Social Acceptability and Acceptance of Photovoltaic Powered Charging Stations

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Abstract - Electric vehicles (EVs) appear to be one of the possible solutions for limiting greenhouse gas emissions from the transportation sector. Hence, the transport sector must be redesigned to allow the installation of EV charging stations powered by renewable energy from photovoltaic (PV) panels. Described as a new innovation, the social acceptability of these PV-powered charging stations should be studied alongside the technical study aiming at improving the project as well as increasing public knowledge. The goal of this study is to determine whether this innovative energy system is socially accepted or not and to analyze the concept limitations from a public point of view. The PV-powered charging station is a system composed mainly of PV sources, stationary storage, and public grid connection as back-up power. The intelligent controller is able to manage the system for EVs charging as well as the new associated services such as vehicle-to-grid (V2G) and vehicle-to-home (V2H) that can be integrated. The social acceptability revealed a very good prospect for electromobility coupled with renewable energies. Regarding the social acceptance, the study shows that the majority of those polled are eager to use PV-powered charging stations and the new associated services V2G and V2H; however, this acceptance is conditional on a number of users' needs and constraints.

Keywords: Social acceptability, surveys, electromobility, photovoltaic energy, smart grid, electric vehicles.

I. INTRODUCTION

The Paris Agreement, adopted by 196 parties at COP 21, is an international treaty on climate change. Its goal is to limit global warming to less than 2°C [1]. To reach this long-term goal, countries aim to reduce global greenhouse gas emissions as soon as possible to achieve carbon neutrality by the mid-20th century. Low-carbon solutions and new markets have emerged, particularly in the power and transportation sectors, which account for 41% and 24% of CO_2 emissions, respectively [2]. In this context, the shift to low-carbon mobility requires the deployment of electric vehicles (EVs), whose emissions depend on their manufacturing process and the energy source that operates them [3]. In fact, in the worst-case scenario, an EV with a battery produced in China and driven in Poland still emits 37% less CO_2 than a gasoline vehicle [4].

However, the growth in EVs implies an increase in power demand, and the public grid would not be able to meet the demand without involving fossil fuel-based power plants, which would result in higher CO_2 emissions. To solve this issue, the integration of renewable energy sources such as photovoltaic (PV) would reduce electricity consumption and the grid power peak while ensuring EVs charging [5] with a large proportion of PV energy. The power generated by the PV sources cannot directly feed the EVs due to their intermittent power. Thus, the best solution for recharging EVs is a microgrid, which combines renewable sources, stationary storage devices, loads, and connection to the public grid [6]. The microgrid also contains a user-machine interface [7] that permits data collection via a communication system and transfers data to an optimization algorithm to ensure real-time power management [8]. Moreover, the installation of this kind of intelligent EVs charging infrastructure (IIREVs) based on microgrids is expected to allow users to charge their vehicles during the day without limitation. Nonetheless, social acceptability and acceptance are central to many debates surrounding energy projects, particularly in urban areas.

Social acceptability is the result of a critical or collective analysis of a new technological object, project, plan, or policy that considers the moral issues that emerge from its introduction. This collective critical analysis may be positive or negative, but it only represents an opinion at a given moment, which may evolve over time. Social acceptability can be described but not quantified, on the one hand, and can be achieved at all territorial levels (local, regional or national) on the other hand [9], [10].

Social acceptance is defined as the respondents' attitudes, including their behavioral responses, and refers to the fact that a new technology is highly accepted, weakly accepted, simply tolerated, or clearly not accepted by a community. Because the opinions of stakeholders are not included in these surveys, the final studies therefore lack relevant empirical data for in-depth ethical evaluation. Therefore, social acceptance surveys cannot include all morally relevant characteristics of risky technologies [9], [10].

Hence, social acceptability and social acceptance are conducted together so that both types of analysis are relevant to the consideration of risks. Finally, social acceptability and social acceptance are, for the most part, complementary.

