World Electric Vehicle Journal

MDPI

Article

Smart Charging Needs, Wants and Demands, Charging Experiences and Opinions of EV Drivers

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Abstract: To reduce emissions of harmful substances (such as CO_2, NO_x and particulate matter) from transportation a fuel transition is essential. Electric transport is one of the most promising options for achieving this. In order to make this new electric transport market function efficiently, new interactions between new and existing parties are required. The growth of electric transport increases the peak demand for electricity. This creates a greater mismatch between moments of supply and moments of demand. In other words, EV drivers want to have their car charged before departure, and grid operators need to allocate resources to meet this demand. Flexibility from both players is required. Charging must be further optimised (become "smarter") to facilitate this flexibility. Smart charging means: controlling and optimising the time and speed of charging. For example, when there is a large supply of solar and wind energy, there is little other demand for electricity and the price for electricity is low. With the contribution of many organisations, the Vereniging Elektrische Rijders (VER) and ElaadNL have jointly investigated the experiences and opinions of electric drivers about the smart charging of electric cars with a broad survey called the "National Charging Research". In total, more than 1800 Dutch electric drivers took part in this study. Among other things, the research paid attention to the way in which EV drivers charge their electric cars, which bottlenecks they experience (at home and away) and what the experience is with smart charging. The main finding was that many EV drivers are familiar with smart charging. They are willing to apply smart charging, but they want to be in control of their sessions. To give them that control, both insight and transparency are essential. To meet the needs and wants of both EV drivers and grid operators, alignment with the momentum of European legislation is required to avoid a mismatch of energy between moments of supply and demand.

Keywords: consumers; cost; electric drive; power; smart charging

Citation: Brey, B.d.; Gardien, L.; Hiep, E. Smart Charging Needs, Wants and Demands, Charging Experiences and Opinions of EV Drivers. *World Electr. Veh. J.* **2021**, *12*, 168. https://doi.org/10.3390/wevj12040168

Academic Editor: Peter Van den Bossche

Received: 19 July 2021
Accepted: 15 September 2021
Published: 28 September 2021

1. Introduction

More and more people drive electrically and charge their cars in their own driveway at home, at public charging stations in the street, at work, or at fast chargers that can now be found throughout the Netherlands [1], and not only in the Netherlands: EV is growing throughout Europe and around the globe. The Netherlands has a fleet of passenger cars of 8,373,244 vehicles [2], of which 191,265 are fully electric, and another 120,105 PHEV [3]. Compared to the EU market, the Netherlands have a high penetration of electric mobility. Of the total passenger fleet of 249,240,316 vehicles only 1,125,485 are EV, and 967,721 PHEV. The same applies for charging infrastructure. In Europe 224,237 recharging points are installed [4], in the Netherlands has 75,032 public and semi-public charging stations (Type 2) and another 2367 fast charging stations [5].

Charging has many challenges at this stage. For instance: are there enough charging stations? Do the stations work? Can EV-drivers find them?

With the green ambitions of the new European Commission, tangible targets have been set for Europe [6], and charging challenges are not only the case in the Netherlands.

Furthermore, the energy transition shows us on a global scale that more and more electricity is being generated by the power of the sun and wind. This growth means that there will be times where there is more energy supply than demand for electricity. To fully use this abundance of power, storage is necessary. What better than to use the growing armada of electric cars to charge at the best possible moments via smart charging? With innovative techniques we can make sure electric cars are charged at optimal moments, for example during the night when the wind is blowing faster and there is little demand for electricity or in the afternoon at the moment the power of the sun is at its peak. This is technically feasible, but how do these users of electric vehicles (EVs) experience the smart charging of their cars? What is going well and what can be improved? A lack of well-substantiated answers to these questions was the reason for a study by the Vereniging Elektrische Rijders (VER)—the Dutch Association for EV drivers—[7] and ElaadNL [8]. With this study, researchers hoped to gain a broad insight into how EV drivers charge their electric cars, how they experience this, and where bottlenecks lie (at home and away). In addition, the research provides insight into the knowledge of, experience with, and opinions of EV drivers about smart charging. With reliable information obtained from EV drivers, direction can be given to the further development of possible solutions for grid operators and policies for the Netherlands, Europe, and the global community. The EV driver—in whatever country he or she lives—plays a central role in this development and it is important that the user's voice is heard.

