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What are the drivers and barriers for Smart Charging acceptance and willingness to pay in Belgium?

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Summary

Electric vehicle (EV) mass adoption will bring its challenges for the electric grid such as congestion, imbalances and peak loads. Smart charging might provide a solution by shifting charging times to balance the load on the grid. This study investigates what the acceptance, intention to use and willingness to pay is of Belgian EV drivers for smart charging, prior to exposure to the technology. A survey was conducted, collecting responses of 120 EV drivers. The results indicate that financial incentives might be a driver for participation to smart charging applications, while range anxiety still seems to be a barrier and limiting the willingness to provide flexibility in their charging .

Keywords: user behaviour, user acceptance, willingness-to-pay, charging, smart charging

1 Introduction

With the expected increasing adoption of electric vehicles (EVs) in the coming years, a large number of EVs will be charging simultaneously. Uncontrolled charging of a large number of EVs can induce negative effects in the grid such as congestion, imbalances, and peaks [1]. Smart charging is seen as a good solution for this problem [2] as it provides a solution to these threats and enables to control the charging process to avoid peaks [3].

Given the importance of smart charging in case of mass EV adoption, it is also important to investigate what facilitates the EV driver acceptance of smart charging. Existing literature highlights different drivers for smart charging. Firstly, ecological motivations seem to encourage the EV drivers to participate, mainly with the objective to shift charging times to optimise renewable energy use [4]-[8]. A complementary motivation is to help stabilise the electric grid [4][6]. Finally, also financial incentives to participate are seen as an important driver [6]-[8]. Next to these drivers, range anxiety is identified as a barrier, mainly as a desire to have control over the charging process [9] and expressing the need of a guaranteed minimum range (especially for flexible mobility needs) [4][5][9].

This study aims at getting a concrete picture of what existing Belgian EV drivers know about smart charging and what they expect from the technology, specifically regarding acceptance, intention to use and willingness to pay (WTP).

2 Methodology

This research is mainly based on obtaining new insights through surveys. Based on the existing knowledge gaps on charging behaviour and attitudes towards smart charging, a survey was drafted to question EV-drivers. The survey was conducted in October-November of 2020. The survey consisted of socio-demographic information, and mobility behaviour as well as charging behaviour to establish a baseline identification of driver types. These driver types will later allow to segment the respondent population and analyse behaviour and attitudinal differences between population segments. The survey further contained a series of questions with respect to the knowledge and interest into the technology, as well as intention to use, which served to establish the general attitudes towards the technology. The WTP was queried by asking relative price requirements for the different charging modes (i.e. uncontrolled versus smart charging) in the given scenarios. The scenarios served to confront respondents with different concrete situations and capture the sensitivity of their flexibility offered for smart charging. Due to the complex and technical nature of the subject, a draft survey was first tested with a limited sample of respondents in the form of questionnaires guided by an expert. This allowed to identify inconsistencies in interpretation of the questions and finetune formulations for a non-expert audience. The total sample size consisted of 120 out of 162 respondents eligible for data-analysis by correct and complete completion of the survey. Descriptive statistics detail the knowledge and intention to use smart charging of the sample. Drivers and barriers are visualised by a plot of their Likert scales. Further in-depth analysis of determinants for the smart charging attitudes (WTP and user acceptance qualitative indicators) and smart charging preferences (quantified smart charging scenarios) follows. The sample was segmented based on respondent preferences profiles, namely, ownership of the EV.

3 Results

3.1 Demographics & baseline charging behaviour

The average surveyed EV-driver is a middle aged, educated, full time employed man, with a company car as EV (mainly BEV), living in a house with a partner and children and an average monthly household income between 3.000-4.900 euros. Out of the 120 respondents, 107 (89%) indicated they drive a battery electric vehicle (BEV), whereas 8 (7%) respondents drive a plugin-hybrid electric vehicle (PHEV). Also, 5 (4%) respondents drive an electric vehicle with a range extender. With this distribution, the average battery capacity lies between 61 kWh and 70 kWh as can be seen in Figure 1 (left). Furthermore, the majority of the respondents (83%) has a charging station at home. In regards to charging habits, results in Figure 1 (right) indicate that respondents tend to charge their EV most frequently at home with 26% of the respondents charging their EV on a daily basis at home while 40% does so several times a week. Home charging is followed by charging at the workplace, where 52% of the respondents indicate that they charge at least several days a week; nevertheless 19% of the respondents indicate to never charge at work. Public charging comes in a close third, with a slightly lower occurrence for public fast charging.

