

An Empirical Assessment of the Feasibility of Battery Electric Vehicles for Day-to-Day Driving

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Abstract

Driven by sustainability objectives, Australia is considering the option of battery electric vehicles (BEVs). In addition to issues of capital and running costs, crucial questions remain over the specifications of such vehicles, particularly the required driving range, recharge time, re-charging infrastructure, and performance. This paper assesses (hypothetically) the extent to which current car travel needs could be met by BEVs for a sample of motorists in Sydney assuming a home-based charging set-up. Five weeks of driving data recorded by GPS technology are used to build up home-home tours to assess the distances between (in effect) charging possibilities. An energy consumption model based on characteristics of the vehicle, and the GPS speeds is adapted to determine the charge used, while a battery recharge model is used to determine recharging times based on the current battery level. Among the most pertinent findings are that over the five weeks, i) BEVs with a range as low as 60km would be able to accommodate well over 90% of day-to-day driving, ii) the incidence of running out of charge increases markedly for vehicles below 24 kWh (170 km range), iii) recharge time in itself has little impact on the feasibility of BEVs because vehicles spend the majority of their time parked and iv) while unsuitable for long, high-speed journeys without some external re-charging options, BEVs appear suited for the majority of day-to-day city driving where average journey speeds of 34 km/h are close to optimal in terms of maximising vehicle range.

Keywords: Electric vehicles; GPS Data;

1. Introduction

Driven by sustainability objectives, Australia like many nations in the developed and emerging world, is considering the option of electric vehicles (BEVs) as an alternative to conventional internal combustion engine vehicles (ICEVs). BEVs aimed at the passenger market became available from 2012, including the Mitsubishi iMieV, Nissan Leaf and Holden (Chevrolet) Volt. This has been slowly accompanied by auxiliary services including (limited) re-charging infrastructure and battery replacement services. The high initial price differential between BEVs and their ICE equivalents (currently around two and a half times higher) has seen initial uptake limited to niche applications and some fleet vehicles. However, it is anticipated that this price differential will come down over time making BEVs a more attractive option to the general motoring consumer.

Capital costs aside, BEVs face many questions/concerns over the extent to which they will/will not meet mobility requirements compared to ICEVs. The BEVs aimed at the passenger market in Australia, have a substantially lower driving range¹, need to be re-charged (re-fuelled) more frequently, take much longer to re-charge (hours versus minutes), and lack the re-charging infrastructure of their ICEV equivalents. Coupled with this are additional questions about the extent to which range/performance might be impacted by both where a vehicle is driven (e.g., particular terrains) and how it is driven (e.g., speeds, accelerations/decelerations etc). In Australia, it is probable that the first BEV owners will most likely have to cope with re-charging facilities being located only at the home location (or in the case of fleet vehicles at the fleet base) with some very limited charging station options. Therefore the feasibility of these vehicles will largely depend on the available re-charging time (i.e., the time the vehicle is parked at the home/base location), the driving range (i.e., home-to-home tour lengths) and how the vehicles are operated, primarily related to speed.

With this in mind, the current paper assesses the extent to which existing ICEV-based mobility patterns could be maintained if (hypothetically) users switched to a BEV with a home-based charging set-up for several weeks. Key to the analysis is empirical information on driving behaviour collected over several weeks, from which it is possible to discern intra- and inter-driver variability in daily driving ranges, time spent at home and vehicle speeds. In 2009, a five-week study of driving behaviour was conducted in which 166 vehicles were equipped with a Global Positioning System (GPS) device as part of a major investigation into driving behaviour in Sydney, Australia (see Greaves et al. 2010). An energy consumption model based on characteristics of the vehicle, and the speeds recorded by the GPS is adapted to determine the energy/charge used, while a battery recharge model is used to determine re-charging times based on the current battery level. The models are used to simulate BEV feasibility under a variety of range, re-charging and driving scenarios before drawing conclusions as to the suitability of BEVs for day-to-day driving and future implications.

2. Literature Review

While much has been written recently about BEVs (see for example, Albrecht et al. 2009) the focus of this paper and hence this review is on the potential for BEVs to satisfy current driving demand. Other than price, the main concerns about BEVs concern limited vehicle range and re-charging opportunities compared to their petrol counterparts (AECOM, 2011).

¹ Current BEV ranges are between 80-180 km although there are a few high-end models capable of travelling much further.

For instance, the two passenger sedans currently available in Australia, the Mitsubishi iMieV and the Nissan Leaf, have indicative ranges of 130 km and 170 km respectively², with recharge times of four to seven hours based on a conventional 'plug-in-the-wall' of 240 Volts. This range is around one-third of their petrol-equivalents, while the re-charging time is hours compared to minutes when refuelling at a petrol station.

While these comparisons do not look favourable for BEVs, arguably the key question that should be asked is how much of a barrier does this actually present to maintaining existing driving habits? The evidence to-date suggests that the majority of day-to-day city driving could be met with BEVs with a range of less than the Mitsubishi iMieV. For instance, recent evidence from Australia suggests that a BEV with 100 km range would be sufficient to cover 85-90% of daily car travel in Sydney and 95-99% in Adelaide (Taylor et al. 2010). Similar conclusions are drawn in studies conducted in New Zealand (Duke et al. 2009) and the United States (Gondor et al. 2007).

While this appears to be a favourable outcome for BEVs, these findings have typically been based on self-reported travel information, often collected for one or two days (Taylor et al. 2010). Researchers have been quick to point out the problems with relying on such snapshots of travel as indicators of potential suitability for BEVs, because this may not capture variations in driving behaviour over time, which may ultimately influence the vehicle purchase decision (Pearre et al. 2011). As a consequence, facilitated through technological developments enabling automated monitoring of travel, there has been interest in using longitudinal travel data to assess BEV feasibility. For instance, Christensen et al. (2010) assess the feasibility of switching to BEVs in Copenhagen, Denmark using GPS-information collected over one month from 360 vehicles. Based on an assumed BEV range of 180 km, they conclude that around 20 percent of vehicles would have run out of charge over the one month period. More recently, Pearre et al. (2011) use GPS-based driving information collected over one year in Atlanta from 484 vehicles to identify those drivers for whom a limited range vehicle would meet daily needs versus those who would need some adaptation. They conclude a vehicle of 150 miles range would meet the needs of 21% of the sample all the time, 35% of the sample all but two days/year, and 60% all but six days/year. Interestingly, they also consider the impacts on electricity load associated with evening-time charging and conclude effects would be less problematic than previously believed due to the widespread times that people return home.

