAMPGROUND	181	380	80.5	306	19.5	74	38	31	Mon - Fri	9
N/A, assumed same as abov	HALLS CREEK	110	380	80.5	306	19.5	74	38	31	Mon - Fri	9
14-15	WARMUN	162	548	74.1	406	25.9	142	69	51	Mon -Sun	11
17-18	KUNUNURRA	199	307	77.2	237	22.8	70	30	23	Mon - Fri	15

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

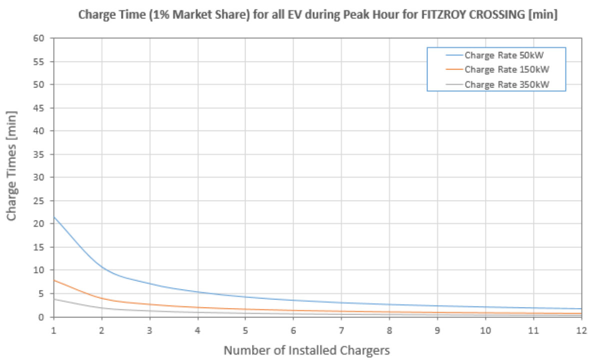
EV SHARE [%]	WILLARE BRIDGE ROADHOUSE	FITZROY CROSSING	ARY POOL CAMPGROUN	HALLS CREEK	WARMUN	KUNUNURRA
1	1	0	0	0	1	0
5	3	2	2	2	3	1
10	7	3	3	3	5	2
20	14	6	6	6	10	5
50	34	15	15	15	26	12
100	68	31	31	31	51	23

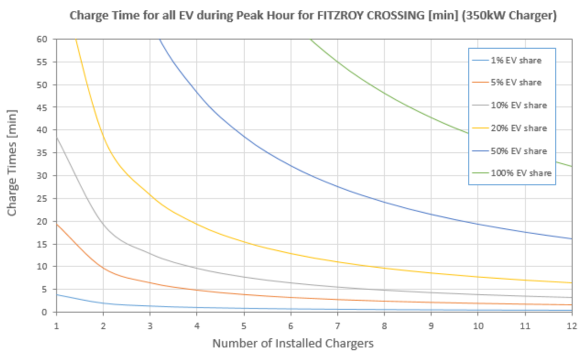
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

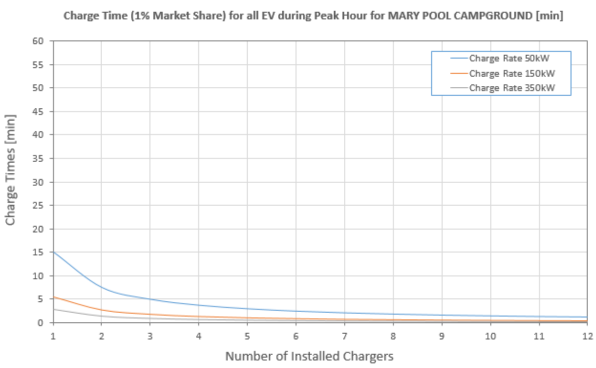
EV SHARE [%]	WILLARE BRIDGE ROADHOUSE	FITZROY CROSSING	ARY POOL CAMPGROUN	HALLS CREEK	WARMUN	KUNUNURRA
1	202	157	111	67	132	94
5	1010	786	554	336	658	472
10	2020	1572	1107	673	1316	943
20	4041	3145	2215	1346	2631	1887
50	10102	7862	5537	3365	6578	4716
100	20203	15723	11074	6730	13157	9433

