Advanced Smart Charging Algorithms and Protocols

Re-ESCAPE whitepaper

May 2023

Abstract

The transportation sector is moving towards electric vehicles (EVs) to decrease greenhouse gas emissions and promote sustainability. The next step is to fully integrate renewable energy sources with smart charging infrastructure in order to maximise the impact on climate goals. This whitepaper focuses on the Dutch government-funded Re-ESCAPE project (Resubmission Experiment Smart Charging Algorithms and Protocols for EVs) to explore advanced concepts of smart charging. The project addresses three main challenges: renewable energy variability, grid stability and congestion, and maintaining the interoperability between stakeholders acting within the EV smart charging market.

The Re-ESCAPE project aims to align charging demand with renewable energy availability by connecting EV charging to electricity prices. By implementing smart charging protocols and forecasting algorithms, the project successfully shifted charging loads from evening demand peaks to the night and early morning. As a result, peak demand was reduced and the use of renewable energy increased, thereby successfully contributing to the sustainability goals.

The findings of this study highlight the benefits and advantages of adopting smart charging solutions. However, further research is needed to fully realize the potential of these solutions. This includes expanding the number of charge points, improving prediction algorithms, and increasing the involvement of EV drivers and manufacturers.

1. Introduction

The transportation sector plays a pivotal role in global energy consumption and greenhouse gas emissions. As societies strive for decarbonization and reduced reliance on fossil fuels, electric vehicles (EVs) have emerged as a promising alternative to conventional internal combustion engine vehicles. The proliferation of EVs brings numerous benefits, including lower emissions, improved air quality, and reduced dependence on finite fuel resources. However, the widespread adoption of EVs also poses significant challenges to existing infrastructure, particularly in relation to charging.

Traditional charging methods typically involve plugging an EV into the electrical grid without considering the overall energy demand, supply, and grid capacity. As the number of EVs on the road increases, this uncoordinated charging behaviour can strain local grids, leading to peak demand spikes, grid instability, and inefficient energy utilization. To overcome these challenges, smart charging has emerged as a crucial concept in the field of electric mobility.
Smart charging refers to the intelligent and optimized management of EV charging processes based on various factors, such as grid conditions, user preferences, and electricity prices. By leveraging advanced technologies, data analytics, and communication systems, smart charging aims to enhance the integration of EVs with the energy grid, enabling efficient and sustainable charging solutions.

This whitepaper delves into the concept of smart charging, focusing on the Dutch government funded Re-ESCAPE project (Resubmission Experiment Smart Charging Algorithms and Protocols for EV's). Main partners involved in this project are GreenFlux Assets B.V., TotalEnergies Charging Solutions NL, Dexter Energy Services B.V., Stichting Nationaal Kennisplatform Laadinfrastructuur (NKL) and the EVRoaming Foundation.

2. Problem statement

The rapid expansion of EVs presents a unique opportunity to reduce greenhouse gas emissions and achieve a sustainable transportation system. However, the seamless integration of EV charging infrastructure with renewable energy sources poses significant challenges. The problem at hand is the efficient and optimized utilization of renewable energy for smart charging, considering the intermittent nature of renewables and the dynamic nature of EV charging demand.

One of the primary goals of smart charging is to align the charging process with the availability of renewable energy resources. By doing so, the utilization of clean energy sources is optimized, reliance on fossil fuels reduced, and the environmental impact of transportation mitigated. Three key challenges that must be addressed to realize the full potential of integrating renewable energy sources in smart charging are:

1. ***Renewable energy variability***
   Renewable energy sources, such as solar and wind, exhibit inherent variability due to weather conditions and time-of-day fluctuations. The intermittent nature of renewables makes it challenging to match the charging demand of EVs with the availability of renewable energy. This variability requires sophisticated forecasting and optimization algorithms to ensure that EV charging can be coordinated effectively with renewable energy generation

2. ***Grid stability & congestion***
   The integration of a large number of EVs charging from renewable energy sources can create grid instability and congestion. Sudden charging load spikes during periods of high renewable energy generation can strain local distribution grids and lead to voltage fluctuations and transformer overloading. Intelligent charging strategies need to be developed to balance the charging demand, manage grid constraints, and ensure the stability and reliability of the overall energy system.

