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"Is the lack of public charging infrastructure a barrier for EV adoption?"

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Abstract

"Will people buy plug-in and battery electric vehicles in the absence of a public charging infrastructure? Do such electric vehicles offer a viable commuting option in the context of limited charging infrastructure? What insights can be gathered from a study of customer needs that can help reduce public charging infrastructure costs and investments?" We ask existing EV customers for their opinion on these matters and compare it with that of those who have not experienced electric mobility.

The purpose of this paper is three-fold –

1. To survey and document the electric vehicle driving experience of our customers over the last 10 years which they have accrued with limited or no public charging infrastructure. We convey the 'voice of the EV user' with regards to the actually experienced need and necessity for public charging;
2. We elicit the 'voice of the non-EV user' on the perceived need for a public charging infrastructure and its importance as a BEV purchasing criteria;
3. To convey insights from these surveys on investments required in public charging infrastructure and suggest ways to enable increased charging opportunities while minimizing investments required.

Keywords: BEV (battery electric vehicle), charging, EV (electric vehicle), PHEV (Plug-in Hybrid EV)

1. Background

Lack of public charging infrastructure is often cited as a barrier to mass adoption of electric vehicles (EVs), especially battery electric vehicles (BEVs). Presence of a public charging infrastructure is often cited as a must to alleviate range anxiety, a term used to describe the feeling of unease when a battery electric vehicle (BEV) is running low on battery charge, and enable mass consumer acceptance and uptake of BEVs and to a lesser extent, plug-in hybrids (PHEVs), as well. We refer to BEVs and PHEVs collectively as Plug-in Vehicles (PEVs) in this paper. In public perception, a public charging infrastructure for PEVs is analogous to a network of petrol/diesel filling stations where conventional internal combustion engine (ICE) cars can refuel. Often, such discourse overlooks one important distinction between ICE and PEVs - that while ICE vehicles can only refuel at a filling station, PEVs can "refuel" at home by simply plugging-in into a wall socket.

Public charging infrastructure development has spawned activities across several areas. First, various countries are investing public funds to set up public charging infrastructure. Notable amongst these are the US "EV Project" [1] and various projects in China, Denmark, etc. Significant attempts are also being made to develop viable business models for privately funded charging infrastructure.

A second area of activity for enabling public charging has been on developing technical standards for public and home charging. For example, the SAE J1772 standard[2] is being promulgated in the US while a Japanese consortium has developed the CHAdeMO DC Fast Charging[3] standard. The goal of standardization is to develop charging equipment that can be installed at publicly accessible places and can charge EVs from different automakers.

A third area of activity, which is longer term in nature, is use smart grid technologies to manage charging profiles so as to minimally impact the electricity grid and enable services such as time-of-day metering, vehicle-to-grid energy flows, etc.

All PEVs are capable of being charged at home, and home charging is expected to remain the dominant location for charging PEVs. Automakers are seeking to address range anxiety in the design of their vehicles. In addition to being capable of home charging, automakers size the battery pack capacity in the BEV to cater to at least 2 or 3 days of average daily commuting distances. Depending on the country, the average daily commuting distance is between 40 to 60 kms. For example, in the US, the average Person Miles of Travel as reported by the National Household Travel Survey 2009 study is ~37 miles/day[4]. So a BEV owner can choose to recharge his or her EV daily at home at night and have enough battery capacity the following morning to cover twice or thrice the typical driving distance. Some EVs automatically transition to an energy conserving mode when the battery capacity runs low. Some automakers also provide smartphone based apps to control charging profiles, locate charging stations, etc.

1.1 Prior Studies and Research

Apart from reports of pilot studies[6,7,8,9], there is limited published literature available that documents the real-life experience and usage behaviour of EV owners. This is partly due to the fact that the number of EVs on-road is small (compared to the overall automobile population) and many EVs have been commercially available only in the last two years or so.