2. Setup

After this paragraph regarding the setup of the research, the authors will begin by examining why electric vehicles will become a big opportunity or challenge for society. First, this will be carried out from the perspective of the EV driver, exploring what EV drivers need. Secondly, the perspective of the grid operator will be discussed, including how they would want to incorporate the demand of EVs into their grids efficiently. Afterwards, both perspectives will be combined and the demands for policymakers given the needs and wants of EV drivers and grid operators will be discussed.

Respondents were acquired through various partner organisations (including the Netherlands Enterprise Agency, RVO [9] the National Association for Sustainable Energy, NVDE [10] and the ev-database.nl), and various channels (such as newsletters, WhatsApp, online media) in order to take the most representative sample possible. This resulted in more than 1800 respondents [11]. Not all respondents answered all questions, therefore in Figures 1–4 the number of respondents is shown by the letter "N". The National Charging Survey will be conducted annually to monitor trends and developments, identify new challenges and evaluate the effects of changes. The results can be divided into separate categories.

2.1. General Characteristics

The respondents were predominantly male (91%) and the most common age categories were "40s" and "50s". The respondents come from 295 (out of a total of 355) different municipalities and from all over the Netherlands.

A large majority (94%) of the respondents drive fully electric vehicles. In the Netherlands, we see a movement towards more fully electric vehicles and a decreasing number of plug-in hybrid vehicles due to tax incentives [12]. Most of the respondents (86%) drive a new electric vehicle. We also see that the second-hand market is gaining momentum: 14% of the respondents drive a second-hand electric vehicle.

Financial incentives schemes by the national government result in a high percentage of business driven EVs, as can be seen in Figure 1.

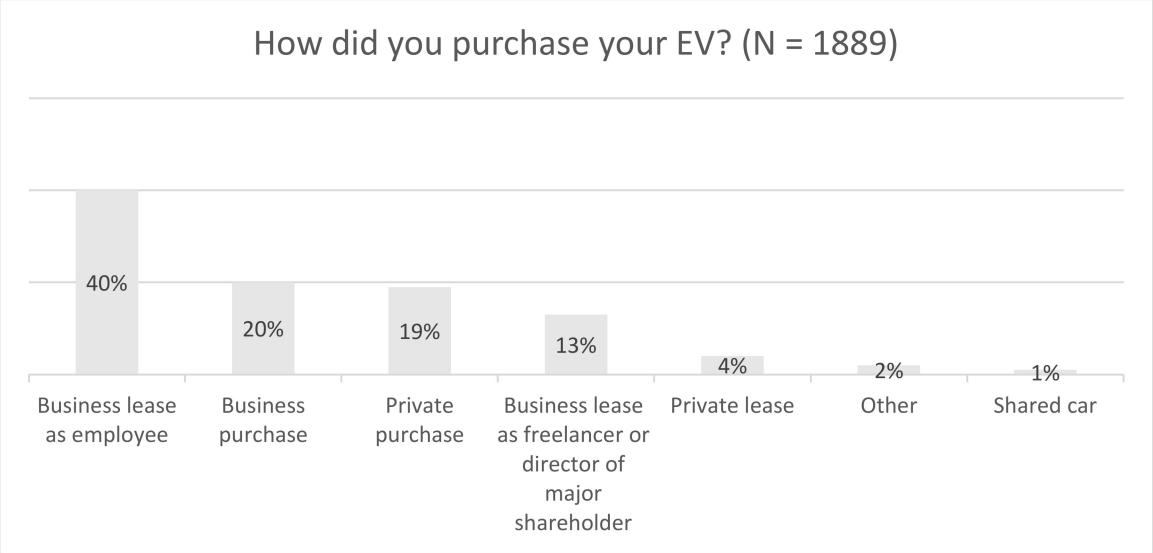

Figure 1. Vehicle procurement.