This paper aims first to present the social acceptability and acceptance studies of IIREVs and new associated services in urban areas. To facilitate and guide the qualitative survey and the quantitative survey, a study on the societal impact of IIREVs was carried out at the beginning. Afterwards, the study highlights the evolution of people's mindsets through the years by comparing the obtained results with a similar survey conducted in 2018 [11]. To sum up, the social acceptability study, defined as the prospective judgment to be introduced in the future, focuses on three questions:

- What primary goals should be accomplished before IIREVs implantation?
- How will city dwellers react to the structures' presence in urban areas?
- How will stakeholders react to this innovation, and how will users change their habits to take advantage of these stations?

The rest of the paper is structured as follows. Section II describes the IIREVs powered mostly by PV sources, while Sections III and IV show their societal acceptability and social acceptance, respectively. Improvement plans based on the survey's results are then mentioned in Section V. Conclusions and perspectives are given in the last section.

II. Intelligent EVs Charging Infrastructure Powered By PV

The IIREVs, based on PV energy and connected with a near a building or home, and its interactions are represented in Figure 1. The microgrid combines PV panels, stationary storage, and public grid connection, all combined with a smart control system that ensures the power management and energy distribution between the IIREVs, the public grid, the EVs, and nearby buildings [12]. The IIREVs will not only provide green energy to the EVs but also may supply the public grid and the building according necessities. The priority is to charge EVs with PV energy, and then the PV excess power will be used to charge stationary storage, supply near buildings (I2H, infrastructure-to-home), or inject power into the utility grid, based on an optimization algorithm that considers several constraints, such as the state of charge of the stationary storage, the grid conditions, the weather forecast, and the energy market costs [8]. In addition, assuming that the EV battery is a flexible load and considering the user's needs, the energy management system may shift the charging period to provide the EV with a significant amount of PV power while avoiding supplying power from the grid during peak hours.

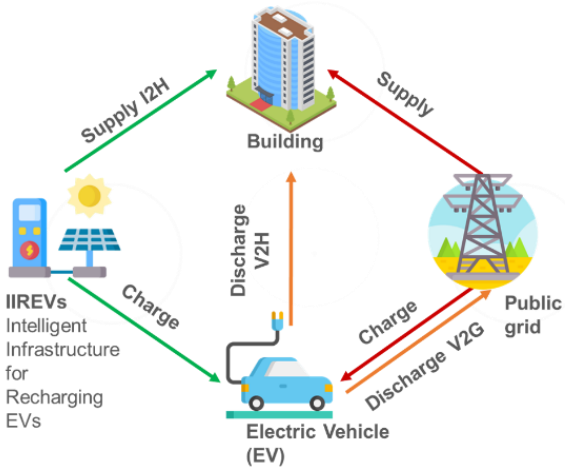


Figure 1. IIREVs and its interactions

On the other hand, the EV battery is seen as an energy reservoir, and could be discharged, with respect to a limit, into the grid through V2G operation mode or into the building through V2H operation mode [13].

Figure **2**. Energy management for IIREVsFigure 2 illustrates the possibilities of energy management [14]. The aim is to maximize the energy from the PV and minimize the total energy price.

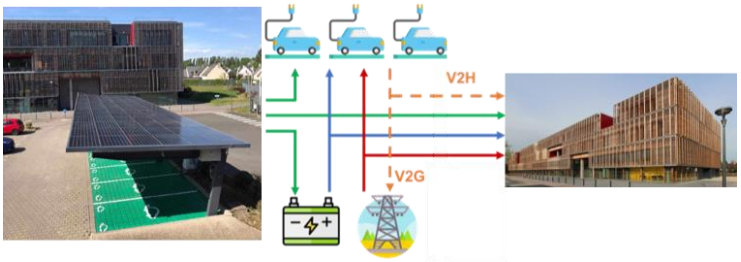


Figure 2. Energy management for IIREVs

The V2G services could help the power grid regulate the frequency, smooth peaks of consumption, and maintain the nominal voltage [13], while the V2H services could smooth the peaks of consumption at the building level and supply electricity during power cut-off. Although various works discuss the potential for employing the V2G to engage in ancillary services, the V2G strategy has not yet been implemented in real life, except some test sites.