A presentation from SAE[5] by Tom T. (last name not mentioned) summarizes experiments carried out by University of California, Davies by the Plug-in Hybrid and Electric Vehicle Research Centre and other public experiments worldwide. Two notable "lessons learned" made in this report are: public Level 2 fast charging is expensive and over-subsidized, and second, people often used public charging for allied benefits – free and/or reserved parking and free electricity.

Another UC Davies study[6] explored PHEV charging patterns to examine the link between charging behaviour and meeting energy and emission goals. A third study by UC Davies on 150 Mini-E drivers[7, 8] reports that a majority of the drivers believed their needs were satisfied by home charging and did not need public charging.

A study by TEPCO[9] that also reported on the influence of public charging infrastructure on distance driven per month in a BEV indicated significant increase in distance driven per month from 203 km/month without public charging to 1,472 km/month after public charging was installed.

We expect a study of real-life experience with electric vehicles to convey insights into the actual need for public charging infrastructure as against the perceived need of non-EV owners that is commonly reported in the media. This paper is an attempt to fill this lacuna in knowledge and represent and compare the 'voice of the EV owner' with those of non-EV owners.

Mahindra Reva Electric Vehicles Private Limited (hereafter referred to as MREVA) is a battery electric vehicle (BEV) manufacturer based in Bangalore, India. MREVA has been selling BEVs since 2001. The BEV is called Reva-i in India and G-Wiz in UK. MREVA's EV's are being used in diverse climatic conditions ranging from the cold climate of Norway to the hot conditions in Delhi, India, from the relatively flat terrain of Bangalore to the alpine terrains of customers in Switzerland. The Reva-i is positioned as an intra-city car. Its small size, high manoeuvrability and lack of a gear

shift mechanism make it appropriate for intra-city use especially in the crowded urban conditions. Women form over 70% of Reva-i drivers.

It has 48V, 200 Ah lead-acid batteries with a maximum range of 80 kilometres and top-speed of 80 km/hr. It can be charged from a 15 A, 230 V AC outlet that is a norm in India, UK and some other countries. At the time of sale, MREVA installs a charging socket near the parking location at the customer's residence and sometimes, even at their office when the customer purchases a Reva-i. When the battery pack is fully depleted, the Reva-i can be fully recharged from such a power outlet in around 8 hours, while 80% charging from a fully depleted condition takes around 2.5 hours. The Reva-i does not support any other charging options such as DC fast charging.

There are over 4,400 Reva-i cars plying in the world, around half of which are in India. It is also relevant to note that Reva-i owners have cumulatively driven over 180 million kilometres (company internal data) in an environment of very limited or non-existent public charging infrastructure in different countries. Another point to note is that most Reva-i owners already own at least one other car which in most cases is an ICE car.

This paper is based on the premise that Reva-i owners are representative of the 'voice of the EV owner'. A survey of Reva-i owners with regards to their *actual* real-life usage and charging patterns will unearth the perspectives of a set of early adopters who have gained significant experience with electric mobility. This perspective of EV owners is compared with a survey of non-EV owners by querying their *perceived* usage patterns and need for EV public charging. This will help establish the convergence or divergence between perception and reality with regards to the need for EV public charging infrastructure.

We then briefly examine the main cost components in setting up a public charging infrastructure, and seek insights from these surveys to deduce ways to enable public charging at lowest possible investments.

2. Research Methodology

MREVA gathered data for this research by means of survey questionnaires administered over the internet using Google Docs. Some questionnaires were also handed out in paper form to customers. The questionnaires for Reva owners and non-Reva owners had different questions due to the different EV related experience of the two groups. Most questions had multiple possible responses. Respondents had to select either one response or as many as appropriate for each questions as directed. The survey gathered information on age group, annual income range and city of residence of the respondents. Respondents could optionally provide feedback or comments as part of their responses. No personally identifiable information was gathered in order to protect privacy. This has the obvious drawback that no further probing of a specific response is possible. Other limitations of such a survey are pointed out in this paper at the appropriate places. All respondents are private vehicle owners and not fleet owners.

