Electric Vehicle Range Anxiety: An Obstacle for the Personal Transportation (R)evolution?

Dario Pevec[1], Jurica Babic[1], Arthur Carvalho[2],
Yashar Ghiassi-Farrokhfal[3], Wolfgang Ketter[3,4], and Vedran Podobnik[1]

[1]University of Zagreb, Faculty of Electrical Engineering and Computing, Croatia
[3]Erasmus University, Rotterdam School of Management, Netherlands
[2]Miami University, Farmer School of Business, USA
[4]University of Cologne, Faculty of Management, Economics, and Social Sciences, Germany

***Abstract*—Trends in the electromobility industry, increasing research efforts related to alternative fueled vehicles, as well as growing environmental concerns are suggesting that the transition from the internal combustion engine technology to electric vehicles (EV) is necessary and inevitable. To ensure and enable rapid market penetration of EVs, one major obstacle needs to be addressed - range anxiety, a fear of running out of electricity before reaching another available charging station. This research employs a survey methodology to assess potential EV owners' perception of range anxiety with the goal of quantifying and explaining it through key EV parameters: *state of charge* (i.e., a relative measure comparing the remaining amount of energy in the EV battery with the maximum capacity) and *remaining range* (i.e., how much distance the EV can still reach without re-charging). Through the survey analysis, we answered two relevant research questions that fall into the range anxiety research agenda: *(i)* how potential EV owners perceive the optimal distance between charging stations in comparison to traditional, well-developed gas station infrastructure; and *(ii)* how key EV parameters influence the decision to charge as well as the distance one is willing to travel to reach another charging station that may or may not be occupied. This research is beneficial for business makers as the knowledge about range anxiety is very important for making decisions about charging station placement, as well as for the research community since range anxiety is a variable that could and should be included in various research areas centered around EVs. Besides business makers and researchers, this work is beneficial to the society in general as it may potentially have a positive impact on raising awareness about the necessity of electrification in the transportation industry.**

***Index Terms*—electric vehicles, green transportation, charging station infrastructure, range anxiety, survey, data science**

I. INTRODUCTION

From the rising seas due to climate change [1] to climate-related illnesses [2], dealing with today's environmental concerns is one of the most prominent challenges societies face. One reoccurring factor in the majority of environmental issues is air pollution, and the **transportation sector** is known to be one of the main contributors to *greenhouse gas* emissions with the largest greenhouse gas footprint [3]. As the fleet of private transportation vehicles is constantly increasing [4], both the transportation industry and research communities are showing increased interest in addressing the aforementioned environmental concerns [5] through proposing alternative means of transportation and alternative fuel vehicles (AFV) [6], [7]. AFVs are vehicles that do not consume conventional diesel and gas, but are rather fueled by solar power, hydrogen, biodiesel, or electricity. This paper mainly focuses on **electric vehicles** (EV) since they are perceived as *clean*, providing that they are sourced through renewable sources [8]. Taking into consideration worrying environmental challenges and technological advancements, together with the interest of many research communities, the transition from *internal combustion engine* vehicles (ICE) to EVs is presumably the next step in the evolution of private transportation.

corresponding author: dario.pevec@fer.hr

The most obvious evidence of the efforts towards EV popularization is in the corresponding market penetration. According to the estimation by the *International Energy Agency* [9], sales of new EVs surpassed 1 million in 2017, which is a growth of 54% compared to 2016. It is estimated by summarizing cumulative sales from 2005 to 2017 that there are currently more than 3 million EVs on the roads around the world. The two main reasons driving the EV sales are: *(i)* battery technology advancements, which causes EVs to be cheaper and have larger autonomy (*i.e.*, driving range) as opposed to the older EVs; and *(ii)* government EV-related incentives such as free charging, lower taxes, and vehicle registration cost reductions [10].

However, despite the growth in the EV sales numbers, they are still not commonly accepted among wider population of potential consumers. According to Statista Dossier [11], most countries, besides Sweden, China, and Norway, have on average less than 1% EV share. This fact shows that despite the increase in EVs' popularity, rising environmental concerns, and technology advancement, EVs are still not present on the road as they perhaps should be. Several studies aim to address such a specific EV adoption challenge. For example, Adnan et al. [12] discovered that the most influential factor in making the decision of purchasing an EV is a phenomenon known as *range anxiety*. Range anxiety is defined as a fear of running out of electricity before reaching an available charging station [13]. The range anxiety challenge can be approached from two different perspectives: *(i)* increasing the EV autonomy;

and *(ii)* the development of charging infrastructure. Motivated by globally underdeveloped charging station infrastructure, we focused on the latter approach in a previous work [14]. Concretely, the proposed framework combines heterogeneous data sources, decision maker's input, and data science to recommend a location for placing a new charger(s). Through sensitivity analysis, it was identified that the range anxiety variable could be very valuable in the process of charging station deployment modelling, provided that such a variable can be measured and calculated based on real-world data.