The respondents in our study generally drive their EV via a business construction (business purchase, business lease as an employee or business lease as freelancer or director of major shareholder): in total, 73%. Almost a quarter (23%) of all respondents drive their EV privately (private purchase and private lease).

When looking at the entire Dutch fleet (including diesel and petrol) we see a different number: approximately 90% of vehicles are privately owned [13]. In general, new vehicles are more often driven for business purposes. This also applies to electric vehicles. It is likely that the share of privately owned EVs will grow in the future due to, among other factors, the rise of the second-hand market. It is plausible that EV drivers that drive their EV privately, have different needs and wants than business drivers. Further research into this new group of users remains important.

If we look at the number of kilometres that fully electric vehicles drive and divide that into two groups: private (private purchase and private lease) and business (business purchase, business lease as an employee or business lease as freelancer or director of major shareholder), we see that EV drivers who drive their vehicles through a private construction drive an average of 20.5 thousand kilometres per year and EV drivers who drive their vehicles for business travel an average of 28.5 thousand kilometres per year. The average annual mileage of all private passenger vehicles in the Netherlands was 11.6 thousand kilometres in 2018. For a vehicle registered to a company, this was 23.0 thousand kilometres, which is more than what people drive in fossil fuel vehicles (private approximately 50% more and business approximately 20% more). This could possibly be explained by the fact that the majority of EVs are "driven for business" and because EVs are mainly financially interesting in combination with higher mileage. Either way, these results refute the fable that electric driving is only practical for people who drive fewer miles

2.2. Charging Mix

Where do respondents charge their EVs according to this study? On average 47% of the charging is completed at home (7% of which is via a socket and not via a charging station), 19% takes place at work, 23% at a public charging point, and 11% of all kilometres are charged via a fast charger. Additionally, 58% of the respondents have a charging point at home. The charging mix is illustrated in Figure 2.