3. ***Interoperability within the smart charging market***
   Ensuring effective interoperability remains a key challenge when developing smart charging solutions. It is crucial for all stakeholders to seamlessly connect and collaborate in order to provide a uniform smart charging experience for the EV driver. For instance, there are multiple Charge Point Operators (CPOs) operating in the public, private, and business domains, offering diverse smart charging options to EV drivers. Also, there are numerous EV manufacturers and many EV driver user profiles. It is essential for these various entities to exchange information and cooperate when developing smart charging solutions. The development of universal smart charging protocols and algorithms plays a vital role in facilitating this collaboration.

Addressing these challenges requires innovative technologies and protocols, advanced data analytics, and effective coordination among stakeholders. In the Re-ESCAPE project, all three challenges were addressed.

3. Proposed solution

To match the charging demand of EVs with the availability of renewable energy, the time of charge was linked to the electricity price. Specifically, the timing and shape of the EV charging load profiles were related to day-ahead electricity prices. The rationale behind this approach was that there is a direct correlation between the amount of renewable energy available on the grid and the cost of electricity, see Figure 1. This correlation indicates that prices tend to be lower during periods of high renewable energy supply. As the energy transition progresses and additional wind and solar energy sources are integrated into the grid, it is anticipated that this correlation will become even more pronounced.

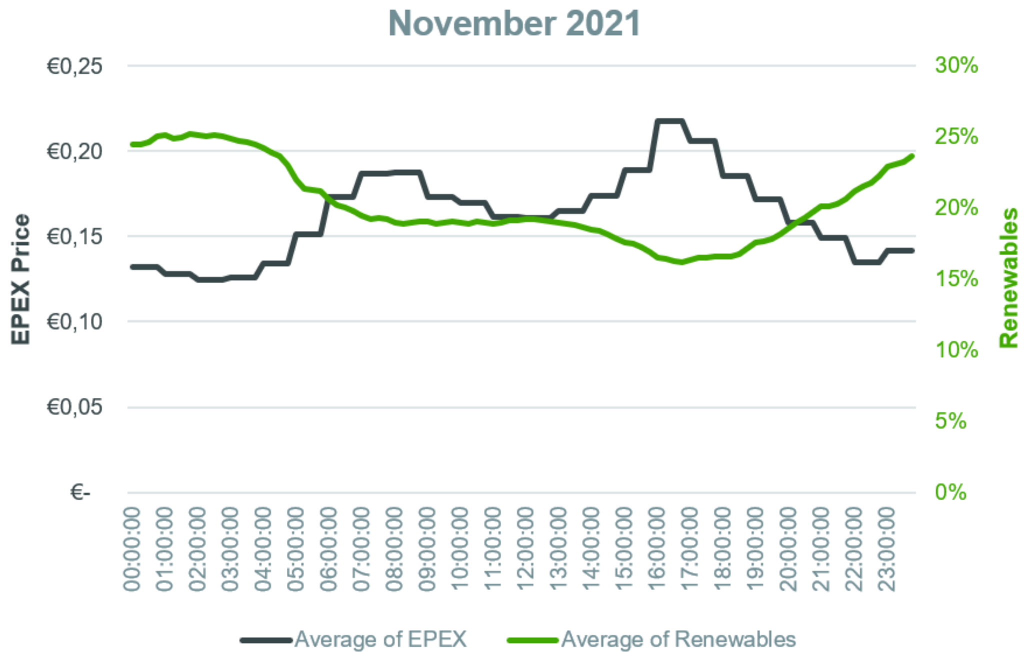

Figure 1: EPEX and amount of renewable energy in the total energy mix over a 24hr cycle in November 2021

The second challenge, maintaining grid stability and avoiding congestion, was not the primary focus of the Re-ESCAPE project, but it was assumed that linking EV charging profiles to electricity prices (and, consequently, to renewable energy supply) would yield a beneficial impact in this aspect as well. The underlying reason for this assumption was the misalignment between the moments of high renewable energy supply, typically occurring in the middle of the day during summer and during the night in winter, and the energy demand peaks that typically happen in the evening and morning.

