Survey on Electric Vehicles and Battery Swapping Stations: Expectations of Existing and Future EV Owners

Vedran Bobanac, Hrvoje Pandžić, and Tomislav Capuder
Faculty of Electrical Engineering and Computing Unviersity of Zagreb
Zagreb, Croatia HR-10000
Emails: {vedran.bobanac; hrvoje.pandzic; tomislav.capuder}@fer.hr

***Abstract*—Due to maturity of the battery technology and public incentives, electric vehicles (EVs) are gaining popularity among drivers. However, there are still both technical and psychological obstacles to the widespread adoption of EVs. The objective technical issues include limited driving range, high purchase cost, limited number of charging stations, and long charging times, among others. On the other hand, some of the psychological issues are range anxiety, skepticism towards new technology and lack of distinctive EV models. In order to gain insight into both technical and social perception of EVs, an on-line survey was conducted. This paper reports the results of the survey and analyses them in order to provide insight into preferences and expectations of the potential EV owners, especially with respect to battery swapping stations.**

***Index Terms*—Electric vehicle (EV), battery swapping station (BSS), supercharging, survey.**

I. Introduction

VEHICLES have been almost exclusively run by the petroleum fuel oil distillates ever since the introduction of the modern internal combustion engine in 1885. As a result, the current transport system is responsible for approximately 23% of greenhouse gas emissions worldwide, and road transport accounts for about 72% of that share [1]. Main contributors to transport associated emissions are: personal vehicles with the share of more than 40%, and trucks, some of which are used to transport fossil fuels for personal road vehicles, with the share of cca. 25% [2]. These numbers indicate that personal vehicles are responsible for at least 10% of greenhouse gas emissions worldwide.

Besides these environmental issues, the volatility of crude oil prices and the advances in alternative fuel technologies have started generating new ideas on more ecological, cheaper, and more efficient personal vehicles. One way of reducing the negative impact of personal vehicles is the production of more efficient engines. However, this can only reduce the problem to a certain point. In the second half of the 20th century, some alternative fuels started emerging. Some of these are biodiesel, ethanol, liquefied natural gas, liquefied petroleum gas, compressed natural gas, and hydrogen. However, all of these fuels still use the internal combustion engine. The only exception is hydrogen that is used to generate electricity to power an electric motor in a fuel cell.

A big commercial step towards higher fuel economy was the introduction of hybrid electric vehicles (HEVs) that combine a conventional internal combustion engine with an electric engine. The most successful brand is Toyota Prius, whose total global sales accounted for 5.7 million units by April 2016 [3]. The next step in this direction was the introduction of plug-in hybrid electric vehicles (PHEVs), whose battery can be recharged by connecting to an electric wall socket. This property enables home emergency backup power and vehicle-to-grid (V2G) applications.

The final step away from internal combustion engines is the introduction of battery electric vehicles (BEVs) that use only chemical energy stored in rechargeable battery packs. World's top selling model is Nissan Leaf, with global sales of 220,000 cars by mid-April 2016 [4], while the second place is held by Tesla Model S [5]. This is a particularly attractive alternative since power generation is moving towards clean renewable energy sources and thus, the negative ecological impact of EVs[1] compared with traditional personal vehicles is expected to be significantly lower.

EVs are typically more expensive than traditional internal combustion engine vehicles. On the other hand, subsequent running costs are much lower for EVs since they use electricity for motion rather than more expensive fossil fuels. Some sources, e.g. [6], claim that, besides the undoubted environmental benefit, EVs may also make sense financially. However, even with the financial aspect out of the way, potential EV owners are repelled by technology issues, e.g. low driving range and charging times, and infrastructure issues. Even the users who are able to install home chargers might have issue installing the household high-power chargers due to the limits of the distribution network. Limited range of EVs, combined with the undeveloped public infrastructure, result in the infamous *range anxiety* issue.