Similar to the Copenhagen and Atlanta examples, this study takes advantage of a longitudinal GPS-based survey of driving behaviour to assess BEV suitability. However, rather than simply using distance as a proxy for range and dwell/parking time for re-charging time, this paper simulates the battery charge level over time using energy consumption and re-charging models. This enables greater reality to be injected into understanding how BEVs might perform under different battery ranges, re-charging options and driving styles. In addition, it adds to the empirical evidence about suitable range and re-charging requirements for BEVs that will inform both manufacturers and policy-makers.

3. Study Methods

² BEV ranges are established using a standard electric vehicle driving cycle known as UN ECE Regulation 101 and Australian Design Rule 81/02. This driving cycle may not reflect actual driving conditions (Taylor et al. 2010).

The approach involved taking information on actual driving patterns collected using GPS technology and assessing to what extent these would/would not have been possible assuming various BEV configurations based around range and re-charging times. The GPS data included second-by-second information on time, latitude, longitude and velocity from which it was possible to infer trip start and end times, activity/stop locations, distances (kilometres), and speeds associated with each trip. In turn, individual trips were aggregated to create tours that originated from and ended at the home location of the study participant to reflect the opportunity to re-charge under the hypothetical scenarios considered here. An energy consumption/discharge model was used to estimate the amount of energy consumed during each tour based on distance, speeds, and auxiliary power requirements. A battery recharge model was then used to compute the state of charge of the vehicle based on the charge after the previous tour and the amount of time the vehicle was parked at home before undertaking the next tour – note, it was assumed that re-charging would occur if the vehicle was parked at the home location for more than 60 minutes. Where the available state of charge of the battery was not sufficient for the next tour, this indicated a tour that would not have been feasible using a BEV of that particular configuration.

Each of these components, the GPS driving data, the energy consumption model, and the re-charge model are now detailed.

3.1 The GPS Driving Data

The GPS data were originally collected for a longitudinal study of driving behaviour in Sydney assessing behavioural change to a financial intervention (Greaves, 2010). Briefly, the study comprised a five-week ‘before’ period in which motorists took an in-vehicle GPS device to monitor their driving patterns followed by a five-week ‘after’ period in which driving patterns were monitored following imposition of a charging regime. The analysis presented here uses data for the 166 vehicles that completed the five-week ‘before’ period.

In line with the objectives of the original data collection, study participants were all drawn from households with only one car and were located in six suburban hubs of the Sydney metropolitan area. To provide some indication of how representative the data were of Sydney driving in general, the GPS-derived car driver distances were compared to the aforementioned Sydney Household Travel Survey (SHTS) as reported in Taylor et al. (2010). Note, for the purposes of this comparison, weekday daily car driver distances were required. Table 1 suggests that while average VKT is broadly comparable, the GPS data includes a higher proportion of shorter tours than the SHTS. While this may be down to some genuine differences in car travel for the GPS-sample and non-genuine no-travel days in the GPS data, it is also likely to be due to the known problem of under-reporting of shorter duration trips from diary surveys (Stopher and Greaves, 2009).

Table 1: Comparison of Weekday Car Driver Distances for GPS Data Compared to Sydney Household Travel Survey Data (Taylor et al. 2010)

Percentile	SHTS (km)	GPS Driving Data (km)
50 th	36	30
85 th	91	69
90 th	113	83
95 th	157	111
99 th	270	256

3.2 Energy Consumption/Discharge Model

The energy consumption of a vehicle is largely dependent on the characteristics of the vehicle (mass, size, types of tyres etc), environmental factors (road, weather) and how it is driven (speeds, accelerations). For the purposes of this study, a simple relationship applied by Duke et al. (2009) for calculating the energy requirements of an ICEV vehicle (which they applied to a BEV) travelling at a constant velocity was used:

$$P_C = \frac{C_d A \rho v^3}{2} + mgRRv \quad (1)$$

Where P_C is the power (W), C_d is the drag coefficient, A is the frontal area (m^2), ρ is the air density (kg/m^3), v is the velocity (m/s), m is the mass of the vehicle (kg), g is gravity (m/s^2) and RR is the rolling resistance. Duke et al. (2009) also provide ranges of typical ICEV values for each parameter (Table 2), which together with information on currently available BEVs in the market-place formed the basis for the 'model values' used in the current study³.

Table 2: Parameter values used in the discharge model

Parameter	Symbol	Value range	Model value
Drag coefficient	C_d	0.3 - 0.4	0.35
Frontal area	A	2.3 m^2	2.3 m^2
Air density	ρ	1.2 kg/m^3	1.2 kg/m^3
Mass of the vehicle	M	1,150 - 1,910 kg	1,600 kg
Gravity	g	9.81 m/s^2	9.81 m/s^2
Rolling resistance	RR	0.010 - 0.020	0.015

*Source of value range: Duke M., Andrews D. and Anderson T (2009). *The feasibility of long range battery electric cars in New Zealand. Energy Policy*, vol. 37, pp. 3455-3462.

To validate the selection of parameters, energy consumption was calculated for the UN ECE Regulation 101 test driving cycles (UN ECE R101, p.51) using the constant speed method and then compared with the driving range of the BEV model (see Figure 1). For the purposes of the validation, parameters broadly representing a Nissan Leaf, which uses a 24 kWh battery with a driving range of around 170 km/h, were used. In essence this is verifying that if participants are assumed to drive in the same way as the test driving cycle, the constant speed approach should calculate the energy consumption such that the battery will last for the estimated driving range. This was done to set the base point for energy consumption and then if a participant used higher or lower speeds, the constant speed method would calculate the differences in energy consumption accordingly. In addition to the energy used for propulsion, modern vehicles use energy for various electrical accessories, such as car lights, stereo systems, on-board computers, air conditioning, heating etc. Another source of additional energy consumption is the battery-to-wheel efficiency, which refers to the power losses between the energy that is drawn from the battery and the energy that goes into

³ BEVs are substantially heavier than their ICEV equivalent because of the battery. For instance, the Nissan Leaf weighs 1,600 kg compared to the 1,140 kg Nissan Tiida, a similar-model ICEV.

moving the vehicle forwards. For the current study, a constant discharge rate of 500 W was used for accessories and a battery-to-wheel efficiency of 90% applied, based on evidence from the literature (Duke et al. 2009).