The IIREVs implantation is quite challenging since economic, social, and environmental factors must be considered. Thus, several studies are necessary before implantation. These

consider all the factors from irradiation, location, power limitations, and financial constraints to environmental factors, like carbon emissions [15]. But here some questions arise: to what degree will users accept these services, and what are the challenges that stand in the way of their development?

III. Social acceptability of IIREVs

The realization of the social acceptability study follows two phases [9]: societal impact and qualitative survey. These are also the preliminary study studies for the acceptance study named quantitative survey. As a first step, the societal impact study defines the product IIREVs, the market, and the actors [16]. In a second step, the qualitative survey, carried out on a limited sample of respondents, reveals their reflections on the IIREVs. This section presents these two studies.

A. Societal impact

The implantation of IIREVs and its services V2G / V2H will impact society and the mobility of its citizens. This marketing and societal impact study defines the IIREVs project, its market, and its actors to reveal their reflections on this innovation and to characterize their expectations and requirements. For the IIREVs, it is possible to distinguish two innovations: charging with PV energy and the V2G / V2H services. They are defined as "technology push" (i.e., users will be encouraged to recharge their EVs) and "market pull" (i.e., in response to an identified market need) innovations. Actually, the IIREVs connect, directly or indirectly, multiple stakeholders in these innovations:

- Active stakeholders: suppliers, productors, constructors, assemblers, design firms, holders;
- Utility grid: energy suppliers, energy distributors, network managers;
- City and state services: local authorities, municipal services, private and public agencies devoted to energy transition;
- Users: EV users, future users, buildings owners, private companies with PV-powered charging stations;
- Others: maintenance agencies.

The societal impact study identified a list of expectations and obstacles at each stakeholder level related to the implantation of IIREVs:

- Socio-economic: the high cost of EVs discourages users from choosing this solution, but note that EVs are considered a long-term investment, and a full charge with electrical energy is cheaper than refueling a combustion vehicle with fuel;
- Political: new policies encourage the development of cleaner transport modes to minimize dependence on petroleum and limit its environmental impact. Polluting vehicles face fines, and new government incentives are available for the purchase of EVs;
- Technological: new technologies are being developed to overcome the main obstacles regarding PV efficiency and EV battery lifespan;
- Environmental: the low environmental impact of EVs and IIREVs encourages their sale and the use of PV energy.

B. Qualitative survey

The purpose of a qualitative survey, which consists of open-ended questions, is to allow respondents to fully and freely express themselves. It will bring out new hypotheses that will aid in building the quantitative survey, i.e., the acceptance study, later. In fact, the qualitative survey makes it possible to examine how these stakeholders will react to the innovation, including how existing users will change their habits and how future users will react. It will therefore be important to use familiar words and avoid technical language to adjust the vocabulary according to each person's background. The methodology used for collecting information is based on three criteria: the age, the socio-professional categories, and the type of vehicle. The amount of 55 stakeholders was interviewed: 3 institutions, 7 private companies, and 45 users, whose vehicle types are shown in Figure 3 compared to the 2018 study.

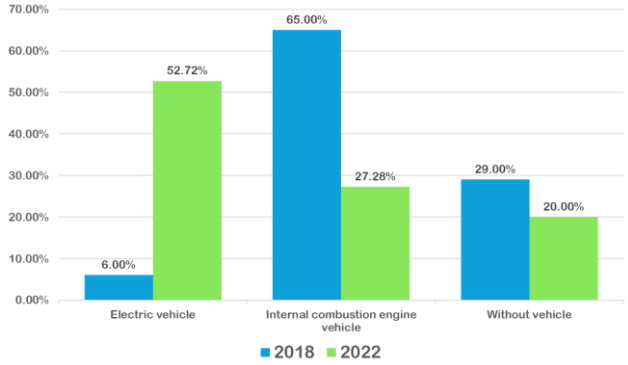


Figure 3. Type of vehicle of respondents

The questions were broken up into three separate sections: a general introduction to the project; a section on PV energy; and a section on the related V2G and V2H systems. Finally, a section with particular questions for professionals and institutions is introduced. This distinction was important insofar as the institutions could provide more details on the installation and management of infrastructures according to their activity.

