Credit-based Scheme for Managing Electric Vehicle Charging Stations: First Results from a Field-Experiment

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SHORT SUMMARY

This paper presents the findings of the first stage of a comprehensive field experiment, designed to investigate the effectiveness of a Tradable Credit Scheme (TCS) in managing Electric Vehicle (EV) charging stations at the European Commission's Joint Research Centre (JRC) Ispra site. The experiment, spanned 17 weeks and involved 136 JRC EV-owning employees. Participants were allocated a certain sum of credits at the beginning of each experimental week, which could be spent on energy to charge their EVs. Along with the tariffs for the energy delivered, a penalty regime was also applied to discourage unfair charging behaviors by limiting charging time to a maximum of three hours and penalizing users who occupied charging slots after reaching 100% charge. The results indicate that, compared to the conditions prior to the experiment, the proposed scheme has led to a more efficient utilization of charging stations, with a decrease of non-use time.

Keywords: Electric Vehicles, Charging Stations Management, Tradable Credit Scheme

1. INTRODUCTION

As the number of EVs continues to expand, the availability of public charging infrastructure remains a critical challenge. Despite the wide EV adoption, the deployment of charging stations has not kept pace in many countries. The European Commission reported that as of early 2023, there were only approximately 300 thousand public charging points across Europe, a number considered insufficient (1). It follows that there is a growing need for innovative solutions that optimize the utilization of existing charging stations and expand access to them. At the same time, it would be essential to reduce private car usage in favor of more sustainable mobility behavior such as using public transport or carpooling. The latter reduction could lead not only to decreased traffic congestion, with relative benefits in terms of emissions and travel times, but also alleviate the abovementioned problem concerning the scarcity of charging stations for EVs. One promising approach might be the implementation of tradable credit schemes (TCS) for EV charging stations management.

In the last decade, TCSs have attracted much interest in the transportation community (2). Most of the proposed TCSs aim to reduce traffic congestion by reallocating the traffic demand either in space or time on a transportation network (3–7). A TCS can be seen as a hybrid instrument that combines price and quantity control. As in the pricing scheme, the central authority (CA), which

usually coincides with the municipality/government, charges travelers for the congestion caused. The charges are expressed in terms of permits or credits, which have a corresponding monetary value meaningful within the trading market of the scheme. As in the quantity policies, such as odd-even license plate schemes, the CA sets the traffic demand to be served by providing credits/permits to the travelers. The latter can save credits/permits and benefit from selling unused ones. As in a cap-and-trade system, the CA can gradually decrease the number of credits/permits allocated (the cap) to steer the system towards a desired goal. The CA can also modify the credits/permits tariffs (2).

The present paper presents the results of the first stage of a very ambitious field experiment we are carrying out at the European Commission's Joint Research Centre Ispra site. The experiment consists of managing the EV charging stations, available to the JRC employees, through a TCS. To the best of the authors' knowledge, this is the third field experiment concerning the application of a tradable credit scheme in the transport sector, and the first concerning the electric vehicles' charging stations management. Specifically, the objectives of this first stage are:

- Decrease the non-use time of the charging stations
- Discourage harmful charging behaviors such as leaving the car plugged in after it has reached 100% charge, thereby preventing another person from charging
- Maximize the number of users accessing the charging service, i.e. promoting the turnover among the users
- Pave the ground for the second stage of the experiment, when participants will be able to earn credits through virtuous mobility behaviors (such as giving a ride to other colleagues), and the tradability of the credits will be allowed

The first stage of the experiment did not consider the tradability of the credits; therefore, it concerns a credit-based scheme implementation. The first stage involved 136 participants and lasted 17 weeks, divided into four phases. At the beginning of each experimental week, participants received a certain sum of credits they could spend on energy to charge their vehicles. Indeed, a time-varying charging scheme was implemented, with tariffs expressed in credit/kWh, to distribute the energy demand in time, enhance the charging infrastructure usage and maximize the number of users who access the charging service. Along with the credit tariffs for the energy delivered, a penalty scheme was also applied to discourage harmful charging behaviors. The four phases differed in the penalty schemes and measures adopted to achieve the set objectives.

