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Finding the sweet equilibrium between societal interest and business opportunities for Smart Charging EVs

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Executive Summary

In our research we have identified institutional bottlenecks and possible solutions that impede the development of the Smart Charging of electric vehicles. In this way, both market and government are assisted with concrete ideas in order to accelerate the development of Smart Charging in the short term. Our study also provides a starting point for the design of an efficiently and effectively functioning market

To facilitate electric driving, the development of new infrastructure is vital. The availability and quality of this charging infrastructure largely determines the future success of electric transport. For the efficient functioning of this new market for electric transport, charging must be further optimised (become 'smarter').

In a demonstration in the Netherlands we test some of the proposed solutions for using as much as possible renewable energy, meanwhile keeping the energy grid in balance and materializing business opportunities. This is done as much as possible with the use of standard or de-facto standard protocols between systems.

We have created a charging system of the year 2025 to test proposed solutions in real-life. For 2 urban areas we have virtually added around 750 charge stations being actually used on a daily basis. We plan to run several tests to qualify the advantages for environment, society and business. In May 2019 we can share the results of our demonstration.

1. The Netherlands

To reduce emissions of harmful substances from the transport in a fuel transition is essential. Electric transport is one of the most important ways of achieving this. In recent years, the Netherlands has been actively involved in stimulating electric transport and have acquired leading role internationally. In 2015, the Dutch share in electric vehicles (EVs) in use worldwide was ~8% (of the approximate 1.2 million vehicles in total).

To facilitate electric driving, the development of new infrastructure is vital. The availability and quality of this charging infrastructure largely determines the future success of electric transport. For the efficient functioning of this new market for electric transport, charging must be further optimised (become ‘smarter’).

‘Smart Charging’ can help to improve the alignment of demand and supply of (renewable) electricity by gearing the time, speed, and charging method to market conditions. This helps to give the e-driver an optimal charging experience, to optimise the use of renewable electricity and to unlock flexibility.

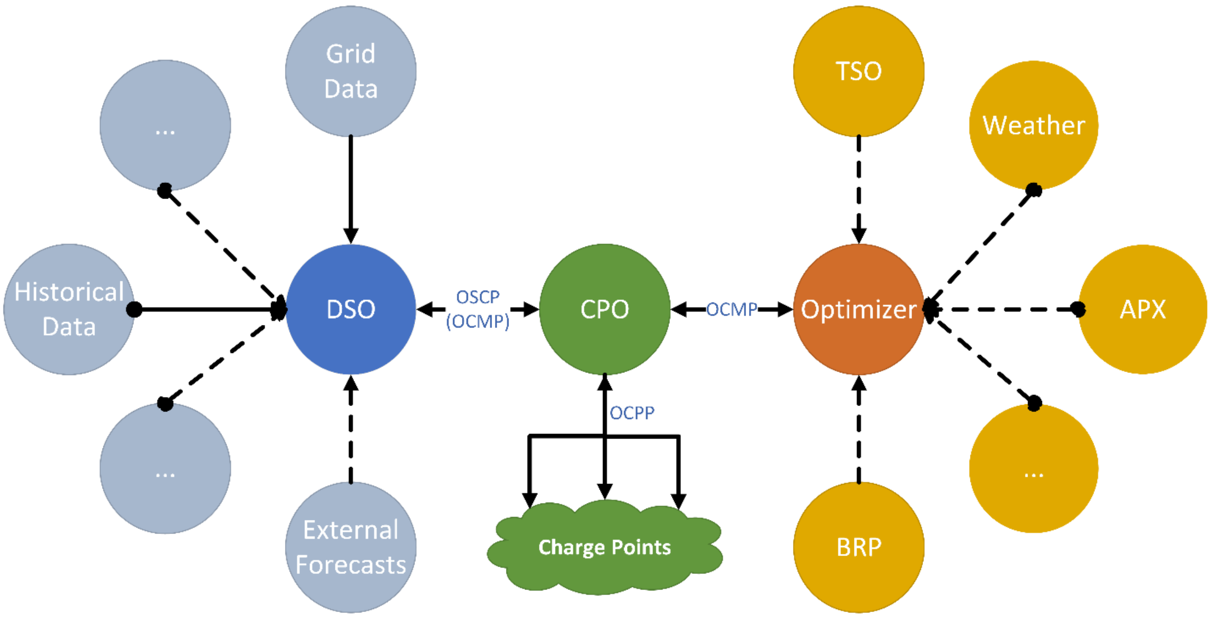
The smart deployment of this storage capacity is particularly relevant to grid operators. Key principles of Smart Charging are: (1) free access to renewable - local - energy (provider chosen by EV driver rather than by charging point owner), (2) optimising local grid load (prevents extra grid investments) and (3) facilitates grid flexibility (storage of temporary excess of energy generated in a decentralised manner).

1.1 Demonstration set-up

For the Invade project the existing charging network of EVnetNL is made available for smart charging tests. This charging network consists of 800 charge stations located across the Netherlands in about 200 municipalities. All charge stations have a 3X35A Grid connection. The charge stations are from a handful of different suppliers and all support OCPP1.6. We have taken two real urban areas and virtually added charge stations actually being used. We can now based on actual data test the charging system of 2025.