Following the qualitative interviews, the people interviewed seemed to easily understand the project and find it attractive after its presentation. It is noted that what appeals to them the most is the ecological aspect, especially when mentioning the use of green energy and the sharing and optimization of electricity. Despite the high number of positive opinions, others find this utopian project financially and socially unfeasible due to the changes in habits that are too important and precocious at this stage of electromobility development. This analysis of the feedback highlighted the needs and expectations of future users of IIREVs that will be developed in the quantitative survey.

IV. Social Acceptance of IIREVs: Quantitative Survey

The quantitative survey aims to gather a significant and quantitative amount of feedback on the IIREVs and associated services. The marketing and social approaches (societal impact) and the results of the qualitative survey were examined in order to retain the main considerations for formalizing the quantitative survey. These main points are: travel habits, obstacles to electromobility development, the impact of ecology, main expectations regarding IIREVs, IIREV locations, IIREV owners, partial EV discharge, PV energy recharge, and parking shades' existence in urban areas.

The quantitative survey was carried out by creating a multiple-choice questionnaire and distributing it to a large number of people. Its objective is to confirm certain common thoughts and verify the acceptability of a possible change in habits. The survey closely resembles the one that was carried out in 2018 [11] to evaluate changes in opinions regarding this subject over the previous four years. It consists of an introduction to the subject to facilitate the understanding of IIREVs, followed by 33 closed-ended questions divided into separate theme sections: information about the person and his travel habits, followed by a section about IIREVs and the discharge / charge system, then a section concerning the use of PV energy, and a last section on the attractions and obstacles.

The distribution of the questionnaire is crucial since it characterizes the sample. It was necessary to vary the sources of diffusion in order to represent the diversity of the population's profile rather than focusing entirely on the entourage of students and teachers, and it was carried out by the following means of communication: the survey team's personal network, the UTC Facebook group, the Facebook group of the city of Compiègne, and the diffusion of a QR code in common places. Within 30 days, 864 responses from different categories were obtained.

A. Profiles of the respondents

Figure 4 shows that all age groups are represented. However, the proportion of 15–25 years old differs from France's actual age distribution. This overrepresentation is due to the distribution of the survey via social networks, where the online format was not suitable for people over 60. Note that this overrepresentation is not a big deal since young people will be affected directly by this innovation in the upcoming years.

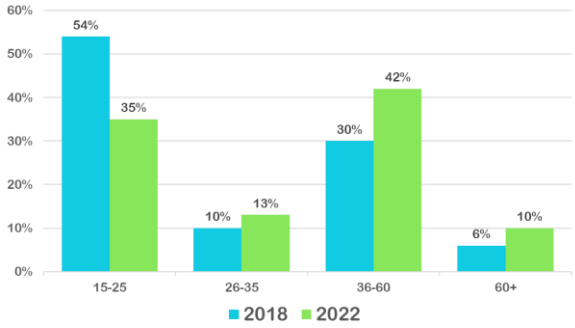


Figure 4. Age repartition of the respondents

Comparing these data with 2018's data published in [11], it could be seen that the percentage of adults has increased, which will influence the socio-professional distribution of the respondents (Figure 5), hence the mean of transport (Figure 6).

Figure 5 presents the strong representation of students and staff, probably because of the project's network. The high representation of staff and the absence of workers and agriculturists is verified by the fact that the purchase of a vehicle is often constrained by the social status of each person.

