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Expectations Towards Charging Infrastructure as Buying Motive for Electrical Cars

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Abstract. *The use of electric cars has increased in recent years and has an accelerating development. Despite its advantages and growing trends, it still faces the challenge of limited autonomy range of batteries and under developed infrastructure. Both aspects are key factors in the decision of consumers to buy an electric car. In order to do so, consumers have to feel comfortable with the autonomy range of their electric car and the possibility to reload it, by having a well-developed charging stations infrastructure. Our paper deals with the perception of consumers regarding the risks associated with the limited autonomy of cars and expectation towards charging infrastructure. In a quantitative study, we analyze from two perspective the level of consumers' comfort related to the autonomy of their electrical mobility. On the one hand we analyze the different perception related to the autonomy of the electric car. On the other hand, we analyze the expectation towards the infrastructure of charging stations. As expected, consumers feel more comfortable with autonomy ranges of more than 500 kilometers for electric cars. For the charging infrastructure, consumers prefer distances shorter than 50 kilometers between charging stations, in order to feel comfortable.*

Keywords: electric cars, autonomy range, charging stations infrastructure, consumer, sustainable consumption

Introduction

The uptake of electric vehicles has increased in recent years and is now accelerating. It is expected that there will be about 130 million electric vehicles in 2035, which is about 125 million more than in 2022. The infrastructure required to charge these vehicles is estimated at about 65 million charging points, out of which 9 million will be public charging stations, compared to 374,000 existing charging stations in 2022 (Silva et al., 2023; Heinisch et al., 2021). However, in spite of the positive image associated with an environmentally friendly behavior (Cuc et al., 2022; Mecu et al., 2023), the switch to electric cars faces several challenges. Besides the increased price for electrical cars and the long amortization period (Bobeth & Kastner, 2020), there are still some inconveniences related to limited autonomy range of electric cars (Buranelli de Oliveira et al., 2022; Graham-Rowe et al., 2012) as well as the development of charging station infrastructure (Heinisch et al., 2021; Corradi et al., 2023). Having a limited autonomy range as well as long distances between charging stations, can cause a psychological discomfort to drives as there is a frequent need to charge the car in order to avoid the running out of electricity. Depending on the

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mobility needs of each consumer the level of autonomy may vary from one driver to another. In order to measure the level of comfort of consumers with the autonomy range of electric cars, we have tested the attitudes of consumers towards three levels of battery autonomy and three levels of infrastructure development and distances between charging stations. By doing this, we can assess the expectations of drivers towards the optimal development of both battery performances and charging infrastructure, in order for consumers to feel comfortable with the autonomy of their electric cars. The paper starts with a literature review on the challenges of developing charging stations networks as well as the consumer behavior related to the use of electric cars. In the following section the methodology and results are presented. The paper ends with conclusions and implications for the future.

Literature review

Electricity distribution system operators play an important role in this segment and are a crucial factor in the rapid and successful transition to electric cars (Brescia et al., 2023; Corradi et al., 2023). Demand is expected to increase by around 30% per year, which will ultimately lead to an increase of 200 terawatt hours by 2030 (Cerruti et al., 2023). The destabilization of the electricity grids would not be caused by the increase in demand and power supply capacity, but by the simultaneous charging of thousands or millions of electric vehicles that need to be supplied with electricity at the same time (Heinisch et al., 2021; Junquera et al., 2016). Ernst & Young experts have developed an analysis of six usage scenarios for charging electric cars, which would increase the maximum load on the electricity distribution grid between 21% and 90% (G4Media.ro, 2022). Smart grids are seen as the solution for transforming the global energy grid into a local grid (Alam & Krishnamurthy, 2021). As a solution to support distribution grid operators, a managed supply would be a great help and could turn the vulnerability of uncontrolled supply to millions of electric vehicles into a valuable resource (Heinisch et al., 2021). The increasing demand for charging stations and the accelerated installation and development of electricity infrastructure, as well as the increasing penetration of electric vehicles, require extensive cooperation between national and local authorities, distribution network operators, vehicle manufacturers, e-mobility service providers and charging station operators (Corradi et al., 2023). Through this collaboration, the road transport system and electric vehicle infrastructure must be designed to serve all consumers over a long period of time (G4Media.ro, 2022).

