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Analysis of using electric car for urban mobility, perceived satisfaction among university users.

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Abstract

Cities, businesses and governments have recognized the value of Electric Vehicles (EV) in building a cleaner, smarter and more sustainable future. This study is focused on users' perception of EV and its impact on users' mobility.

The main problem EV users report is its limited autonomy compared to Petrol-Fuelled Vehicles (PFV), a factor causing range anxiety to users.

A 3-months experiment has been conducted in the UPM in order to study the academic population. The sample size is 48 people, equally distributed between men and women, students and workers and private car and public transport users. Every user used the EV for a day and was controlled and evaluated through a customized on-line survey, where different aspects were rated on a scale from 1 to 5.

The main outputs of the analysis of results are:

- The general experience of EV drivers has been positive (4,5).
- Lack of noise (4,9), acceleration (4,7) and safety (4,6) are the best rated variables.
- Autonomy (2,8) and autonomy accuracy (3,8) are the worst rated variables.
- 95% of users would pay more for an EV than for a PFV.
- Younger people have a higher average consumption than older people.

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Keywords: electric car; perceived satisfaction; range anxiety

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1. Introduction

Shortly after the Industrial Revolution, the invention of the internal combustion engine and the mass manufacture of automobiles revolutionized the transportation of people and goods (Otto, 1877). Since then, the ease of getting cheap and readily available fuel combined with the affordable price of mass-produced vehicles has radically changed the world we live in and the air we breathe.

The number of cars on earth currently exceeds one billion and is forecasted to reach the two billion mark soon because of the rapidity with which the emerging countries are increasing their car ownership (Sperling and Gordon, 2009). This revolution in the mobility of goods and humans has lead us to a severe addiction to crude oil as more than 90% of transport fuels are derived from this commodity (Sperling and Gordon, 2009).

In addition, the transport sector contribution to greenhouse gas (GHG) emissions has increased from 14,9% in 1990 to 23,2% in 2014 (Eurostat, European Environment Agency), intensifying the unease over the imminent climate change induced by anthropogenic GHG emissions.

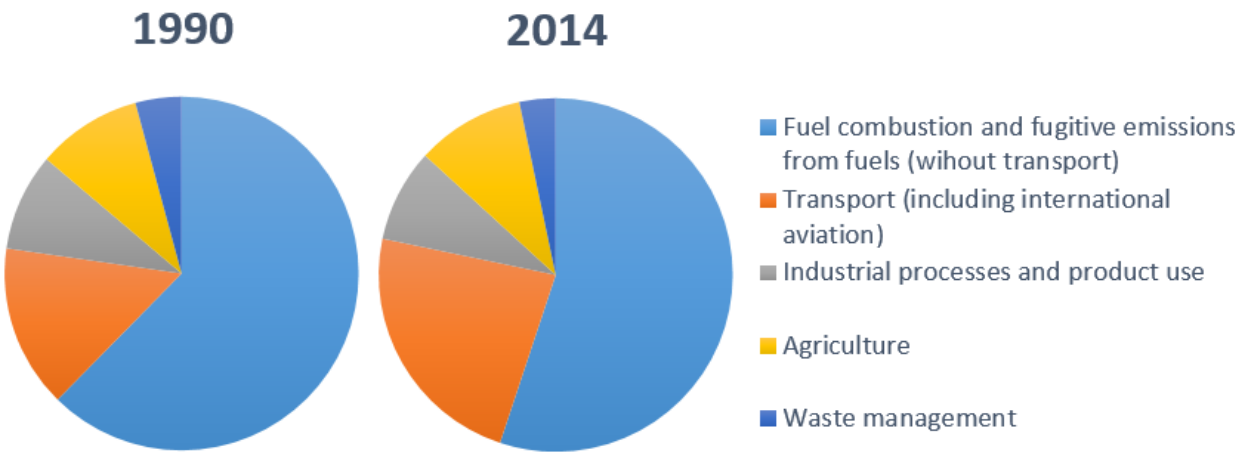

Fig. 1. Greenhouse gas emissions, by source sector, EU-28, 1990 and 2014 (Eurostat, European Environment Agency).