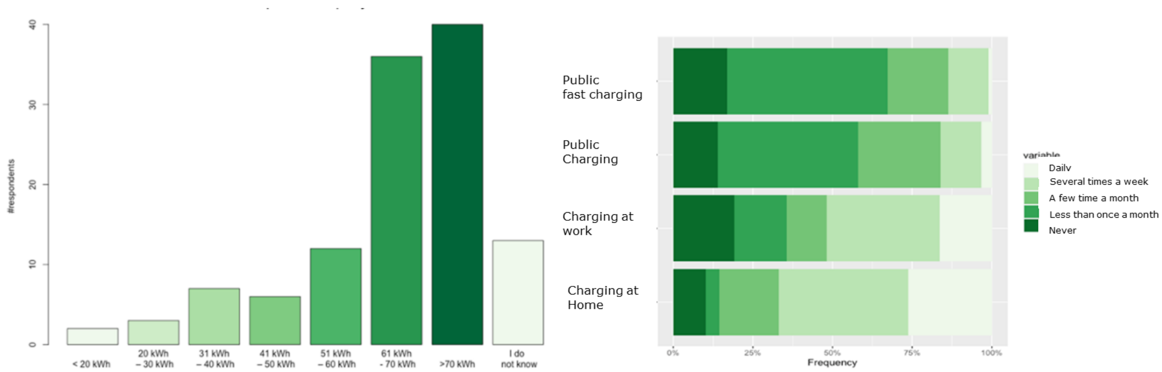

Figure 1 Respondents' BEV battery capacity (left) and charging frequency per location (right)

When asked about the triggers for charging, the large majority of respondents is in agreement with charging when their EV's State of Charge (SoC) falls below a certain threshold (82%); this is based on an estimation of the desired SoC for their next trip (73%). Other tiggers questioned, such as the link to the place of charging or daily routine, are more balanced between agree and disagree within the population, as can be seen in Figure 2. Figure 2 depicts the agreement within the population on the triggers for charging where the different colours represent the agreement level on a Likert scale (1-7).