Another challenge could be the electrification of petrol stations and their use for charging electric vehicles. Studies show that companies in the petrol station industry have already started to change their business model and revise the concept (Cousins, 2022). By adapting refueling stations, an external network can be developed that has a major impact on the architecture of cities (Cousins, 2022). There are several challenges when setting up the charging infrastructure, including petrol stations. To ensure the best possible operation of the infrastructure, it is necessary to comply with all European regulations. Another challenge is entering the electricity infrastructure market. The market has been changing rapidly recently and it is important that decision-makers act as quickly as possible in order to better position themselves in the electromobility market and make profits in a short period of time. Companies in the petrol station sector must first invest a lot of time, financial resources and expertise to successfully adapt and change their business model in order to offer customers fuel sources for e-mobility (Bobeth & Kastner, 2020).

The utilization of synergies can be a great asset to the existing business model if e-mobility platforms are integrated into the business model. For charging stations to be successful and both

support the transition to e-mobility and not lose customers in the future, they must utilize a strong combination of powerful charging station hardware and intelligent software from the outset to offer customers the best experience (Cousins, 2022). A major challenge in this sector is to ensure a coordinated response between the automotive and energy sectors (Junquera et al., 2016). One challenge for reducing the cost and increasing the performance of electric cars is the inclusion of battery types other than lithium-ion batteries, having an impact on the estimated cost development. Other areas may include recycling, but also accidental damage that needs to be considered. For all these situation standards have to be developed.

Another challenge for electric cars is their range and limited range (Silva et al., 2023; Buranelli de Oliveira et al., 2022; Graham-Rowe et al., 2012). A major challenge for manufacturers is the range of electric vehicles, i.e. the distance the vehicle can travel on a single charge before the battery is fully discharged. This challenge can also be seen as a barrier to the development of electric cars. The range is currently limited until new technical solutions are developed that improve this situation. Many electric cars are not able to drive more than 290 kilometers on a single charge. For consumers who regularly have to travel long distances, range is the most important issue. Many consumers who are concerned about range can in some cases develop a specific form of anxiety, known as range anxiety (Fontainhas et al., 2016; Corradi et al., 2023). The problem arises from the fact that many consumers who travel long distances in conventional fossil fueled vehicles can travel longer distances on a single tank of fuel and have much better refueling infrastructure (Junquera et al., 2016). In addition, the time to refuel is extremely short compared to fully recharging an electric car (Bobeth & Kastner, 2020; Savaia et al., 2020; Graham-Rowe et al., 2012; Junquera et al., 2016; Corradi et al., 2023).

To overcome this major problem for consumers who want to switch from a classic car to an electric car, several solutions are currently being developed. Improving battery capacity, developing and automatically expanding charging stations could significantly help to increase consumer confidence in electric vehicles and enable a faster switch to this type of vehicle (Bobeth & Kastner, 2020; Brescia et al., 2023). Electric cars can be charged at any socket, but the charging speed varies depending on the charger. Charging times are a representative challenge for electric cars. There are three different types of chargers on the market for electric vehicles. In order to make the development of charging infrastructure as efficient as possible and to make the best decision when selecting and installing a charging station, a balance must be made between the needs and convenience of the driver and the cost of installing the charging station (Cerruti et al., 2023; Buranelli de Oliveira et al., 2022; Corradi et al., 2023). Compared to internal combustion engine cars, where all cars can stop at any petrol station to refuel without the need for adaptations to refuel electricity, the use of different types of chargers to power electric cars can be another barrier to the rapid transition and adoption of electric cars (Silva et al., 2023). Another aspect to consider when supplying electric cars with power is the availability of charging infrastructure (Cerruti et al., 2023; Fontaínhas et al., 2016; Corradi et al., 2023). Electric vehicles need to be plugged in to be charged, and many electric vehicle owners typically charge their vehicles in the garage or at home using wall-mounted charging stations. This type of charging is sufficient for a day's use of the vehicle in an urban environment (Buranelli de Oliveira et al., 2022; Fontaínhas et al., 2016; Corradi et al., 2023). For owners of electric cars who live in flats, difficulties arise as car parks in apartment blocks can rarely provide a charging infrastructure and the installation of charging stations is associated with considerable costs (Brescia et al., 2023). Additional costs come from the high energy consumption associated with charging vehicles at shared outlets, so building managers will need to have mechanisms in place to monitor electric vehicle charging so that the driver of each