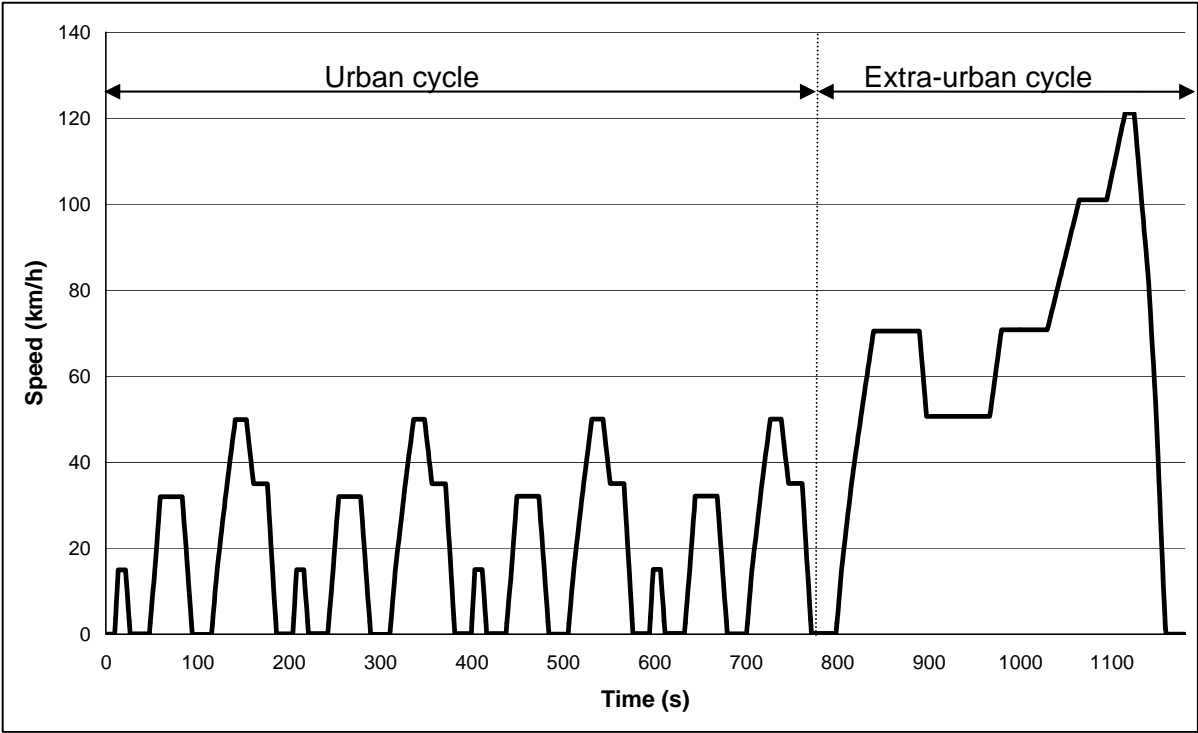


Figure 1: The UN ECE R101 test cycle

Based on these assumptions, the energy consumption calculation for the UN ECE R101 test cycles was made. After combining the energy consumption and the travelled distance, the estimated driving range was calculated. The results, shown in Table 3, matched the BEV model range well so it can be assumed that this discharge model would give good estimates of how much energy is consumed when driving at different speeds. It is interesting to note, that the energy consumption per kilometre is much greater for the extra-urban component (around 0.158 kWh/km) than the urban component (around 0.114 kWh/km). Given the majority of driving from the GPS study was in urban conditions, an *a priori* expectation was that the estimated driving range would be closer to that of the ‘urban cycle’ component than overall.

Table 3: Comparison of the constant speed method with the UN ECE R101 test cycles

	Four Urban Cycles	Extra Urban Cycle	Overall
Energy Consumption (kWh)	0.46	1.11	1.58
Distance (km)	4.07	7.02	11.08
Time (seconds)	780	400	1,180
Average Speed (km/h)	18.76	63.17	33.82
Energy per km (kWh/km)	0.114	0.158	0.142
Est. Driving Range (km)	210.0	151.7	168.9
BEV model range (km)			170

Using this discharge model it is possible to model the differences in power consumption due to speed. Figure 2 graphs the relationship between speed and power consumption per distance travelled. Evidently the 'optimal' speed for energy consumption/km is around 30 km/h but increases exponentially as speeds go higher. Travelling at very low speeds on the other hand makes the constant discharge from car accessories a relatively more important factor implying the energy consumption per distance grows again. In many ways the pattern is strikingly similar to conventional petrol-fuelled cars.