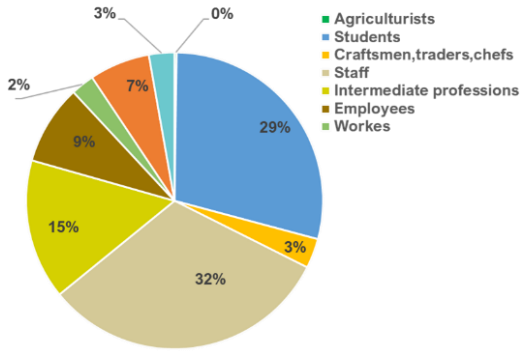


Figure 5. Socio-professional distribution of the respondents

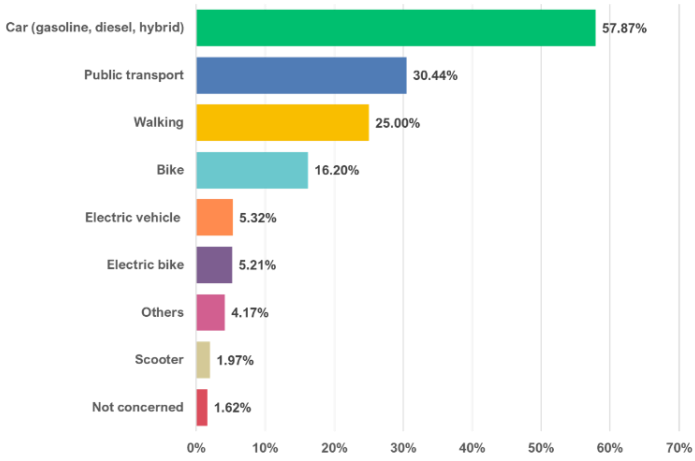


Figure 6. Mean of travel

Combustion or hybrid vehicles remain the most reliable and practical means of transportation for going to work or for leisure. In fact, 58% prefer them. Combining this criterion with the place of residence of the respondents, one notes that they are mostly residing in rural areas and small cities. However, the share of public transport has increased significantly since 2018 [11], from around 21% to 30.44%. Of this 30.44%, 75% of respondents live in medium-sized or large cities where car traffic is complicated. The percentage of people who cycle to work has nearly doubled since 2018 [11], from 9% to 16.2%. This can be explained not only by ecological awareness but also by the COVID-19 pandemic impact. Thus, this could be an indicator of how flexible the French people are to changing their mobility habits.

The answers to the last question in this section concerning the main obstacles that prevent each person from purchasing an EV are represented in Figure 7.

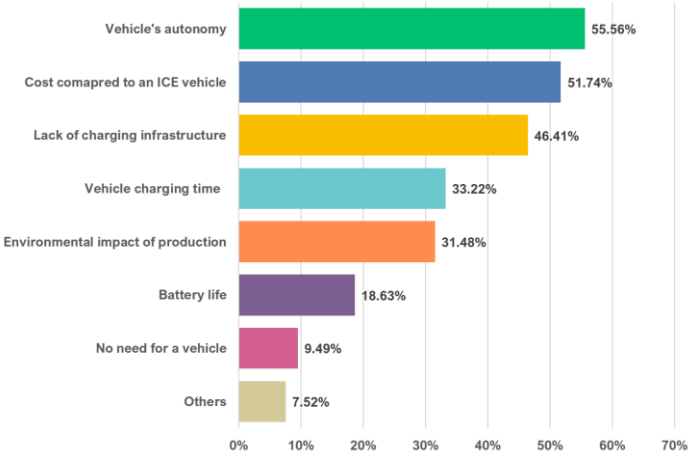


Figure 7. Mains obstacles to the acquisition of an EV

The results are not surprising because the autonomy of the vehicle, its cost compared to a conventional vehicle, and the lack of charging stations had already been identified a few years earlier. Users are still hesitant about the possibility of making long journeys with an EV without having to stop for a long time to recharge the battery. In fact, the environmental issue has increased from 20% in 2018 to 31.48% in 2022, and the questionees are now more aware regarding the ecology.

B. Generalities on IIREVs: discharge/charge

This section of the quantitative study examines public perceptions of IIREVs and related services for discharge and charging systems such as V2G and V2H. It focuses on the conditions that will let the users accept the idea of discharging and recharging their vehicles regularly. At the same time, it focuses on the profit they would like to get after the discharge.

The locations, the availability, and the charging mode of the charging terminals are the main expectations concerning their characteristics. It is interesting to note that their percentages are comparable at around 59%. Otherwise, for older people, ease of use is critical, whereas for young people, fast charging is essential. Subsequently, the respondents mentioned the preferred places to have charging terminals (Figure 8), with the workplace being the most prevalent.