Considering the above-mentioned context, this work identifies two research questions that are focused on measuring and analysing variables that contribute to range anxiety. The first research question is formulated as: *"How do potential EV owners perceive **charging station** infrastructure in comparison to the existing **gas station** infrastructure?"*. This research question can potentially clarify how scarcity of charging stations affects range anxiety, and to what extent the scarcity is emphasized when compared to traditional gas stations. The second research question is formulated as: *"To what extent do different key EV parameters influence the range anxiety among non-EV owners?"*. The second research question can answer how *state of charge* (SoC), i.e., remaining battery capacity, influences the decision to charge the vehicle as well as whether range anxiety is triggered more by the SoC or by the remaining range that an EV can cover. We addressed both research questions through a survey analysis, which is by the defined scope of this research aimed towards non-EV owners. This design choice is due to non-EV owners having less knowledge about EVs and, therefore, they manifest a higher level of range anxiety [15]. Besides the higher level of range anxiety, non-EV owners' perception of the optimal charging infrastructure is important for further infrastructure development since the (r)evolution of private transportation is highly dependent on their transition to *alternative fueled vehicles*. In a follow-up research, we aim at collecting similar data for EV owners, which will enable us to generate even more relevant insights about range anxiety as well as to compare preferences and behavior of non-EV users and EV-users.

The rest of the paper is organized as follows: Section II positions this research against related literature. In Section III, we describe our research methodology as well as the survey design with emphasis on the explanation of important variables for answering our research questions. Section IV reports our data analysis, while Section V discusses the results as well as observed anomalies alongside explanations. Finally, Section VI summarizes all the findings throughout this research and present ideas for the future work.

II. Literature Review

In this section, we position our research against other relevant research in this domain. Literature review is performed from two perspectives: first, research tackling range anxiety, i.e., the phenomenon associated with consumers' perception of the available driving range [16]. This perspective is the driver for the most relevant research in this field - how range anxiety is perceived and what are the key factors that evoke range anxiety. Secondly, we review research that employs a similar methodology as ours (surveys) in the domain of electric vehicles.

Research by Jung and Steiner [17], as well as the research conducted by Franke and Krems [18], aim to explain how the experience with EVs influences range anxiety. In their research, Jung and Steiner [17] addressed how the EV's user interface influences range anxiety. They provided 73 test participants with a 19 mile EV drive experience. The test scenarios were differentiated by low and high SoC at the beginning of a drive, and with low or high ambiguity of user interface. The authors concluded that a low starting SoC, as well as a high ambiguity of user interface have significant influence on range anxiety, trust towards the vehicle, and driving behavior.

Similar to the work by Jung and Steiner, Franke and Krems [18] based their research on participants that were provided with EVs for 3 months of test driving. The goal of that research was to investigate the factors that influence range preferences and how they change over time. Franke and Krems [18] concluded that range preferences changed during the time of three months, which indicates that owning an EV and understanding the EV basics is a highly significant factor for range anxiety.

On the other hand, the work by Rauh et al. [16] is aiming to describe range anxiety from the perspective of long-term EV owners versus non-EV owners. The test scenario is once again based on driving an EV on a predefined route with predefined SoC. The authors concluded that the range anxiety is significantly lower for long-term EV owners, although this was induced by specific test parameters, which is an evidence that range anxiety can be influenced. What was unanswered was whether range anxiety can be reduced.

Research by Bonges and Lusk [19] and by King et al. [20] is trying to answer the previously-stated question by proposing theoretical frameworks. King et al. [20] proposed access to on-demand vehicles as a service to alleviate a form of EV range anxiety. They developed a business model and modelled the price of the proposed business scheme, which in turn can be substantially lower than the cost of accumulated subsidies for EV promotion. Bonges and Lusk [19] proposed an approach for reducing range anxiety through parking layout modifications alongside policies and regulations. The main idea is to introduce EV-only parking spots, and that the charging station is placed to enable as many vehicles to charge as possible, i.e., in the center of a parking lot instead of corners.