Major achievements and results for the Dutch pilot are realized in software development, incorporating all stakeholders. The following software building blocks are created:

1. DSO: Prediction of Electricity Grid Usage - on District level
2. Optimizer: INVADE platform Energy management - on District level
3. CPO: Controlling Charge Transactions – on Grid Connection level
4. Integration Exchange of information between roles via standard protocol OCMP



DSO: Prediction of Electricity Grid Usage - on District level

ElaadNL is founded and funded by the Dutch DSO's and represents them in the EV-domain. DSO's manage the Low - and Mid Voltage Electricity Grid, also referred to as Distribution Grid. The distribution grid in the Netherlands (and Europe) is historically designed for peak demand. For the Low Voltage Grid, this has resulted in a situation where the sum of the total capacity of household connected to a substation is usually much higher than the capacity of that substation. Given the fact that households never use the available full capacity at the exact same time, this has proven itself as an effective means to restrain the costs for the Electricity Grid . However, with the coming of EVs, those household connections, and explicit EV charger connections, is expected to lead to congestion issues at a certain point in time.

It is the legal task of a DSO to maintain a stable electricity grid. The current/future situation, that is to be changed, is related to actual demand by connected users. Currently the grid connection is measured as a summarized effect of all devices behind the connection. For payment of energy consumed this is adequate, but for optimal flexibility management this is insufficient. There is an endless number of different devices that can consume energy behind a metered connection, but within the Invade project we have divided them into two simple categories:

1. Flexible load: Devices that can/could have a delayed function, like heating, cooling, washing. Theoretically these devices could be turned on a bit later or earlier without discomfort to the owner. Having control over these devices (within margins) could help in managing grid usage during peak moments.
2. Non-flexible load: devices that cannot be delayed, such as cooking, TV, light, etc. Influencing behavior of these type of devices would have immediate and unacceptable impact for the owner.

Having flexible load devices metered separately, knowing exactly how much of the total load from a connection is flexible and at what times, is a first step towards more detailed balancing capability that would have the least impact on the life of consumers.

Optimizer: INVADE platform Energy management - on District level

ElaadNL is founded and funded by the Dutch DSO's and represents them in the EV-domain. By Dutch law, DSOs are not allowed to engage in commercial activities, such as energy management including generation, supply and balancing of electricity. For the nationwide transmission the TSO is responsible, by law.

As stated before, the legal task of a DSO to maintain a stable electricity grid which in the eMobillity industry translates to managing (peak) capacity. However, other stakeholders in the eMobility industry have other interests such as balancing demand/supply (BRP), maximizing use of renewable energy (Generator), frequency (TSO) and effective use of charging infrastructure (CPO). All these interests need to be aligned with the mobility need of the driver. In the Invade project we have defined an Optimizer role for this. Within the boundaries of the maximum available capacity in the electricity grid, the Optimizer can enhance this profile to take into account the other mentioned interests. The result of this enhancement results in a new Optimal capacity profile on a district level. The Invade Platform is the pivotal part of this value adding optimization.

CPO: Controlling Charge Transactions – on Grid Connection level

The outcome of the previous two software building blocks, is a multi-actor optimized district charging profile. This district charging profile needs to be transferred to charging profiles for individual charging sessions. This is the scope of the software building block described in this section.

We have defined an algorithm which takes the optimal capacity profile as a basis. At any point in time, the number of active charging sessions is extracted from the CPMS. If the charging speed of all active charging sessions exceeds the optimal capacity, all sessions will be limited. We use a minimum threshold of 13A, to limit the user impact. Whenever a session stops or a new session starts, the calculation is repeated.

In the remainder of the project we will enhance the algorithm, taking into account calculated user needs. As we have historic data of the anonymous RFID and the location it is used, we can make an prediction of the charging time. If the prediction is considered accurate, we will include the expected energy need and finish time, to optimize the charging transactions.

Integration: Exchange of information between roles via standard protocol OCMP

To connect and integrate the software building blocks described before, two protocols are implemented. We use the Open Capacity Management Protocol (OCMP) to communicate between the three roles, and the Open Charge Point Protocol (OCPP) to translate measures to be taken into concrete actions for charge points.