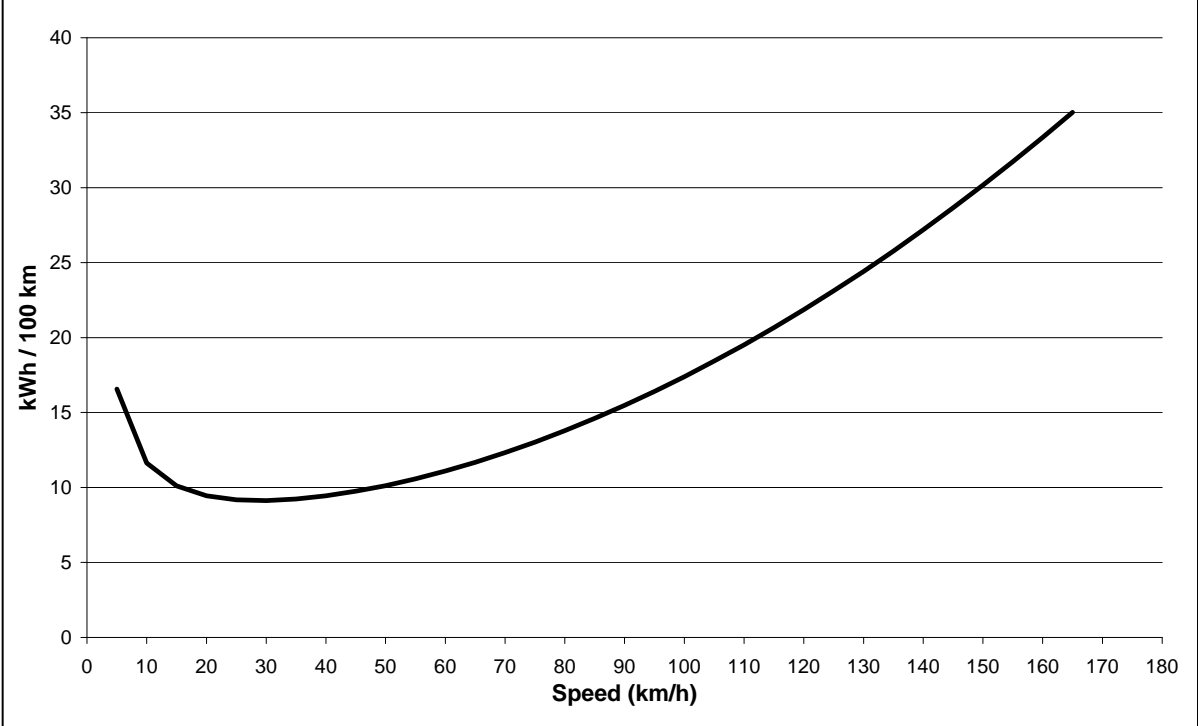


Figure 2: Impact of Driving Speed on Energy Consumption

3.3 Recharge Model

Recharging time of BEVs is complex and depends on the capacity of the battery, the age of the battery, how many times it has been charged, the pre-existing charge, the electricity voltage, and environmental factors (temperature in particular). In Australia, electricity is supplied at 240-volts, enabling a car to receive 240 volts at 30 amps (6.6 kWh/hour) implying a 24 kW vehicle should be rechargeable in under four hours. However, typical recharging recommends charging up to some level (e.g., 80 percent) and then cutting back on the charge to avoid battery overheating⁴ so around 6-7 hours is more reasonable/realistic.

There are two implications of this. First, battery re-charging is a highly non-linear process with the highest charging rates at the lowest charge. Second, the higher the pre-existing charge, the quicker the time to reach capacity – of course this assumes the vehicle is not unplugged during a charge and then immediately plugged in again. For the purposes of the current study, a simple exponential re-charging function for BEVs proposed by Garcia-Valle and Vlachogiannis (2009) was adapted:

⁴ auto.howstuffworks.com/electric-car5.htm.

$$P_{EV}(t) = P_{EV,max} \cdot (1 - e^{-\alpha/t_{max}}) + P_{EV,0}$$

where $P_{EV,0}$ is the current battery status (kWh), $P_{EV,max}$ is the maximum battery capacity (kWh), t_{max} is the maximum charging time (h) and the parameter value α can be used to fit the curve to the recharge time.

For this recharge model the effect of a lithium-ion battery taking 80 percent of its total charge during the first third of the charging time was assumed. The parameter α was calculated as 4.83. The functional form of the charging status is shown in Figure 3: Recharging Function Figure 3 for a seven hour charge, reflective of a recharge for a Nissan Leaf.