Unlike studies that are focused primarily on range anxiety, the work by Neuber and Wood [13] is focused on the effects of range anxiety and charging infrastructure on EV lifetime utility. The research was conducted employing computer simulation methods using year long trip data for modelling human driving decision behavior. The authors observed that drivers with increased range anxiety achieved up to 8% lower utility factors. The authors also stated that an extension of the existing public infrastructure would be beneficial for lowering range anxiety and increasing EV lifetime utility.

Based on the above discussion, it is evident that tackling range anxiety is a very relevant challenge in the research community. Unlike previous work in this area, our study explores how the electric vehicle range anxiety is perceived in contrast to traditional ICE vehicles. More specifically, we explore how the charging station infrastructure is compared to the gas station infrastructure, as well as how key EV parameters influence potential consumers' range preferences.

The methodology used in our research is based on data collection through a survey, which is a commonly used methodology for data gathering in the domain of electric vehicles. For example, Dorcec et al. [21] and Babic et al. [22] used surveys to assess the willingness to pay for EV charging service. Besides the willingness to pay assessment, surveys are also widely used when forecasting EV market penetration (Jensen et al. [23], Lebeau et al. [24]), as well as for understanding the factors influencing EV adoption (Higgins et al. [25], Ko and Hahn [26]).

III. Research Methodology

The methodology employed in this study is motivated by relevant survey-design work [27] as well as by the well-known CRISP-DM methodology, which is widely used in data modeling and data mining [28]. We illustrate our methodology in Figure 1. The following subsections describe the end-to-end implementation of our methodology and, since we employed a survey approach for collecting data, the structure of the questionnaire.

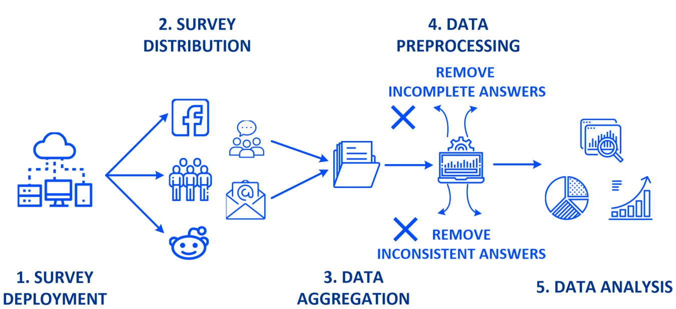


Fig. 1: Research methodology, from data collection to data analysis

A. Data Flow

The survey was created using LimeSurvey [29] and hosted on our server for additional control of access. As can be seen in Figure 1, the survey was distributed via multiple communication platforms and social medias in order to maximize reach and the diversity of the participants. In particular, we distributed the survey link using various EV-specialized forums, Facebook, Reddit, and via a word-of-mouth approach. The main reason to distribute the survey through multiple different communication platforms is to capture more variance in demographics, e.g., the age of the participants, knowledge about the topic, income, or the difference in the settlement hierarchy based on population density. As expected, the vast majority of participants accessed the survey via Facebook, as it is arguably the most influential social network.

The next phase of the methodology is *data aggregation*, a step in which the data collected from different sources are combined into a dataset to be further analyzed. Specifically, the data aggregation step of the methodology simply instantiates a new survey and stores the collected data. The phase of *data processing* precedes the final step of the flow, *data analysis*, which we describe in Section IV. During the data processing phase, all incomplete or inconsistent answers are removed as part of the usual data cleansing so that a high-quality dataset is available for the data analysis phase. Besides removing specific records from the dataset, this phase is used for transforming variables of the dataset so that they follow an appropriate format.

B. Survey Design

The survey comprises of three thematic sections: *(i)* demographic questions; *(ii)* a questionnaire about the satisfaction with existing gas station infrastructure and a comparison with EV charging infrastructure taking into consideration settlement hierarchies; and *(iii)* five randomly generated scenarios based on which participants should provide opinion about their willingness to charge.

The demographic-themed section of the survey is composed of a standard set of questions (*e.g.*, gender, age, country, income, employment, and education), and extended with a couple of EV-specific questions (*e.g.*, questions about EV ownership, EV model, EV battery capacity, and at what *state of charge* (SoC) a person on average decides to charge).

The next group of questions is designed to investigate potential consumers' satisfaction with the current state of **gas station** infrastructures, as well as the current state of **charging station** infrastructures. Throughout this set of questions, we aim to compare two different "refueling" infrastructures from the consumers' comfort perspective by taking into consideration settlement hierarchies.