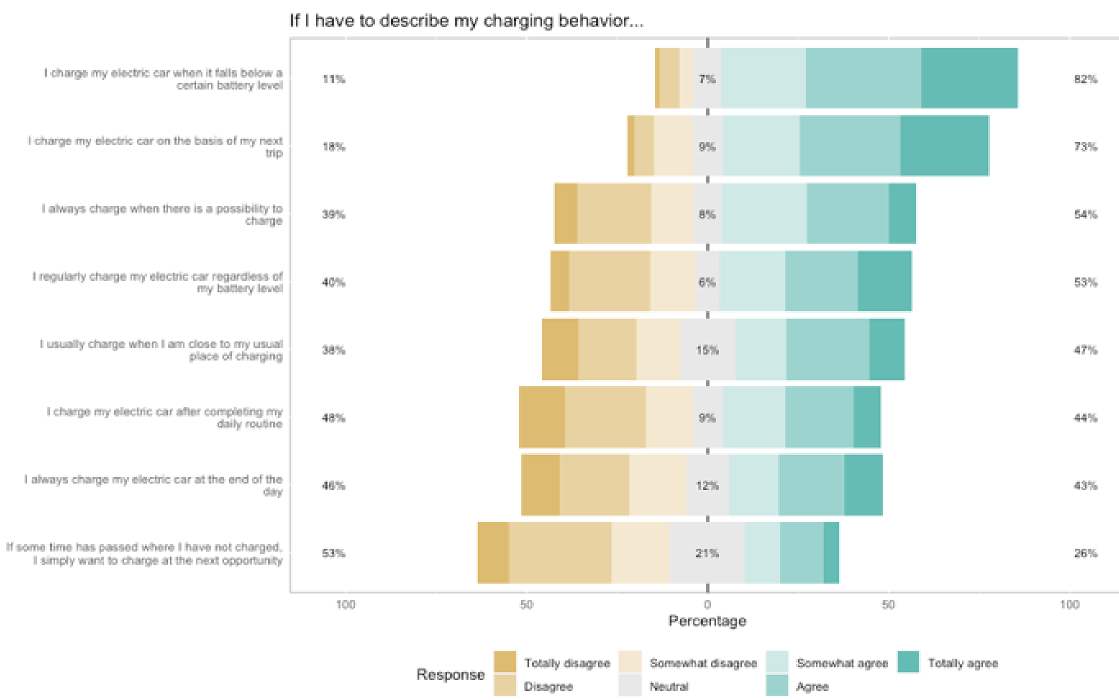

Figure 2 Triggers for charging among respondents

Respondents furthermore indicate that, when charging, their minimum target SoC (Figure 3 left) and desired SOC (Figure 3 right) are mostly based on their distance from home or a fixed percentage for emergencies. The minimum target SoC is hereby defined as the SoC level the driver wants to reach as fast as possible (with the maximum available power) and the desired SoC as the SoC level that can be achieved just prior to departure. The difference between these SoC values is a measure for the potential for fast charging as it is during that part of a charging session that power levels can be set flexible. The very similar values for both minimum SoC and desired

SoC seem to indicate the respondents' limited openness to smart charging as the same factors seem to influence almost equally both SoC levels. Moreover, a high percentage of respondents set their desired SoC level on either a threshold percentage for an emergency (65%) or a full battery for an emergency (47%), leaving respectively limited space (depending on the battery capacity) and no space for smart charging. However, on a closer look on the change in percentage between the minimum and desired SoC for these categories, a significant drop of 9% (from 74% to 65%) can be observed for the need of fixed battery percentage in case of emergency, while an increase of 13% (34% to 47%) is noticed for the need of a full battery. At the same time the requirements of the presence of a fast charger drops as well by 10% (56% to 46%). This indicates a significant part of the respondents do indeed differentiate between what they "need as soon as possible" (=minimum SoC) and "need later" (=desired SoC), opening up a window for smart charging, and the presence of a fast charger can be of influence.

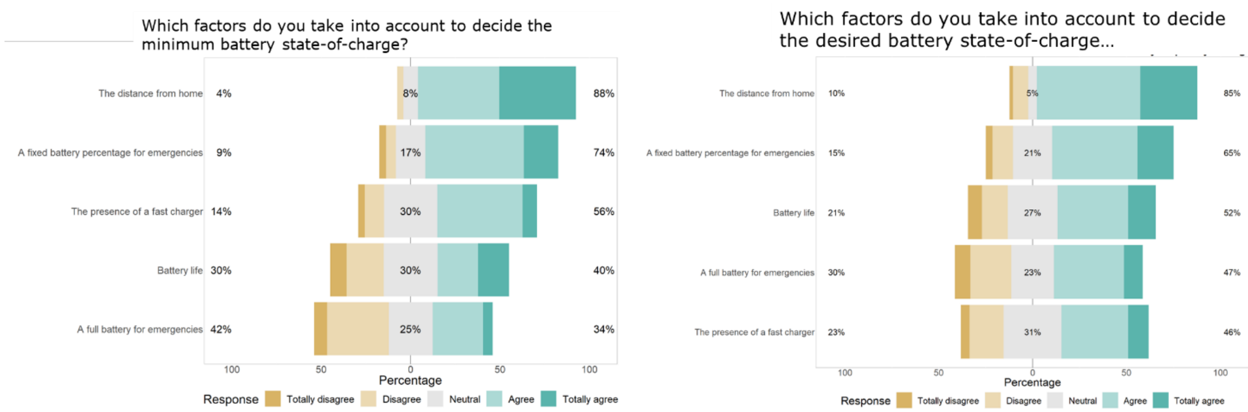

Figure 3: Factors taken into account concerning minimum (left) and desired (right) SoC.

