ANALYSIS OF WESTERN AUSTRALIAN ELECTRIC VEHICLE AND CHARGING STATION TRIALS

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Abstract

An Electric Vehicle (EV) trial and an EV Recharging Research Project are being simultaneously undertaken in Perth, both the first of their kind in Australia. The EV trials involve 11 locally converted Ford Focus vehicles, while the EV Recharging Study involves the use of 17 charging outlets (final configuration 23 outlets) from Level 2 AC recharging stations. Data is being logged from both the vehicles and the recharging stations and is transmitted to a server at The University of Western Australia's (UWA) Renewable Energy Vehicle Project (REV), where it is used for statistical evaluation, analysis and modelling.

Key words: *Electric vehicle trial, charging station trial, charging network, charging statistics.*

1. Introduction

Rising fuel costs, growing public awareness and concern over environmental issues such as local urban air quality and global warming, combined with higher performance batteries mean that electric vehicles (EVs) are becoming an attractive alternative to internal combustion engine vehicles (petrol/diesel). Increased market penetration of electric vehicles will increase electricity loads, may place increasing demands on electricity grids. It will also require the installation, management and maintenance of compatible recharging infrastructure. Careful analysis, planning and management will be needed to reduce the costs of and to optimise placement of this recharging infrastructure and to minimise the impacts on electricity grids.

The goal of this study is to determine the optimal number and locations of electric vehicle charging stations in the area supplied by the main electricity grid in Western Australia, taking account the expected location, number and movement/ charging patterns of electric vehicles. This initial study shows electric vehicle usage patterns from telemetry data that has been collected from the WA electric vehicle trial and EV recharging project, consisting of eleven trial vehicles and 17 charging stations currently in use in Western Australia. As part of the recharging project, the UWA Business School is conducting EV driver satisfaction surveys as well as household surveys for potential EV buyers (Jabeen et al. 2012).

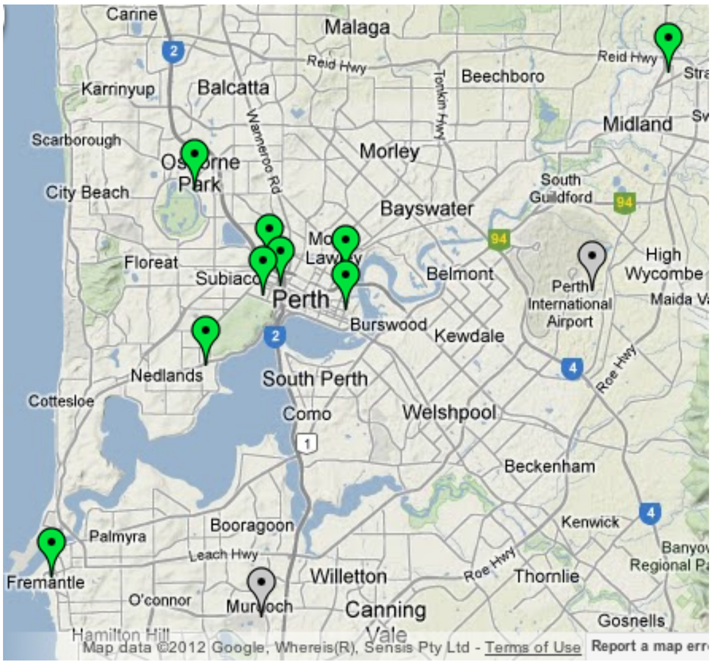
The trials form part of a road mapping exercise for business and government and is also being used to assist in the development of relevant standards and regulations (IEA 2011). The analysis of the vehicle charging times and locations may provide further insight into several EV research areas. While the likely slow uptake of electric vehicles (AECOM 2009; Järvinen et al.

2012) make it unlikely that electric vehicle charging will create significant problems for electricity grids such as the South-West Interconnected System (SWIS) in Western Australia (Mullan et al. 2011), the ability to compare the results of simulation studies of EV charging patterns based on vehicle fleet patterns with the results of real trials is very useful (EPRI 2007, 2011; Weiller 2011; Ashtari et al. 2012; Kelly et al. 2012; Shahidinejad et al. 2012). The trial results will also provide useful insights into the viability of vehicle-to grid-technologies and the ability to test the validity of analyses that have found that the high technology and infrastructure costs associated with some vehicle-to-grid (V2G) options are likely to be too large to render those V2G variants economically viability in most locations (Mullan et al. 2012).