Regarding the interoperability aspect, Re-ESCAPE algorithms and protocols were developed by adding functionalities to existing protocols. These functionalities will become part of the OCPI 3.0 released later this year. OCPI stands for 'Open Charge Point Interface' and is an open standard protocol for communication between EV drivers, CPO platforms and service providers. The purpose of OCPI is to provide a standardized way for different charging networks and eMobility Service Providers to exchange information about charging sessions, pricing, availability, and other relevant data. This helps to make EV charging more accessible and convenient for EV drivers, regardless of which network or provider they use.

4. Setup & methodology

The roles and relationships between the different actors in the project were based on the definitions as defined in ECISS (E-mobility Communication & Information System Structure) shown in Figure 2. In Re-ESCAPE, a number of roles have been combined within the project partners, as visualised in Figure 3.

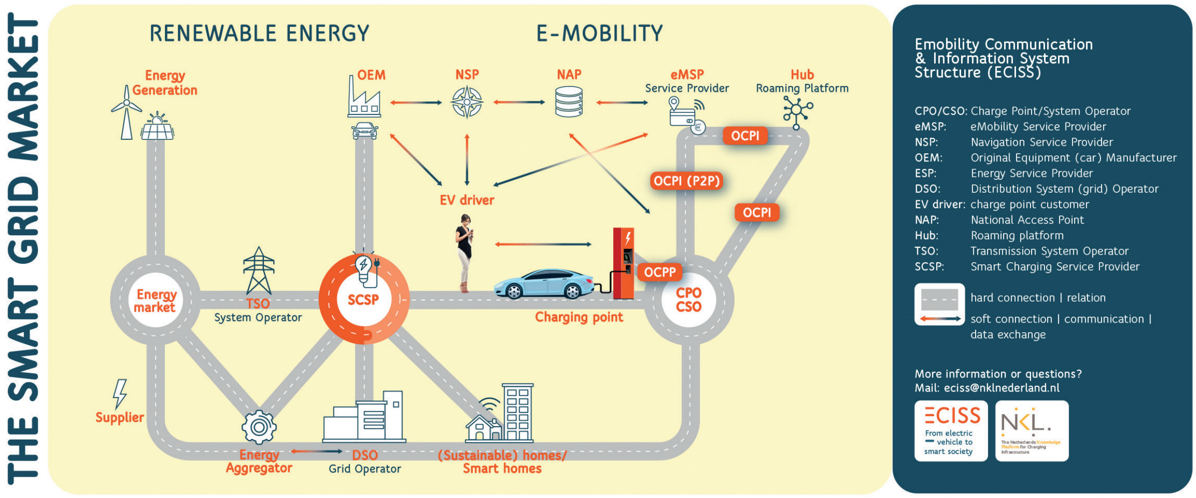

Figure 2: Actors within the smart grid market as defined in ECISS (https://evroaming.org/eciss)