2. METHODOLOGY

Infrastructure

The infrastructure used in the experiment consists of nine charging stations for electric vehicles with an individual nominal power of 7,4 kW (32 A). However, a power of 3.7 kW (16 A) was supplied all over the experiment. The stations, also featuring a photovoltaic system connected to the grid, were all located at the JRC Ispra site. **Figure 1** shows the charging spots and a typical charging station in detail. The charging stations were installed in 2023 and, for approximately one year, their use was not regulated. Anyone with access to the JRC site and who accepted the terms and conditions for using the charging stations could charge their EV (either fully electric or hybrid plug-in) for free, without restrictions on the duration of charging or the amount of electricity supplied. People were merely invited to perform only one charge per day. Moreover, no action was taken for those who occupied a charging spot with their car without actually charging.

(a) (b)

Figure 1: (a) Charging spots for electric vehicles available at the JRC Ispra site; and (b) a charging station in detail.

Experimental phase and set-ups

The experiment was divided into four experimental phases. The phases differed in duration, number of participants and set-ups of the implemented credit-based scheme. 127 participants were registered in the first week of phase 1. This number increased to 136 for the last week of phase 4. All the participants were owners of either fully electric or hybrid plug-in vehicles. At the beginning of each experimental week, participants received 20 credits per working day of the week. Therefore, a maximum of 100 credits per user was allocated for a complete working week. After registration, users could authenticate themselves at the EV charging stations using their staff badge, which serves as personal identification for accessing the JRC site. The allocated credits were virtually transferred to their personal credit wallet, also accessible through a web-based page. These credits could then be used for charging. The adopted credit tariffs, expressed in credit/kWh, are presented in **Figure 2**. The tariffs varied over the day, depending on the measured energy demand before the experiment started. Specifically, higher tariffs were associated with times of day when energy demand was higher. The implemented tariff scheme was designed in a way to reallocate in time the energy demand, aiming to maximize the utilization rate of the charging stations.

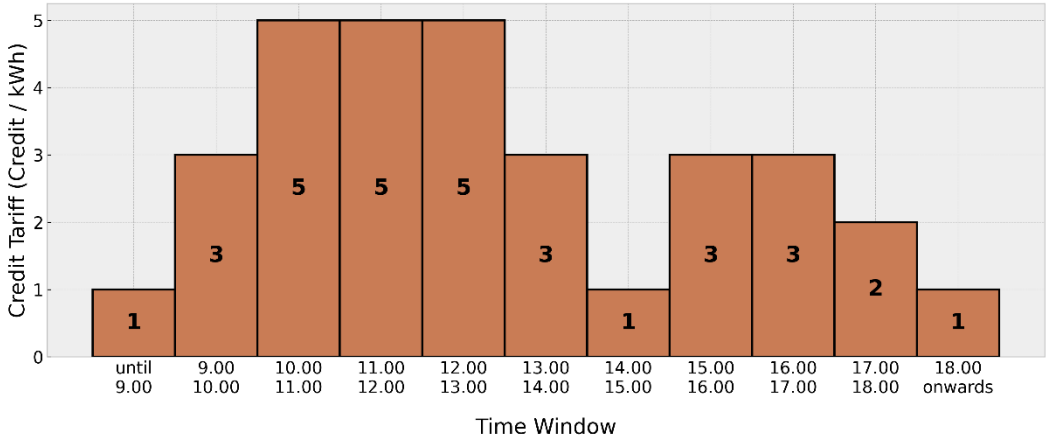


Figure 2. Credit tariffs.

Along with the credit tariffs for the energy delivered, a penalty scheme was implemented to discourage harmful charging behaviors. The latter consists of improperly occupying a charging station, to the detriment of other users. Specifically, during phase 1, a penalty of 1 credit every 5 minutes was applied if a user left the vehicle in charge after reaching the 100% battery status or for more than three hours. From phase 2 until the end of the experiment, the penalty regime doubled, increasing to 2 credits every five minutes. During phases 1 and 2, the charge did not stop in case users ran out of credit while charging. However, users with a negative balance could not start new charging sessions. From phase 3 onwards, the charge stopped immediately in case users ran out of credits. However, in phases 3 and 4, users could still accumulate a negative budget through penalties. In phase 3, incurring a negative balance at the end of the week did not produce any effect, as users received a new allocation of credits at the beginning of the following week. Vice versa, in phase 4, if a user went into a negative balance during a week, the negative credits were deducted from the user's credit allocation for the following week.