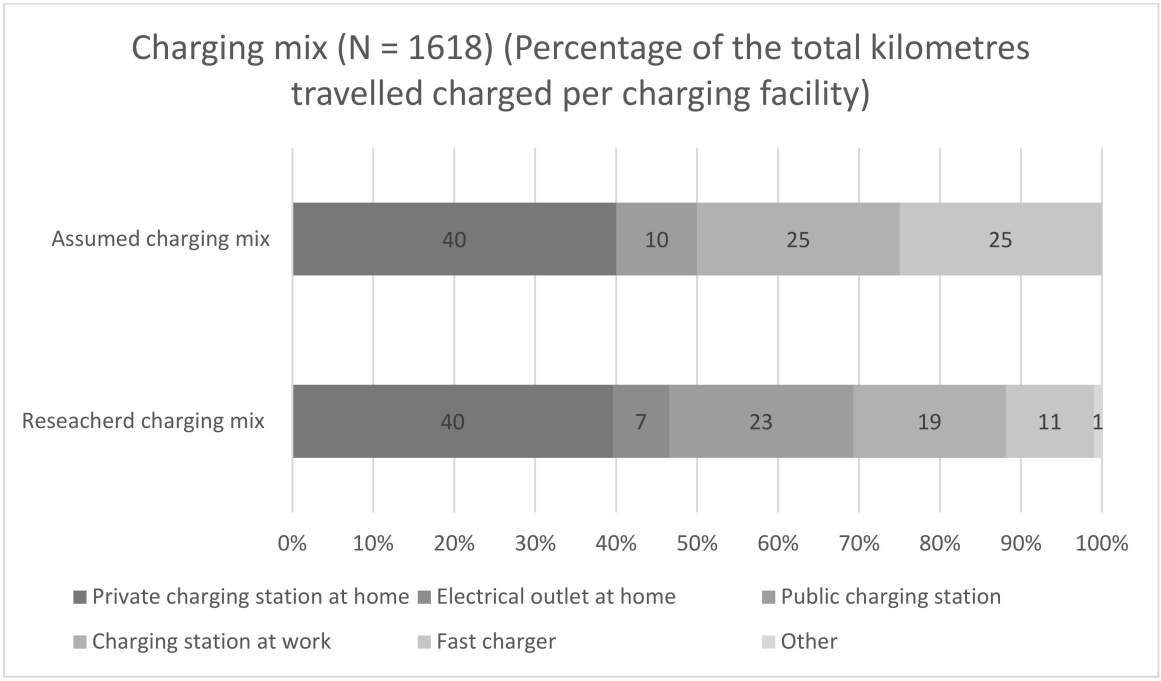

Figure 2. Charging mix.

Most Dutch households (approximately 75%) do not have their own driveway in which to charge a vehicle. In light of this percentage, it is remarkable that 40% of the kilometres in the charging mix are charged with a private charging station at home. People with their own driveway therefore seem overrepresented within the "EV drivers" group. The share of public charging is expected to increase in the future, precisely because the majority of Dutch households do not have their own driveway to charge their vehicle. Among the 1% "other" answers were given as "on the camping site" or "on home-built battery with solar panels".

3. Perspective of the EV Driver: Bottlenecks with Charging

In the past decade, range anxiety was a hot topic among EV drivers. Nowadays, Dutch EV drivers experience relatively little range anxiety [14]; they are often dissatisfied with other aspects of charging. In our research, we made a distinction between private and public charging to identify bottlenecks.

3.1. Private Charging

There are hardly any bottlenecks in private charging. About 90% of respondents were satisfied with their private charging point. Access to low-cost home charging is one of the most significant economic factors in EV adoption, so it is not surprising that single-family home residents dominate the demographics in the survey. Other international research, such as the survey of Plugin America [15] shows a different pattern. Apartments and condominiums may have a garage or parking lot with dedicated parking spaces, or a parking lot with non-dedicated spaces, or may not have parking at all (requiring residents to rely on street parking). Installing charging infrastructure for such buildings does carry a higher capital cost or could give rise to other problems. According to the research, of consumers who apply for a charging station via their Homeowners' Association (HOA) or a comparable collective, 31% of these applicants did not experience any problems with finding an available parking point, while almost 70% did.

3.2. Public Charging

Of all EV drivers in the Dutch survey, 78% sometimes charge at a public charging station on the street. A great diversity of bottlenecks is experienced:

72% of all respondents who use "public chargers" think that there are not enough charging points in the area. The increase in the number of electric vehicles is currently faster than the increase in charging infrastructure: it is therefore getting busier at the charging stations. In addition, not all municipalities have a well-developed charging station policy, which means that EV drivers are not always able to easily request a charging station.

More than 60% of respondents indicated that they did not know, at least once or more in the past year, what the costs are of charging at a public charging station.

Furthermore, 55% of the respondents indicated that they have experienced the charging speed at public charging stations as "too low" in the past six months. In any case, it is almost never clear what the charging speed (at that time) is with public charging stations.

Finding a charging station can occasionally be problematic as well: 38% of respondents experienced one or more times in the last six months that the charging station could not be found. The accuracy of the charging apps could be improved: the location in the app does not always correspond to the actual location.

These results are being confirmed by research performed by NewMotion [16] where 5000 electric vehicle drivers across the UK, Germany, France, and the Netherlands have taken part in a survey that reveals the biggest concerns and anxieties about EV ownership is the lack of charging infrastructure. The key takeaway from the results is that 45% of drivers have the most anxiety about a lack of charge points.

The previously mentioned research performed by Plugin America regarding public charging shows that over 50% of drivers have experienced problems with public charging. These problems were more prevalent in those who drove non-Tesla EVs; Tesla drivers have access to a charging network that differs in several key respects from other networks. The most common problem reported was that public chargers were out of order. At best, this is a nuisance or inconvenience. At worst, an EV driver could be stranded. Negative experiences caused by non-functional charging stations could adversely affect the EV market. In the US, many public chargers are funded through grant programmes. Such programmes can impose reliability requirements on stations receiving funding; these may include requirements for redundancy (multiple chargers at a given charging location), uptime (establishing a minimum percent of the hours in year that each charger must be functional), and maintenance and repair (stipulating a time requirement in which repairs must be initiated after the moment of notification that a charger was found to be nonfunctional).