2. EV Trial Cars

Beginning in early 2010 a consortium of eleven WA-based organisations have collaborated with the Renewable Energy Vehicle Project (REV), which is led and coordinated by the University of Western Australia (UWA) and local company CO2Smart. The organisations involved are learning through doing, with the goal of discovering viability and creating appropriate approaches to the emerging technology, as recommended by Garnaut (2011). Each of the participating companies purchased a standard 2010/11 model Ford Focus sedan and funded the conversion from petrol to electric drive, which was undertaken by WA company EV Works. The converted vehicles have a battery capacity of 23 kWh and a road-tested range of over 130 km. As automotive charging connectors were not available at the commencement of the trial, all vehicles were initially fitted with Australian three phase plugs (32A) as well as Australian single phase plugs (10A). The chargers in the vehicles will draw up to 4.8kW which allowed the vehicles to be charged from empty to full in about 4 hours or 10 hours, respectively.

Figure 1: Charging Station Network (using Google Maps 2012)

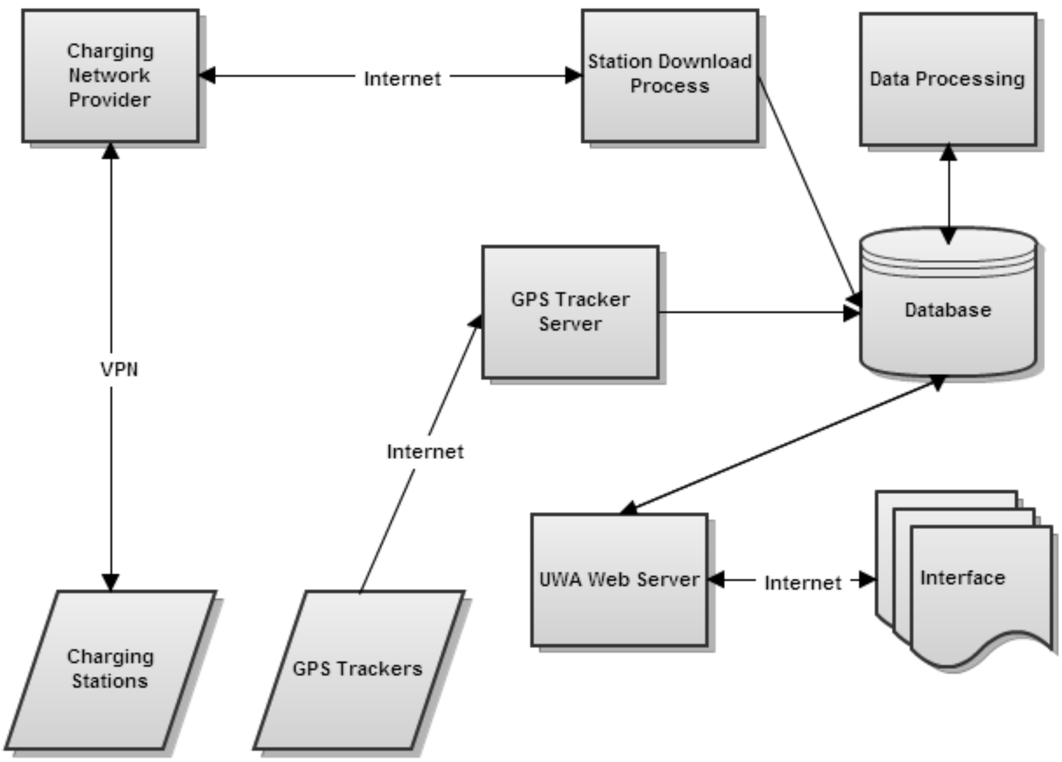


The trial subsequently adopted the European standard IEC 62196 Type 2 connectors and vehicle inlets (“Mennekes”), and vehicle inlets are currently being converted over to this new standard (IEC 2011). The advantage of the IEC 62196 Type 2 (“Mennekes”) over the US/Japan standard IEC 62196 Type 1 (“SAE J1772”), is that it supports single phase as well as three phase power, which the US/Japanese standard does not. Although Standards Australia has recommended that IEC 62196 be adopted as a whole, it has so far not made a recommendation on connector Type 1 or 2. Standard and regulations are important for electric vehicles and charging stations to ensure safety and to increase consumer confidence (Brown et al. 2010) and research aimed at informing new policies for introduction of EVs into Australia has been commissioned by the CSIRO (Dunstan 2011).

To measure the energy usage of the vehicles, GPS tracking devices with five digital inputs and one analogue input were installed in each of the cars and used to measure air conditioning status, heater status, headlights status, charging status, ignition status and the vehicle battery charge level. GPS positions and line inputs are uploaded onto the UWA server either every one minutes or ten meters (see Figure 2). For the last six months of the trial (ending 2012-08-22), 2,298,038 data rows were inserted into the database from the eleven EVs. The data is processed using a batch script and displayed to the trial participants via a web interface that displays telemetry data, driving and charging statistical heat maps for each and all of the vehicles. The data processing generates journey, charge and parking events.