The concept that requires the least changes compared to the current driving habits is the battery swapping station (BSS), where the EVs come to swap their depleted batteries with fully charged ones and pay a fee for the service. The most common BSS concept is the one where the batteries are owned by the BSS and leased to the customers. Since all the battery-related

[1] In the remainder of the paper "battery electric vehicle (BEV)" is referred to simply as "electric vehicle (EV)".

cost, i.e. operation, maintenance and degradation costs, are managed and remunerated by the BSS, the customers are not concerned by the battery state-of-health. Additionally, users that use only BSS do not have to invest in home charging equipment. From the customer's point of view, the idea of leasing the battery from the BSS instead of purchasing it with their EV becomes more appealing because the price of the battery constitutes a large share of the EV's total price. As battery prices are dropping, the idea of leasing the batteries may seem less appealing. However, this trend also potentially reduces the battery leasing prices.

Also, there are users who would predominantly use home and/or public charging, and BSS services only occasionally, e.g. during longer trips. These users are generally interested in taking care of their own battery and would not be interested in having their battery swapped for one of unknown characteristics, i.e. state-of-health. For these type of users, the BSS would be used to swap on the way to their long-distance destination, and they would require another swap on their way back, where they would retrieve their original battery, which has been charged in the meantime.

II. Literature on EVs and BSSs

In the concept of decarbonizing the energy sector and moving to an all-electric energy system supplied by renewable energy sources (RES), the electrification of transportation is one of key pillars. The variable and uncertain nature of RES requires balancing and participation of flexible and controllable sources, especially on the consumer side. As EV are parked during most of the day, by plugging them and enabling their individual charging requirements in time, they become a valuable resource for mitigating the intermittent nature of RES [7]. Providing these additional flexibility services results in lower power system operating costs, meaning that the EV owner could in return also have substantial benefits [8], [9]. While this might eventually happen, majority of strategies today evolve around making EV charging available at as many locations as possible and shortening the time for service provision by installing fast chargers. The belief is that the experience of owning an EV should match that of owning a conventional vehicle since an average user will not choose a new product if it does not provide the same level of comfort. Detailed analysis of travelling behaviour has shown that EVs can match driving needs for 84% of travels taken; this number increases even more if the users are willing to make small changes in driving behaviour, such as more frequent charging [10]. Further development of the technology, by increasing the battery's specific energy to an Advanced Research Projects Agency-Energy (ARPA-E) target value of 200kWh/kg while keeping its mass constant, would mean EVs can satisfy almost 96% of traveling demand with no changes in users behaviour [11]. It is interesting to notice that while several research surveys, from a couple of years back, have shown large interest in EVs as the next vehicle of choice [12], less than 2% of personal vehicles today are electric [13].

Challenge of having more EVs on the road lays as much in social acceptance as it does in overcoming technical barriers. In order to overcome the anxieties potential users have on range, charging times, charger locations and charger availabilities, especially during longer travel distances, different business models and options are being developed. The concept of BSS is intriguing due to several aspects; besides providing the charging service times superior to even classical gas stations, it maintains the capability of slow chargers to provide flexibility to the power system [14]. By combining these two effects BSS concept seems as it might be an appealing option to both the utilities/system operators and EV users. There is an increasing number of papers and technical reports dealing with the BSS siting, sizing and operation, e.g. [15], [16].

The BSS business and operational models have not only been treated in theory. Commercial businesses have developed around the BSS concept to take advantage of the existing EV owners and to attract new ones. The company that was the most serious about this business was called Better Place. Their idea was to separate the car ownership from battery ownership, which would make the cost of an EV comparable to the cost of an internal combustion engine (ICE) vehicle, since battery cost would be excluded from the initial car purchase. Better Place developed a business model and launched in 2008, with $200 million in venture funding and partnership with Renault-Nissan [17]. Within first 18 months Better Place had reached agreements and partnerships with governments in six countries and started entering markets for full-scale commercialization. However, after strong start, business was not developing according to the plan and Better Place filed for bankruptcy in 2013. The company's financial difficulties were caused by the high investment required to develop the infrastructure and the lower than expected market penetration [18].