3. RESULTS AND DISCUSSION

The results regarding how the usage time of the charging infrastructure changed before and during the experiment are shown in **Figure 3**. The figure refers to the type of occupancy, expressed in percentage of time, of the nine charging stations recorded during the time window from 8:00 AM – 6.00 PM, which reflects the duration of a typical working day. Each bar is divided into three parts. The green part indicates the percentage of actual usage time, i.e. the percentage of time during which the charging stations were actively charging vehicles. The yellow part reflects the percentage of time during which the stations were available and ready to be used. Finally, the red part represents the percentage of time during which the stations were improperly occupied, meaning that vehicles were plugged in, but the charging had already finished because the maximum charging time limit had been exceeded, or the vehicle's battery had already reached 100%. The first bar on the left concerns 3 weeks prior to the experiment, during which the charging behavior of people had been monitored. The four bars on the right of the figure correspond to the period under the proposed scheme, with each bar representing one of the four experimental phases.

As shown in the figure, before the beginning of the experiment, charging stations were actually charging 58.2% of the time within the 8:00 AM – 6.00 PM time window. The remaining 41.8% was non-use time. Specifically, stations were free and ready to be used only for 20.6% of the time, while for the remaining 21.2% they were improperly occupied. This latter condition is the most detrimental to the system's operation since undue occupancy not only results in the underutilization of the infrastructure but also prevents its potential use by other users. On the other hand, an increase in the percentage of usage time was observed all over the experiment, as shown by the green parts of the four bars on the right of **Figure 3**. Particularly, the percentage of time within the 8:00 AM – 6.00 PM window during which the charging stations were actively charging vehicles reached values between 65.7% and 70.6% (69.2% in average) across all four phases of the experiment, thus reflecting an increase in average of 11% (58.2% - 69.2%) compared to the period before the experiment. It follows that, under our credit-based scheme, a decrease in the non-use time of the charging station has been achieved. Notably, also the "quality" of the non-use time has been improved. Indeed, across all four phases of the experiment, there was a reduction of approximately 70% (from 21.2% to 6.6, 5.9, 5.8, 6.9%) in the percentage of time spent in undue occupancy, in favor of an increase in the percentage of time during which the stations were free. Overall, the results obtained in phases 1, 2, and 4 are almost identical, while a reduction in percentage of usage time was observed in phase 3.

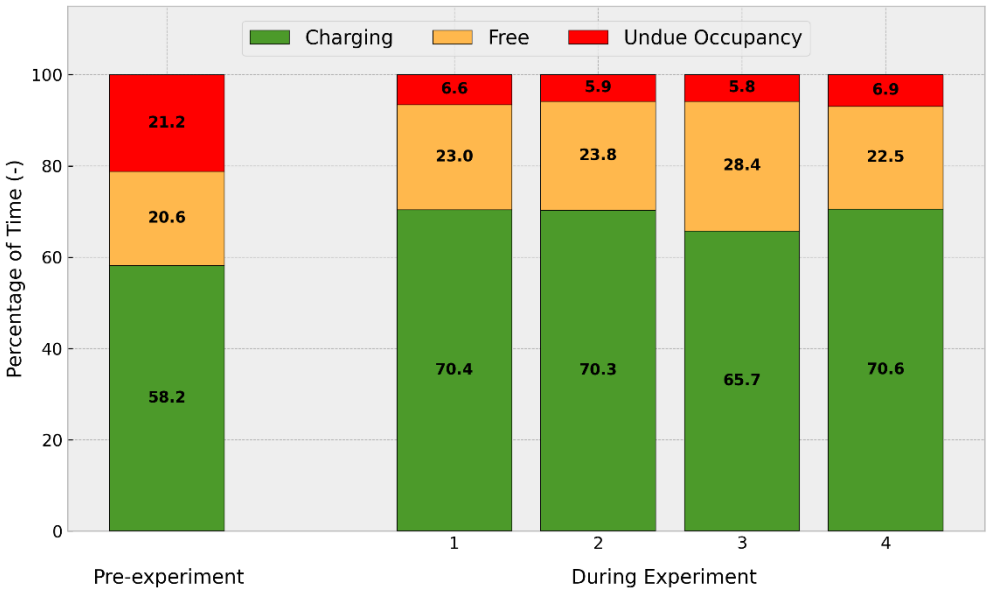


Figure 3: Occupancy of charging stations (Percentage of time) before and during the experiment, for the 8.00 AM – 6.00 PM time window.