vehicle pays for the used electricity (Brescia et al., 2023). Vehicle price can be seen as an important factor in the decision between electric cars and fossil fuel cars. Electric cars are more expensive than petrol cars. The higher price is due to the materials used and the complex processes involved in manufacturing the batteries (Bobeth & Kastner, 2020). Even though the long-term savings are considerable, the purchase price of an electric car is still important, and in order to compete with classic cars, affordable and perhaps even comparable purchase prices are needed to encourage buyers to switch to electric cars more quickly.

Methodology

The objective of our research is to determine the optimal battery autonomy and charging infrastructure in order to make the consumer feel comfortable when driving an electric car. An online survey has been developed in order to measure the comfort levels of respondents to different autonomy levels of electric cars as well as the distances between charging stations. The scale for the applied questions in the survey ranged from 1 to 7, with 1 indicating complete agreement and 7 indicating complete disagreement. The survey was completed by a sample of 202 people, while 3 people did not answer the questionnaire completely. Responses were collected from people of different ages and incomes, as well as from car owners and non-car owners. The questionnaire also aimed to obtain information on consumers' willingness to switch to electric cars. It was structured in order to better understand consumer behavior and to find out which advantages and disadvantages could persuade consumers to switch to an electric car. In our analysis we compared the perceptions of consumers younger and older than 30 years. The sample consisted of 202 respondents. There were 86 respondents younger than 30 years and 116 respondents older than 30 years. Using the T-test, we were able to determine whether there was a difference between the two age categories. This analysis is important to identify the age categories which feel more comfortable with the autonomy range of both electric cars and charging infrastructure. The probability to switch to electric cars depends on the comfort level of using it.

Results and discussions

The first analysis refers to the autonomy of the battery of an electric car. For three different rages we have measured both the sufficiency and psychological comfort of using an electric car. The first question in this category aimed to determine consumer perception regarding the sufficiency of an autonomy range of up to 100 kilometers. A large proportion of the answers were on the scale between 4 and 7, which means that the respondents tend to want more autonomy. To analyze the data, we conducted T-tests for the two groups of respondents. The first group aged up to 30 years obtained an average of 4.686 and the average obtained for people over 30 years was 4.344. The T-test value of 0.189 shows that the choices of the two groups do not differ in a significant way and that there is no difference in the propensity to consume between the two groups.

A second question refers to the sufficiency related to a battery autonomy range of 100-500 km. The majority of respondents were neutral on this question and tended to answer in the positive range on the scale, with answers between 4 and 1. The average obtained for the under 30 age group was 3.647 and the average obtained for the over 30 age group was 3.722. The T-test value of 0.735 shows that the two groups of respondents have similar tendencies and there are no differences between them. Again, it shows that there is no difference between the two categories of respondents and that the consumption tendencies and the willingness to switch to an electric car do not differ

between the two groups when it comes to using a vehicle with a range between 100 and 500 kilometers to use an electric car.

The next question referred to the sufficiency of a battery autonomy range of more than 500 km. In the case of this question the average result was 2.848 for the under 30 age group and 3.042 for the over 30 age group. The T-test value obtained for this question was 0.445, which shows that there are no differences between the two groups. The proportion of answers from the two groups of respondents is evenly distributed, which shows that there are no differences in the tendency of consumers to use an electric car if the electric car can offer a range of more than 500 kilometers. Respondents choose an electric car according to their needs and not according to age. These results can be observed in table 1.