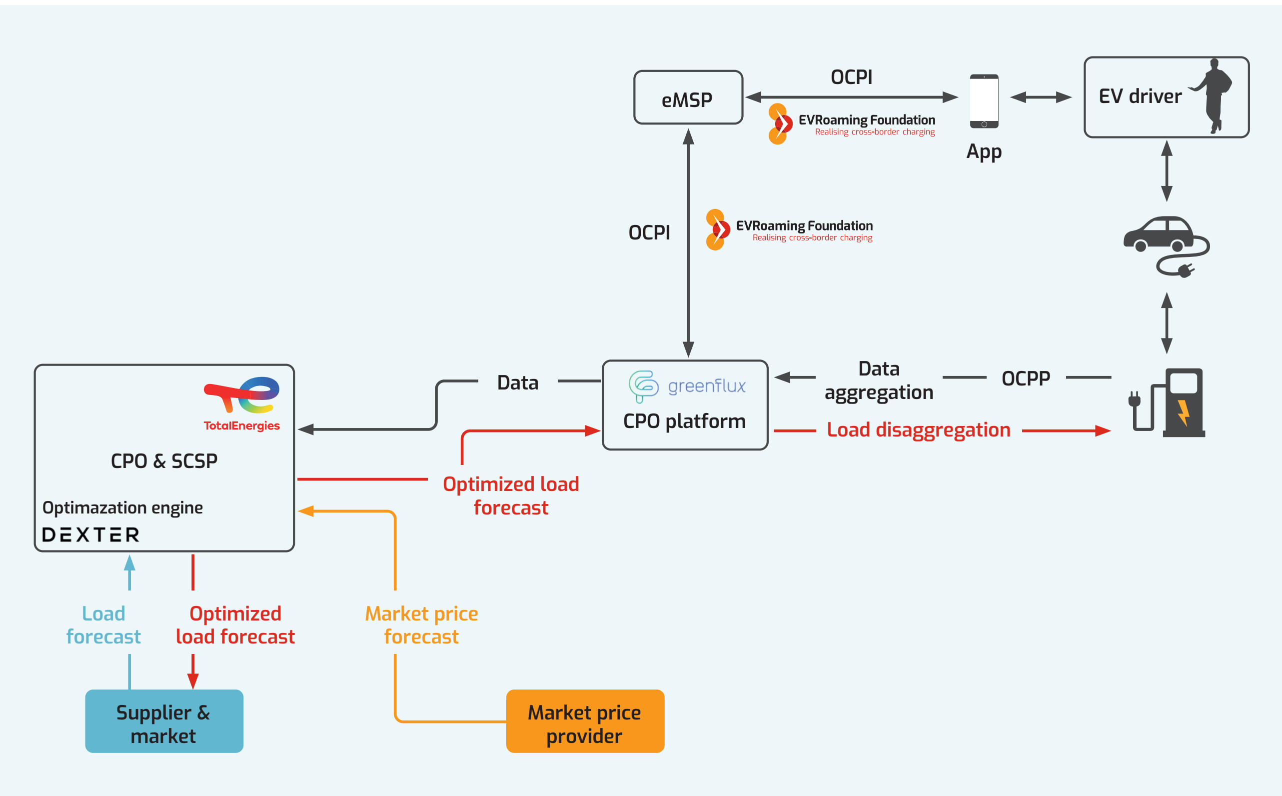

Figure 3: Actors as defined in the Re-ESCAPE project

The Re-ESCAPE roles and relationships are further described as follows:

1. TotalEnergies took the role of both the Smart Charging Service Provider (SCSP) and the CPO. As the SCSP, TotalEnergies was responsible for load forecasting and determining the optimized load profile. Additionally, acting as the CPO, TotalEnergies managed and operated the charging infrastructure.

2. GreenFlux served as the CPO technology provider. This included among others, providing a cloud based smart charging algorithm that disaggregates the load profile to individual steering signals for the charge stations.

3. Dexter, specialized in optimization technology, developed optimization models used by TotalEnergies to achieve an optimal charging process and improved efficiency.

It is important to note that while the roles of SCSP, CPO, and eMSP (eMobility Service Provider) are distinct in the ECISS overview (Figure 2), within the Re-ESCAPE project multiple roles were fulfilled by a single partner. Also, the Re-ESCAPE consortium deliberately did not include an eMSP such that this role can be fulfilled by any party active in the field.

The project consisted of two phases. In the first phase, GreenFlux developed smart charging algorithms to be able to steer EV charging load profiles as function of energy market prices on TotalEnergies' public charging network. Further, Dexter Energy Services developed algorithms to predict day-ahead energy prices and optimize the EV charging load. In addition to the development of smart charging algorithms, contributions were made to the OCPI protocol, enabling improved information exchange and EV driver interaction. These contributions not only improve the efficiency of the smart charging algorithms but also provide the capability for EV drivers to interact with their charging session and hereby improving the overall charging experience. In the second phase, the effectiveness of the newly developed algorithms and protocols was evaluated during a pilot project, setup and managed by TotalEnergies.