Indeed, EVs are generally parked all day; this will be in line with the use of IIREVs with slow charging to maximize the use of PV energy. The place of residence comes in second, followed by the highway's stop. It is worth noting that the results are very similar to those obtained in 2018 [11], but one should add that some users are concerned about the installation of IIREVs in city centers (26% in 2018) [11]; they do not want massive installations in big cities to encourage the use of public transport, cycling, or walking.

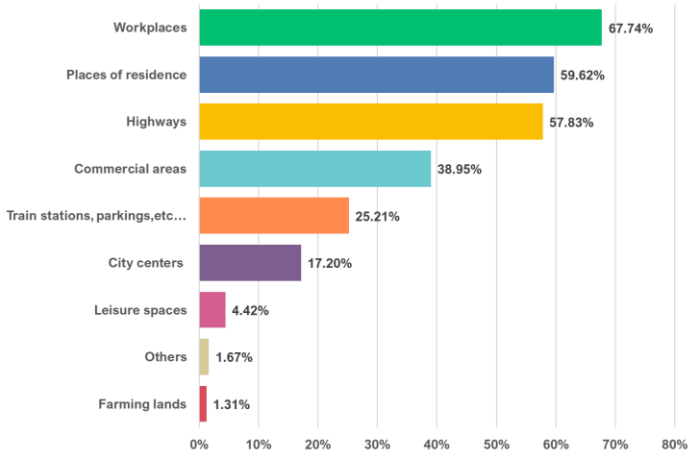
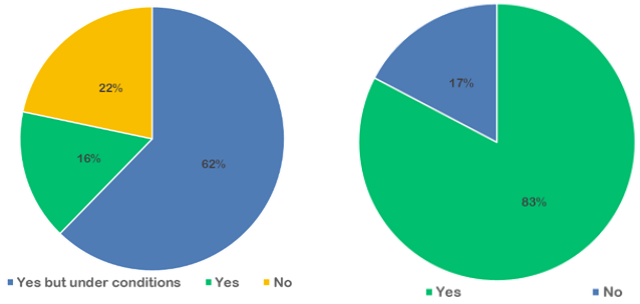


Figure 8. IIREVs location preference

The question of whether or not to approve the discharge was raised twice in the survey to assess acceptability with and without certain information. The first time it was at the beginning of this part, then, and the second time was after a few questions regarding the discharge conditions, compensations, etc. At the beginning, 78% of the respondents answered "Yes" or "Yes, but under certain conditions", with a large majority of "Yes, but under certain conditions" i.e., 62% of the total number of respondents, and 22% showed complete refusal (Figure 9 (a)). However, some of them changed their mind after the upcoming questions regarding the compensation and the profits; 83% of the respondents answered "Yes" and 17% answered "No" (Figure 9 (b)).



(a) (b)

Figure 9. (a) Acceptability of the discharge initially (b) Acceptability of the discharge after several questions

In fact, half of drivers who accept the V2G / V2H, would be ready to discharge their vehicles as long as there is no additional cost, and only 31% would like to be able to financially benefit from the V2G / V2H. Therefore, the primary desire is not necessarily financial. However, only 4% accept clearly the discharge without any conditions.

The next question was about the desired compensation as a contribution to their energy shares. Not everyone wishes to benefit equally from the V2G / V2H services. With 60% of the votes, the deduction on the electricity bill comes first. This is a very logical option since it is electricity that is discharged from

the EV's battery. In addition, it would make it easier for them to be automatically compensated via bank transfers. Free parking came in second with 52% of the vote; citizens always chase services that are becoming increasingly rare and expensive in the cities. Then there is the financial compensation and the tax deduction, which are 39% and 33% respectively.

Another question was asked about the desire to know the destination of the battery energy, and 65% showed the intention. This means that this information can encourage and motivate EV users to share their electricity.

In conclusion, the respondents are mostly tolerant toward V2G / V2H services, but the user must still be sure of being able to leave with the minimum amount of energy required. It is sufficient to keep him informed about important information via an interface and, above all, to ask him for his consent in advance.

C. Integration of PV energy and shades structures

The last part of the questionnaire concerns the PV energy and shading structures, which are essential to the operation of the IIREVs. An image of the STELLA platform (Smart Transport and Energy Living Lab) of the Université de Technologie de Compiègne, shown in Figure 2, preceded the questions to help visualize this type of structure.