3.3. Costs of Charging

Respondents were asked to what extent they agree with the statement "The costs of charging at a public charging station are always known to me in advance". This was assessed on a scale from one (completely disagree) to five (completely agree). Respondents scored average a 2.31: a score between "disagree" and "neutral". The costs of charging are therefore often unknown.

Respondents were also asked to what extent they agree with the statement "I want to know what the costs for charging are before I start charging at a public charging station". This was assessed on a scale from one (completely disagree) to five (completely agree). Respondents scored an average of 3.55: a score between "neutral" and "agree". People who have to determine the costs themselves (private drivers, business purchase, and self-employed/DGA) most frequently want to understand pricing in advance. The business lease drivers who drive their cars as employees are significantly less interested in this. That is in line with expectations: those who have to pay for it themselves are usually more interested in the costs.

These results are similar to the results of research performed by EVA England [17]. Comments in EVA England's survey also suggest the need not only for a transparent

pricing metric, but also for transparency in the costs associated with using a public charger. Drivers strongly prefer to pay for their charge in pence/kWh. Furthermore, transparent pricing of the cost to charge a vehicle should be separated from other fees associated with charging, such as parking fees and connection fees.

4. Perspective of the Grid Operator: Smart Charging

Smart Charging [18] is a proven technique used by grid operators, energy suppliers and charge point operators to optimise the charging of an electric vehicle [19–21]. Smart charging is achieved by aligning the time, speed, and charging method with the e-driver's preferences and prevailing market conditions. For example, when one or more of the points below apply:

- a high supply of solar and wind energy;
- little other demand for electricity, for example by households;
- the price for electricity is lower;
- the electricity network is able to process the demand for electricity.

At ideal times, for example, charging is sometimes faster and cheaper than normal. Smart charging can also mean that electric cars do not charge or charge more slowly at less optimal moments, especially when the opposite of the four points applies. For example, at less ideal moments, no or slower charging takes place and it is sometimes more expensive than normal. In these circumstances it is important that the electricity network is able to handle the demand for electricity so that charging remains reliable, safe, and affordable. EV drivers can charge smartly themselves by using apps, for example, or smart charging is performed automatically at the (public) charging station where charging takes place.

Smart Charging also depends on the maximum charging speed available, as this determines the bandwidth of charging capacity. Charging speed is expressed in kilowatts (kW) and depends on a number of factors.

Firstly, the car has a maximum charging speed which differs between models and brands. Secondly, the charging point determines the maximum available power which depends on the type and whether several cars are charging at the same time. Finally, the connection from the charging station to the grid has a maximum capacity. Therefore, the charging speed is determined by the weakest link in the chain.

Thus a car's own capacity, the charging station, or the connection to the grid determine the car's charging speed at any given moment in time [22]. If many cars are simultaneously connected to a charging station or centre, the maximum charging speed is adjusted downwards. This simple form of Smart Charging is called "local load balancing". There are many other options.

At home, for example, information from the smart meter can be used to adjust the car charging speed to household consumption: the speed can be optimised to match electricity consumption in and around the house. Cars can charge less or not at all at times of peak demand; they can even supply extra power (V2H, Vehicle to Home). This shows that a lot is possible even within the existing grid connection. This is also true for an office location, where the charging needs and grid connection can be determined on the basis of the annual peak power consumption.

Smart Charging can therefore be used to optimise the total energy consumption at the location and to minimise the size (and therefore the costs) of the grid connection. Most employees with an electric car will be in their office for a large part of the day, therefore the time when their EV is charged becomes less important. The office building's energy management system can optimise charging. On sunny days, for example, the afternoon would be optimal for EV charging, using the power from solar panels, and in poor weather conditions, the first cars could be charged in the morning.