Finally, NKL (the Netherlands Knowledge Platform for Charging Infrastructure) together with the EVRoaming Foundation (the OCPI management entity) was responsible for sharing gained knowledge within the EV community and ensuring open-source access for the protocol improvements through the OCPI development process.

The pilot project ran during the month November 2021 and included 96 charging points distributed over the two locations in the Netherlands, i.e. Zeist and Heerhugowaard (part of the Metropolitan Region Amsterdam and represented by project office MRA-E). These 96 charging points were selected by TotalEnergies after analysing historical charging data and filtering on evening peak loads. Active steering / load shifting took place from 17:00 until 08:00 in the morning. All EV drivers automatically took part in the pilot unless explicitly stating otherwise via a mobile application.

5. Results

The main result was that the charging loads that normally took place in the evening, were shifted towards the night and early morning. This concept is visualised over a 48hr cycle in Figure 4. The blue line represents the unsteered load profile that peaks in the early evening between 18:00 and 21:00 when the EV driver plugs-in after arriving home from work. The red line represents the shifted load profile based on the EPEX (European Energy Exchange) price (green line). Interesting to note is that load steering still takes place after 08:00 while the timeframe for active steering was defined between 17:00 and 08:00. This observation will be considered further when discussing the results.

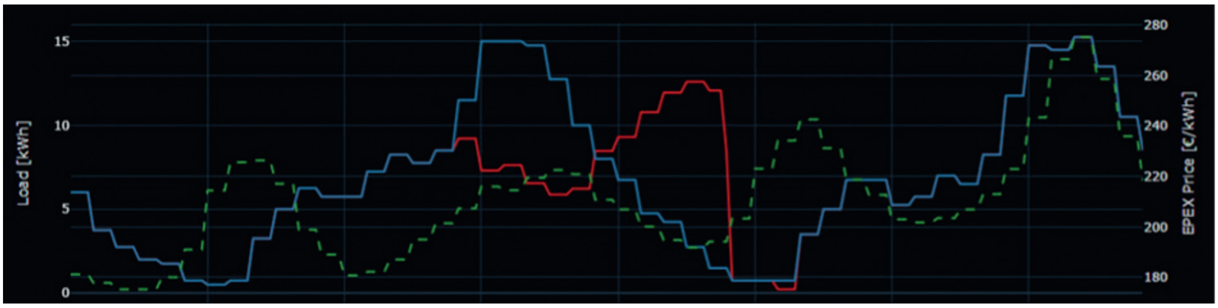

Figure 4: Concept of shifting load profile from evening to night an early morning based on energy prices

In Figure 5 the results are visualised over a period of one week. Again, it can be seen how the evening peak is shifted towards the night and early morning. This not only increased the average use of renewable energy (green line, Figure 5) but also reduced the evening energy demand peak.