3.2 The concept of smart charging and its drivers & barriers

Smart charging has been defined in the survey of this research as the "flexible charging of electric vehicles where the time and speed of the charging is controlled by an operator to achieve a secondary objective (such as cost reduction, reducing grid lad, or maximizing use of sustainable electricity) while guaranteeing the wanted driving range at the foreseen moment of departure". Most of the respondents (86%) indicated to be familiar with smart charging and 76% of the respondents to be currently interested in using smart charging. However, Figure 4 shows that the intention to use smart charging in the next two years is mixed, as only 26% of the respondents have the intention to use smart charging frequently within 2 years (score 8 to 10). On the other hand, 27% of the respondents have very little intention to use smart charging within two years (score 0-2). Factors that significantly correlate with the intention to use are whether the driver has a company vehicle and his frequency of charging at public charging infrastructure or at home.

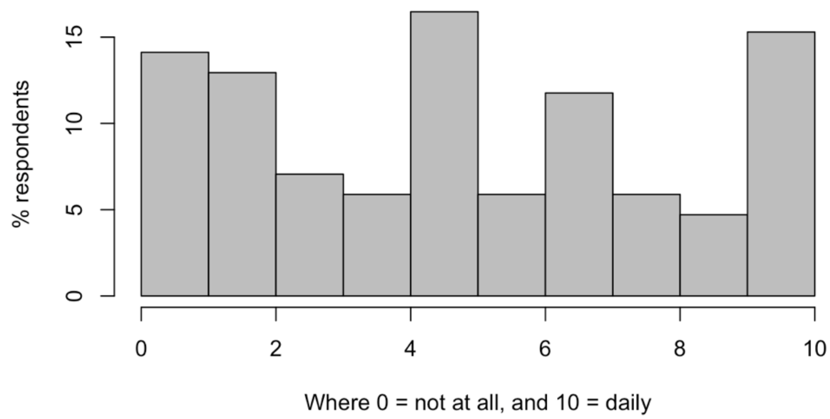

Figure 4: Intention to use smart charging within 2 years

The most important drivers for choosing smart charging are mainly price related, as noticeable in Figure 5. However, only the driver "receiving an annual bonus" significantly correlates with the intention to use smart charging within 2 years.