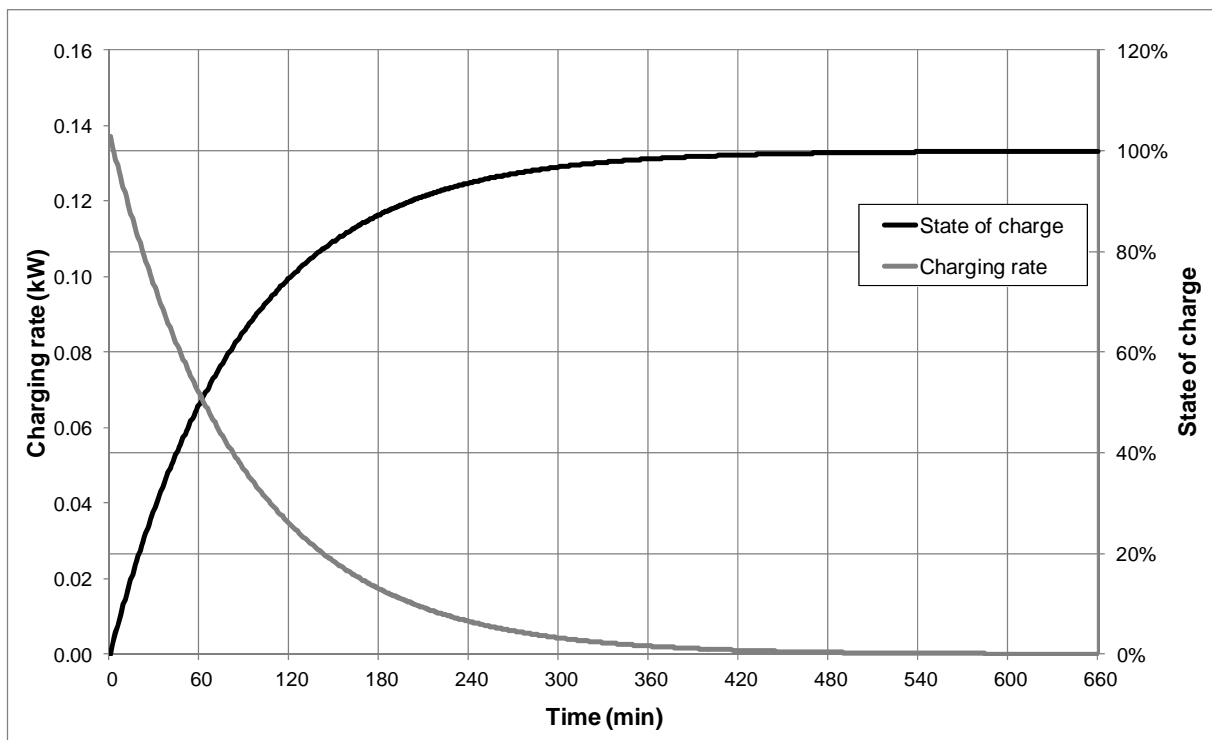


Figure 3: Recharging Function

3.4 Scenarios

A range of scenarios were investigated to determine the impacts of range and recharging time on the tour feasibility. In terms of vehicles, six scenarios were considered in which the battery capacity was varied from 8 kWh – 26 kWh, approximating a driving range of 60-255 km. In terms of recharging time, three scenarios were considered: a 7-hour standard charge, a 3-hour augmented charge, and a 1-hour fast-charge.

4. Results

In total, the 166 participants made 8,280 home-home tours over the five week monitoring period, an average of 1.43 tours/day. The average tour was 24 kilometres in length taking 43 minutes at an average speed of 34 km/h while the average time between tours was over ten hours. While averages are of interest, it is the distribution of tour distances and time between tours that is of most relevance here, because this gives some initial sense of what proportion

of tours might/might not be feasible under various range/charging scenarios. Figure 4 shows the distribution of tour distances and time parked at home between tours. In terms of tour distances, only 611 (7%) of tours exceed the lowest range BEV being assessed here of 60km, while less than 1% exceed the 170 km range of the Nissan Leaf. In terms of the time between tours, around half the tours were separated by more than 7 hours, the most conservative scenario for re-charging, while 20% of tours had less than one hour for recharging. This suggests the vast majority of tours should be possible with a BEV of even lower ranges than currently being considered for the Australian market, but recharging time could be an issue.

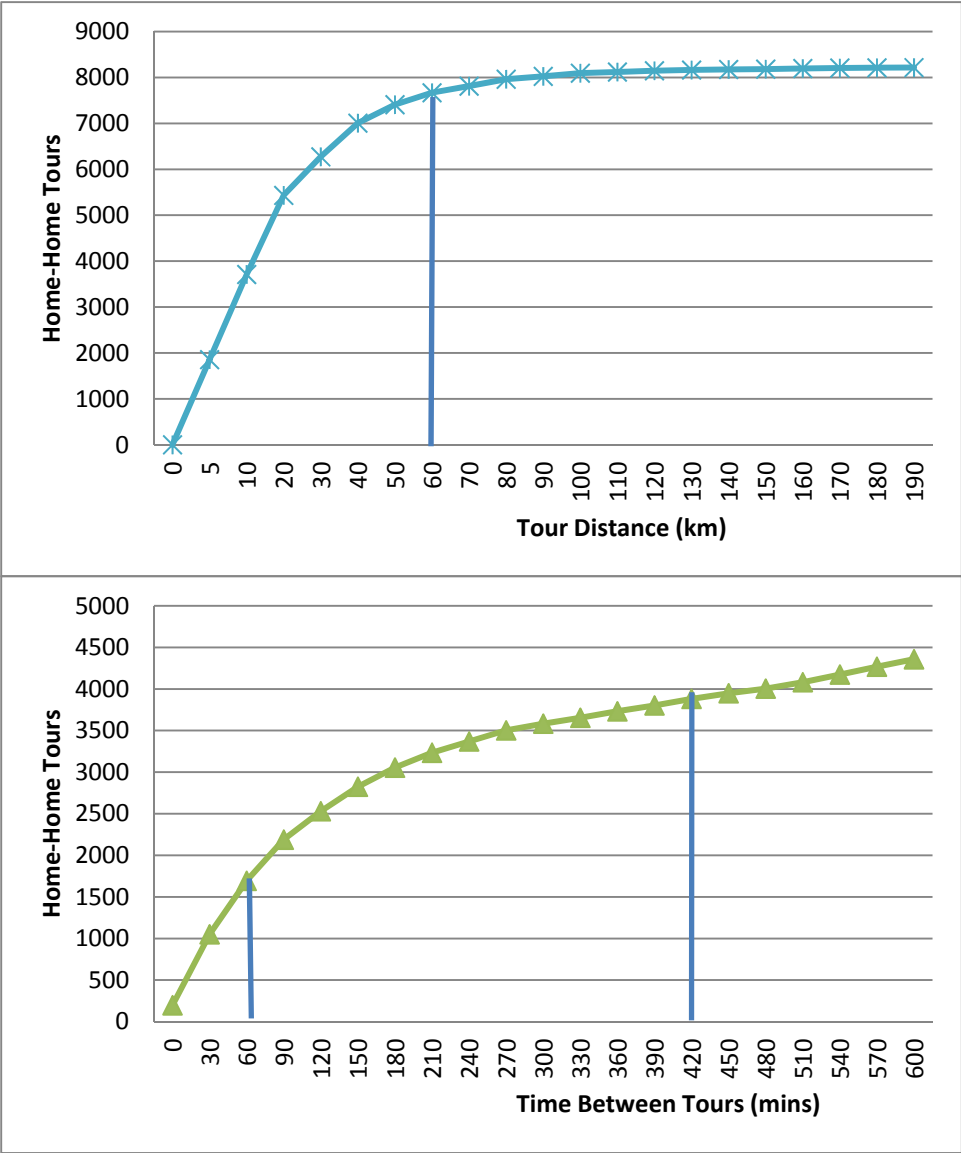


Figure 4: Distribution of Home-Home Tour Distances and Time Between Tours

Tour distance (mean = 24.2km, median = 11.7km, standard deviation = 54.2 km); time between tours (mean = 622.9 mins, median = 530.5 mins, standard deviation = 810.9 mins)

4.1 Vehicle Range

Applying the energy consumption and battery recharge model to the GPS driving data, results shown in Table 4 suggest 807 (around 10%) of tours would not have been possible even for the lowest range (60 km) vehicle considered. At the other extreme, less than 1% of tours would not have been possible for the highest range vehicle. However, when viewed in terms of the number of participants that would have run out of charge at some point over the five weeks a different story emerges. In this case, 123 (almost three-quarters of) participants would have run out of charge with the lowest range vehicle, while over 20% of participants would have run out of charge with the highest range vehicle.