Journeys have a starting time and location, ending time and location, total distance travelled air conditioning usage time, heater usage time, headlight usage time and the estimated battery. Journeys are started when the ignition is detected as being on and ending when the ignition is turned off.

Figure 2: System Diagram



Charges have a starting time, ending time, location, distance travelled (between charges), energy used (kWh), time charging and time maintaining charge. The charge events are generated starting when the vehicle charging door (the door covering the charging plugs) is opened and ending when the charging door is closed. When an EV is in a location and does not have either its ignition on a parking event is created from the last journey to the next journey. The parking events are then compared to charging events and if a vehicle charges while parking the charge is linked to the parking event.

The GPS tracking units log only when they have a GPS fix. A GPS fix is normally obtained when the antenna has an unobstructed view of the sky (Kaplan and Hegarty 2005). Throughout the trial, vehicles were parked on occasions within heavy indoor areas, such as parking structures or underground, and have been charged without an active GPS fix. When vehicles have a gap in their data logging of greater than 15 minutes and have a battery level increase of more than 10%, a charge event is created for the duration of the data loss. In those cases, the charge event is created entirely by estimation using the time the GPS signal was lost to the time the GPS was re-established as the start and end times. If a vehicle loses GPS fix while driving, the distance between the point before GPS loss and the point where the GPS is re-established and taken to be the distance travelled during the period.

There is also the possibility of a bad GPS fix caused by a weak or unreliable GPS antenna signal. In those cases, it is unreliable to confirm a vehicle's position from one co-ordinate. All the coordinates gathered throughout the duration of the charge and within two standard deviations are therefore averaged out to make an estimated position. If that location is within a certain range of a known charging location, the coordinate is repositioned to the charging location.

3. EV Charging

3.1 Charging Stations

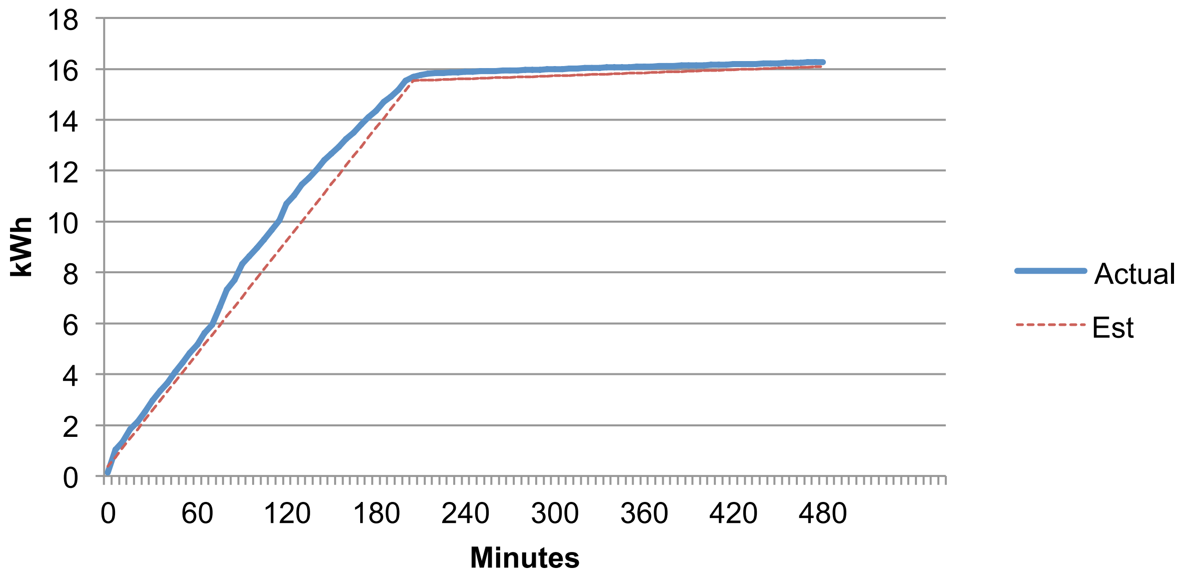
All charging station (locations shown in Figure 1) outlets log customer IDs, start time, end time, as well as the amount of energy used for potential customer billing. Charging station data is downloaded via GSM to an external server every four hours. The external server is checked every thirty minutes using a batch process and new charge events are downloaded to the server at UWA (see Figure 2).