Another example is Tesla Motors company which in 2013 introduced battery swapping technology for their EVs [19]. However, it looks like Tesla owners are not very interested in battery swapping, so the development of Tesla battery swapping system is currently on hold.One might say that examples of these two companies are proof that battery swapping does not work, but it is worth noting that Tesla Motors uses completely different business model from Better Place (Tesla's core business is car production, while Better Place's core business was battery swapping). Namely, Tesla Motors does not offer the option to lease the battery (reduced initial car price) and they offer free supercharging, while battery swapping is being charged for. Therefore, battery swapping offers no financial benefit to Tesla owners and this is probably the reason why they are showing no real interest in this technology, in spite of the fact that only people with higher incomes can afford to buy Tesla.

In addition to the above, there is a question on BSS social acceptance and, again, change in perception of ownership might be the obstacle to its acceptance. The survey presented in Sections III and IV focuses, among others, on these social aspects.

III. Methodology: Survey

An on-line survey was created and used in this research, in order to collect data from the existing and potential EV

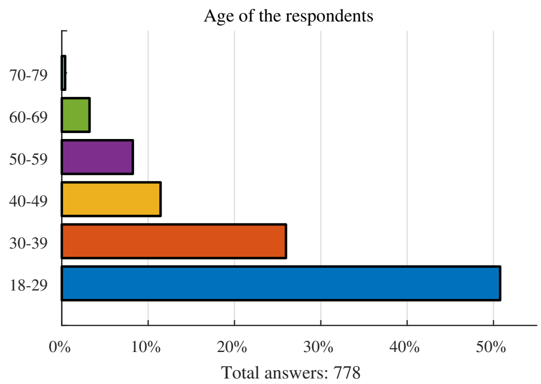

Fig. 1. Age of the respondents

owners. The survey has two main goals: (i) identifying problems and reasons that make people defer their purchase of an EV, (ii) gaining insight into people's perception of battery swapping. The questions were formulated in a way that both current and potential EV owners can answer them.

A similar research can be found in [20] where authors are referring to the term "social-technical" and argue that social barriers may pose as much of the problem as technical barriers to the integration of EVs into the mainstream personal vehicle market. However, our research features a larger sample size, while our paper presents the results in a much clearer fashion (graphically as opposed to tabular). Other researches on this topic can be found in [21] and [22]. Research in [21] is, in our opinion, not extensive enough, thus providing too little information, while on the other hand, research in [22] is overly extensive and cluttered with results, thus making it hard to distinguish important from unimportant information. We believe that research presented in this paper makes a good trade-off between informativeness and compactness. Furthermore, all three referenced researches are concerned only with the adoption of EVs, while the research presented in this paper deals with both EVs and BSSs. The survey results are intended to be used in development of various BSS business models.

The survey consists of two main parts. In the first part the respondents provide some information about themselves, e.g. age, gender, country of residence. This part of the survey is presented in the sequel (Section III-A). The second part of the survey consists of series of questions about EVs and BSSs. Most of the questions are multiple choice (pick one answer), while some questions require a certain value to be entered (e.g. expected driving radius) and some questions are open-ended (i.e. respondents are supposed to write their answer into a comment box). This part of the survey is presented in Section IV.

A. *Sample description*

Total number of people that have taken the survey amounts to 791. However, not all of them answered all the questions, and some unreasonable answers had to be neglected. This is the reason why there is a different number of answers on each question. Total number of valid answers is noted at the bottom of each figure and this is the number the shown percentages refer to.

The survey was taken by a lot of students and young people of different professions (Fig. 1). Representation of the male population is much higher compared to female population (69% to 31%). Vast majority of respondents come from Europe (Fig. 2) and drive[2] traditional non-electric (ICE) vehicles (Fig. 3). The most common EV in this poll is Nissan Leaf, which is owned by 23 respondents. Tesla is owned by 11 respondents, while Renault Zoe, Bolloré Bluecar, Mitsubishi MiEV, and Mahindra e2o are owned by a single respondent. Additionally, one respondent owns a home-adapted Opel Kadett. Most of the EVs in this poll are owned in the USA (17 respondents), Great Britain (6), and Germany (5). Majority of the respondents make between $10,000$ and $20,000$ kilometers per year (Fig. 4), which is in line with the European data of around 14,000 km [23], and slightly below the US average of 21,500 km [24].

IV. Results and Discussion

This section presents and discusses the results of the survey. The processed answers are displayed in the figures, while questions are given in the figure titles.