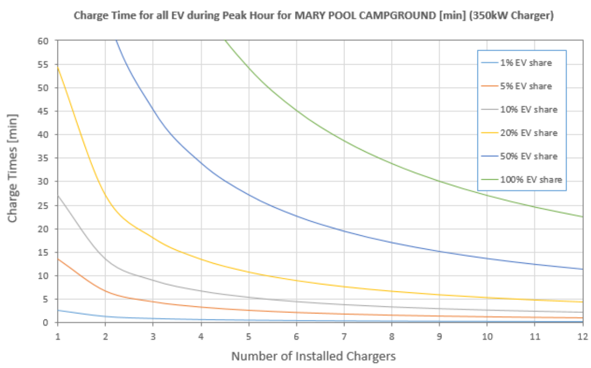
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	WILLARE BRIDGE ROADHOUSE	FITZROY CROSSING	ARY POOL CAMPGROUN	HALLS CREEK	WARMUN	KUNUNURRA
1	23	16	11	7	17	9
5	113	79	55	34	83	46
10	227	157	111	67	166	92
20	453	314	221	135	331	184
50	1133	786	554	336	828	461
100	2266	1572	1107	673	1657	922









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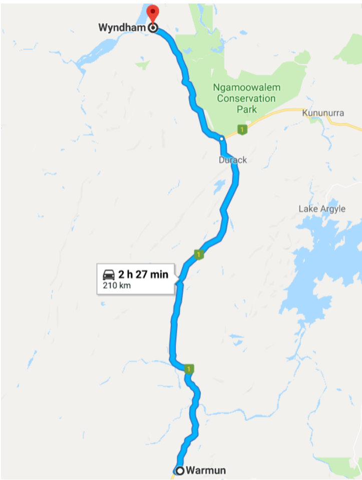
[1] EV Market share [%] refers to the share of passenger vehicle fleet

WARMUN to WYNDHAM



WARMUN to WYNDHAM

DATA FOR [YEARS 20xx]	WARMUN - WYNDHAM	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
15-16	WARMUN WYNDHAM	210	283	82.3	233	17.7	50	29	24	Mon-Sun	10

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

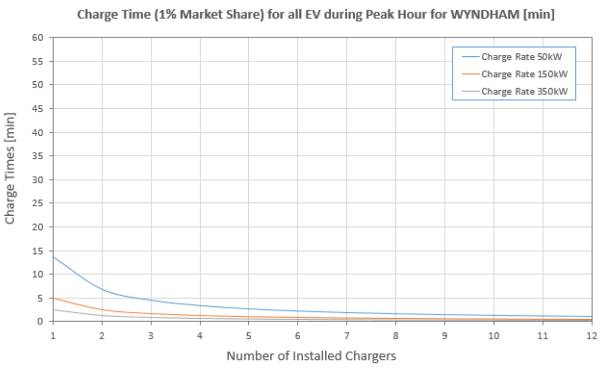
EV SHARE [%]	WYNDHAM
1	0
5	1
10	2
20	5
50	12
100	24

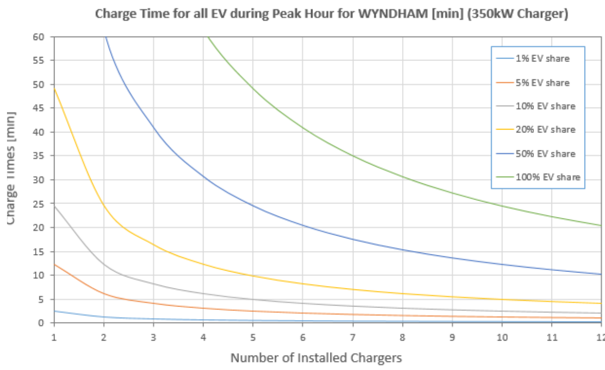
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

EV SHARE [%]	WYNDHAM
1	98
5	489
10	978
20	1956
50	4891
100	9782

ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	WYNDHAM
1	10
5	50
10	100
20	200
50	501
100	1002