Table 4: Participants and Tours Running Out of Charge Over the Five Weeks

Vehicle Characteristics		Recharge Time (hours)		
Battery capacity (kWh)	Estimated driving range (km)	7	3	1
8	60	123 (807)*	122 (792)	123 (799)
12	85	87 (394)	86 (388)	87 (391)
18	130	63 (202)	62 (196)	62 (202)
24	170	52 (129)	52 (127)	52 (127)
30	210	43 (89)	41 (85)	41 (84)
36	255	37 (73)	35 (69)	36 (70)

Participants (Tours)

Figure 5 presents further insights into this issue by assessing the frequency with which participants who ran out of charge at some point actually did so. Evidently, the lower-range vehicles would be unviable without some out-of-home charging option, for a sizeable proportion of motorists – 28% would have run out of charge at least once/week for the 60km vehicle. Even with the highest range vehicles, a small proportion of participants would still be running out of charge on a frequent basis – 10% would have run out of charge at least twice for the 255km vehicle. In reality, it is unlikely BEVs would be used for long-distance travel, reducing further the number of infeasible tours.

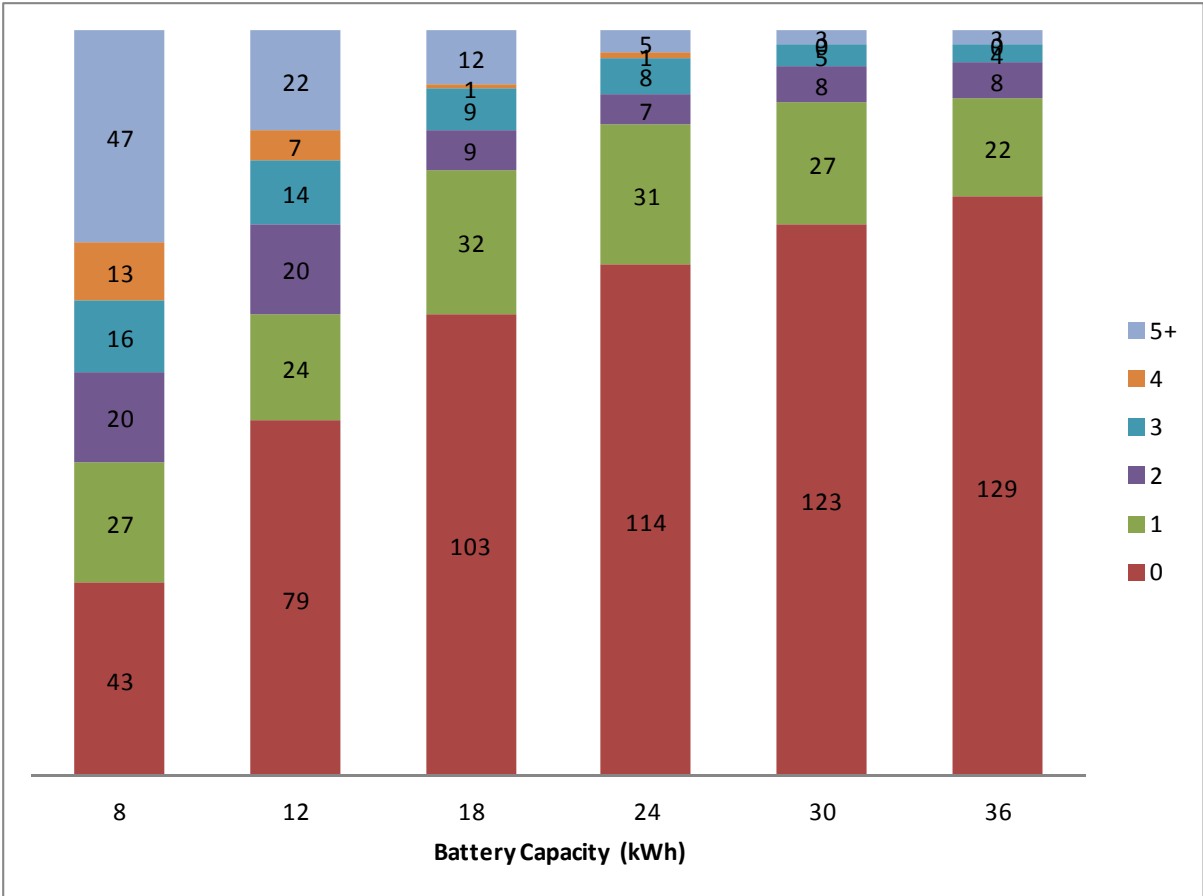


Figure 5: Frequency of Running Out of Charge

4.2 Recharge Time

Perhaps surprisingly given the earlier information in Figure 4, the results in Table 4 suggest that available recharge time in itself appears to have little discernible impact on the feasibility of tours. The reasons for this are that unless participants went out of town, there was generally a sufficient amount of time over the day when the vehicle was parked at home to re-charge the vehicle. In fact, the majority of tours were made on a fully charged vehicle even for the lowest range vehicle (52%) increasing to 70% for the highest range vehicle. Given we were also assuming people would re-charge if they had more than an hour parked at home and a vehicle takes on most of its charge in the first third of charging time, the implications were that many tours were possible on partly charged vehicles. Relaxing this assumption made a marginal difference – for instance for the 170 km range vehicle, assuming people would only re-charge if they had at least two hours parked at home increased the number of participants running out of charge increased from 52 to 54 and the number of tours from 129 to 154.

4.3 Driving Conditions and Style

The average energy consumption across participants was 0.128 kWh/km, which was around 10% lower than the test cycle discussed in Section 3.2. In practical terms, this meant, for instance, that the 24kWh vehicle (aka the Nissan Leaf) had an effective range of almost 190 km rather than 170 km. This was as expected because the majority of driving was in urban conditions and the average speed was 34 km/h, close to the 'optimal' speed for BEVs depicted in Figure 2.