A control signal is normally all that is needed for simple forms of Smart Charging. For example, the charging station can then transmit more or less power at specific times within the available bandwidth. However, for a more optimal and complex use of Smart Charging, you need data. The more information available, the better the system can be customised to

your needs. The charging station can then base charging decisions on information about how full the car's battery is, the time the driver has to leave, or whether nearby solar panels can provide extra power, and of course, much more.

The next step in Smart Charging is using the car for energy storage for purposes other than driving. This means that you not only use power as required by the car for driving, but that your car acts as a power supply. This technique is commonly referred to as V2G (Vehicle to grid) or V2X (Vehicle to anything). Others speak of bidirectional charging or "power recycling". The power stored in your car can, for example, be used to power your own home, the neighbourhood, or even fed back into the grid [23].

4.1. Experience with Smart Charging

The majority of the respondents who have experience with smart charging generally did not notice anything about smart charging (59%), 26% positively experienced smart charging. In the explanation, the respondents indicate that they are positive because of: financial benefits, charging on their own solar panels, that it gives a good feeling, the contribution to a stable electricity network and the unburdening of their own installation at home. However, 12% of the respondents had a negative experience of smart charging. In the explanation, the respondents indicate that they are negative because the car was insufficiently charged in their experience, due to a problem with the car or the app, due to a longer charging time and uncertainty about charging speed and charging time. This concerns the experience of the respondents and it is not possible to determine whether there were (partly) other reasons for these negative experiences.

It goes without saying that a situation in which the car is not sufficiently charged to reach the next destination and loading location is undesirable for EV drivers. A possible way to prevent this is by letting users indicate how much they want to charge and at what time they think they will leave. This can then be taken into account by a smart algorithm or system. Smart charging is precisely intended to ensure that the growing fleet of electric cars can be charged sustainably, affordably, and reliably. An increasing range with new car models and more charging points also contribute to the certainty of reaching the desired destination without any problems. People who chose the "other" option often responded with both positive and negative experiences.

4.2. Arguments for (Not) Wanting to Charge Smart

Respondents were asked how important certain arguments for wanting to charge smart and for not wanting to charge smart are. Four reasons for charging smart were given: "Making optimal use of sustainable energy", "Contributing to a stable energy network", "Financial advantages" and "Shorter charging time". All reasons are classified as important, with "making the best use of renewable energy" as the most important. Financial benefits and a short loading time are seen as the least important. In Figure 3, reasons to charge smart are illustrated.

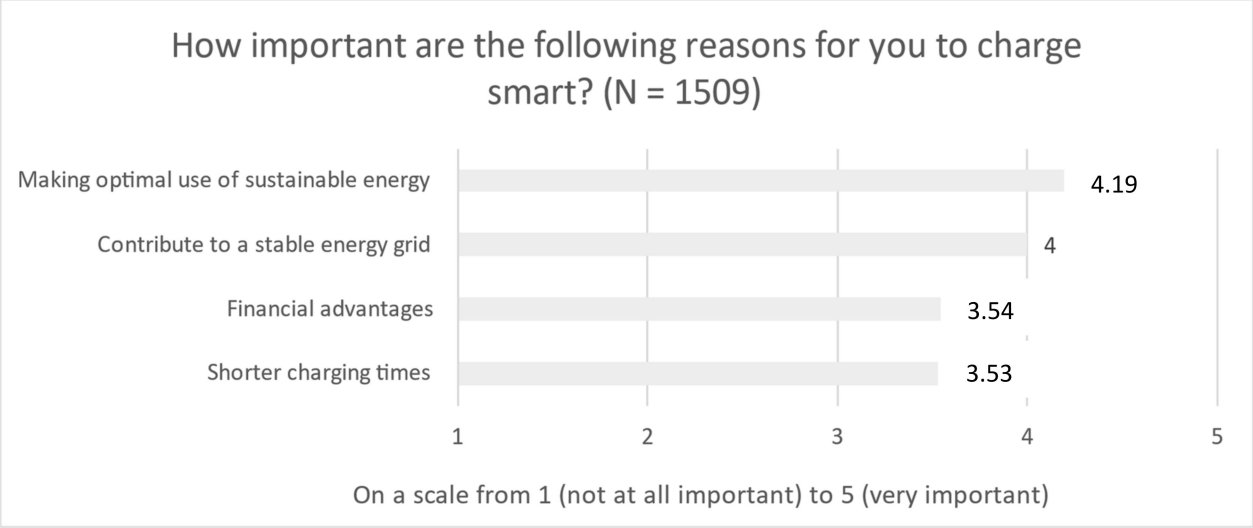

Figure 3. Wants of EV drivers for smart charging.