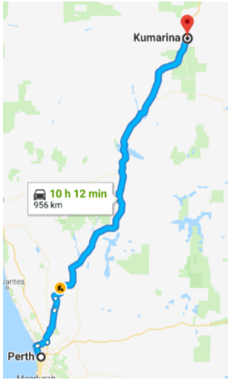


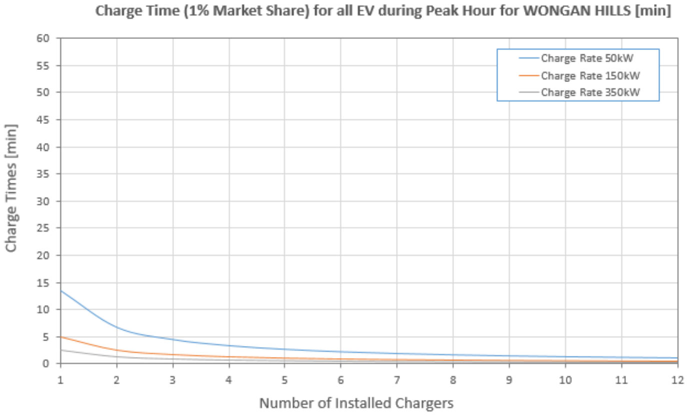


The full data set is available at: http://REVproject.com/traffic/regional.xlsx

180 [1] EV Market share [%] refers to the share of passenger vehicle fleet

PERTH to KUMARINA (GOLD MINE)





Peak traffic

PERTH to KUMARINA (GOLD MINE)

DATA FOR [YEARS 20xx]	PERTH - KUMARINA(GOLD M.)	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC TOTAL WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	PERTH										
17-18	WONGAN HILLS	191	299	76.6	229	23.4	70	34	26	Mon - Fri	8
17-18	WUBIN	109	539	44.2	238	55.8	301	45	20	Sat - Sun	10
12-13	PAYNES FIND ROADHOUSE	156	589	38.5	227	61.5	362	44	17	Sat - Sun	2
15-16	MOUNT MAGNET	145	674	57	384	43	290	59	34	Sat - Sun	2
17-18	MEEKATHARRA	195	492	40.7	200	59.3	292	38	15	Mon - Fri	12
N/A, assumed be as above	KUMARINA (GOLD MINE)	182	492	40.7	200	59.3	292	38	15	Mon - Fri	12

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

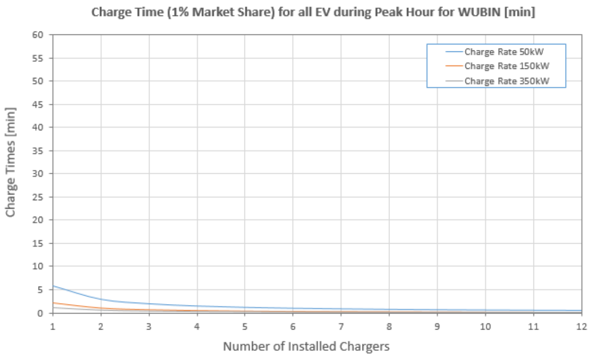
EV SHARE [%]	WONGAN HILLS	WUBIN	'AYNES FIND ROADHOUS	MOUNT MAGNET	MEEKATHARRA	:UMARINA (GOLD MIN
1	0	0	0	0	0	0
5	1	1	1	2	1	1
10	3	2	2	3	2	2
20	5	4	3	7	3	3
50	13	10	8	17	8	8
100	26	20	17	34	15	15

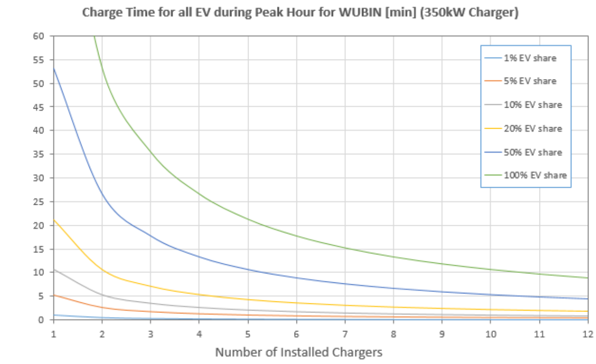
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