The last set of questions is related to the range sensitivity analysis. Through five scenarios, we ask participants two questions about their willingness to charge and about the range preferences in case they want to charge. The exact text of the question is as follows, where the expressions inside square brackets are replaced by numbers in real-time after being calculated based on randomly-created data for the individual scenarios:

When full, your EV can achieve maximal distance of $[intval((battCap * 1000)/190)]$ *km. Your current state of charge (SoC) is* $[SoC\%]$*. With that SoC you can travel the maximum of* $[intval(((battCap * 1000)/190) * (SoC/100))]$ *km. Would you like to charge your EV in this circumstance during your daily city commute?*

The variable **battCap** represents the EV battery capacity and has a random value between 16 and 60 kWh, i.e., the interval that corresponds with the most popular EV battery capacity [30]. The variable **SoC** represents the current EV *state of charge*. The constant 190 is derived from the average range of the most popular EV [30]. The main difference in the five scenarios we present to survey participants is in the SoC value. In the first scenario, that value is between 5% and 100%, i.e., it is enough to cover most of the real SoC cases. In every following scenario, that value is lowered by 20% to ensure the existence of a scenario that would potentially create range anxiety. The maximal distance is calculated based on the average energy consumption per km for the most popular EVs today [30]. If the participant answered the question about a hypothetical charging scenario affirmatively (i.e., (s)he wants to charge), (s)he is then prompted with the following additional question to express the maximal range (s)he is willing to travel to reach a charging station:

What is the acceptable ***additional*** *distance (in km, 1 km = 0.62 miles) to travel to the charging station which* ***may or may not be occupied****, taking into consideration the* ***time*** *that is needed to cover that distance? (Example: for 10 km in Europe, average time is 25-35 minutes.) In this situation, you must carefully consider your answer since you are either unsure how far the next charging station will be or whether the next station will be unoccupied!*

The question about the range a person is willing to travel to reach a charging station, which may or may not be occupied, specifically asks about how one perceives distance, which is the reason we emphasize the words *additional distance*, *time needed for greater distances*, which is calculated from the average driving speed in populated area, and *the fact that the charger may be unavailable*. It is important to note that the same survey participant potentially answered this question several times, i.e., if (s)he answered affirmatively to more than one question from the set of five hypothetical charging scenarios.

IV. Survey Results

The previously described survey was distributed to 170 participants through different channels. None of the participants owned EVs, but they were nonetheless interested in or have at least basic knowledge about EVs. After the data pre-processing phase, 134 survey responses were considered valid, and the rest (36) were discarded due to one of the following three reasons: ***(i)*** *incomplete answers* where participants left the survey before finishing; ***(ii)*** *inconsistent answers* that were manifested through extremely different answers for very similar scenarios, e.g., for the battery capacity that differs in less than 5 kWh and SoC that results in less than 10 km difference in the remaining range, some participants answered in one scenario with the lowest possible value, and with the highest possible value in the other scenario; and ***(iii)*** *trivial answers* where participants always provided the same answers regardless of the differences in scenarios. Besides automatically detected invalid answers, some of the outliers, that have significant deviation comparing to the mean values, were also detected and discarded from the final dataset, which is common procedure for noise removal [31].

TABLE I: Participant demographic statistics.

Category	Subcategory	% of Participants [N = 134]
Working status	Employed	67.5
	Students	29.0
	Retired	3.5
	Unemployed	0.0
EV Knowledge	Very familiar	45.0
	Know something	45.0
	Heard of	10.0
Driving licence	Have	85.0
	Not have	15.0
Gender	Male	70.0
	Female	30.0

The demographic characteristics of the participants are inline with the demographics of people interested in EVs [32]. In particular, most of the participants have higher education and are employed. Furthermore, EV specialized forums have a larger percentage of males, which is also consistent with our demographic data since the majority of the participants in our survey are male (70%). As a consequence of using the Facebook social network, most (more than 80%) of our sample is between 20 and 40 years old, which corresponds with the age of the majority of Facebook users. The age and gender distribution of participants can be observed in Figure 2. The rest of the participant demographic statistics are described in Table I.