Three-quarters of the respondents find that the use of renewable energy sources influences their opinion of IIREVs' acceptability, and 95% of people are in favor of charging EVs with PV energy. This proportion is much higher than for the qualitative survey, in which the results on this question were more contrasted. During the qualitative interviews, the barriers that emerged regarding the PV panels were the low efficiency and the intermittent production.

However, the results in Figure 10 confirm the hypotheses since efficiency comes first with 48% of the votes. Although the yield of PV is quite low (about 20%), this technology is known as an alternative to fossil fuels and remains more advantageous. Second, the recycling of photovoltaic modules is an obstacle. Currently, 90% of panels are recyclable, but the misinformation the public receives makes them see PV recycling as a problem. The pollution during the production of PV is classified third, with 39% of the votes.

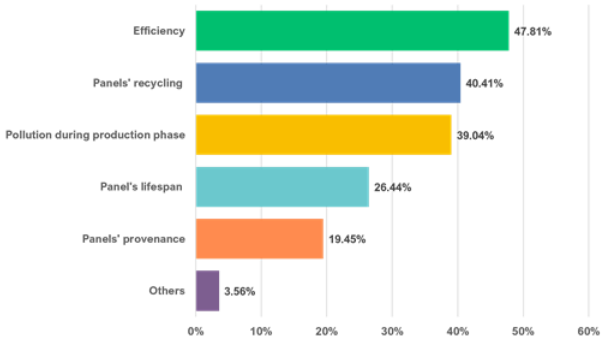


Figure 10. Main obstacles to the use of PV panels

Regarding the installation of car parking shade structures with PV sources, the first question gathered the general opinion on the use of shade structures, and 95% do not see its use as a brake on the project's adherence. The minority considers this infrastructure a problem for aesthetic reasons; among them, 81% would support the implementation of IIREVs if they were asked about their desire in advance.

To satisfy the future user, it was important to ask the respondents about the main places that would bother them with the integration of a car parking shed. The results are given in Figure 11, where half of the respondents do not see any disturbing points for shade installation. For the other half, tourist areas, agricultural areas, city centers, and residential areas are the most disruptive places to install this type of infrastructure. Conversely, cinemas, stadiums, highway gas stations, supermarkets, shopping malls, and workplaces are no problem for the installation of these IIREVs.

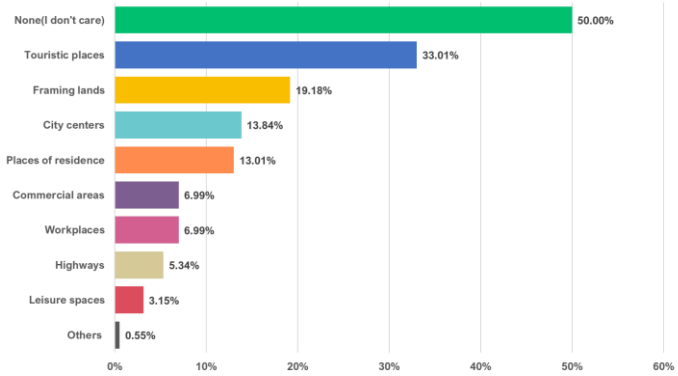


Figure 11. Disturbing places for the establishment of shade structures

Otherwise, older people are more reluctant to install these car shades at their place of residences. It should be noted that, when compared to the 2018 study, these places were cited nearly in the same order and with approximately the same percentage (Figure 12).