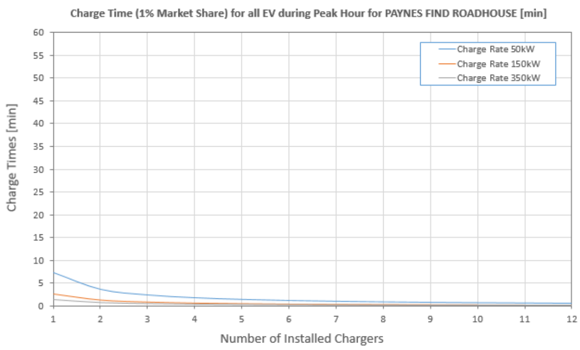
EV SHARE [%]	WONGAN HILLS	WUBIN	'AYNES FIND ROADHOUS	MOUNT MAGNET	MEEKATHARRA	:UMARINA (GOLD M
1	87	52	71	111	78	73
5	437	260	354	557	390	364
10	875	519	708	1114	781	729
20	1750	1039	1415	2228	1562	1458
50	4375	2597	3538	5571	3905	3644
100	8749	5194	7075	11141	7810	7289

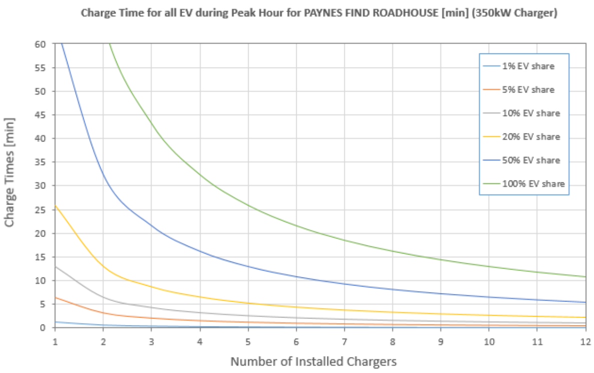
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	WONGAN HILLS	WUBIN	'AYNES FIND ROADHOUS	MOUNT MAGNET	MEEKATHARRA	:UMARINA (GOLD
1	10	4	5	10	6	6
5	50	22	26	49	30	28
10	99	43	53	98	60	56
20	199	87	106	195	121	113
50	497	217	264	488	302	281
100	995	434	529	975	603	563









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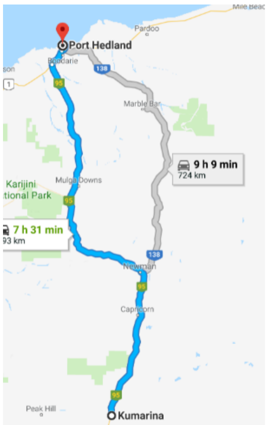
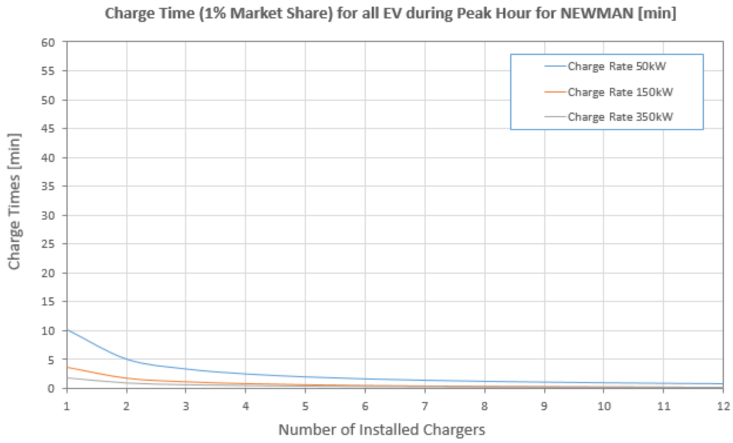
[1] EV Market share [%] refers to the share of passenger vehicle fleet