The focus of the questionnaire for Reva-i owners was two-fold:

(i) To understand their current usage and charging patterns, and,
(ii) To gauge how these patterns *might* change if a public charging network were in place.

The questionnaire for non-Reva owners clearly conveyed that EV's can be charged conveniently at home and that the battery capacity of most commercially available BEVs is sufficient for the typical day's intra-city commutes.
The focus of the questionnaire for non-Reva owners was three-fold:

(i) to understand the perceived importance of having a public charging infrastructure in place on making the decision to buy a BEVs;
(ii) to understand how their usage of a BEV may change if a public charging infrastructure were to be in place.

A total of 183 Reva-i owners responded to the survey. This represents around 4.2% of the population of Reva-i owners. The response rate to the survey indicates a margin of error of 2.8% on a confidence interval of 95% for the given sample size and population. 281 responses were received from non-Reva owners.

Over 95% of the respondents were from India, making this survey representative of the EV ownership experience in India. However, these results may be extrapolated for other countries as public charging infrastructure is not widespread in most major urban areas that also have large numbers of EVs.

3. Reva-i Owners Survey Results

The first goal of the survey was to understand current usage and charging patterns. The first 7 questions sought to understand usage and charging patterns and specific experiences relevant to EV usage. A summary of responses to these questions is given below:

1. **Ownership term:** 64% of the respondents had owned a Reva-i for >3 years, 28% for 1 to 3 years and the rest for <1 year. In other words, 92% of respondents had used the car for at least a year. This indicates that the most respondents had a fair amount of EV usage experience.
2. **Distance driven**: In terms of distance covered in the Reva-i, 14% had covered >50,000 kms, 48% had covered between 20,000 and 50,000 kms and 38% had covered less than 20,000 kms. Thus, 86% had at least 20,000 kms of EV driving experience. We believe this is sufficient time for users to become conversant with their cars. This survey represents the experience of approximately 3.7 million customer driven kms in a BEV.
3. **Daily driving distance**: 60% said their daily driving distance on most days was under 40 kms, which is half the maximum range of the Reva-i. Another 25% said they travel 40 to 60 kms per day. 5% said they drive over 60 kms per day. Thus, a third of the EV owners drive long enough distances to require charging daily.
4. **Getting stranded with no charge**: 50% of the respondents stated they had experienced running out of charge before completing a journey. 6% said this had happened over 10 times, 4% said 6-10 times and 40% had such an experience 1-5 times. This survey does not reveal why this happened.
5. **Charging pattern**: 89% indicated they mostly charge their cars at home, 6% said they mostly charge at their workplace while 19% indicated that they occasionally charge at their workplace. Since the sum of these percentages adds up to more than 100% it may be surmised that some charge both and home and at work.
6. **Range anxiety**: The subsequent questions were increasingly subjective. We first wanted to understand whether range anxiety reduces with increased familiarity and usage of the BEV. 59% agreed that range anxiety wanes with usage, while 20% disagreed. We surmise that even after a year of usage, a significant minority continued to feel range anxiety. This follows from the fact that only 7% had owned a Reva-i for less than a year, while 20% disagreed. This might merit further study.
7. **Need for public charging:** We next presented the statement – "Lack of public charging infrastructure is a major detriment to using my Reva" – and respondents were asked to agree or disagree to this statement. 71% of the respondents, all EV owners, agreed that this was indeed the case. Again, it is not possible to go deeper into why and how the lack of public charging was a detriment but it is a high enough number for EV makers to not ignore.

The next set of questions focused on understanding intended behaviour if a public charging infrastructure were in place.