While averages are useful, of more interest is how the variability of range was impacted under actual driving conditions, particularly driving speed. Ignoring trips below the range of the test cycle, 11 km, Figure 6 shows the relationship between average tour speed⁵ and effective range for the 24 kWh vehicle ($r = -0.7$). Arguably, the most striking fact is that the effective range varied so markedly from 118 km to 240 km depending on driving speed. The lower ranges were generally associated with very high tour speeds, which in turn were linked with longer journeys on higher-speed roads, compounding the effects of longer distance travel on battery consumption. Around 90% of trips exceeded the 170 km range specification, with 20% of trips exceeding the urban range of 210 km. This suggests that urban journey speeds (at least in Sydney) are generally more optimal for BEV range, than those being used in the standard test cycle.

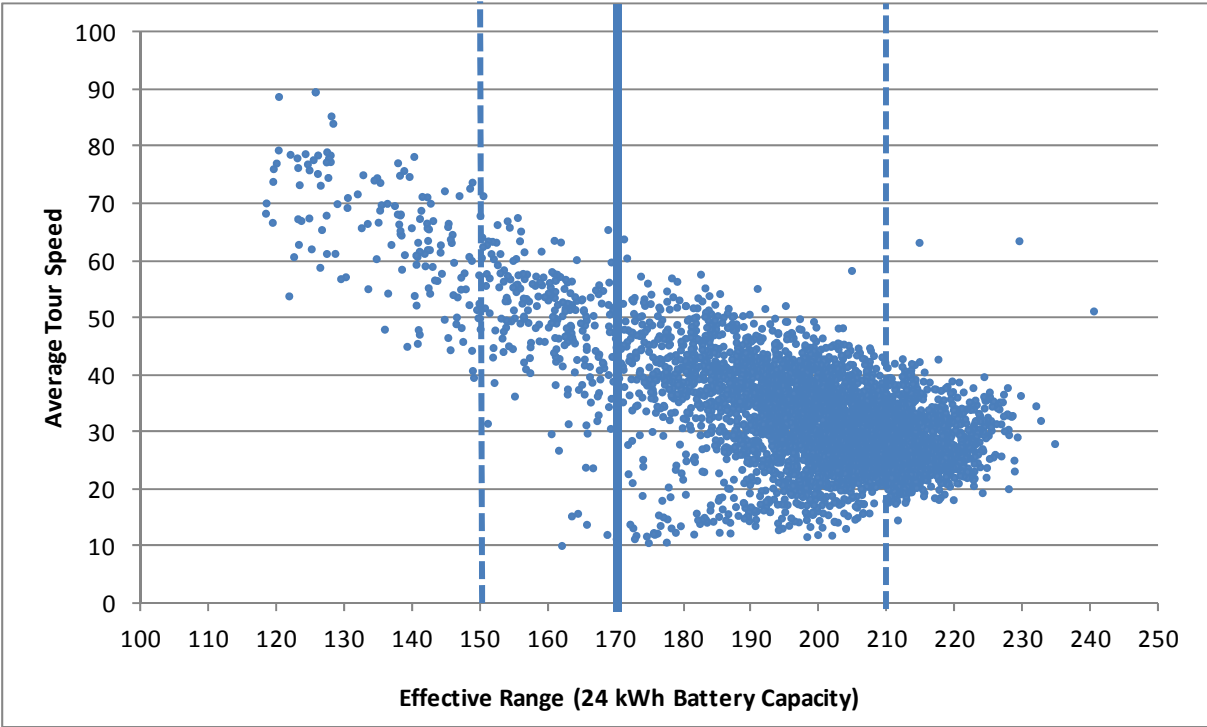


Figure 6: Relationship Between Effective Vehicle Range and Average Tour Speed

In addition, to speed, the other main factor impacting range is the use of auxiliaries such as lights, heaters etc. While detailed information on power-drain is clearly needed, the issue here is simply to demonstrate the impact of this (often overlooked) component of BEV performance by varying the assumption about the constant discharge rate. The current test

⁵ Obviously this reflects the distribution of speeds, but for the sake of this analysis, average tour speed is used as a proxy.

cycle assumes 500 W/hour is used for accessories. If this is doubled, the effective range is reduced by around 10%, which for the Nissan Leaf would lower the range to 153 km. The net effect of this would be to increase the number of participants running out of charge at some point from 52 to 56 and the number of infeasible tours from 129 to 134.

5 Discussion

While the results will differ depending on the travel patterns of the particular application context, it is never-the-less important to place the findings here in a broader context. In the closest parallel to what was done here, Christensen et.al, (2010) investigated the feasibility of different BEV configurations in Copenhagen, Denmark, using GPS data collected over one month from 360 drivers from one-vehicle households. Unlike the study here, they did not use a battery re-charging model, instead assuming the vehicle was fully charged at the beginning of the day, and they did not include the effects of speed on range. They also computed the number of days for which a vehicle ran out of charge, whereas in this study, it was the number of tours – it was possible for a vehicle in this study to require additional capacity more than once during one day if two long tours were made on the same day, but this was a very rare situation. With these differences in mind, Figure 7, presents a comparison of the number of days/times tours ran out for this study superimposed on results provided by Christensen et.al, (2010) for a configuration approximating a Nissan Leaf. The pattern is remarkably similar and holds for other vehicle range comparisons (figures not shown). Clearly, the longer the duration, the more likely a driver will make trip(s) that exceed the available range. For instance, the Atlanta study, which had a year’s worth of data found that only 10% of drivers with a vehicle of 100 mph (160 km) range could have met all their needs.