In addition to this direct questioning method, it was also indirectly tested which arguments are important for smart charging. This was achieved by testing which arguments predict how important find people smart charging and how high their willingness is. With this indirect method of testing, there is little chance that social desirability will influence the results. The results of this indirect analysis are consistent with the results when we ask directly about it and reinforce the findings. Making use of sustainable energy and a stable network therefore do not appear to be arguments arising from social desirability, but are important arguments for smart charging.

Five reasons for not wanting to charge smart were given: "The fear of not being fully loaded", "I think it's too much hassle", "Financial disadvantages", "A longer loading time", and "I want to keep control myself". Respondents indicate that the biggest barrier to smart charging is the fear of not being sufficiently charged. This argument is followed by the lack of control over the loading session and a longer loading time. Possible "financial disadvantages" and "I think it's too much hassle" are not seen as barriers. Other reasons mentioned in the answer option "other" included problems experienced with smart charging with an app or in the car, the lack of transparency, or no "belief" in smart charging. If we look through the indirect analysis of which of the barriers are blocking smart charging the most, we see a slightly different pattern. Through the indirect test, "too much hassle" appears to be the main barrier, followed by the longer loading time and the need to keep control. Both analyses therefore show that the fear of not being sufficiently charged and the need for control are important reasons for not charging smartly. In addition, the indirect analysis suggests that it is also especially important to make smart charging easy. Reasons not to charge smart are illustrated in Figure 4.

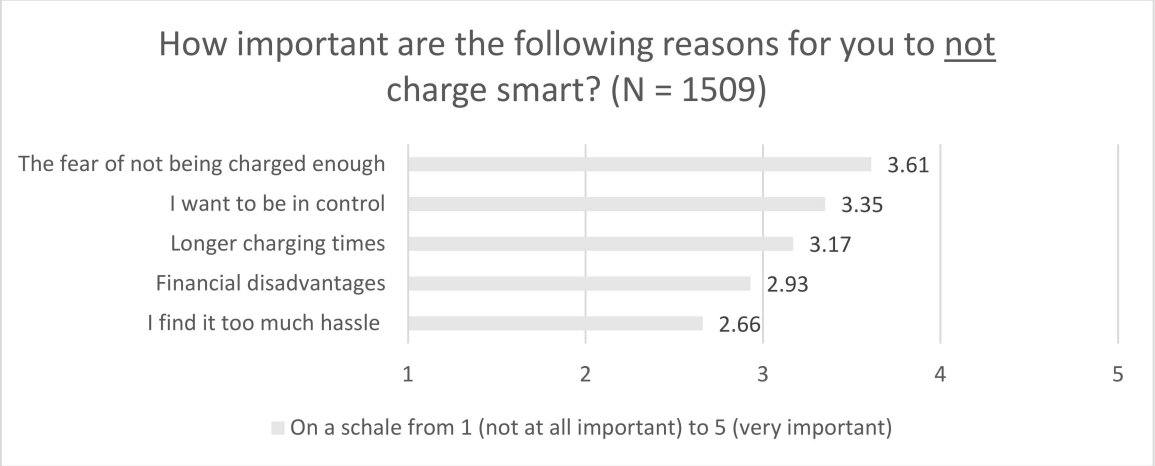

Figure 4. Reasons not to charge smart.

4.3. Statements on Smart Charging

Respondents [N = 1510] were presented with statements about smart charging and asked them to indicate to what extent they agree or disagree on a five-point scale from one (completely disagree) to five (completely agree).