8. **Increased usage with public charging**: First, we posed the issue of whether EV owners would use their Reva-i even more if they had access to a public charging infrastructure. 82% said 'yes'.
9. **Public charging alleviates anxiety**: Next, we posed the statement: "With a public charging infrastructure in place, I will feel reassured in using my Reva". Again, an overwhelming 78% agreed to this. We correlate this with the point 7 above in which 71% of respondents indicated that lack of public charging is a "major detriment" to using their EV. The two numbers seem to agree.
10. **Fast charging:** Lastly, an overwhelming 89% said that they would use their Reva

even more than they do today if they had access to a fast charging network (fast charging was defined as getting 20 kms or more of range in under 20 minutes of charging).

It is evident that the existing owners of BEVs have indicated a strong interest in and need for public charging infrastructure to alleviate anxiety and also increase usage of their vehicles more.

However, the authors wish to point out a couple of caveats that must be considered when interpreting these results:

1. While this survey reveals that with public charging Reva-i owners *may* use their vehicles even more that they do currently, *it does not conclusively indicate how often they will use the public charging stations*. These results are in line with other studies such as that by TEPCO[9] with regards to the fast charging infrastructure.
2. Reva-i vehicles have a maximum range of 80 kms based on lead-acid batteries which, as with any battery electric vehicle, will decrease over the years. Given that current generation BEVs are using lithium-ion technologies and have around twice this range, range anxiety issues and the intensity for the need for public charging may be less of a concern for owners of current generation vehicles. Only a future survey of such vehicle owners can tell.

4. Results of the Survey of Non-Reva Owners

A total of 283 responses were received from non-Reva users. The population size is pretty much that of the entire population that can drive a four-wheeler, so no estimates on accuracy are possible.

With regards to the influence of public charging on a BEV purchase decision, 59% indicated they will buy a BEV only if public charging infrastructure were in place. This should be considered in the light of the fact that 61% also agreed that a BEV offers sufficient range for their intra-city commuting needs, and 65% indicated that their daily intra-city commuting distance is <60 kms per day. This further points to the fact that range anxiety, an emotional response to an unknown, dominates rational considerations of actual usage.

82% of respondents indicated that with a public charging infrastructure in place, they will "feel reassured in using their BEV". 82% also said they will use their BEV even more if they had access to a fast charging infrastructure.

These results indicate that the presence of a public charging infrastructure is an important purchase decision criteria for BEVs and it is also perceived as having an important influence on the usage of the same.

5. Interpreting the survey results

The results from non-Reva owners are largely along expected lines. These results reinforce the fact that for those who have not experienced electric mobility, the availability of public charging will favourably influence BEV purchase consideration.

Among those who have indeed experienced electric mobility, there are a few insights that bear further scrutiny. While 60% travel <40 kms per day thereby using only half the capacity of their battery packs, 71% indicated that lack of public charging was a major detriment to their using a BEV. One possible explanation for this could be that though the maximum range of their vehicles is well within the range of their daily commutes, they are often caught in a situation where the extant charge in their batteries is insufficient for an unforeseen journey that they need to undertake.

The Reva-i owners overwhelmingly indicated that they will use their vehicles even more if a public charging infrastructure were in place. As pointed out earlier, while this does not necessarily mean that they will use the public charging points, it might indeed increase vehicle usage if we also consider that 71% felt public charging will alleviate one of the 'major detriments' to their EV usage. This would correlate with the TEPCO study in Japan[9]. On the other hand, one must also keep in mind that the range of these EVs is restricted to 80 km while upcoming models from MREVA and available models from other OEMs have twice the range. It can be conjectured that this may alleviate the need for public charging to some degree but

only a similar survey after a few years may validate or invalidate this.

Lastly, the survey does not allude to the possible cost that may have to be borne by EV users for access to public charging stations. This topic is discussed in greater detail in the next section but it bears noting that the price of getting access to public charging may skew usage patterns as well as adoption rates of PEVs.