It is important to note that the majority of the participants (around 90%) have at least some basic knowledge about EVs, while more than 80% have a driving licence and experience with driving a car. Driving experience is a variable of significant importance for this survey since the quality of our results is highly dependent on the correct approximation of the distance between existing gas stations and the desired distance between charging stations, which in turn implicitly relies on knowledge about driving cars. The majority of the participants are from Croatia (three quarters of the dataset), where the charging infrastructure is underdeveloped and EVs are not a popular option for private transportation. The last quarter of the dataset is comprised of participants from 14 different countries, including Finland, Netherlands, Germany, USA, and the United Kingdom, where EVs have significant market penetration. This distribution of countries is especially convenient for our research goals since the participants from the countries with underdeveloped infrastructure are arguably more likely to be under the influence of range anxiety.

The first research question, formed as *"How do potential EV owners perceive charging station infrastructure in comparison to existing gas station infrastructure?"*, led us to some interesting findings about the potential EV owners' preferences. As can be seen in Figure 3a, potential consumers' preferences regarding gas stations are that there are currently too many gas stations, and that the distance between them can be greater than it actually is. In Figure 3b, we can notice that potential consumers are not satisfied with the current charging station infrastructure, and they would prefer to have charging stations deployed in a manner more similar to the existing gas

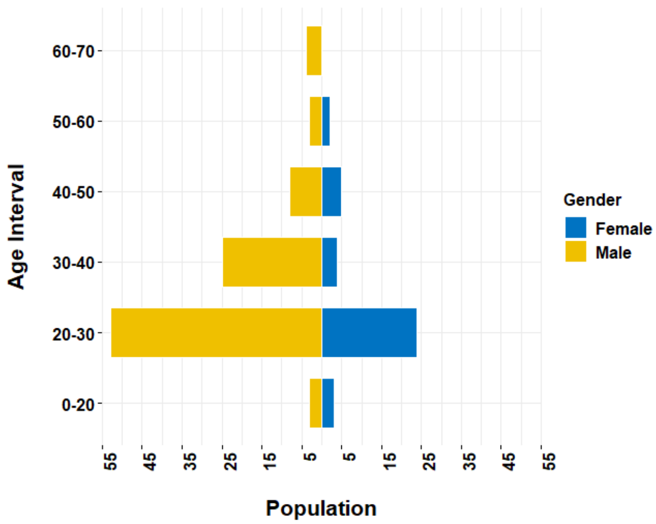


Fig. 2: Age and gender of survey participants.

station infrastructure deployment, since they are accustomed to traditional gas station infrastructure planning. The resulting mean distances can be observed as dashed lines in Figure 3a and Figure 3b.

Our results further show that more than 20% of the participants prefer charging stations more closely distributed than the gas stations are, while 50% of the participants are satisfied with the distances between existing gas station infrastructure, and prefer that exact distance mirrored on the charging station infrastructure, according to the compared answers for desired distances between gas stations and charging stations. On average, survey participants stated that the distance between charging stations should be **0.12 km** lower than the distance between gas stations. It is important to mention that we did not attempt to compare existing and desired charging station infrastructure since charging infrastructure might be heavily underdeveloped in some countries and, consequently, some participants might not be aware of the distances between chargers.

Besides the preferences about the existing and future infrastructure, it is important to observe how the size of the living area influences the preferences about the distance between charging stations. Before asking the survey participants questions about preferred distances, we asked about their settlement hierarchy, i.e., whether they live in a village, (large) town, (large) city, or metropolis. We notice certain patterns regarding the relationship between the settlement hierarchy and the desired distance to a charging station. In particular, larger settlements with high population density have a negative impact on potential EV consumers' desired charging station distance. As depicted in Figure 4, in the settlement hierarchy with the highest population density - *metropolis*, potential EV consumers tend to prefer distances of less than 5 km between charging stations, with lower variance compared to the other levels of hierarchy settlement that have significant deviations from the mean value. A more detailed overview of range preferences in comparison to settlement hierarchy can be observed in the Table II.