KUMARINA (GOLD MINE) - PORT HEDLAND





Peak traffic

KUMARINA (GOLD MINE) - PORT HEDLAND

DATA FOR [YEARS 20xx]	KUMARINA (GOLD M.)- PORT HEDLAND	DISTANCE [Km]	TOTAL TRAFFIC	CARS [%]	CARS	TRUCKS [%]	TRUCKS	PEAK TRAFFIC TOTAL WITHIN ONE HOUR	PEAK TRAFFIC(CARS) WITHIN ONE HOUR	PEAK TRAFFIC (DAYS OF THE WEEK (CARS)	PEAK TRAFFIC (CARS) TIME OF THE DAY [24h]
	KUMARINA (GOLD MINE)										
m South only, used data from M	NEWMAN	240	492	40.7	200	59.3	292	38	15	Mon - Fri	12
17-18	AUSKI TOURIST VILLAGE	192	532	39.8	212	60.2	320	47	19	Mon - Sun	14
15-16	WODGINA MINE	157	813	41.3	336	58.7	477	61	25	Sat - Sun	5
17-18	PORT HEDLAND	111	1473	23.2	342	76.8	1131	101	23	Mon - Fri	9

EV SHARE (NUMBER OF CARS) WITHIN PEAK HOUR

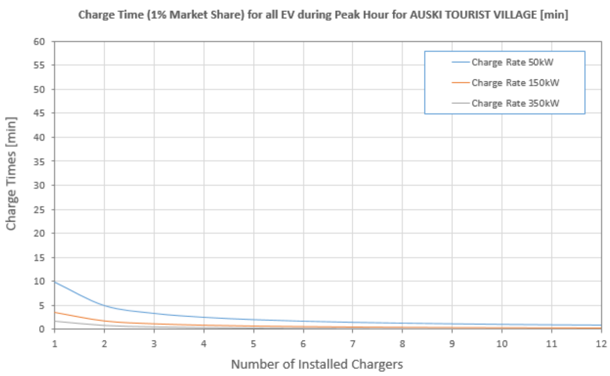
EV SHARE [%]	NEWMAN	AUSKI TOURIST VILLAGE	WODGINA MINE	PORT HEDLAND
1	0	0	0	0
5	1	1	1	1
10	2	2	3	2
20	3	4	5	5
50	8	9	13	12
100	15	19	25	23

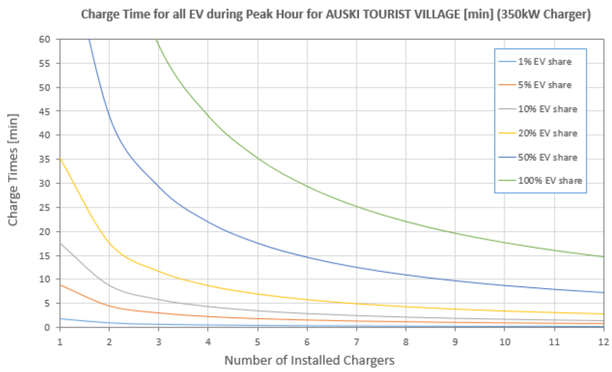
ESTIMATED ENERGY DEMAND PER DAY [kWh] FOR MONDAY TO SUNDAY

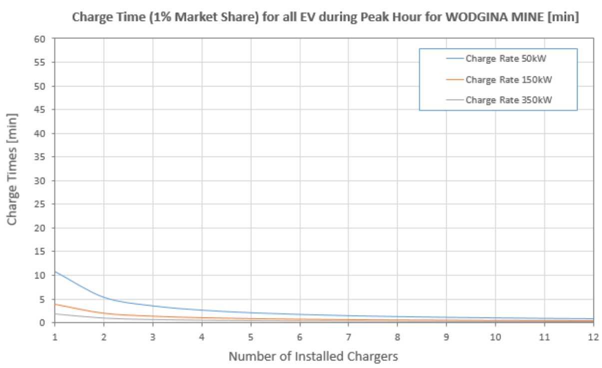
EV SHARE [%]	NEWMAN	AUSKI TOURIST VILLAGE	WODGINA MINE	PORT HEDLAND
1	96	81	105	76
5	481	407	527	379
10	961	813	1054	759
20	1922	1626	2109	1517
50	4806	4065	5272	3793
100	9612	8131	10543	7587