6. Public Charging – Understanding Deployment Scale Requirements

It is quite clear from the survey of non-Reva owners that automakers who are serious about attracting more customers to PEVs need to address the issue of lack of public charging. The fear of a adopting a new technology for commuting, especially in the presence of mature ICE vehicle technologies that have been around for over 100 years, can be a challenge for most consumers to overcome. When this is overlaid with range anxiety, it can easily become a significant barrier for mass adoption.

The surveys also yield the insight that the availability (of public charging) is necessary but usage in uncertain. Given the uncertainty of usage, it is imperative that a low-investment approach is sought for putting in place a public charging infrastructure.

Private enterprises are hesitant to invest in charging infrastructure due to the absence of large numbers of vehicles on the road, while mass uptake of PEVs is hampered by the absence of public charging facilities, leading to a classic "chicken-and-egg" problem.

In order to understand the costs involved at a subjective level, we first ask the question: *how many charging locations are required in a city to provide "reasonable assurance" against range anxiety?* We rephrase this question as: "what is the number of charging locations required in a city such that an EV user is not more than X kms away from a public charging station"? Lower the value of X, higher the perceived assurance but the number of charging locations required also increases.

We consider an ideal grid of evenly spaced charging stations covering a city. Let us assume the city can fit within a rectangle of dimensions L kms x W kms. We wish to find the number of charging stations such that from any point within the city, the nearest charging station is no more than X kms away.

A grid of evenly spaced charging stations will resemble an array of squares with charging locations on each corner of the square. The length of each side of the square (A kms) is calculated as follows –

$A = X\sqrt{2}$ *kms.*

The number of charging station in a single 'row' is then –

$N_w = W/A + 1$

And the number of such rows is –

$N_l = L/A + 1$

Thus, the total number of charging stations required to satisfy the maximum distance to charging station claim is:

$N_c = N_w * N_l$

Or, $N_c = (W/A + 1) * (L/A + 1)$.

This is illustrated with the example of Los Angeles City below.

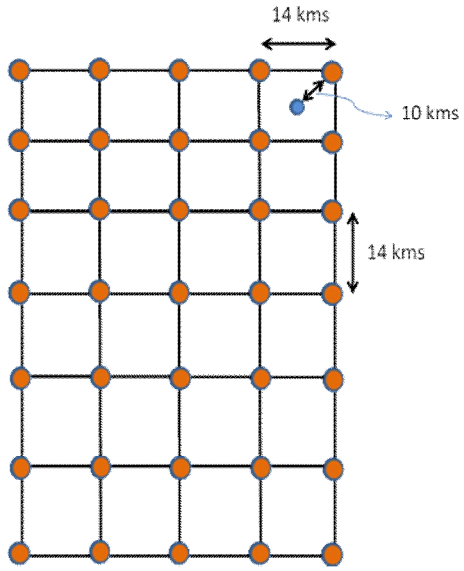

Figure1: A 'Grid' of charging stations to cover LA

The city of Los Angeles has an area of ~1,300 sq. kms[4]. It extends ~71 kms longitudinally and ~47 kms laterally, which we approximate to a bigger area of 84 kms by 56 kms (i.e. L = 84 kms, W = 56 kms). Let us further assume that the nearest charging point from anywhere within the city should not be more than 10 kms away (the value of X for this calculation). If we further assume a grid of evenly spaced charging locations (an idealization no doubt), we see that a total of 35 charging locations can meet this requirement. These shall be located 14.1 kms from each other in the grid. The longest distance is from the centre of a single square grid and will be ~10 kms. From this, A is calculated as ~14 kms.

In reality, it may not be possible to have charging locations established in such an evenly spaced manner. However, this will not lead to a significant increase in the total number of locations required. Thus, it can be seen that even for a large city such as Los Angeles, the number of charging locations required to cover the city is not very significant – it is in the low to mid tens and not in hundreds.

7. Public Charging Costs and Insights from the Surveys

We next look at some of the key cost components of a public charging infrastructure that could be true of any country.