3.2 Other Charing Points

When an EV is recharged at a charging station, the exact amount of electricity used (kWh) is recorded from the charging station's meter. If an EV charges elsewhere (e.g. at home or at a business), or station data is missing, the amount of electricity used is approximated from the battery level of the vehicle, the recharging time, the distance the vehicle travelled before charging, and the level of power supplied. Each vehicle has a 30A charger installed, and the measured power loss from the power socket to the battery pack is 83%.

When the vehicle battery is full, the charger switches to a maintain charge mode, which maintains the batteries at full charge, the trial EV chargers use on average 0.12 kW to maintain the charge level. Once the battery charging level is estimated, the vehicle is assumed to be drawing power at that level for the remaining time that it is plugged-in. Figure 3 shows the energy drawn from a charging station with the energy meter readings (blue) and the estimated charging kWh (red). Using this information, the vehicle charging profile can be estimated.

Figure 3: EV Charging profile



3.3 Charging Locations

94% (1126 of 1203) of the recorded EV recharging events over the last six months of the trial occurred at 29 locations with a determined maximum power of 2.4 kW, 3.6 kW or 7.2 kW (10, 15 and 30 Amp sockets/stations at 240V), the latter information being obtained through site visits. The vehicles when charging at 10 or 15 amp sockets will draw 1.8kW and at 30 amp sockets and charging stations will draw at 4.8kW. The vehicles do not draw the full 2.4 kW at 10 Amp outlets for additional safety, related to results from audits showing 20% of Australian households having serious electrical safety faults (MEA 2011). Each location is also categorised as either:

1. Home, at a EV users residence
2. Business, at places of business such as work, but not at a charging station
3. Stations, at one of the installed charging stations

If a vehicle is recharged within a certain radius of a known charging station location, it is assumed to be charging at that location. The radius for each charging location is determined by the accuracy of the average GPS fix at that location. The other 7% of charging locations are labelled as unknown and are always assumed to be 2.4 kW.

3.4 EV Driver Influencers

The trials' electric vehicle drivers reported being influenced by the following factors, which may affect the statistical results:

- All EVs are company fleet vehicles and some organisations have restrictions on their use, such as not taking the vehicle home.
- Some EVs had dedicated drivers, whilst others were shared pool vehicles.

- Most EV drivers were not reimbursed for electricity usage in their homes.
- Four organisations had a charging station installed on their premises, specifically for their vehicle.

4 Driving Statistics

In 2010 the average distance a passenger vehicle travelled for business in Western Australia was 11,700 km per year or 32.0km per day (ABS 2011). The overall average for the trial over the last six months was 17.56 km per day, almost half than the West Australian average (Table 1). Over the time period, the EVs averaged 2 journeys per day. The estimated annual energy usage for the EV's is on average 1.13MWh, driving 17.56km and maximum of 3.33MWh driving 48.53km. The West Australian business average of 32km per day equates to 2.06MWh per annum. On average the air conditioner is on 29%, the lights 16% and the heater 3% of the time while driving.

Table 1: EV journeys (accumulated over six months)

Vehicle	Number of Journeys	Average Journey Time (mins)	Average Distance Travelled (km)	Average kWh Used (kWh)	Daily km (km)	Percentage		
						Air con	Lights	Heat
1	235	18.79	10.31	1.97	13.50	0%	21%	0%
2	252	19.49	9.75	1.86	13.73	0%	0%	1%
3	605	12.44	6.84	1.30	23.10	34%	22%	0%
4	120	23.77	14.25	2.72	9.53	34%	26%	18%
5	410	9.13	4.89	0.93	11.19	47%	19%	0%
6	432	13.70	5.52	1.05	19.21	78%	8%	7%
7	275	8.49	4.97	0.95	9.17	5%	1%	6%
8	354	13.03	7.67	1.46	15.41	27%	1%	5%
9	133	15.61	7.39	1.41	6.59	14%	13%	0%
10	712	19.39	12.22	2.34	48.53	63%	39%	0%
11	442	16.20	8.24	1.57	20.44	22%	22%	9%
Average	361	15.23	8.19	1.56	17.56	29%	16%	3%

The maximum average daily kilometre was 48.53, using only 37.33% of the vehicles maximum range. Over the last six months the maximum distance an EV drove in one journey is 71km, being the only journey greater than half of the vehicles range.