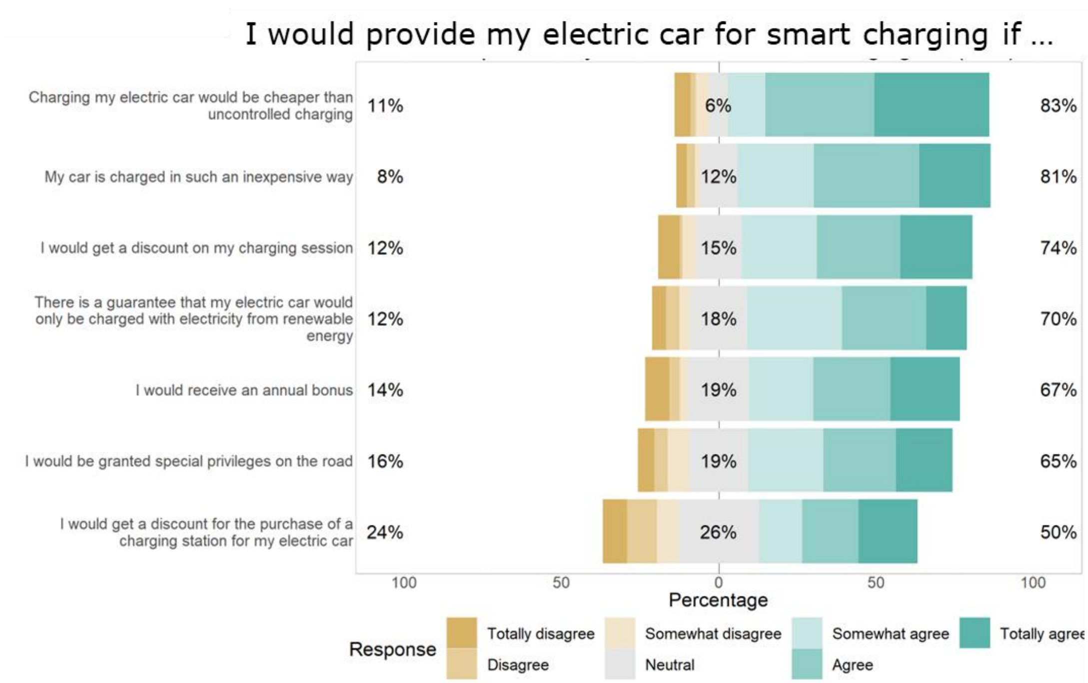

Figure 5 Drivers for providing the car for smart charging

Figure 6 shows that the barriers of smart charging are mainly charging uncertainty and the problem of not being in control. Overall, most of the respondents seem confident they will not be negatively impacted by smart charging. About one third of the respondents would be afraid that the battery will not be sufficiently charged after a smart charging session to continue a car journey. The barriers "I would feel limited in my freedom and independence", "I would be afraid that the battery would not be sufficiently charged if I wanted to start a car journey", "My journeys are not predictable enough to give up my car for smart-charging", "The distances I have to travel are too long" show a significant negative correlation with the intention to use smart charging within two years.

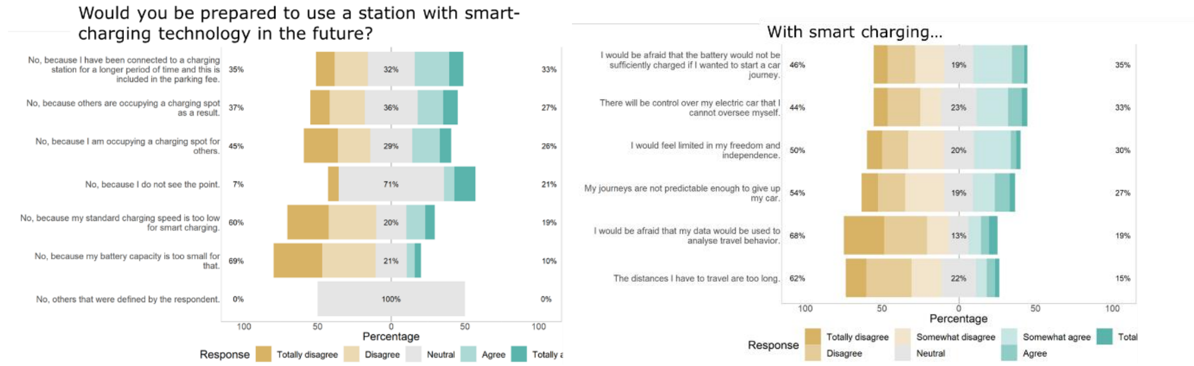

Figure 6: Barriers for providing the car for smart charging

3.3 Charging scenarios

In order to quantify the flexibility which respondents exert with respect to smart charging in different situations, they were presented with 2 charging scenarios which consist of a charging location, a current remaining SoC capacity, a time period until the departure to the next meeting and the required battery SoC to reach the destination. Respondents were given the possibility to skip the scenario if they felt it did not apply to them. The scenarios were drafted by expert knowledge to be able to see whether location, remaining time period or SoC values affected the desired and minimum SoC requirements from the respondents. Respondents were informed that in any case, the desired SoC was guaranteed prior to departure. An overview of the scenario parameters is shown in Table 1The distributions of the desired and minimum SoC as replied by respondents on scenario 1 and scenario 2 is shown in Figure 7.

Table 1 Overview of the scenario parameters for the 3 charging scenarios for smart charging

Scenario (n= number of respondents)	**Location**	**Current battery SoC**	**Needed SoC**	**Period until departure**
1 (n=109)	Work	20%	80%	8h
2 (n=63)	Home	20%	75%	Next morning