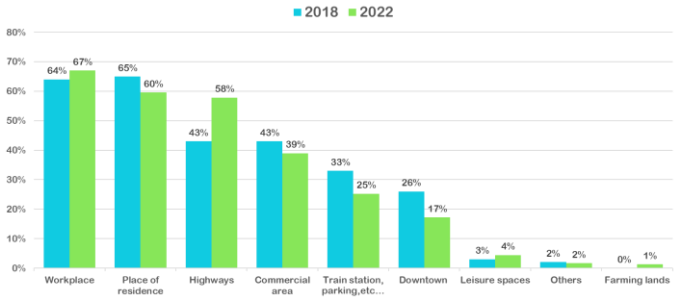


Figure 12. Places for the establishment of shade structures

D. General comprehension

The results of the quantitative survey show that the project has been evaluated since 2018 and the IIREVs are well accepted socially by the respondents. One notes that 78% of respondents are in favor of the discharge process V2G / V2H and 95% have no objection to their EV being recharged by PV. In addition, 95% support the installation of shading structures to place PV

panels. EV users appear to be interested in EV discharge and PV energy use: 75% of them accept discharge at the time of parking and recharge later during low consumption periods in return for financial compensation.

People who showed an interest in V2G / V2H services do not desire additional costs when using such an infrastructure, and some others see it as a way to gain money or make other profits by sharing their energy. In addition, almost three-quarters of the respondents believe that public authorities should own the IIREVs and be responsible for their implementation and maintenance. A last point to mention is the preference of the respondents to have a proper graphical user interface, as they want to keep updated about two main pieces of data: the vehicle's autonomy and the state of charge of their battery. Other data, like remaining charging time and operation history, are less important. They want to get as many details as possible from the interactive pages, as long as they remain simple to use.

V. Project Limitations and Improvements

This final section focuses on understanding the subject and its limitations. As seen in Figure 13, only 9.73% still believe there are no boundaries to IIREVs development in France, while 35.62% find the investments and the costs of developing, installing, and maintaining these facilities to be too high. Therefore, they constitute the most important limitations of the project. It is hard for the population to imagine the benefits of these structures given the significant changes in habits that their implementation would cause. In fact, when compared to the 2018 study, the importance of these limits appears to have decreased by 15%. The low efficiency of PV modules and the ecological benefits also seem to be the limitations of the project, as indirect pollution occurs during the manufacturing process of PV cells and EV batteries. Around 30% also highlight the low impact of IIREVs if they are deployed on a small case, and 25.34% fear that the charge/discharge process could affect their EV batteries' lifespan.

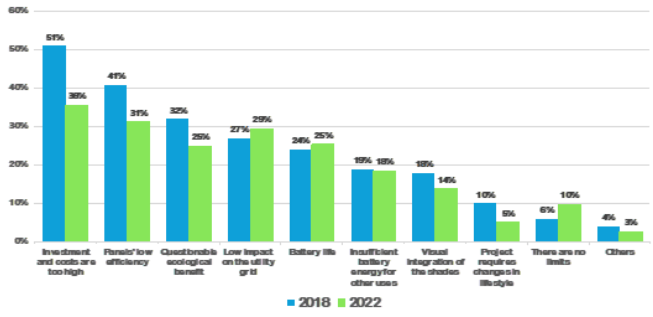


Figure 13. Project's Limitations

A general question on the project's complexity makes it possible to evaluate whether the participants have correctly understood the topic or not. The more they understand, the more valuable their answers are for study. In 2022, the project was easier to understand (80% of the respondents answered "yes"), and its data indicate greater confidence in survey results.

For the development of IIREVs, people mention that it will be necessary to address some weaknesses and enhance them to improve social acceptability. It is mandatory for them to establish a sustainable business model that adapts the charging price and benefits of V2G / V2H services to the user's needs. Once this business model has been established between IIREVs owners, network operators, and users, it is important to set up a communication plan to encourage electromobility and inform individuals about related new technologies. Finally, users need an appropriate interface to simplify their operations and control their EV batteries. The suggested activities are interesting and might be the focus of new research that aims to customize IIREVs to adapt to actual demands.

VI. Conclusion and Perspectives

This paper directly questioned the population to know their tendency and thus to make certain hypotheses on the current acceptability of electromobility, IIREVs, and associated services. It was shown that 80% of the population is in favor of using PV energy and would like to highlight its environmental impact. Regarding V2G / V2H services, they are willing to share their energy under certain conditions and in exchange for financial compensation. It can also be observed that there is a higher level of acceptability for IIREVs when the general public is polled before the installation of these infrastructures. The researchers' work and the analysis of this survey will set up new studies to test their relevance and feasibility.

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