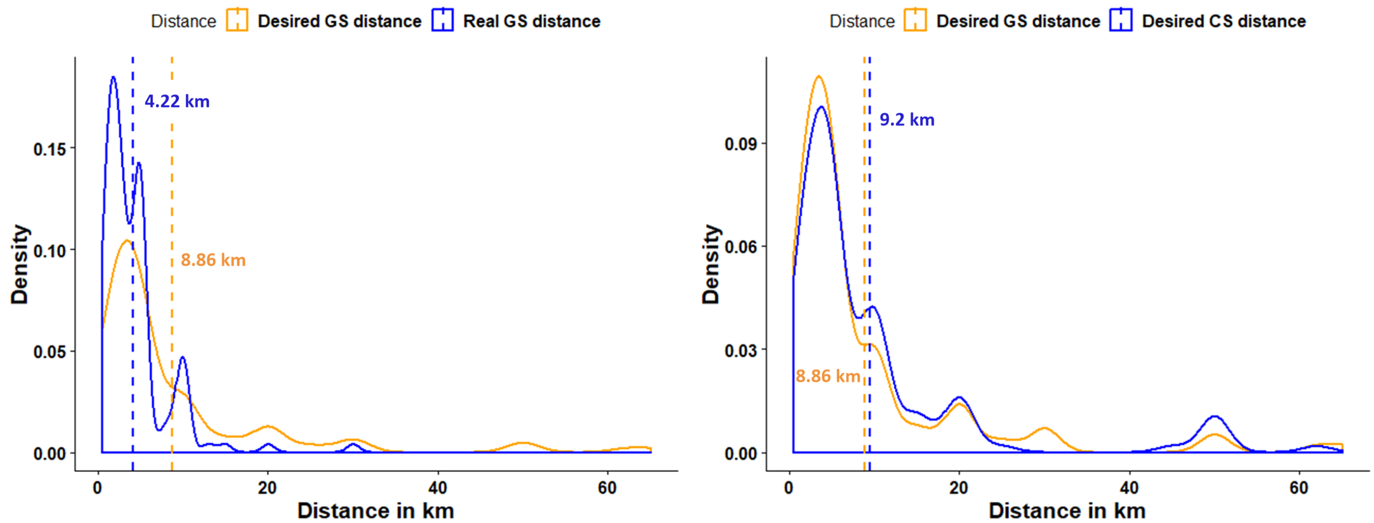
TABLE II: Range preferences in comparison to settlement hierarchy.

Settlement Hierarchy	Mean Distance [km]	Min Distance [km]	Max Distance [km]	Percentage of Participants
Village	8.44	2	20	6
Town	10.60	1	30	13
Large Town	8.01	1	20	7
City	6.30	1	20	12
Large City	6.00	0,5	40	52
Metropolis	4.10	1	10	10

We attribute the previous results to the fact that refueling infrastructure is often well-developed in bigger areas. That is, gas stations are closer to one another in locations where there is a higher demand for them, such as in the case of big cities. Consequently, consumers are used to higher availability of refueling stations and expect the similar service with charging stations. A more detailed overview of the preferred distance to charging stations with respect to the settlement hierarchy is depicted in Figure 4.

Based on the last part of the survey, i.e., the five different state of charge and driving range scenarios, we can answer our second research question: *"To what extent do different key EV parameters influence range anxiety between non-EV owners?"*. The observed charging decision patterns (see Figure 5) clearly indicate that the vast majority of participants would like to charge when their SoC is under 30%, which roughly corresponds to the standard low battery warning at around 20% [33]. The highest concentration of scenarios where the participants are willing to charge is where SoC is below 15% and the remaining driving range is below 50 km. Figure 5 depicts that not all participants who are on less than 10% battery capacity want to charge, as well as the fact that few participants who are above 90% want to charge. This phenomenon can be explained through different refuelling habits, place of residence, and a poor perception of distance expressed in kilometers. The observed behavior of outliers can also be explained through the settlement hierarchy. Potential consumers who live in smaller areas, in houses with an opportunity to install a private charger, can charge whenever they would like to, which can result in a decision to charge even on 80% of remaining SoC.

Our final research goal was to determine how SoC and the remaining driving range influence the preferred range to a charging station when the desire to charge is present. Since we aim to observe how each participant would behave in different situations, each participant answered five times if they are willing to charge and, if they are, then how far they would like to travel to charge. The aforementioned resulted in multiple answers about range preferences from one participant, and multiple answers from the same participant should not be considered as independent as they are rather inter-dependent variables. Therefore, to assess the influence of two key variables on range preferences, we must use *mixed*



(a) (b)

Fig. 3: Comparison of infrastructure preferences: (a) current and desired gas stations distances; (b) desired gas vs. charging stations distances