Majority of respondents think that there will be more EVs on the roads in the future than there is today (Fig. 5), in fact over 35% of the respondents believe that they will own an EV before the 2020 (Fig. 6). Although the total number of EVs on the roads in 2020 will probably be lower in reality, these findings point out to the growing need of developing charging (and/or battery swapping) infrastructure and the belonging business cases. It is interesting that over 40% of respondents believe that EVs will never become as popular as gasoline-powered vehicles, while 3% believe that EVs will never become interesting to the majority of people (Fig. 5).

High initial cost of EVs is often mentioned as a significant obstacle for higher EV uptake and this is confirmed by the responses shown in Fig. 7. In spite of this fact, the results of the survey in Fig. 8 show that only minority of people (roughly 17%) are not willing to pay more for a new EV, while lot of people are willing to increase their initial investment (to

[2] In case of younger people not yet owning a car, it is assumed that they drive their parents' cars.

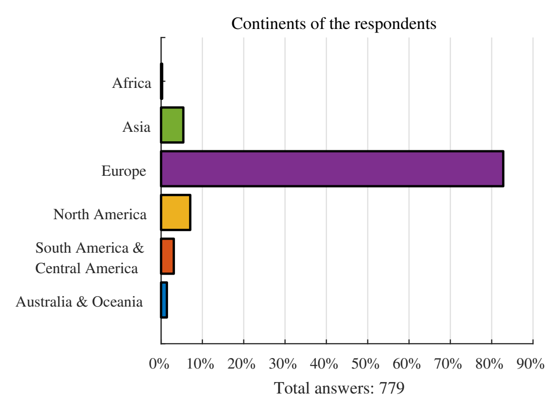

Fig. 2. Geographical representation of the respondents

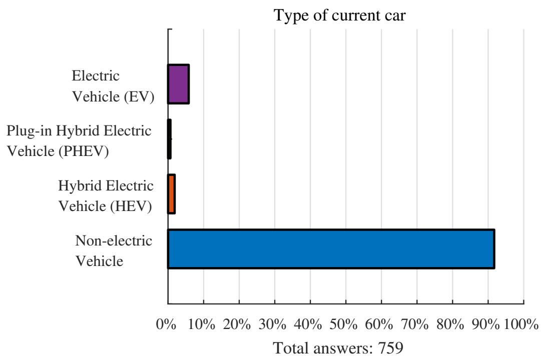

Fig. 3. Type of current car

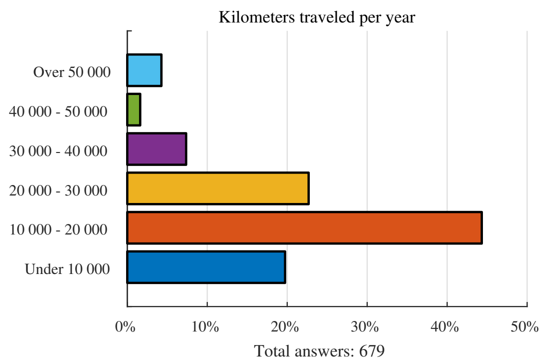

Fig. 4. Kilometers traveled per year

a certain point) provided subsequent reduction in the cost of driving. These findings suggest that even smaller reductions of EV's initial price might attract new buyers.

The results shown in Fig. 9 indicate that most respondents expect a 50% reduction in operation costs from an EV. The high number of 0% cost reduction comes from the respondents already owning an EV or a PHEV.

The results of the survey also indicate that 83% of respondents are willing to buy an EV provided their driving comfort remains the same. Furthermore, 88% of them would switch to an EV if the transition would be seamless in terms of the available infrastructure and driving habits, i.e. driving distances and stopping intervals.