Figure 4: EV travel distance by time of day (accumulated over six months) for each of the 11 vehicles (1 – 11)

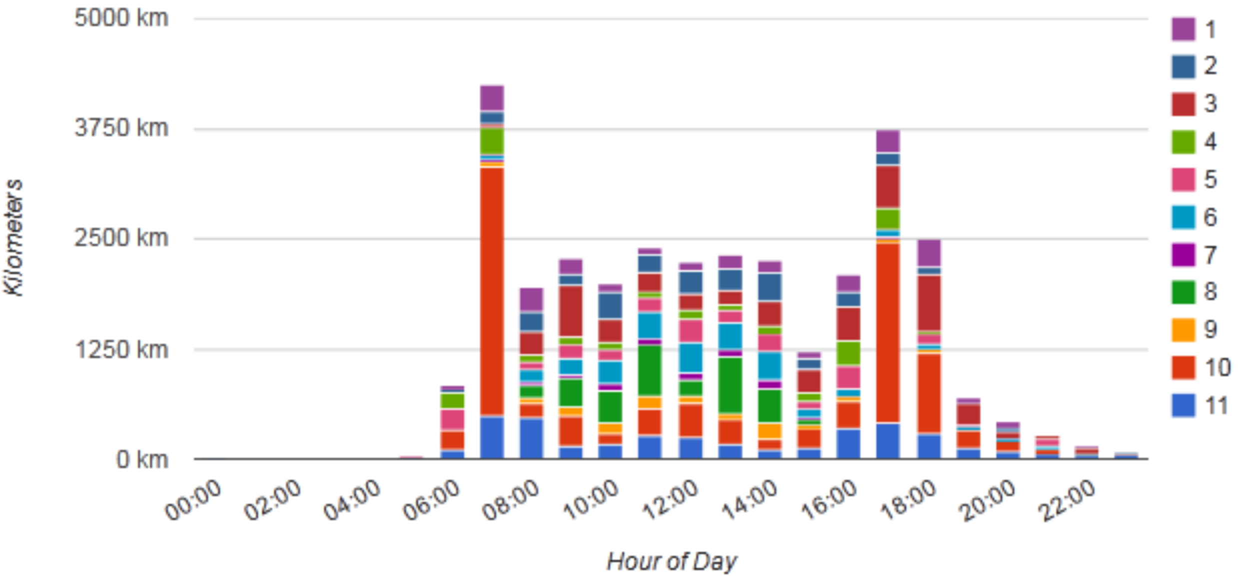
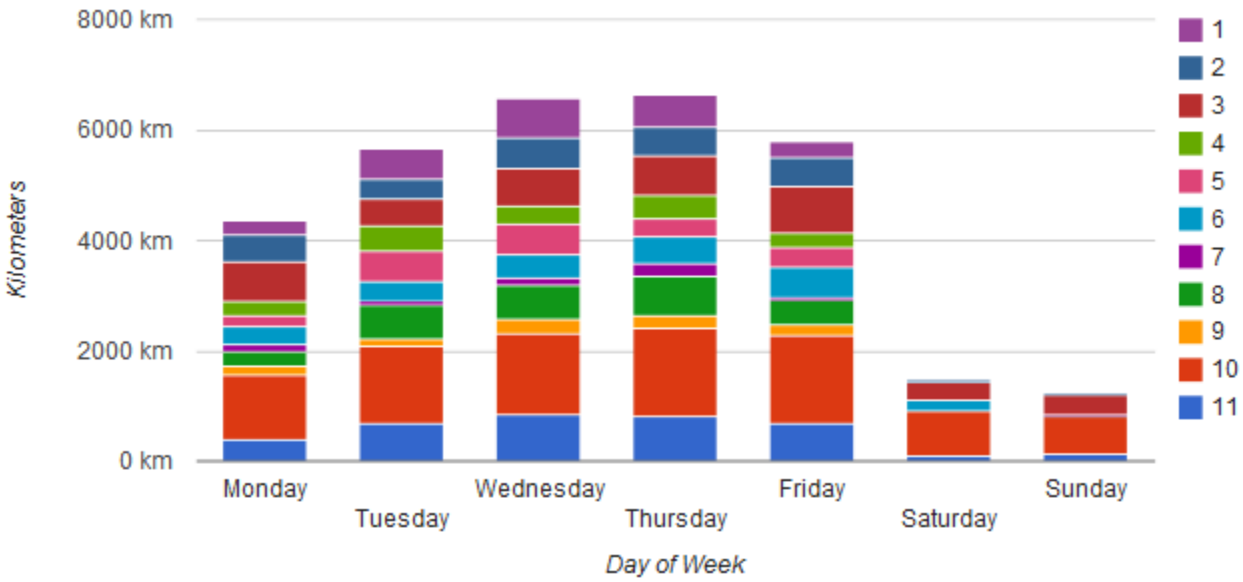


Figure 4 shows the distance travelled by the hour of day, with 92.28% of the total distance travelled occurring between 7am and 7pm. The peaks of distance travelled are at 7am and 5pm where vehicle 10 (which contributed 27% of the total km driven) arrives at and leaves work. Just over half (53.20%) of the total distance is travelled is undertaken between the hours of 9am to 5pm. The results in figure 4 are similar to the number of motorised trips by time of day in Melbourne reported by the CSIRO (2011) and the percentage of trips by vehicle each hour as reported by Clement-Nyns et al. (2010). The vehicles travelled 88% of their total distance on week days (see Figure 5), with most vehicles not being used on weekends.