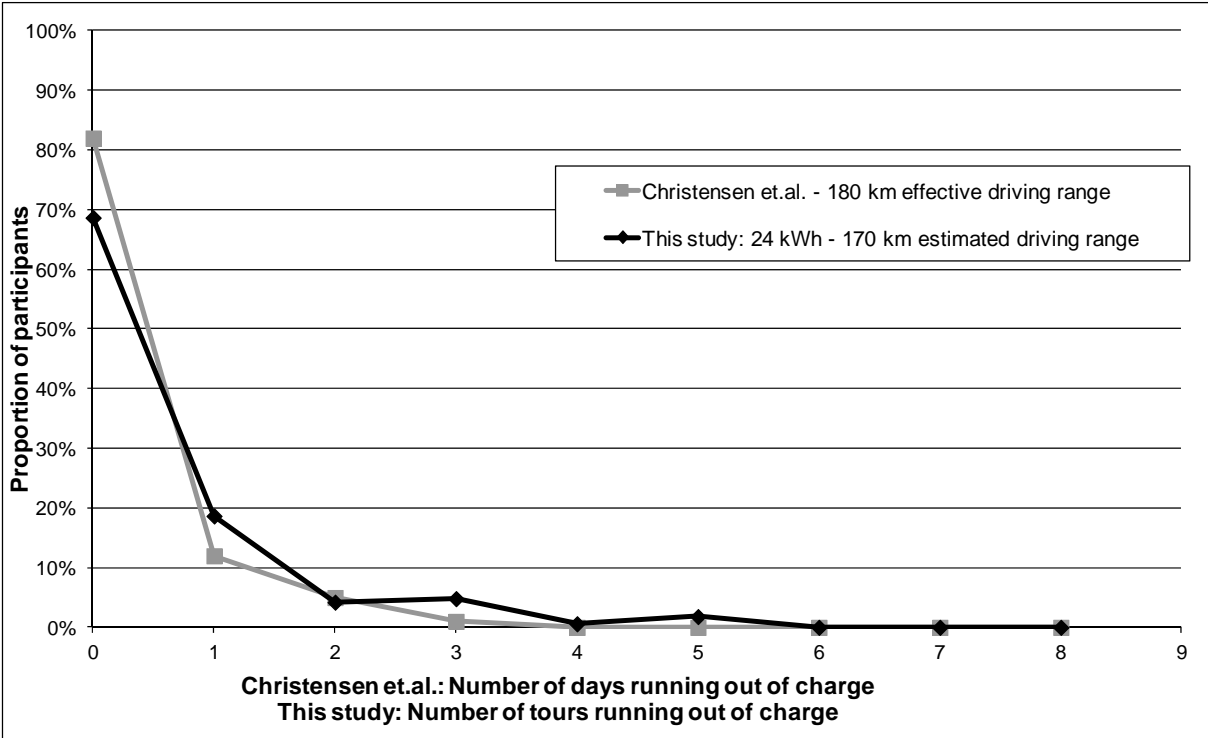


Figure 7: Comparison with Copenhagen Results from Christensen et al., (2010)

Given the difficulty and expense of collecting longitudinal data travel, this raises the question of an appropriate time-period over which travel should be monitored to assess BEV requirements. Relying on one or two days is clearly problematic, because it does not capture

the frequency with which drivers run out of charge over time, which seems essential in assessing likely uptake of BEVs. A year may be ideal because it captures seasonal differences and is more likely to capture infrequent, long trips (Pearre et al. 2011). However, it is our belief that BEVs are not likely to serve the long-distance, infrequent passenger market and as such it is of more value to capture the variation in day-to-day travel to truly assess BEV needs, which can be done with 4-5 weeks of travel as done here and Copenhagen.

A second question raised by this study is charging infrastructure requirements, which again has been put forward as integral to encouraging BEV uptake. The empirical findings presented here suggest that a simple plug-in-the-wall home-charging option will satisfy the vast majority of consumer needs and little will be gained by expediting the charge, which requires purchase of more expensive equipment. A bigger barrier is likely to be the practicalities of home-charging, which requires easy access to an electricity outlet, something most amenable to being parked in a garage. Ironically, several factors are working against this (at least in Australia) resulting in relatively fewer vehicles being garaged – increasing residential density and vehicle ownership, larger vehicles, garages used for other purposes etc.

A third issue that has been raised by this analysis is the validity of using standardised driving-cycles to assess BEV range. Such drive-cycles are designed to capture an average/typical trip, but it has been argued for many years that this is inappropriate for assessments of petrol-based vehicles, where the context has been better vehicle emissions estimates, because of the heterogeneity in real-world driving (Zito, 2004). We have shown here that it needs re-visiting for assessing BEV range, an issue of extreme importance for manufacturers and consumers alike. Specifically, it appears that BEVs may be even more suited to urban driving conditions, because network speeds are in the optimal range for performance. Clearly, this assertion needs to be tested further.

6 Conclusions

This paper provides a hypothetical assessment of the extent to which current car travel needs could be met by electric vehicles in Sydney assuming a home-based re-charging set-up. Taking advantage of a several weeks of detailed driving information collected using GPS technology, the paper develops energy consumption and re-charging models designed to inject greater reality into understanding how BEVs might perform under different battery ranges, re-charging options and driving styles. Among the most pertinent findings are over the five weeks, i) BEVs with a range as low as 60km and a simple home-charge set-up would be able to accommodate well over 90% of day-to-day driving, ii) however the incidence of running out of charge increases markedly for vehicles below 24 kWh (170 km range), iii) recharge time in itself has little impact on the feasibility of BEVs because vehicles spend the majority of their time parked and iv) while unsuitable for long, high-speed journeys without some external re-charging options, BEVs appear particularly suited for the majority of day-to-day city driving where average journey speeds of 34 km/h are close to optimal in terms of maximising vehicle range.

There are of course acknowledged limitations to this analysis. First, we have assumed similar configurations of vehicles other than the battery size – this could be improved by using the actual manufacturer specifications. Second, the assumptions about the battery re-charge model may be quite optimistic, but given the aforementioned conclusions about

recharge time are unlikely to make a substantial difference. Third, we have only assumed people will re-charge at home – in reality there could be re-charging opportunities at certain destinations, which would obviously reduce the number of infeasible tours. Finally, in replacing current vehicular travel with a BEV configuration, we have assumed a like-for-like substitution. In reality, people may adapt their driving behaviour, potentially using a BEV for their day-to-day urban driving and other options for longer, infrequent trips including short-term rentals or car-sharing.

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