Fig. 10 displays that most respondents expect an EV to provide a driving radius of 250-500 km, which today can

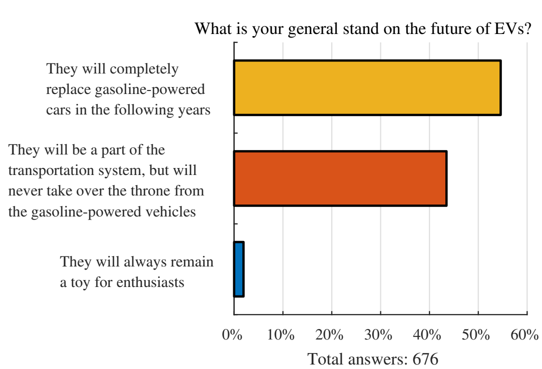

Fig. 5. General stand on EVs

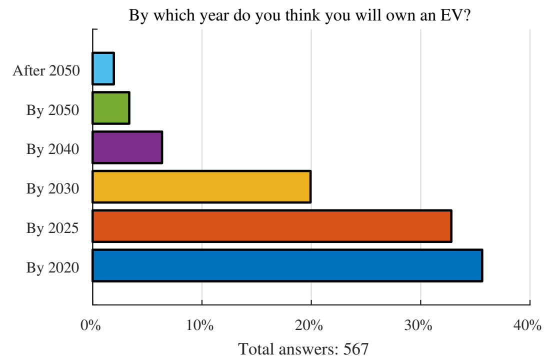

Fig. 6. Owning an EV

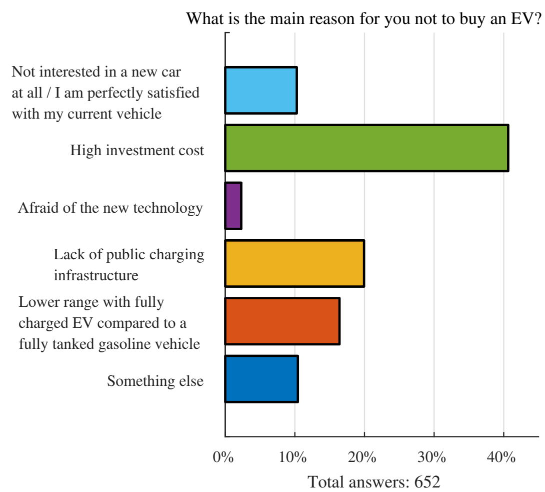

Fig. 7. Reasons against EVs

be achieved by most non-electric, hybrid electric and plug-in electric vehicles, as well as some electric vehicles (Tesla). However, all the other currently available EVs (other than Tesla) are far away from this driving radius - they typically achieve 100-140 km on a single full charge [25].

The poll indicates that almost 45% of the respondents would be unable to charge their EV at home, which is a significant obstacle for owning an EV, since using exclusively charging stations would probably be inconvenient and time consuming. Therefore, prospective EV owners from this population might be interested in some sort of battery swapping system.

When talking about longer trips, responses shown in Fig. 11 suggest that interest for battery swapping definitely exists. Almost 60% of the respondents would like to have an option of battery swapping, while over 20% is willing to pay extra to use a battery swapping station. Furthermore, 55% of the respondents are unwilling to prolong their business trips time-wise as a consequence of battery charging, which is inevitable on longer trips. Battery swapping may be the way to attract this population to EVs.

It has been previously stated that the biggest obstacle in wider adoption of EVs is the high investment cost (see Fig. 7). On the other hand, this problem may be relieved by some form of battery leasing, thus reducing the initial investment. In specific, 74% of the respondents are more likely to buy an EV