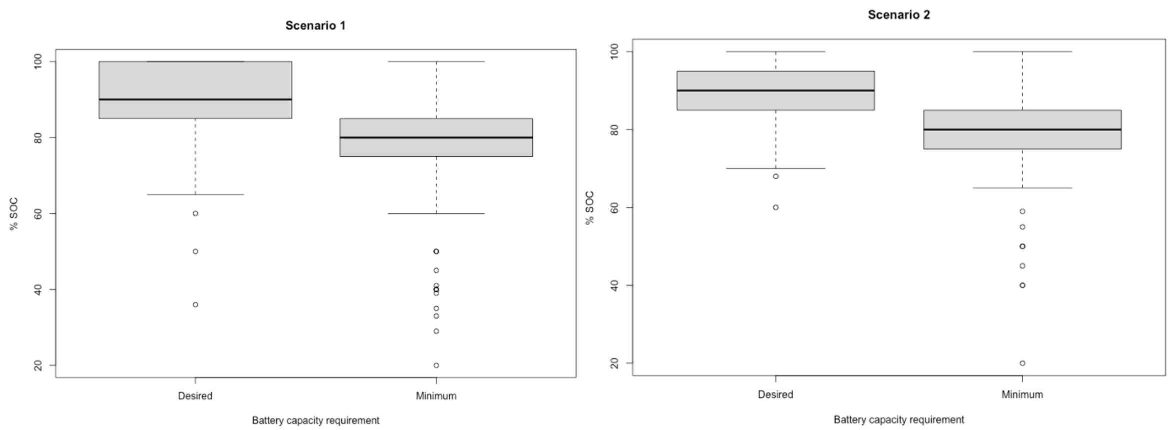

Figure 7 Distribution of the desired and minimum SoC as replied by respondents on scenario 1 and scenario 2

The results show very similar preferences (distributions) in both scenarios where the average minimum SoC is around 80% and average desired SoC around 90%. This leaves little room for flexible charging. The location and ample time until departure does not seem to impact the preferences. The survey also contained additional scenarios generated per driver based on prior answers but requires analysing these results by zooming into individual drivers and is not yet included in this study. These observations also seem to indicate a specific elaborate survey with many scenarios to single out determinants for the minimum and desired SoC seem to be a good approach for further study. Due to time constraints on the respondent willingness to participate in a survey, this was not fully included here.

3.4 Willingness-to-pay for smart charging

The willingness-to-pay for smart charging is investigated by using the price sensitivity of respondents to the location for charging (home, public, work) and type of charging (uncontrolled and flexible). Uncontrolled charging at home thereby serves as the baseline price set to a fictional value of 100 price units per kWh. **Error! Reference source not found.** (left) shows the impact of the location on the WTP for uncontrolled charging at 3 different locations. The respondents evaluate that an uncontrolled public charging session can be on average 15% (median = 20%) more expensive, while an uncontrolled charging session at work should be on average 36% cheaper (median = -20%). Some respondents indicate that charging at work should be free of charge.

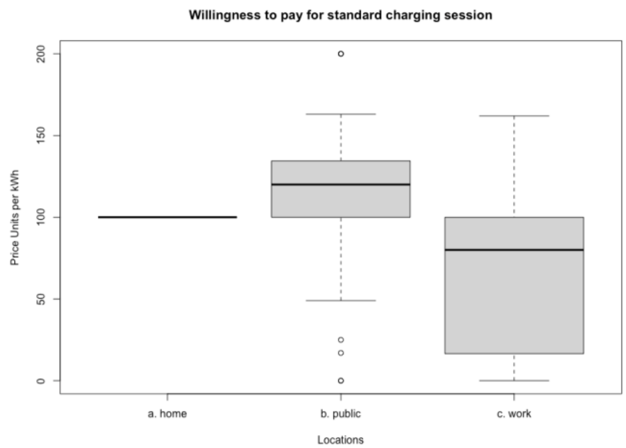

Figure 8 Boxplots for the WTP for uncontrolled charging session in the public and workplace as compared to the baseline of home charging

Now a comparison can be made between the prices that respondents are willing to pay for smart charging at the different locations compared to the uncontrolled home charging baseline price. Table 2 provides an overview of the relative price deviations as a measure for the WTP. Overall, the respondents expect to pay less for flexible charging than for uncontrolled charging at home. The respondents want to pay on average 32% less for flexible charging at work, 19% less for a flexible charging at home, and 4% less for flexible charging on public infrastructure compared to the baseline price of standard (uncontrolled) charging at home. Respondents without home charger seem less willing to pay for public flexible charging (-11%), while respondents with no interest in smart charging expect to pay much less at work (-41%). The WTP for flexible public charging is never significantly different than for uncontrolled charging at home, suggesting that an equivalent price would be acceptable.