The crude oil addicted transportation culture has hence two main problems. The input problem is the declining fuel supply, since at current demand conventional oil reserves are forecast to run out by 2035 (King 2010). The output problem are, among others, the increasing GHG emissions.

As a matter of fact, temperature levels on the earth's surface have risen by between 0.74 ± 0.18°C over the last 100 years, according to the Intergovernmental Panel on Climate Change and a further increase of between 1.1 and 6.4 °C is likely this century (IPCC, 2007) as the rate of warming doubled (Trenberth, 2007).

This rapid climate change is largely attributable to anthropogenic GHG emissions – carbon dioxide (CO2), methane (CH4), and nitrous oxides (NOx) (Walker and King, 2009).

Technological innovations have the potential to reduce GHG emissions in the transport sector. These innovations include advancement in vehicle design and drivetrain engineering and alternative fuels. A focus should be placed on ways to use our current fuels more efficiently in the short-term while studying the replacement of fossil fuels by renewable energies in the mid and long-term (King 2010).

Given the limitations of oil resources and the aim to reduce CO2-emissions in the transportation sector, battery electric vehicles (BEVs) are regarded as one of the most promising solutions to enhance the sustainability of today's transportation system (King 2010).

The objective of this study is to understand users' perception of BEVs and compare its impact on environment and users' mobility and costs with other conventional transport modes.

2. Context

In July 2016, a collaboration agreement contract was signed between Alphabet, BMW's car renting company, and the Universidad Politécnica de Madrid (UPM) in order for the UPM to participate in Alphabet's mobility forum. This forum deals with citizen's mobility habits with the objective of understanding them and consider this feedback in the design of future mobility products and services. The UPM would help incorporate the academic population feedback, both students and staff, into the forum.

Since Alphabet was promoting the use of BEVs and in particular, its electric car-sharing program, it was interested in studying and better understanding driving habits and e-mobility acceptance and perception of the academic population. In order to do this Alphabet agreed to provide to the *Escuela de Ingenieros de Caminos, Canales y Puertos* (Civil Engineering Faculty) of the UPM a BMW i3 electric car for 3 months for free as well as the installation and service of a charging point in this faculty.

This car would be used by UPM students and workers in order to create data that TRANSyT, the UPM Transport Research Center, would then collect, analyze and exploit, performing thus the experiment that will be hereunder explained.

3. The experiment

3.1. Objective

The experiment was designed to study the perception of the academic population on the battery electric vehicle.

3.2. Methodology

The main idea of the experiment is allowing participants to use the car for one day and then collect data from different sources to conduct the study.

Each participant would pick up the electric car, a BWM i3, in the afternoon, then someone from the experiment staff would explain everything the participant needs to know. A previous e-mail was sent to each participant with a guide on how to use the car and participate on the experiment, so when they came to pick up the car only some specific things should be explained in person, like how to charge and use the car and fill a file card with data from their driving experience provided by the car interface.

Then, the participant could use the car and do as many trips as wanted provided that he didn't deplete the car battery, break the traffic laws and that he brought back the car before 10 am on the following morning.

3.3. Data sources

There are three data sources available for the study:

- Data from the file card filled by each participant with the car's interface data. It includes distance travelled by the user (km), battery charge before and after using the car (%), average speed (km/h) and average electrical consumption (kWh/100km)
- Survey data. A survey hosted in *surveymonkey* is sent to each participant after the driver returns the car, in order for him/her to be able to answer with the maximum accuracy while the experience is fresh. More on this survey will be detailed further on.
- GPS data. A GPS data collector has been implemented on the car in order to collect all the data from the experiment. The basic data collected includes global position coordinates, height and time. From these basic data many new variables can be stemmed. Telematic data from the car cannot be obtained for privacy reasons from the car provider.