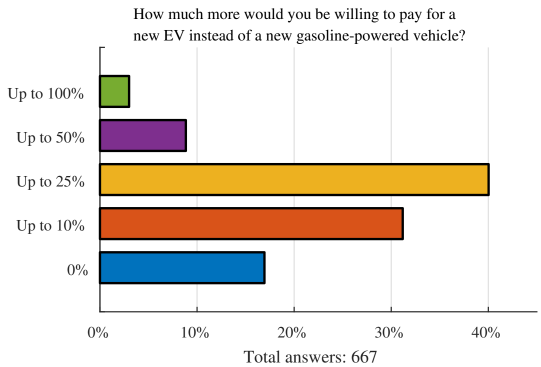

Fig. 8. Buying new EV

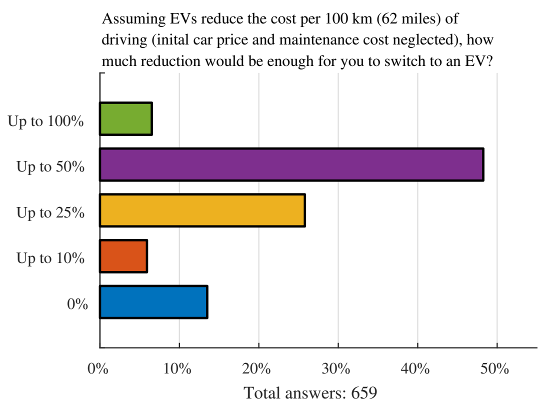

Fig. 9. Cost reduction

if it could be purchased without the battery pack and lease the batteries instead, assuming there are many swapping stations around.

Fig. 12 shows that considerable amount of respondents is willing to pay more for battery swapping as compared to supercharging. This can be due to the presumed reduction in initial investment or simply the matter of convenience since battery swapping offers significantly shorter waiting times compared to supercharging. Only one quarter of the respondents are not willing to pay more to use battery swapping system.

Half of the respondents do not want to calculate with their driving range and would charge their EV every night (Fig. 13).

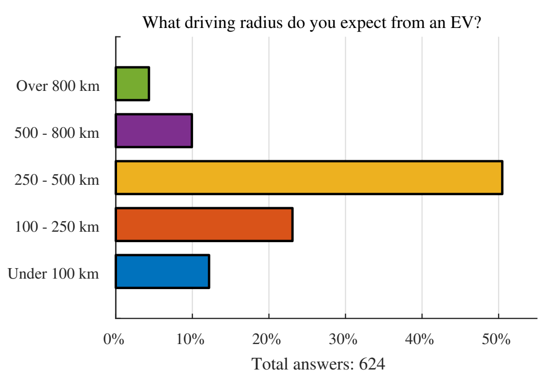

Fig. 10. EV driving radius

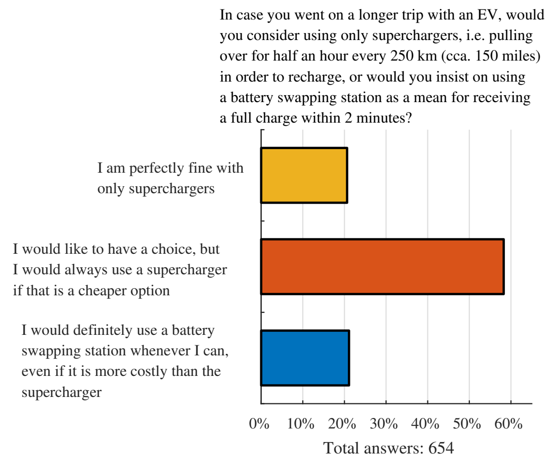

Fig. 11. Longer trips with EVs

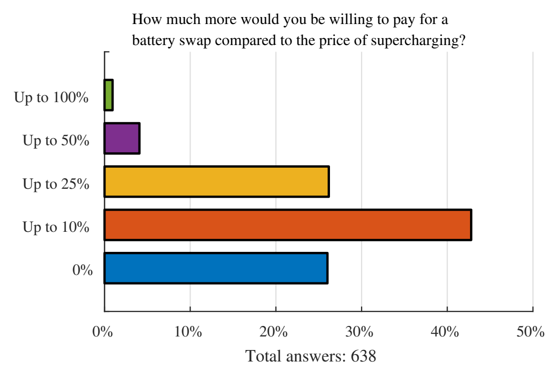

Fig. 12. BSS vs. supercharging (different price)

This confirms the presence of the already mentioned range anxiety concern. Less than 10% of the respondents would gamble and wait until the last possible moment to charge their battery. The issue of the charging schedule should also be tackled from the technical side, as deep discharging cycles significantly reduce battery life [26].

From Fig. 14 and 15 it can be concluded that the interest for both supercharging and battery swapping exists. It is therefore not reasonable to expect that battery swapping could supersede the supercharging, but rather that both technologies might coexist and be used as a supplement or alternative to one another.