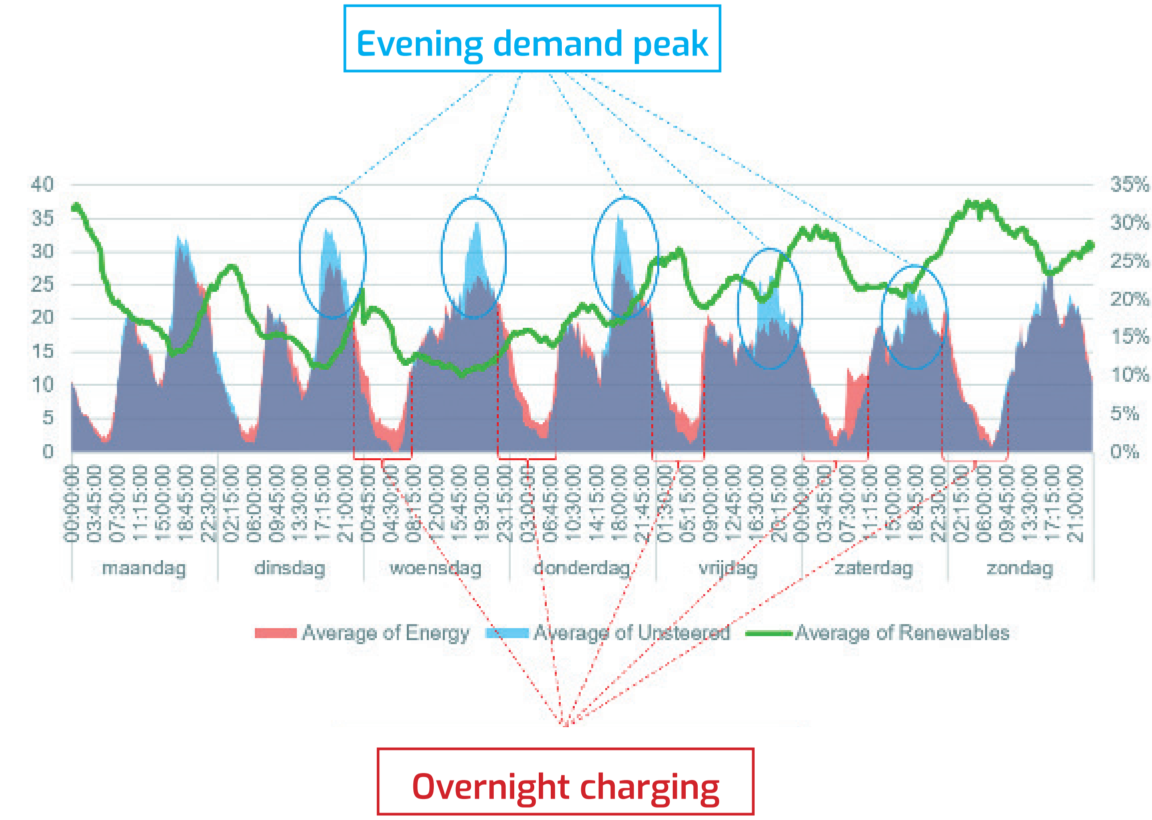

Figure 5: Load steering over period of one week

In numbers, over the total test period of one month, 6% of the load was shifted, resulting in peak demand reductions up to 17% and an increase in average renewable energy of approximately 1.5%.

To put the increase in use of renewable energy into perspective, simulations were performed as described in Figure 6. The simulation results showed that under optimal conditions and under the boundaries as defined within the pilot project, a maximum 3.5% increase in renewable energy use can be achieved by active steering load profiles based on energy prices.

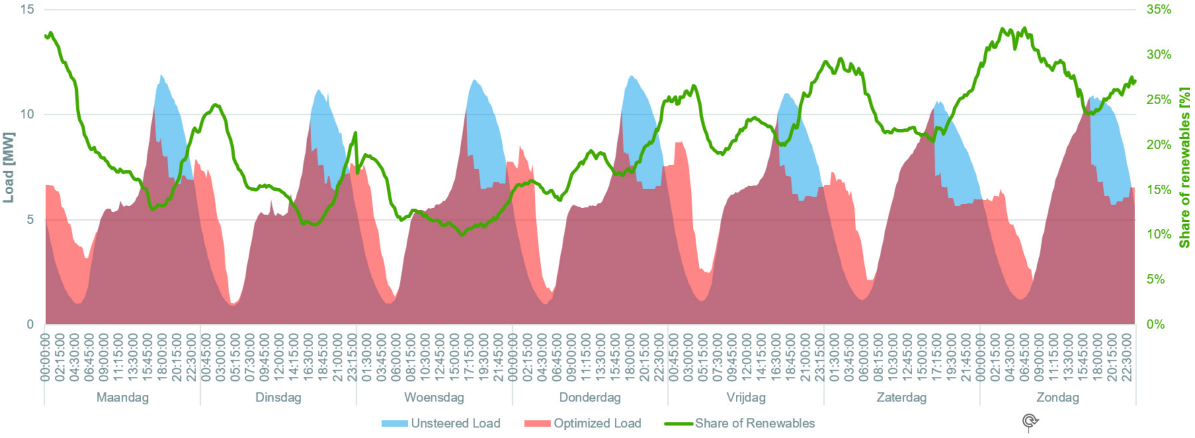

Figure 6: Potential of load steering optimized for maximum use of renewable energy