Figure 5: EV travel distance by day of week (accumulated over six months) for each of the 11 vehicles (1 – 11)



5 Charging Statistics

The number of charging events over the last six months is 1,203, with 236 (19.62%) charges not charging to full. The charges are made up of 186 home charges, 392 station charges, 548 business charges and 77 in unknown locations. In these locations 541 charge events occurred at a high powered outlet (32A) and 585 at low power outlets (10A or 15A) with 77 at an unknown location and socket. Of the number of charges not full, 69 occurred at high powered outlets (13% of all high powered charges), 141 occurred at lower power outlet (24% of all low powered charges) and 26 occurred at an unknown location (34% of all unknown charges).

The charging statistics shown in Table 2 show the average charging time for an electric vehicle is 2:06 hours, while at a higher powered socket the EV's are charged in 1:26 hours and at a lower powered socket the vehicles are charged in 2:32 hours. After the vehicles are charged they remain plugged into the socket for 17:06 hours on average, of the total time parked only 12.9% is spent charging on average.

Table 2: Charging amounts and times (accumulated over six months)

Vehicle	Average kWh	Average Charging Time	Average Maintaining Time	Sum of charges at 10, 15 A outlet	Sum of charges at 32 A outlet	Average 10 Amp charge time	Average 32 amp charge time
1	4.16	2:05:41	34:03:59	81	11	2:00:32	0:41:12
2	12.27	2:41:18	36:37:08	2	47	1:56:12	2:34:37
3	5.41	1:45:50	2:02:43	104	100	2:13:34	1:06:26
4	9.05	1:21:28	54:34:51	0	61	None	1:18:46
5	7.13	1:17:54	5:47:43	5	83	0:03:55	1:20:54
6	7.73	3:44:34	31:21:08	79	0	3:43:52	None
7	5.46	2:30:04	13:42:11	24	1	2:35:46	0:13:16
8	14.33	6:36:34	29:20:12	51	0	6:36:34	None
9	2.08	1:15:04	55:43:09	58	1	1:08:36	0:02:08
10	8.01	2:17:16	6:07:38	109	99	2:23:13	1:54:15
11	4.89	1:12:20	5:41:32	72	138	1:00:23	1:10:07
Average	7.08	2:06:47	17:06:11	585	541	2:32:59	1:26:40

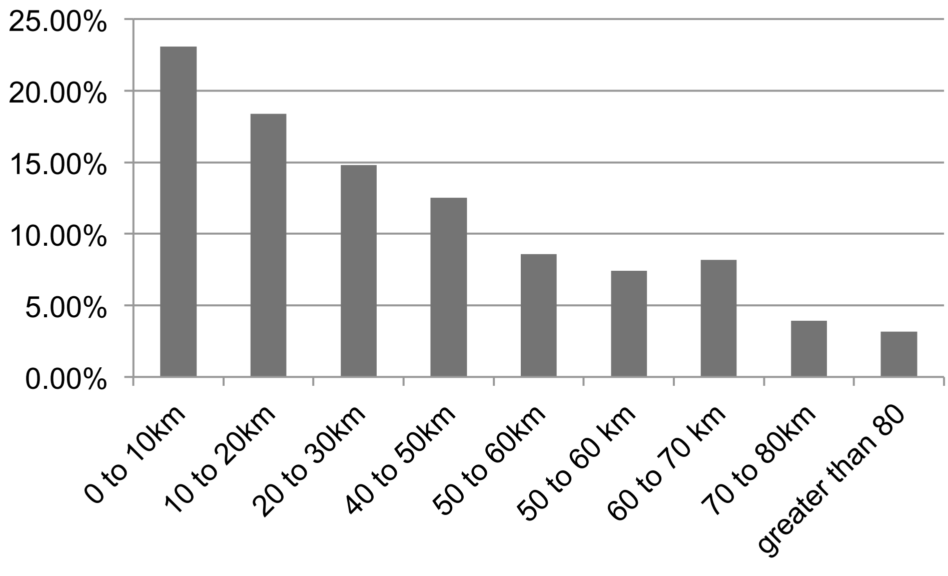
4.1 Vehicle Time Usage

Table 3: Vehicle time usage (accumulated over six months)