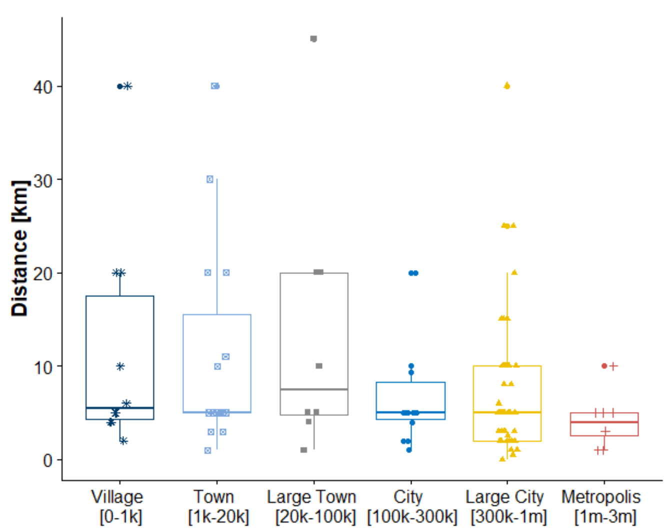


Fig. 4: Consumers' preferences regarding the distance between charging stations grouped according to settlement hierarchy.

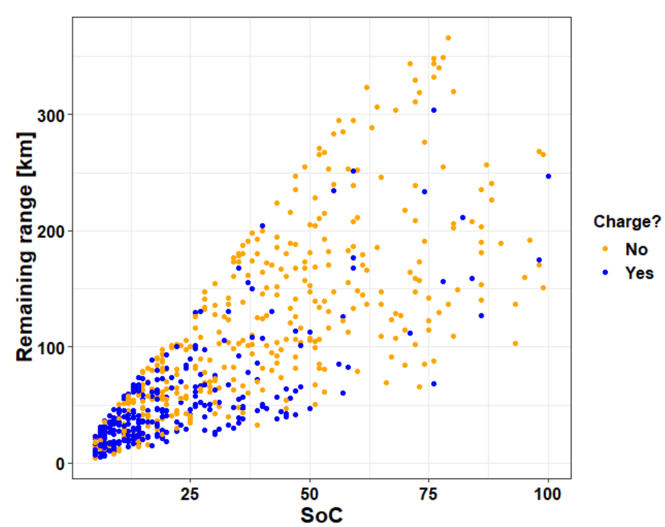


Fig. 5: Charging decision with different SoC and driving range.

effect analysis where we add a random effect to account for individual participant variation. We formed our regression formula, using standard R notation as follows:

$$distance\_to\_travel \sim SoC + driving\_range + \\ + (1|participant\_id) + \epsilon \quad (1)$$

In Equation 1, *SoC* and *driving_range* represent independent variables, *i.e.*, variables with predictable influence on a target variable, while $(1|participant\_id)$ represents the random effect, *i.e.*, another independent variable that captures idiosyncratic variation that is due to individual differences. That random effect is interpreted as an intercept that is different for each participant, thus making his or her responses dependent on one another, while still being independent with respect to the responses of other participants. The results of our regression model are presented in Table III.

TABLE III: Random effect regression model: distance to the charging station as a function of SoC and remaining range.

Random effects:		
Groups	***Name***	***Std.Dev.***
participant_id	(Intercept)	13.27
Residual		14.73
Fixed effects:		
(Intercept)	SoC	driving_range
-1.84	0.08	0.22

The results of the developed model point to the following conclusions: for each unit increase in *SoC*, the distance participant is willing to travel will increase on average by $0.08km$ when everything else is held constant. Similarly, with every unit increase of *driving range*, that distance will increase on average by 0.22 km when everything else is held constant. To assess the importance of each variable, we compared our model containing both variables with a model that contains only one of the variables, i.e., a baseline model, using the ANOVA test. According to the tests, the *SoC* variable is not significant for the model, while the *driving range* is, with p-value of $4.449e-10$. One reason for those results lies in the fact that those variables are partially related, i.e., lower SoC means lower driving range. The previously described model states that if a participant owns, say, a Nissan Leaf that has battery capacity of 30 kWh, i.e., when full this EV can achieve a driving range of 160 km, and that battery is currently on 15% SoC, i.e., 24 km remaining range, then on average a participant will be willing to travel for additional 5.2 km to reach a charging station regardless of whether it is occupied.

From the results depicted in Figure 5 and in Table III, it is obvious that potential EV owners are more influenced by the remaining range than the SoC regarding the distance they are willing to travel to reach available charging stations. This is the result we expected since at the same state of charge, the remaining driving range can differ for up to 100 km depending on the EV's battery capacity. For example, Mitsubishi MiEV can cover 26 km on a 30% SoC, while Nissan Leaf and Tesla S 85 can cover, respectively, 48 km and more than 100 km on the same SoC. As for the decision to charge, both variables are strong indicators that a participant is most likely willing to charge (90% of the cases) when the remaining SoC is less than 30% or when the remaining range is less than 75 km.