7.1 Real estate cost

To recharge, an electric vehicle needs to park for anywhere from 10 minutes to an hour or more depending on the amount of charge required by the customer and the charging power levels available at the site. Furthermore, such a site must be available when a vehicle needs it, or charging equipment must be within reach of a spot where a vehicle has space available to park. In any case, this is a case of statistically varying usage of a permanently allocated asset. Greater the usage, higher the asset utilization and lower the cost per user. Costs vary widely within cities, from city to city and between countries but can be the most significant component of operating costs.

7.2 Charging equipment cost

Charging equipment, also referred to as Electric Vehicle Supply Equipment or EVSE, is a second element of the cost of charging infrastructure. Cost can vary depending on the power levels of the charging equipment, whether they are for indoor or outdoor use, degree of sophistication in terms of payment methods, monitoring and control, etc. Home chargers may cost a couple of hundred dollars, Level 2 public chargers may cost a couple of thousand dollars while DC Fast Chargers may cost around $15,000 or more. The EVSE type chosen can also impact both setup and operating costs – some EVSE are wirelessly connected requiring network services and thereby adding to operating costs. Maintenance costs can also be accrued under operating costs.

7.3 Setup and Installation costs

Preparing the site for installation of EVSE, including catering to safety requirements, is typically a one-time setup cost. This cost depends on the type and number of EVSE being installed.

7.4 Electricity costs

The cost of electricity used to charge the electric vehicle is an operating cost that is in proportion to the amount of charging done at the station.

7.5 Administrative costs

The cost of administering this service including having tie-ups with utilities, monitoring, control, billing and maintenance costs.

Of these costs, the single biggest recurring cost is real estate costs. Charging equipment costs, setup and installation costs and administrative costs can be managed by right design choices, scale and operational efficiencies. Malls, public parking lots, and other commercial areas are commonly cited candidates for locating charging stations, but these carry high real-estate costs unless the owner of the commercial establishment is willing to bear the same.

From the surveys, we note that close to a fifth of the Reva-i owners also charge their vehicles at their workplace. It is not clear if this number will be higher if more owners had access to charging at their workplace. Assuming it is possible to have

another charging point at their workplace, we can posit that setting up *charging points at workplaces of EV owners would dramatically increase available range per day at almost no real estate cost while scaling up the infrastructure at a rate equal to that of EV sales*. While such infrastructure is not publicly available, it assuredly doubles access to charging for BEV owners at almost no cost to them. Workplaces with dedicated parking for their employees have already paid up for real estate cost of parking vehicles. The only additional costs would be setting up an extra Level 1 or Level 2 charging point and the electricity costs, which are typically rather nominal.

This conjecture is also alluded to in Tom T.'s presentation at SAE[5] wherein he states "90% of charging events will take place at home for most PEV drivers .... but workplace opportunities could shift that percentage".

Given the strong need for public charging infrastructure expressed by non-EV owners and high costs of public charging infrastructure roll-out, this paper suggests that automakers should actively invest in and participate in such roll-out. By estimating the increase in sales in a given city by investing in charging stations, a clear trade-off can be established by each automaker as to the level of investment required.

8. Summary

This paper reveals insights from EV customers with regards to their usage patterns and charging behaviour, as well as voicing their opinion on their need for public charging. Many EV owners feel a need for public charging to alleviate their anxiety and use their vehicles unhindered. This must be viewed in light of the fact that these EV owners drive a vehicle with a maximum range of 80 kms only. Non-EV owners perceive charging infrastructure to have a strong influence on BEV purchase decisions.

This study reaffirms the notion that home charging is the dominant location for EV charging events. While other findings may merit further study, it important for OEMs to acknowledge these customer voices and face up to the challenge of finding low cost models for creating and operating public charging points. This paper suggests OEMs look into investing in this space not so much as to earn returns from the sale of electricity (at least in the near term) as much from increased sales of their electric vehicles.

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