Vehicle	Total logged hours (hours)	Driving time per day (mins)	Average distance before charge (km)	Time driving	Time plugged in	Parking without plugged in
1	4307	0:24:17	18.02	1.69%	77.25%	21.06%
2	4293	0:27:27	57.81	1.91%	44.86%	53.23%
3	4308	0:41:44	19.00	2.90%	18.04%	79.06%
4	4305	0:15:54	26.32	1.10%	79.26%	19.64%
5	4300	0:20:41	22.13	1.44%	14.52%	84.04%
6	2980	0:46:53	27.87	3.26%	93.02%	3.72%
7	3578	0:06:19	18.39	0.44%	15.49%	84.07%
8	4228	0:26:11	51.75	1.82%	43.35%	54.83%
9	3580	0:13:36	10.12	0.94%	93.90%	5.16%
10	4304	1:15:53	36.23	5.27%	40.67%	54.06%
11	4274	0:40:12	16.26	2.79%	33.89%	63.32%
Average	4042	0:31:02	25.22	2.16%	49.01%	48.83%

On average, the EVs were not being driven for 97.84% of the time, or 23:29 hours per day. 49% of the hours where EVs were parked, they were also plugged in. Figure 6 shows the percentage of charges with distance travelled between charges. 84% of charges occur before the EV travels a distance of greater than 60km without charging.

Figure 6: EV charging distance travelled before charging (accumulated over six months)



4.2 Charging Location type

Table 4: Charging location type (accumulated over six months)

Vehicle	Time parked in known location	Time parked in unknown location	Charging probability at home	Charging probability at work	Charging probability at station	Charging probability unknown	Total Known locations used	Known locations charged at
1	83.68%	16.32%	27.27%	92.59%	53.33%	11.76%	17	11
2	75.46%	24.54%	0.00%	65.49%	0.00%	11.11%	12	4
3	72.77%	27.23%	20.63%	49.12%	90.53%	3.46%	11	9
4	80.13%	19.87%	Never	Never	95.08%	5.17%	2	2
5	77.19%	22.81%	66.67%	3.08%	97.67%	2.15%	4	4
6	95.77%	4.23%	Never	66.67%	0.00%	1.45%	3	2
7	98.65%	1.35%	66.67%	39.62%	100.00%	0.00%	8	5
8	49.24%	50.76%	Never	97.83%	0.00%	0.00%	3	1
9	89.55%	10.45%	0.00%	98.53%	100.00%	32.14%	6	5
10	88.79%	11.21%	37.37%	88.00%	0.00%	1.59%	7	5
11	49.77%	50.23%	34.78%	57.69%	86.08%	5.98%	11	6
Average	77.10%	22.90%	28.94%	63.28%	85.62%	3.89%	8	5

EVs driven and parked at the drivers' homes were recharged only 29% of the 463 times parked. EVs at the various known businesses locations were recharged 63% of the 806 times parked and those parking at charging stations charged 86% of the times 438 parked. EVs were parked at 2,058 different unknown locations and charged at those locations 4% of the times parked. On 77% of an EV's total parking time occurred in 8 different known locations and 49% of charging cases occurred in five different known locations.

Table 4 shows that for all the EVs in the trial, 96% of charges took place in each EVs top three locations, with on average 86% of charging taking place in one location for each EV. This can be interpreted as the EVs having one primary charging location where the majority of power is consumed.