(a) "I am willing to charge smart."

Eighty percent (a score of four or higher) of the respondents indicate that they are willing to charge smart.

(b) "I want to keep control of my smart charging sessions."

Seventy-six percent (a score of four or higher) of the respondent indicate they want to keep control of their smart charging sessions. It is wise to consider this when developing smart charging applications. For example by giving users the option to charge at full speed under certain conditions. Previous research by ElaadNL and partners showed that users participating in a smart charging trial at home found having control in the form of an "emergency button" to charge at normal speed very important, but this option was hardly used in practice [24]. The presence of the function was sufficient.

(c) "I want to have insight into the progress of my smart one afterwards charging sessions."

Sixty-six percent (a score of four or higher) of the respondents want insight into the smart charging session afterwards.

To summarise, EV drivers are willing to apply smart charging, but they want to keep control of their sessions. For control insight is necessary. To meet the needs and wants of both the EV driver and grid operator, alignment with the momentum of European legislation is required to avoid a mismatch between moments of supply and moments of demand.

5. European Legislation

To make the development and deployment of clean, electric mobility a success, the wants of EV drivers and the needs regarding smart charging have to be met. The revision of Directive 2014/94/EU on the Deployment of Alternative Fuels Infrastructure (AFID) comes at a critical time. The AFID provides many possibilities for improvements on transparency. For example, article 7 states that, "Member States shall ensure that, when available, the data indicating the geographic location of the (publicly accessible alternative fuels) refuelling and recharging points (. . .) are accessible on an open and non-discriminatory basis to all users. For recharging points, such data, when available, may include information on real-time accessibility as well as historical and real-time charging information" [25].

The location of recharging points (GNNS coordinates, address) is not the only static data that is important to both EV-drivers and grid operators. Other important data to

enable smart charging should include also opening hours, power offered (AD/DC, kW), and an option for roaming options and the source of electricity offered (renewable or not).

At the moment, the Sustainable Transport Forum works on the topics above [26]. In our opinion the directive should be replaced by regulation to ensure an accelerated, harmonised rollout of EV charging infrastructure across the EU. This improves transparency and market governance across Europe, allowing interoperability by the adoption of open, non-discriminatory, and uniform communication protocols (such as the Open ChargePoint Protocol, OCPP) and related standards. It will ensure the necessary conditions for roaming so EV drivers can travel seamlessly across the EU.

By taking a consumer-centric approach it is made sure both the EV driver and grid operators have quality data on networks, charging locations, and price transparency, which are the demands of a seamless system needed to make smart charging a success.

6. Conclusions

Although we are lucky in the Netherlands with the highest number of charging stations per EV, it still is not enough. To keep the costs of installation of charging infrastructure low, the electricity grid should be utilised more efficiently. This can be achieved by smart charging. Smart charging is largely implemented and adopted. The EV driver—in whatever country he or she lives—plays a central role in the development of smart charging and it is important that the user's voice is heard. For EV drivers, range anxiety seems to no longer be an issue, but information to be in control of smart charging sessions is the new hot topic. Information on price, speed of charging, location, and availability of the charging station are important indicators of success or failure.

Many EV drivers are familiar with smart charging. The largest group of EV drivers who indicate that they sometimes charge smart do this at home on a private charging station. They deliberately charge mainly at night outside peak hours. Greater transparency for e-drivers about the charging speed and the current costs of electric driving will ensure that they can better assess the financial benefit of a smart charging initiative. Other reasons for smart charging are: making optimal use of renewable energy, followed by contributions to a stable network. The most important barriers to not charging smartly are the fear of not being fully charged and not having control over the charging session.

To summarise, EV drivers are willing to apply smart charging, but they want to be in control of their sessions. For control insight, transparency is necessary. To meet the needs and wants of both the EV driver and grid operator, alignment with the momentum of European legislation is required to avoid a mismatch of energy between moments of supply and demand.

Author Contributions: Writing—original draft preparation, B.d.B.; writing—review and editing, L.G., E.H.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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