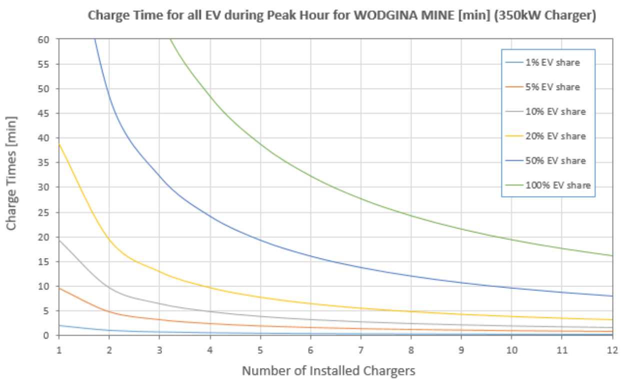
ESTIMATED ENERGY DEMAND DURING PEAK HOUR OF THE DAY [kWh]

EV SHARE [%]	NEWMAN	AUSKI TOURIST VILLAGE	WODGINA MINE	PORT HEDLAND
1	7	7	8	5
5	37	36	40	26
10	74	72	79	52
20	148	144	158	104
50	371	359	396	260
100	742	718	791	520









The full data set is available at: http://REVproject.com/traffic/regional.xlsx

 [1] EV Market share [%] refers to the share of passenger vehicle fleet

Appendix D
Consulted Stakeholders

The following organizations have been consulted in the process of writing this study.

Government

- WA Dept. of Transport — Brett Hughes, Exec. Dir. Transport Strat. & Reform; Graeme O'Neil, Act. Manager Strategic Transport Reforms; Wei Fisher, Analyst Transport Strategy & Reform
- MainRoads WA — John Erceg, Executive Director Regional Services; Leo Coci, Executive Director Infrastructure Delivery; Louis Bettini, Principal Sustainability Advisor; Steve Atkinson, Principal Analyst Strategic Planning
- LandCorp WA — John Clifton, Manager Strategy and Innovation
- WALGA — Ian Duncan, Executive Manager Infrastructure; Chris Hossen, Senior Planner
- WA Dept. of Primary Industries and Regional Dev. — Amy Tait, Manager Energy Futures
- WA Dept. of the Premier and Cabinet — Lance Glare, Director Infrastructure Policy

Utilities

- Western Power — Alison Morley, Head of Business Devel. & Strategy; Nathan Kirby, Michael Chung
- Synergy — Allen Gerber, Manager, Retail Sales
- Horizon Power — Terry Absolon, Manager Strategy & Marketing; Imran Johari, Strategic Development Manager

OEM

- Mitsubishi — Crag Norris, National PHEV Sales Manager
- Holden — Marinos Panayiotou, Director Planning
- Tesla Motors — Sam McLean, Business Development and Policy
- Volkswagen — Kurt McGuiness, Public Relations Manager
- BMW — Lenore Fletcher, GM Corporate Communications
- Hyundai — Scott Nargar, Manager Future Mobility & Govern.
- Porsche — Ingo Appel, Product & Planning Manager

EVSE and Consortia

- Tritium — Calem Walsh, Senior Design Engineer
- Chargefox — Tim Washington, Co-Founder, Dir. of Partnerships
- Fast Cities — Paul Fox, Head of Corporate Development, Andrew Simpson, Head of Operations and Planning
- ABB — Steven Amor, Product Marketing Manager AUS/NZ; Anurag Alung, Dino Hadzic, Business Development
- e-Station, Circontrol — Patrick Finnegan, Director
- ChargePoint — Geoff Mewing, National Manager - Australia
- Gemtek — Florian Popp, Director
- Energy-Tec — Ed Nellan, Chief Operations Officer; Mark Timsin, Renewables and Retail Energy Manager

Trade Organisations, Interest Groups, Other

- EV Council — Behyad Jafari, CEO
- Freight and Logistics Council of WA — Kellie Houlahan, Executive Officer
- AEVA Perth Branch — Christopher Jones, National Secretary
- TOCWA Tesla Owners Club of WA — David Lloyd, Member; Rob Dean, Committee Member
- RAC of WA — Alex Forrest, Manager Vehicles & Sustainability
- Hydrogen Mobility Australia — Claire Johnson, CEO
- AustRoads — Chris Jones, Project Manager - Automated Vehicles