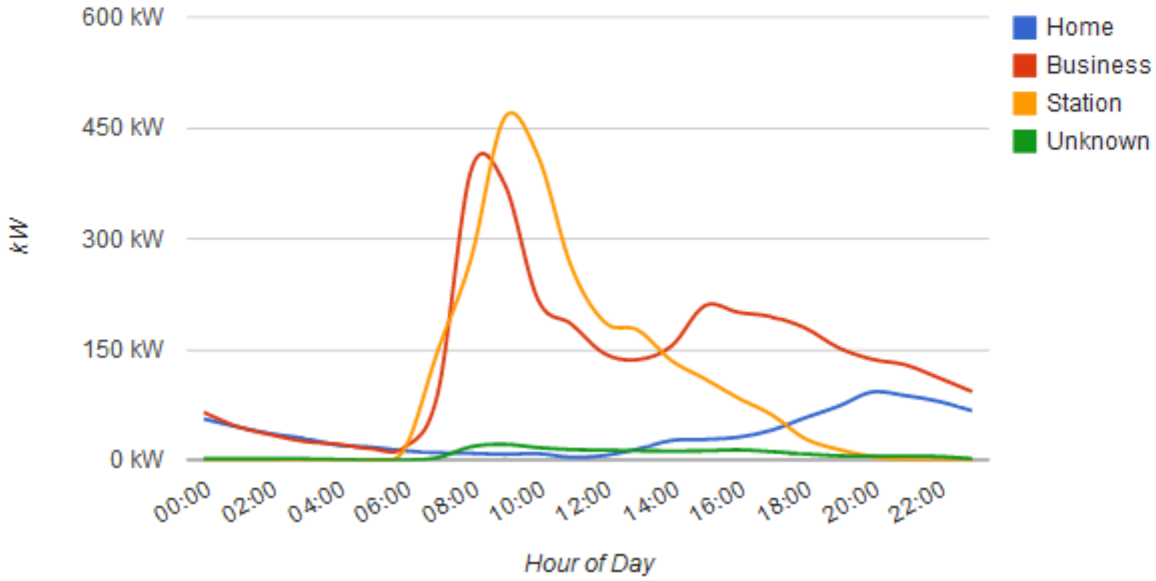
Table 5: Percentage of total charging energy (kWh) provided by top three used stations for each EV (accumulated over six months, each EV has different locations)

Vehicle	1	2	3	4	5	6	7	8	9	10	11	AVG
Location 1	73%	94%	56%	99%	100%	100%	82%	100%	89%	67%	83%	86%
Location 2	*8%*	*5%*	*15%*	1%	*0%*	*0%*	13%	0%	*7%*	28%	6%	8%
Location 3	5%	1%	13%	0%	0%	0%	2%	0%	3%	*2%*	*5%*	3%
Total of 3	87%	100%	84%	100%	100%	100%	98%	100%	99%	98%	93%	96%

4.1 Charging Power

The power (kilowatts) drawn by the electric vehicles over time of day are shown in Figure 4. The station and business charging power peaks at 8am and 9am as the electric vehicles are driven from the business the previous day, then returning the next morning and parked to charge for the total distance. At 3pm business power usage also spikes as the EV's are returned back to the businesses. At 8pm the home charging peaks as the vehicles are driven home to slow charge, and the power used slowly reduces throughout the night until the next morning. The business and station charging patterns is similar to the workplace charge load done simulated by Weiller (2011). Other simulations performed by Ashtari et al. (2012), Clement-Nyns et al. (2010), EPRI (2007) and Shahidinejad et al. (2012) use home charging profiles that don't reflect the results from the trial, where vehicles charge predominantly at business and stations (78% of charges).

Figure 7: EV charging distribution over day-time (accumulated over six months)



6 Conclusion

The early results from the EV charging gained from both the WA Electric Vehicle Trial and the ARC Linkage Project at UWA on EV Charging indicate that despite the initial concerns that electric utilities that EV charging will create a new demand peak in the early evening hours, this based on the results of this trial this appears to be highly unlikely in the case for fleet vehicles at least. The typical fleet car usage pattern has a charging in the mid-morning with a lower rate in the early afternoon hours. This almost exactly matches a solar photovoltaic (PV) pattern, so fleet EVs could ideally be offset by local solar PV systems.

The EV's charge primarily at one location (86%) and additional charging locations are not normally used as vehicles with a range of 130km can easily manage the maximum daily average of a trial EV, 48.53km, leaving and returning to their primary charging location. This is especially evident in that the EV drivers would only charge their vehicles 29% of the times parked at home, and only spend 23% of their time parking in unknown locations. Also in only 16% of charges had an EV travelled further than 60km, which is less than half of the vehicles range. It would appear that investment in additional level 1 or level 2 charging points outside of the primary charging location is unnecessary as it may not be fully utilised with a small number of active fleet vehicles.

When the vehicles use a business or stations as a primary location the peak power usage for the vehicles occurs between 8am and 11am with business having another peak at 4pm. The vehicles travelled mostly during the day with the distance peaking in the morning at 7am to 8am and in the afternoon between 5pm and 6pm, a pattern that is similar to Melbourne and overseas driving patterns. The similarity in the driving patterns of EV's and other passenger vehicles has shown that other research simulations of business charging can present accurate charging profiles.

In this trial the vehicles were only equipped for level 1 and level 2 charging points, and didn't fully utilise the level 2 infrastructure. Vehicles with fast DC charging capability, using connectors such as the IEC COMBO standard, to allow for fast-charging up to 50kW, and COMBO stations should be investigated in the future.

As the initial EV market over the next half decade is expected to be heavily biased towards the fleet market, these findings are even more important.

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