3.4. Survey design

A survey was designed during the pilot experiment in order to obtain the necessary data for the study. It was created on the *surveymonkey* platform in a way that it could be sent to the participant's mail just after he returned the car and he could complete both through his smart phone or computer in only 5 minutes while his experience with the e-car was still fresh.

The survey is made of four different parts:

- The participant 's regular transportation experience. This part is made of 4 different questions about the participant's mobility habits and the transportation modes he uses.
- The e-car driving experience. Here are included 6 questions about the use the participant has made of the car and 4 qualitative questions about his experience.
- Car-sharing. This is a declared preferences part of the survey which consists of 3 questions about car-sharing preferences in different hypothetical scenarios.
- Socio-economic data. This last part asks the respondent 6 basic questions about his socio-economic situation.

3.5. Participants profile

In order to be able to study the differences between diverse profiles, the sample is divided by three binary variables:

- Gender (Male / Female)
- Occupation (Student / Worker)
- Regular transport mode (Public / Private)

This make for 8 different profiles, corresponding 6 participants to each profile which totals 48 participants. This is described in the next table.

Table 1. Participants' distribution by profile

Gender	Occupation	Transport mode	Participants
Male	Student	Public	6
Male	Student	Private car	6
Male	Worker	Public	6
Male	Worker	Private car	6
Female	Student	Public	6
Female	Student	Private car	6
Female	Worker	Public	6
Female	Worker	Private car	6

3.6. Car features

The car is a BWM i3 lent by Alphabet with a fully comprehensive insurance covering each user. Its features are as followed:

- Powered by a 170 hp / 130 kW electric motor.
- Sustained by a 22 kWh and 204 kg battery, with a useful capacity of 18,8 kWh.
- With an average consumption of 15 kWh/100km, the autonomy would be of 125km.
- 4 meters long and 1200 kg heavy
- 4 seats, 5 doors

3.7. Hypotheses to be confirmed

From the pilot experiment and the casual interviews made to the participants, the following hypotheses were formulated in order to be tested during the experiment and to be confirmed once the data was gathered and analyzed:

- Men rate their overall satisfaction with the BEV's driving experience higher than women.
- Men are more satisfied with the car's acceleration and safety than women, maybe due to their lower aversion to speed and danger.
- Public transport users rate lower their satisfaction with the car's safety than private transport users.
- Younger people have a higher average consumption than older people due to their lesser experience driving.
- Driving range is the worst rated feature of the car.

4. Experiment results

4.1. Data variance analysis and comparison of means

Participants were asked about their satisfaction with the overall BEV driving experience and with different parts of it. In order to measure their satisfaction a 1 to 5 scale was used. The satisfaction was measured for the following factors:

- Overall experience
- Safety
- Lack of noise
- Acceleration
- Regenerative braking
- Range
- Range forecasting reliability
- On-board computer interface

Differences among the answers to these questions, as well as indicators as average speed and consumption, by different type of respondents (like genre, occupation, age and transport mode) have been studied. The statistically significant differences as well as the tested hypotheses are compiled in the table shown below:

Table 2. Satisfaction on driving BEV. Test-T statistically relevant results (likert scale 1-5)

Variable	Average	St. Dev.	Average	St. Dev.	T-test p-value
	Male		Female		
Overall experience	4,29	0,91	4,75	0,53	0,038
Safety	4,67	0,57	4,46	0,83	0,316
Acceleration	4,75	0,53	4,71	0,55	0,791
Range	2,46	0,88	3,17	1,20	0,025
	PT user		Private Car user		
Safety	4,29	0,86	4,83	0,38	0,007
On-board computer interface	3,83	1,09	4,46	0,78	0,027
How much more would you pay for a BEV than for a PFV?	13,75%	7,70%	18,75%	10,76%	0,071
	Student		Worker		
Consumption (kWh/100km)	17,86	3,34	16,50	2,54	0,134
Regenerative braking	4,18	0,77	4,55	0,51	0,051

4.2. Hypotheses validation

Through the previous analysis, several researcher's initial hypothesis were validated, as follows:

- *"Men rate their overall satisfaction with the BEV's driving experience higher than women."* This hypothesis does not only happen to be false but also the opposite is true, with the T-test showing a statistically significant difference between men and women with regards to their satisfaction with the overall experience.
- *"Men are more satisfied with the car's acceleration and safety than women, maybe due to their lower aversion to speed and danger."* It is true that the results show that male participants are more satisfied in average than the female participants with car's acceleration and safety, but conclusions cannot be drawn since this difference is not statistically significant.
- *"Public transport users rate lower their satisfaction with the car's safety than private transport users."* This hypothesis is confirmed.
- *"Younger people (<30 years old) have a higher average consumption than older people due to their lesser experience driving."* Even though the difference between both groups seems to be significant, this is not confirmed by the T-test, at least with the current sample size.
- *"Driving range is the worst rated feature of the car."* The average rating for the different elements' satisfaction is 4,18, being the 95% confidence interval [4,06;4;29]. The average rating for the battery range is 2,81, with its 95% confidence interval being [2,49;3,13]. Thus, we can conclude that the driving range is not only the worse rated feature but also rated statistically significantly lower than the rest of the features.

4.3. Other findings

Other statistically significant findings besides the previous ones were made. Please, note that a part of this is only the results and interpretation of a stated preference survey and it should be checked with real data on purchase behavior.

- Woman have a higher satisfaction with the battery range than men. While one might think that this is due to the fact that women make shorter trips as the literature shows (Abidemi 2002), in this experiment women performed in average longer trips (17,0 km) than men (15,8 km).
- Private transport users are more satisfied with the driving's on-board computer interface than public-transport users.
- The reliability of the estimated range is one of the worst rated variables (3,8/5 vs. 4,5/5 for general satisfaction). This has already been discussed previously by Neumann and Krems (Neumann 2015), who stated that drivers had difficulty understanding electrical units and the energy consumption of the BEV.
- Private transport users are also willing to pay more for a BEV in relation to a PFV than public transport users, though this difference in the studied sample is not so statistically significant (93% confidence interval). Also, 22/24 private transport users are willing to pay more for a BEV versus 21/24 public transport users, resulting in a 90% of users, similar results are shown in other studies (Prakash 2014). However, further research is needed on this topic, since logic seems to point out that public transport users are more concerned about environmental issues and, hence, the perceived value should be higher for them.
- Older participants (>= 30 years old) show higher satisfaction with the regenerative braking than the younger population (< 30 years old).
- 65% of users have benefited from free unlimited parking in the city center due to driving a zero emissions car. The increased number of BEV in the future could encourage their owners to use the car even when going to the city center.

Other variables have been studied but without statistically significant results. This may be because of the limited size of the population sample, which is 48, and when divided in 2 groups each group is comprised of less than 30 persons. To better perform the study, the sample size will be increased to 112 by June 2017 and the results will be tested again.

5. Conclusions

Some of our preconceptions about the perception of BEV's driving among different profiles in the academic population have been shown in some cases to be actually true while in others cases the complete opposite can be concluded to be true. While a larger sample has to be prepared in order to draw better and more precise conclusions, and this is currently in process, the following points can be concluded:

- Woman have a higher satisfaction both with the overall driving experience and with the battery range than men.
- Private transport users are more satisfied both with the driving's safety and with on-board computer interface than public-transport users.
- Private transport users are also willing to pay more for a BEV in relation to a PFV than public transport users (to be confirmed with bigger sample).
- Older participants (>= 30 years old) have a higher satisfaction with the regenerative braking than the younger population.

The other take away message from this experiment is that clearly the aspect of the BEV that needs to be improved the most to better satisfy drivers is its battery autonomy and the reliability of its estimation. The car from this experiment has a range of 120 km approximately, but it seems that drivers are asking for a bigger range in order to feel more comfortable to perform their daily trips and reduce their range anxiety.

In order to better confirm the conclusions it is necessary to install this experiment with a larger and less biased sample size, which, if possible, the team behind this experiment will hopefully do on the near future.

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