V. Discussion

According to our survey analysis, people are more influenced by the remaining driving range than the state of charge when they have to decide how far they are willing to drive to reach another charging station that may or may not be occupied. This is a positive result since most electric vehicles currently provide an accurate prediction of the remaining driving range. However, state of charge is an important variable in the decision to charge, as our results indicate that people are uncomfortable when their SoC is below 30%.

One can argue that the inconsistent distance perception exhibited by the participants is one limitation with our survey approach. Indeed, some of the participants reported as acceptable distances between chargers greater than 50 km. Some also reported that they are willing to drive all of their remaining range to reach a charging station that may not be available. This observed behavior is expected since some participants are more risk-seeking than others. To solve this issue, as previously mentioned, a few of the aforementioned answers were considered outliers based on their deviation from the mean value and, hence, removed from our analysis. However, although some of the answers have significantly greater value than the corresponding mean, they nonetheless could not be considered outliers. This is natural since the mean distance-to-charger value was primarily dictated by the majority of the participants who are from big cities and, as discussed in Section IV, participants from smaller settlements are expected to drive greater distances between charging stations and, hence, affect mean distance values.

The survey was distributed strategically to attract a diverse set of participants targeting mainly non-EV owners. We have focused on these population because we believe that many EV owners have a charger installed at home, which can drastically affect range anxiety. For example, by being able to charge an EV at home, the scenarios where SoC is less than 20% become unrealistic. Nonetheless, as future work, we do plan to collect opinions from EV owners since some of them might not have the possibility to charge at home, e.g., EV owners who live in residential buildings in large cities. This would allow us to measure how the perceived range anxiety of EV-owners contrast to non-EV owners. Besides the inclusion of EV owners, there is also some room for improvements in our experiments by removing certain survey limitations, e.g., by targeting more participants from a specific settlement. Results about the influence of the population and size of a settlement on range anxiety would then be more precise with a balanced number of participants from each hierarchy level.

VI. Conclusion and Future Work

By providing insights into range anxiety, this research also provides insights into the potential EV owners' preferences regarding charging station infrastructure. In particular, our results allow one to determine how far charging stations should be from each other so as to reduce range anxiety. This in turn can, hopefully, lead to more potential consumers deciding in favor of purchasing an EV, instead of a traditional ICE vehicle. Taking the aforementioned into account, we argue that this research covers the range anxiety phenomenon from three different perspectives - *people*, *profit*, and *environment*.

Using the data collected via the survey described in Section III, we are able to answer both of our research questions introduced in Section I. In particular, potential EV owners do not require a charging station infrastructure as dense as the current gas station infrastructure. Moreover, we are able to infer that there currently are more gas stations than it is needed. However, the survey respondents seem accustomed to the high availability of existing gas stations, and they seem to prefer the distance between two charging stations to be *less than 5 km*. As for the influence of key EV-related variables, *SoC* and *driving range*, we draw the following conclusions: *(i)* SoC has a more meaningful impact on making the decision about whether to charge; and *(ii)* the driving range demonstrates higher influence on the decision about the distance one is willing to travel to reach a charging station.

For future work, we plan to expand the survey participant pool with targeted audience, e.g., by including EV owners in order to compare what constitutes (and what the effects are of) range anxiety from the perspectives of both EV owners and those who do not (yet) own an EV since, as we discussed in Section V, EV owners have, as a consequence of experience, different understanding of key EV parameters. We also plan on incorporating the results presented in this paper on range anxiety modelling into a broader research on the development of a framework for extending the existing EV charging infrastructure, partially described in the work by Pevec et al. [14]. This step is crucial to unlock *smart markets* [34] in the context of the EV ecosystems. Understanding and being able to quantify the range anxiety phenomenon is not only an extremely important prerequisite for realistically modelling *charging station infrastructure planning*, but also a significant component for faster and sustainable EV acceptance in general.

Acknowledgements

The authors acknowledge the support of the Croatian Science Foundation under the grant DOK-2015-10-1777. This research has also been partly supported by the European Regional Development Fund under grants KK.01.1.1.01.0009 (DATACROSS), KK.01.2.1.01.0020 (RASCO-FER-SMART-EV) and KK.01.2.1.01.0077 (bigEVdata).

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