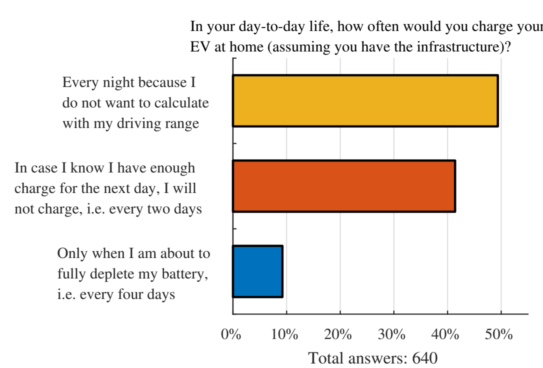

Fig. 13. Charging EVs at home

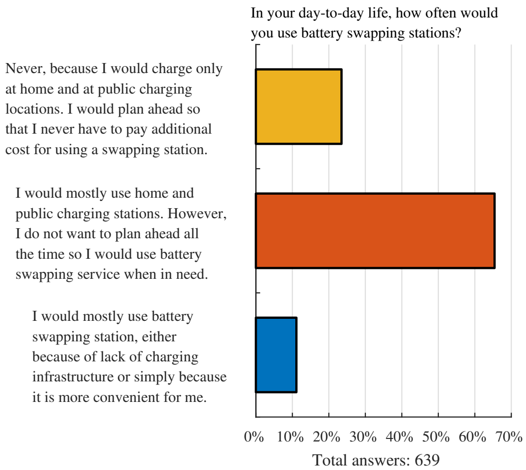

Fig. 14. Using battery swapping stations

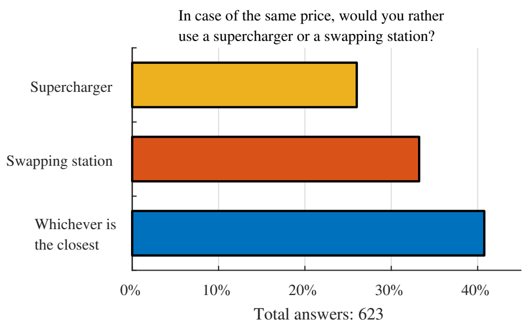

Fig. 15. BSS vs. supercharging (same price)

V. Conclusion

The results of this survey suggest that the respondents are generally open to EVs and to the idea of battery swapping. The biggest obstacle in wider adoption of EVs is high investment cost. This concern may be relieved by the deployment of BSS, i.e. initial investment could be reduced by leasing the batteries from the BSS instead of buying them with the car. It seems that the EV integration issue boils down to overall expenses (initial investment + subsequent cost of driving, maintenance, etc).

The biggest problem of the battery swapping concept is the compatibility between different car brands and models. Standardization of battery packs that are being swapped would greatly facilitate spreading of the BSSs, thus increasing battery availability and relieving the range anxiety issue. Despite reduced waiting times, it is not likely that battery swapping will supersede supercharging, but rather that it can become an alternative. It is reasonable to expect that early adopters of battery swapping would be taxi and company fleets.

VI. Acknowledgement

This work has been supported in part by Croatian Science Foundation under the project IP-09-2014-3517.

References

[1] R. Sims, R. Schaeffer, et al., "Transport," in *Climate Change 2014: Mitigation of Climate Change. Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, 2014.

[2] World Business Council for Sustainable Development, "Mobility 2030: Meeting the challenges to sustainability," The Sustainable Mobility Project, Full Report 2004. [Online]. Available: http://www.wbcsd.org/web/publications/mobility/mobility-full.pdf

[3] Toyota Global Newsroom, "Worldwide Sales of Toyota Hybrids Surpass 9 Million Units," 2016. [Online]. Available: http://newsroom.toyota.co.jp/en/detail/12077091/

[4] Nissan Newsroom Europe, "Nissan lands its largest electric taxi fleet deal," 2016. [Online]. Available: http://newsroom.nissan-europe.com/EU/en-gb/Media/Media.aspx?mediaid=144669

[5] J. Cobb, "Plug-in Pioneers: Nissan Leaf and Chevy Volt Turn Five Years Old," 2015. [Online]. Available: http://www.hybridcars.com/plug-in-pioneers/

[6] M. Boxwell, "Do electric cars actually make sense financially?" 2011. [Online]. Available: http://www.thechargingpoint.com/knowledge-hub/hot-topics/Electric-car-costs.html

[7] European Commission, "Delivering a New Deal for Energy Consumers," Brussels, 2015.