Table 1. Evaluations of autonomy range for electric cars

Question	Average for consumers younger than 30 years	Average for consumers older than 30 years	T-test
I believe that a range of 1-100 km would be sufficient for an electric car.	4.686	4.344	0.189
I believe that a range of 100-500 km would be sufficient for an electric car.	3.647	3.722	0.735
I believe that a range of over 500 kilometers is sufficient to use an electric car.	2.848	3.042	0.445
I find that a range of less than 100 kilometers gives me psychologically comfort of using an electric car.	4.779	4.184	0.027
I find that a range of 100-500 km gives me the psychologically comfort of using an electric car.	3.662	3.923	0.240
I find that a range of more than 500 kilometers gives me the psychologically comfort of using an electric car.	2.511	2.983	0.061

Source: Authors' own research

The next questions refer to the level of comfort associated to the different autonomy ranges of car batteries. The first question intends to determine the psychological comfort level of the consumer to use an electric car with a range of less than 100 kilometers. The majority of responses disagreed with this statement having responses between 4 and 7 on the proposed scale. The respondents with ages under 30 years obtained an average of 4.779, and the group of respondents with ages over 30 years had an average of 4.184. In this situation, the average response was higher among respondents under the age of 30, as they agree less with this statement. From a psychological point of view, people younger than 30 feel less comfortable than people older than 30 years with this autonomy range. As a result, younger consumers are more susceptible towards a range of more than 100 kilometers, while people older than 30 years feel psychologically more comfortable and are more willing to use an electric vehicle with a range of less than 100 kilometers. The T-test has a significant value of 0.027, showing that the two groups perceive in different ways the level of comfort with the battery autonomy. It can be seen that there is a significant difference in the propensity and willingness of consumers to use an electric car with a range of less than 100 kilometers in relation to the differences between the two age categories.

The next question refers to the comfort level with an autonomy level between 100 and 500 kilometers. Most respondents answered with 4-neutral and 3-plus agreement, showing a higher comfort with this autonomy range. For people younger than 30 years old the average was 3.662 and for people older than 30 years the average was 3.923. The T-test value of 0.2404 showed no significant differences between the groups. The tendencies of the two consumer categories do not differ, so that no difference can be made between the tendencies of consumers in terms of

psychological comfort when using an electric car with a range between 100 and 500 kilometers. In contrast to the answers to the previous question, the answers to this question were balanced and there was no difference in the distribution of answers.

The last question referred contains information about the mental comfort of the consumer with autonomy ranges of more than 500 kilometers. The majority of responses in this case were 1 and 2, with more than half of the respondents agreeing or strongly agreeing with the psychological comfort of using an electric car with a range of more than 500 kilometers. The average obtained in this case was 2.511 for people younger than 30 years and 2.983 for people older than 30 years. The T-test showed an acceptable value of 0.061. In this case, it appears that there is an acceptable difference between the two groups of people. The group of people younger than 30 year had a lower average value of responses, showing that they feel psychologically more comfortable in using electric cars with a range of more than 500 kilometers. This response rate and the result of the T-test could also mean that young people would be more willing to switch to electric cars and that a range of more than 500 kilometers would be enough to give them the psychological confidence to use an electric car.

The next questions refer to the development of charging infrastructure for electrical cars. In order to determine the optimum level, we have measured the level of comfort for different distances. The first question refers to a charging infrastructure with distances lower than 50 km between stations. The majority of responses to this question were between 4 and 1, indicating that the questionnaire participants rated this question favorably. The purpose of this question was to determine whether a distance of less than 50 kilometers between charging stations is acceptable for users to feel comfortable for using an electric car. For the group of persons younger than 30 years the average was 2.895, while for persons older than 30 years the average was 3.462. The T-test has a value of 0.012, which is highly significant. According to this result, a significant difference can be found between the two categories of respondents. According to the T-test analysis, it can be seen that the group of respondents younger than 30 years agree more with this statement, which can be related to the fact that respondents in this category are more willing to use electric cars. They can easily make the switch to electric cars, and they are also more concerned about a shorter charging stations distance because respondents in this category would travel long distances in an electric car without running out of range and being stranded. On the other hand, people older than 30, might feel less comfortable with such a distance because they would use electric cars for a shorter distance. They might be more cautious about range due to their experience and age and therefore feel less comfortable than the younger respondents.