Table 2: WTP for flexible charging at specific locations relative to the WTP for uncontrolled charging at home

Respondent profiles	**Home**		**Public**		**Work**	
	Mean	**Sd.**	**Mean**	**Sd.**	**Mean**	**Sd.**
All respondents (n = 93)	*-19%**	*20%*	*-4%*	*27%*	*-32%**	*34%*
Company car (n = 66)	-21%*	21%	-5%	26%	-33%*	32%
Private car (n = 19)	-15%*	15%	-1%	30%	-29%*	40%
Home charger (n = 59)	-16%*	17%	0%	26%	-30%*	31%
No home charger (n = 17)	-26%*	26%	-11%	30%	-36%*	41%
Interest smart charging (n = 67)	-19%*	18%	-4%	27%	-33%*	34%
No interest smart charging (n = 11)	-27%*	34%	-7%	31%	-41%*	31%
More intention to use smart charging (n = 47)	-17%*	17%	-3%	28%	-28%*	34%
Less intention to use smart charging (n = 30)	-19%*	19%	-6%	28%	-35%*	29%

* p-value < 0,05 for diference with uncontrolled home charging

Additionally, the question was raised if the WTP would depend on the motives of the charging operator, namely if the charging operator aims at a reduction of the load on the electricity network or if the charging manager strives at the use of 100% renewable energy. Figure 9 shows that respondents are less willing to pay (-10% on average) if the aim of the charging manager is to reduce the load on the electric grid. No real price difference can be noticed between flexible charging in public, not knowing the aim, and flexible charging striving towards 100% renewable energy. These observations are in line with fact that price and sustainability were the biggest drivers of respondents for adopting smart charging.

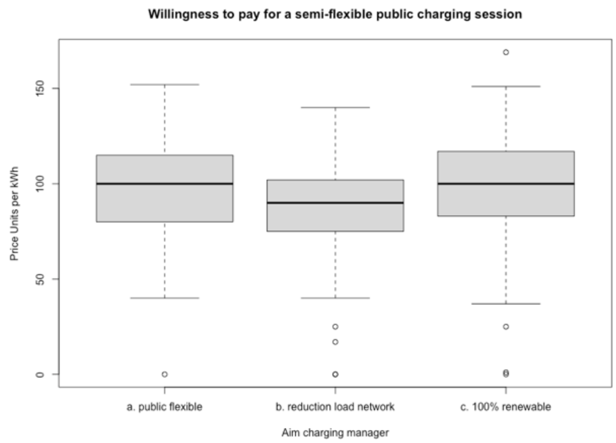

Figure 9 Willingness to pay for a flexible charging session in function of the charging operator's objective

On the question whether drivers would buy a smart charger for their home, cost savings and use of renewable energy are considered most important and more important than avoiding risk of overloading the home network. This might be indicating users are not aware of the consequences of overloading the home network.

