Transportation Research Part A 66 (2014) 226–237

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

An empirical assessment of the feasibility of battery electric vehicles for day-to-day driving

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ARTICLE INFO

Article history:
Received 23 August 2013
Received in revised form 21 May 2014
Accepted 23 May 2014

Keywords:
Battery electric vehicles
Global positioning system data

ABSTRACT

Driven by sustainability objectives, Australia like many nations in the developed world, is considering the option of battery electric vehicles (BEVs) as an alternative to conventional internal combustion engine vehicles (ICEVs). 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, performance, and other attributes that will be of importance to consumers. With this in mind, 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, which is likely to be the primary option for early adopters of the technology. The approach uses five weeks of driving data recorded by GPS technology and builds 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 speeds recorded by the GPS is adapted to determine the charge used, while a battery recharge function is used to determine charging 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 60 km 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 tours requiring out-of-home charging 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) effective range can be dramatically impacted by both how a vehicle is driven and use of electrical auxiliaries, and (v) 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 in big cities where average journey speeds of 34 km/h are close to optimal in terms of maximising vehicle range. The paper has implications for both policy-makers and auto manufacturers in breaking down some of the (perceived) barriers to greater uptake of BEVs in the future.

1. Introduction

Driven by sustainability objectives, Australia like many nations in the developed and emerging world, is considering the option of battery 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 and Nissan Leaf. This has been

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http://dx.doi.org/10.1016/j.tra.2014.05.011
0965-8564/

accompanied by limited re-charging infrastructure and battery replacement services. The high initial price differential between BEVs and their ICEV equivalents (currently around two and a half times higher) has seen uptake largely limited to niche applications and some fleet vehicles. However, it is anticipated that this price differential will come down over time making BEVs a potentially 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. BEVs aimed at the passenger market in Australia, have a substantially lower driving range,[1] 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 operated (e.g., speeds, use of electrical auxiliaries 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 viability 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.

With this in mind, the current paper assesses the extent to which existing ICEV-based mobility patterns could be maintained if users switched to a BEV with a simple 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 function 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 operational scenarios before drawing conclusions as to the suitability of BEVs for current day-to-day driving and future policy implications.

2. Literature review

Much has been written recently about BEVs (see for example, Albrecht et al., 2009). However, 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 issues around BEVs concern limited vehicle range and re-charging opportunities compared to their ICEV counterparts (AECOM, 2009). 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 respectively,[2] 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 presenting a more positive 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 does 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 a BEV range of 200 km, which they argued gave an effective range of 180 km, they estimate around 18% of vehicles would have required some out-of-home recharging options. 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 adaption. They conclude a vehicle of 240 km range would meet the needs of 21% of the sample all the time, 35% of the sample all bar two days/year, and 60% all bar 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. Similarly, Khan and Kockelman (2012) use GPS data collected from 255 Seattle households over a one year period to determine the feasibility of replacing ICEV with either a BEV or plug-in hybrid (PHEV). Assuming a range of 160 km, the authors report that 50 percent of single-vehicle

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

[2] EV 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).