The next question aims to identify consumer tendencies related to the mental comfort when using electric cars in situations where charging stations should be located less than 150 kilometers away. The average obtained for the age group younger than 30 years is 3.882, while the average obtained for people older than 30 years is 4.025. The result of the T-test of 0.549 shows that the difference between the distribution of the two groups is only slight and that there are no significant differences between the two groups. The tendencies of the two groups of respondents do not differ. In contrast to the previous question, where a significant difference between the groups could be observed, in the case of infrastructure distances between 50 and 150 km, there is no difference in the level of comfort between groups. In summary, it can be said that there is no difference in psychological well-being between the two age groups in relation to the location of charging stations less than 150 kilometers away. These results can be observed in table 2.

Table 2. Evaluations of infrastructure development for the use of electric cars

Question	Average for consumers younger than 30 years	Average for consumers older than 30 years	T-test
I think that the minimum distance between charging stations should be 50 kilometers in order to feel comfortable using electric cars.	2.895	3.462	0.012
I think that the minimum distance between charging stations should be less than 150 kilometers in order to feel comfortable using electric cars.	3.882	4.025	0.549
I think that the minimum distance between charging stations should be less than 300 kilometers in order to feel comfortable with electric cars.	4.906	4.117	0.006
Do you think that petrol stations should also be equipped with charging stations for electric cars?	2.941	3.226	0.250

Source: Authors' own research

The last question refers to the level of comfort related with distances shorter than 300 km between charging stations. The highest proportion of responses was the answer with the number 7, meaning complete rejection. The group of respondents younger than 30 years had an average response rate of 4.906 and respondents older than 30 years had an average response rate of 4.117. The T-test value of 0.0063 shows a highly significant results and represents the large difference between the tendencies of the two groups. It is very easy to see the difference between consumers' willingness to use an electric car and the psychological comfort consumers may have in using an electric car when charging stations are less than 300 kilometers away. In this case, it can be seen that respondents younger than 30 years have a higher level of psychological discomfort than people older than 30 years. This could also be due to the fact that younger people are more willing to use electric cars and therefore the level of psychological discomfort is lower when the charging stations are so far away when using an electric car. In contrast, the group of respondents older than 30 years would not feel as uncomfortable in the situation of using an electric car, probably because in a situation where charging stations are less than 300 kilometers away, they would prefer to use a fossil fuel powered car and would be far less willing to use an electric car.

A final question refers to the situation where petrol stations should also be equipped with charging stations for electric cars. The majority of responses had values between 1 to 3, showing that consumers agree that petrol stations should also be equipped with charging stations for electric cars. The average response value for people younger than 30 was 2.941, while the average response value for people older than 30 was 3.226. The result of the T-test analysis is 0.250 and shows that there is very little difference in the distribution of responses between the two groups. This shows that there is no difference between the preference of consumers to have petrol stations equipped with charging stations for electric cars. The mean value of the answers of the two groups is close to each other and it seems that both groups are more in favor of equipping petrol stations with charging stations for electric cars. The result of this question suggests that petrol stations equipped with charging stations for electric cars make consumers feel more comfortable when they know that charging stations are available at petrol stations.

Conclusion

The results of our research show that consumers expect and feel more comfortable with both higher autonomy ranges of batteries and charging stations infrastructure. It is interesting to observe that the group segment younger than 30 years is the one to feel more comfortable with both an autonomy

range of batteries of more than 500 km and charging stations infrastructures with distances smaller than 300 km. This shows that for them these values are enough in order to use and opt for an electric car. The level of comfort of the age segment older than 30 years is lower, showing that they have higher demands from both the autonomy range of electric cars and charging infrastructure. These results show that there are still improvements that have to be made in both directions, in order to facilitate the trend towards electric cars.

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