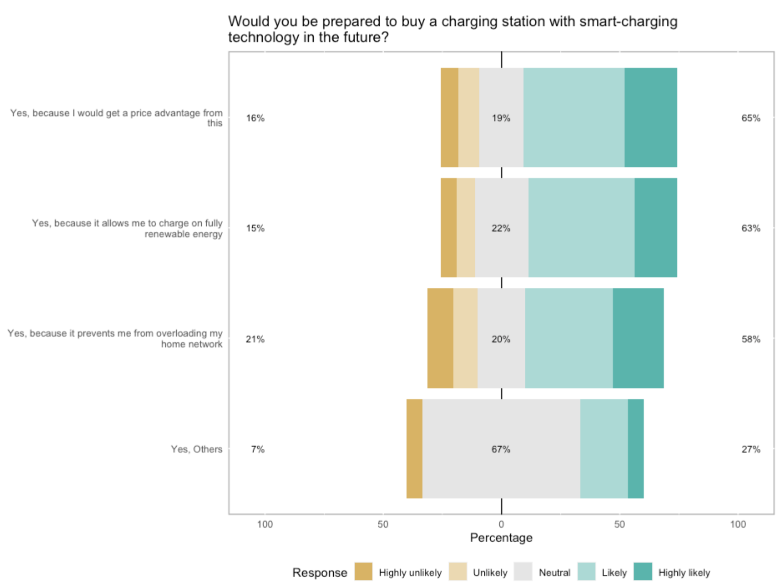

Figure 10 Willingness to invest in smart charger for home charging

3.5 Differences between user population segments

Within the test population, many segmentations based on respondent characteristics could be investigated in-depth as they might have different attitudes with regards to charging behaviour. However, considering the sample size and objectives of the paper, this is considered beyond the scope of this study. Nevertheless, since price and location have demonstrated to be important aspects in the charging attitudes of the respondents in this study we do present the main observations when segmenting according to car ownership (private Vs. company car. Privately owned vehicles tend to have smaller batteries, charge most commonly at home and on public infrastructure, and are generally more susceptible to price aspects and are slightly less open to smart charging, though their relation to its drivers and barriers is virtually the same.

4 Discussion

While this study presents very interesting insights with regards to attitudes and WTP of EV drivers towards smart charging prior to exposure to this technology (as it was virtually non-existent), it does not necessarily translate to their actual behaviour if presented in real-world. As a follow-up of this study, real-life smart charging data will be gathered in combination with conducting surveys to validate the results of this paper or observe any changes in attitudes after exposure. Moreover, this study was conducted in end of 2020 and therefore respondents can still be considered early adopters where major barriers were still the availability of charging infrastructure and range anxiety, rather than security of electricity supply and electricity price. With EV adoption uptake and the current issues on the energy crisis, challenges and attitudes might change under the changing context. Another important parameter in this are the average driving ranges (battery capacities) of the EVs on the market which will relate differently to the daily driven distances and by that affect the minimum and desired SoC levels of drivers.

5 Conclusions

The goal of this study is to shed light on factors that influence the acceptance and intention to use and the willingness-to-pay (WTP) for smart charging of the Belgian electrical vehicle (EV) driver. The study establishes a baseline of charging behaviour and WTP for standard (uncontrolled) charging. Drivers charged mostly at home, followed by work place and public (to work place and public inverse for the segment of privately owned cars). Respondents indicate charging at work should be cheaper (-36% on average) and can accept more expensive prices for public charging (+15% on average) in comparison to the price paid at home.

Three quarters of the respondents are interested in smart charging, but respondents differ on the intention to use smart charging within two years. Financial incentives are the most popular compensations for using smart charging, with an annual bonus correlating significantly with the intention to use. These results are in line with the literature [4-9] and suggest that charging managers should propose a form of financial compensation (i.e. annual bonus) to the participants of their smart charging applications, while also avoiding systems that do not allow flexibility. Additionally, most respondents do not think they will be negatively impacted by smart charging. However, barriers related to range anxiety (mainly for flexibility reasons) have a significant negative correlation with the intention to use. The average respondent expects to pay less for smart charging compared to the baseline price of standard (uncontrolled) charging at home with a reduction of 36%, 19%, and 4% for smart charging at work, at home and on public infrastructure respectively. This again suggests that the EV drivers expect some financial compensation for their participation in smart charging schemes. The reason for smart charging (reducing grid loads, using renewable energy), while being important in drivers attitude towards smart charging, has little to no influence on the price expectancy.

When presented with several charging scenarios with different SoC levels and stay durations, drivers demonstrate quite conservative behaviour where the minimum SoC is close to the desired SoC, indicating only limited part of the battery capacity can be used in a flexible way for smart charging, which is in line with the observation that a large percentage of drivers tend to charge to fixed threshold SOC or full battery regardless of the situation in case of an emergency travel. The observations from this limited scenario analysis also suggest detailed scenario survey to be good approach for singling out the determinants for drivers preferences with regards to minimum and desired SoC

Overall this study presents some interesting insights into the attitudes of driver towards smart charging as well as quantifies the exerted flexibility in usable SOC ranges for mart charging and the WTP. The study however, limits itself at this point to the attitudes prior to exposure to smart charging and should validate or observe changes in attitudes in real-life smart charging, as well as contextual changes since the conduction of the survey (such as increasing penetration rate of EVs and public infrastructure, volatile and rising energy prices, increasing battery capacities of EVs on the market,

Acknowledgments

List acknowledgments here, if appropriate.

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