Figure 4 presents how the percentage of actual usage time varies over the day. On the x-axis, there are the time intervals of the day. For each of these time intervals, we calculated the average actual usage times recorded before the experiment and in each experimental phase. The results show that the adopted tariff scheme succeeded in distributing the energy demand throughout the day, as after the 09:30 peak, the percentage of actual usage time remained consistently between around 60% and 80%, showing an evident improvement compared to the pre-experiment situation, when the percentage dropped to 40%. The percentage of actual usage time progressively decreases as the end of the working day approaches. In general, no significant difference in the percentage of actual usage time is observed across the different phases. The curves concerning the first and second phases (blue and red curves) exhibit nearly the same trend. However, it can be inferred that in phase 3, the time spent charging was lower (see the results in **Figure 3**), as the yellow curve, corresponding to phase 3, is often below the other curves (excluded the pre-experiment one). Finally, it appears that the measures implemented in phase 4 had a slight effect in shifting the charging demand towards the afternoon, as the green curve, corresponding to phase 4, lies above the others from the 14:00 interval onwards.

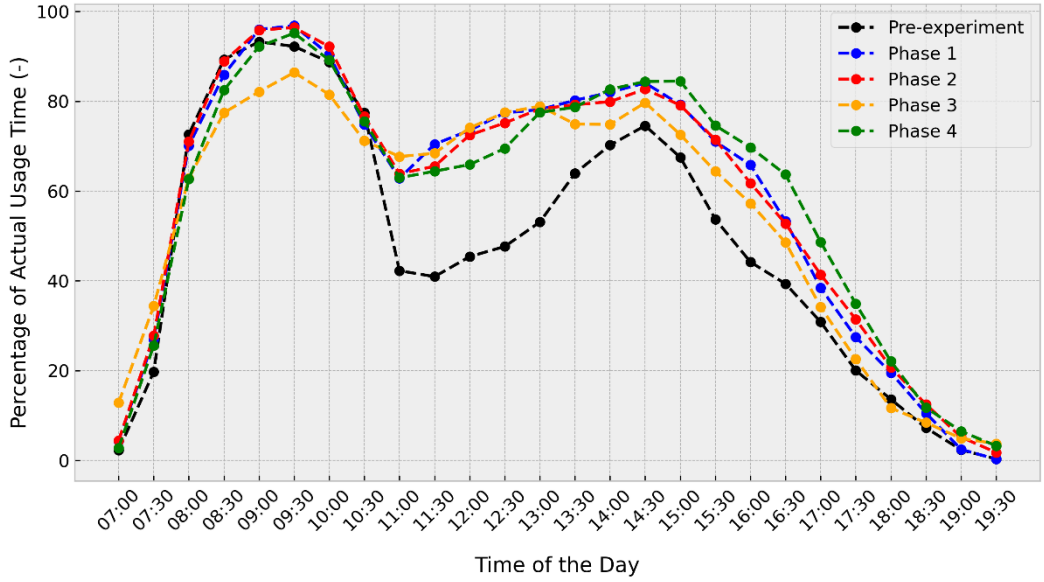
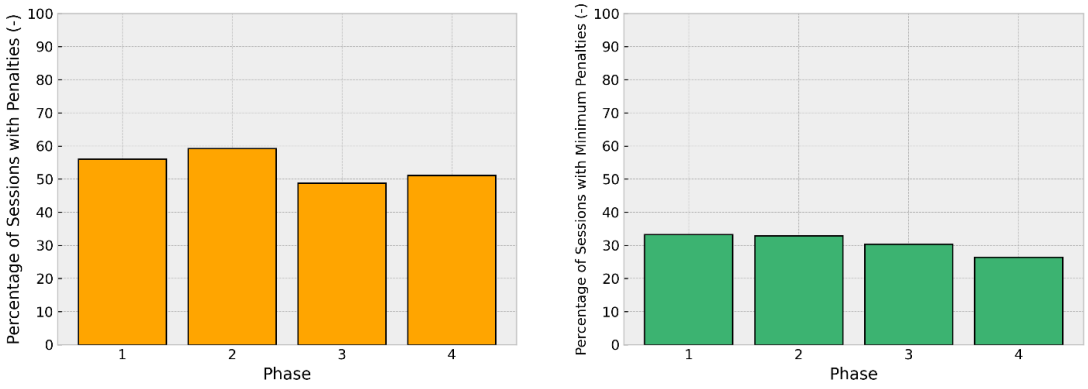


Figure 4: Variation of the percentage of actual usage time throughout the day.