[8] I. Pavić, T. Capuder, and I. Kuzle, "Low carbon technologies as providers of operational flexibility in future power systems," *Applied Energy*, vol. 168, pp. 724–738, 2016.

[9] T. Brijs, K. de Vos, C. De Jonghe, and R. Belmans, "Statistical analysis of negative prices in European balancing markets," *Renewable Energy*, vol. 80, pp. 53–60, 2015.

[10] N. S. Pearre, W. Kempton, R. L. Guensler, and V. V. Elango, "Electric vehicles: How much range is required for a day's driving?" *Transportation Research Part C: Emerging Technologies*, vol. 19, no. 6, pp. 1171–1184, 2011.

[11] Z. A. Needell, J. McNerney, M. T. Chang, and J. E. Trancik, "Potential for widespread electrification of personal vehicle travel in the United States," *Nature Energy*, vol. 1, no. 16112, 2016.

[12] Deloitte, "Global Automotive Consumer Study - The changing nature of mobility - Exploring consumer preferences in key markets around the world," 2014.

[13] European Automobile Manufacturers Association, "New passenger car registrations by alternative fuel type in the European Union," 2016.

[14] M. R. Sarker, H. Pandžić and M. A. Ortega-Vazquez, "Optimal Operation and Services Scheduling for an Electric Vehicle Battery Swapping Station," *IEEE Trans. Power Syst.*, vol. 30, no. 2, pp. 901–910, 2015.

[15] Y. Zheng, Z. Y. Dong, Y. Xu, K. Meng, J. H. Zhao, and J. Qiu, "Electric Vehicle Battery Charging/Swap Stations in Distribution Systems: Comparison Study and Optimal Planning," *IEEE Trans. Power Syst.*, vol. 29, no. 1, pp. 221–229, 2014.

[16] J. S. Neubauer and A. Pesaran, "Techno-Economic Analysis of BEV Service Providers Offering Battery Swapping Services," NREL, 2013.

[17] "Better Place: Charging into the Future?" William Davidson Institute at The University of Michigan, 2010.

[18] I. Kershner, "Israeli Venture Meant to Serve Electric Cars Is Ending Its Run," *The New York Times*, 2013. [Online]. Available: http://www.nytimes.com/2013/05/27/business/global/israeli-electric-car-company-files-for-liquidation.html

[19] Tesla Motors, "Battery Swap Event," 2013. [Online]. Available: https://www.teslamotors.com/videos/battery-swap-event

[20] O. Egbue and S. Long, "Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions," *Energy Policy*, vol. 48, pp. 717–729, 2012.

[21] S. Carley, R. M. Krause, B. W. Lane, J. D. Graham, "Intent to purchase a plug-in electric vehicle: A survey of early impressions in large US cites," *Transportation Res. Part D: Transport and Environment*, vol. 18, pp. 39–45, 2013.

[22] Z. Shahan, "Electric Cars: What Early Adopters And First Followers Want." [Online]. Available: https://gallery.mailchimp.com/a897522b53d0853c85abbf9fa/files/Electric_Cars_What_Early_Adopters_And_First_Followers_Want.pdf

[23] EEA, "ENERDATA - Annual distance travelled by cars."

[24] U.S. Department of Transportation - Federal Highway Administration, "Average Annual Miles per Driver by Age Group." [Online]. Available: https://www.fhwa.dot.gov/ohim/onh00/bar8.htm

[25] E. Schaal, "10 Electric Vehicles With the Best Range in 2015," 2015. [Online]. Available: http://www.cheatsheet.com/automobiles/top-10-electric-vehicles-with-the-longest-driving-range.html/?a=viewall

[26] T. B. Reddy and D. Linden, *Linden's Handbook of Batteries*, 4th ed. The McGraw-Hill Companies, Inc., 2011.