Finally, it was noted that a few EV drivers experienced problems in the EV response to the varying charge load and received confusing push-messages from their EV mobile application stating that the charging session was interrupted.

6. Discussion

The results obtained from the pilot project show that it is possible to optimize the integration of renewable energy and thereby reduce CO_2 emissions by applying smart charging solutions to charge EV's. However, there are a number of points to consider when interpreting the results.

At first, the number of charging points included in the test is limited. To improve the load forecasting and more accurately quantify the impact of smart charging on renewable energy usage, the test should be expanded to include more charging points.
It is presumed that the load steering that took place after 08:00 (Figure 4) is caused by a mismatch between the predicted load demand, based on historical data and the actual required charging load on the day itself. It is expected that by increasing the number of charging points, the prediction will become more accurate and this effect will disappear.
Further, the charging load forecast was based on unsteered historical data. Because the load shifting itself has an effect within the historical data set, the prediction algorithm should correct for this. In the pilot test this was not considered.

Also, the level of involvement of EV drivers was limited, only providing an 'opt-out' option for EV drivers who did not want to participate in smart charging. However, there is significant room to further involve EV drivers. Currently, CPOs and eMSPs have limited access to EV driver information. Enhancing this access can enable more advanced optimization strategies. For instance, if the CPO receives feedback from the EV regarding its state of charge and the amount of energy already charged, it would be possible to consider specific user preferences such as desired state-of-charge and preferred time of departure. By incorporating this information into the charging process, a more personalized and tailored charging experience can be provided to EV drivers.

Finally, following the EV driver feedback, a recommendation is to include the EV manufacturer in the test. It is important that the EV itself and its (mobile) applications are compatible with the smart charging solutions and do not cause any inconvenience for the EV driver

7. Conclusions & recommendations

Smart charging plays a crucial role in integrating renewable energy sources into our energy system. The Re-ESCAPE project explored this potential by linking EV charging profiles to electricity prices. This approach was motivated by the fact that there is a correlation between the amount of renewable energy available on the grid and the cost of electricity.

Algorithms were developed to forecast EV charging load demand and day-ahead electricity prices. Also, smart charging protocol specifications were developed to be able to steer the EV charging loads in relation to the energy market fluctuations. These protocols were extended versions of existing open-source protocol standards (e.g. OCPI) to maintain effective interoperability between charging networks, service providers and EV drivers.

Results obtained during a pilot project in the Netherlands with 96 charging points, showed that load shifting based on energy prices resulted in a shift of charging loads from the evening to the night and early morning, leading to reduced peak demand and increased use of renewable energy.

While the Re-ESCAPE project showed promising results, more work is required to further scale this advanced smart charging solution. The first recommendation is to increase the number of charging points using this methodology to test scaling effects. Expectations are that the algorithm applications will become better with larger numbers. Secondly, the prediction algorithms should be improved to account for the load steering itself. Also, EV driver involvement needs to be thoroughly tested as part of the full proposition. The question to answer is how to engage with the EV driver and to include personal charging preferences in the load steering algorithms. Finally, EV manufacturers should be involved to ensure full compatibility between the EV and its (mobile) applications and the smart charging solutions.

Overall, the Re-ESCAPE project successfully demonstrates the potential of smart charging to increase renewable energy usage by exploiting the direct relationship between charging profiles and electricity market prices, which is another step towards a greener and smarter future in the transportation sector.

greenflux

TotalEnergies

DEXTER

EVRoaming Foundation
Realising cross-border charging

NKL
The Netherlands Knowledge Platform for Charging Infrastructure