The measures adopted in phases 3 and 4 appear to have had a small positive effect on the percentages of sessions with penalties, as depicted in **Figure 5a**. Moreover, they had an effect in reducing the number of sessions for which the time spent under the penalty regime was lower than 10 minutes. The percentages relative to these latter cases are presented in **Figure 5b**. Each green bar refers to the number of sessions associated with a penalty equal to 1 credit for phase 1 and 2 credits for the other phases, i.e. the number of sessions for which the minimum penalty was registered, implying a time in penalty lower than 10 minutes. From phase 2 on, the bars start slightly decreasing. It follows that the measures adopted during the experiment promoted an increase in participants' attentiveness, reducing the occurrence of sessions with penalties, particularly those with short penalty times, which are typically due to distraction or inattention.



(a) (b)

Figure 5: Percentage of sessions for which penalties were triggered (a); Percentage of sessions in penalty concerning a time spent in penalty lower than 10 minutes (b)

112 out of 136 participants charged at least once their vehicles. **Figure 6** shows the percentages of participants according to the number of charging sessions performed each week. The figure concerns only weeks consisting of five working days. During the experiment, the percentage of users charging at least once in the single week, indicated by a blue dashed curve, remained between 40 and 50%. This outcome suggests that a good turnover in charging has been achieved all

over the experiment. However, the strategies implemented from phase 2 onwards did not affect this turnover. On the other hand, the percentage of users performing 1 or 2 charging sessions (red and purple dashed curves respectively) appears to increase, at the expense of users who charged 3 or 4 times. The latter outcome is more evident during phase 2, and it is in line with the objective of increasing the turnover in charging. A mild increase in the percentage of users charging at least once seems to start from phase 4.

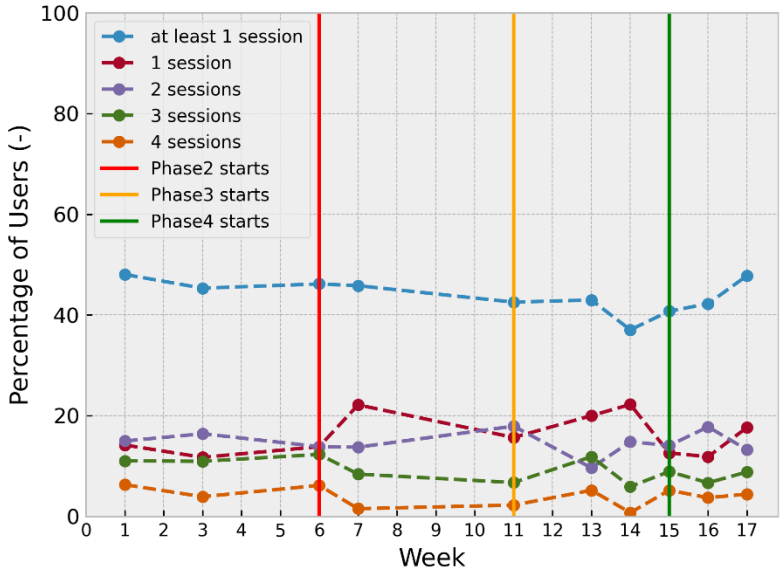


Figure 6. Percentage of users according to the number of charging sessions performed.

4. CONCLUSIONS

The present paper presents the results of the first stage of this experiment, which aimed to implement a credit-based scheme without allowing the tradability of credits. The results suggest that, under the proposed scheme, the charging stations were well exploited, i.e. their non-use time was limited. Specifically, the non-use time was reduced compared to the pre-experiment conditions, with the energy demand uniformly distributed throughout the day. Notably, approximately 70% reduction in improper occupation time of the stations was achieved across all four phases of the experiment. Additionally, the average number of charging sessions per day remained nearly constant and close to the optimal value throughout all phases of the experiment.

The results also showed that the measures adopted during the experiment promoted an increase in participants' attentiveness, reducing the occurrence of sessions with penalties, particularly those with short penalty times, which are typically due to distraction or inattention. However, only minimal changes in users' unwanted charging behavior were observed across the different phases. During the experiment, the percentage of users charging at least once per week remained between 40 and 50%, suggesting that a good turnover in charging has been achieved. However, the strategies implemented from phase 2 onward did not affect this turnover. On the other hand, the percentage of users performing 1 or 2 charging sessions appeared to increase, at the expense of users who charged 3 or 4 times.

ACKNOWLEDGEMENTS

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