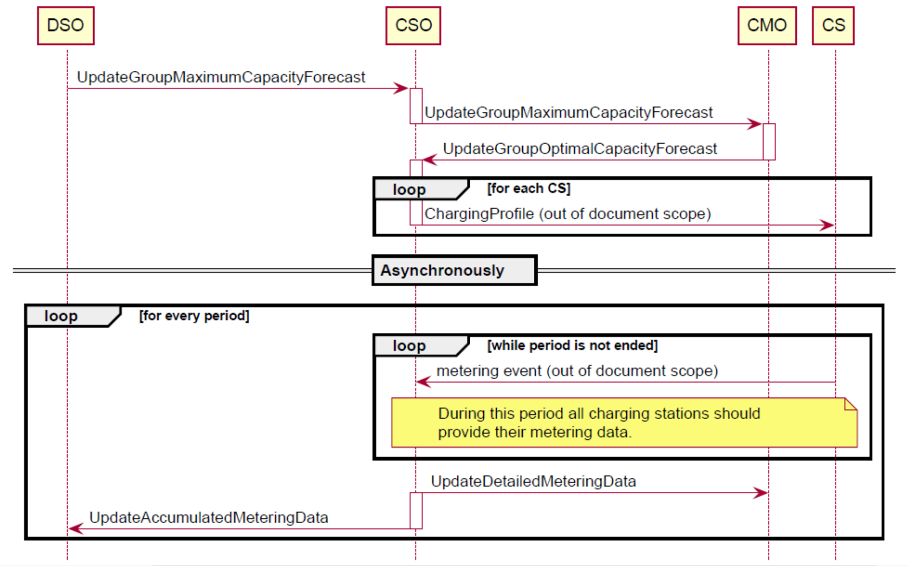
OCPP

The first version of the Open Charge Point Protocol dates back to 2009 and is used to authorize users for charging, register charging transactions and allow for remote maintenance of chargers. It is currently maintained by the Open Charge Alliance and the latest version released is 2.0. Because we use charging schedules the minimum version required for INVADE is 1.6. For the INVADE project we use OCPP1.6, without any modifications.

OCMP

The Open Capacity Management Protocol has been created as a temporary protocol specifically for the INVADE project. It is based on OSCP 1.0, also from the Open Charge Alliance. Originally we intended to use a different protocol, OCPI, but as we further detailed the architecture and data needs, we found OSCP to be a much better match.

The official OSCP 1.0 protocol lacked some features that we needed, and to avoid naming confusion (as the version we are using is a modified, unofficial version of OSCP) we decided to use a different name. As it is a temporary protocol there is no explicit version number associated with OCMP. A new version of OSCP is in the making and we submitted our changes and OCMP experiences to the standardization group, so that ultimately OCMP can be replaced by an official protocol. For future replicability we recommend using the new OSCP protocol and not the temporary OCMP protocol. To illustrate OCMP, you find below the main Sequence Diagram of OCMP:



1.2 Practical implementation

DSO: Prediction of Electricity Grid Usage - on District level

At the moment DSO therefore lack information to create a bottom-up picture of energy consumption in the grid. Metering of separate charge points is available for the Charge Point Operator. However, at this moment these measurements are not made available to DSOs. Reason for this is that DSOs are tied to a very strict regulatory framework that does offer room for experiments in this area but offers limited possibilities to create structural solutions. And in addition to that there are also very strict privacy laws limiting the usage and combination of data for new purposes.

Given the situation described above, within the Invade project we have chosen to reverse-engineer a normal neighborhood consumption from substation, available grid data, estimation of non-flexible load, EV car and driver information publicly available. First, we have decided to use postal codes as a way of defining an area. There is a lot of information available on postal code level about population build up, types of houses, industry, etc. One postal code in itself is still too small an area to be really representative and well-balanced. So, we have chosen two districts of postal codes that we already have experience with (and have data on) in the cities of Arnhem and Ede. To prove scalability, we matched over 680 charging stations of our nationwide public charging network for this test, equaling close to 1.000 charging points. With this mapping, in the Invade project we "virtual move" actual charging behavior of our nationwide charging network to two district.

Location: Ede – Doesburgerbuurt

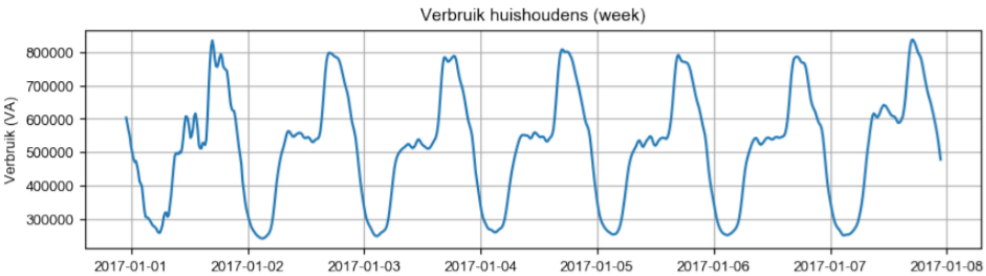
Household grid Connection: 490
Consumption: 3.14 GWh
Number of cars (1st): 349
Expected consumption EVs: 0.9 GWh
Number of (virtual) charge stations: 364

Location: Arnhem – Schuytgraaf-Noord

Household grid Connection: 305
Consumption: 1.16 GWh
Number of cars (1st): 217
Expected consumption EVs: 0.5 GWh
Number of (virtual) charge stations: 322

Households – non-flexible loads

Based on the information we have on the postal codes, we extracted information on the number of households per district. We combined these households with standard profiles for energy consumption to estimate the non-flexible load for the district. If we zoom in to look at an average week, the energy consumption graph looks like this:



Electrification of mobility per district

According to the Central Bureau for Statistics (CBS), 71,3% of the households in our postal codes own a car. Given the fact that the sale of new non-electric vehicles will be banned in the Netherlands by 2030, and because we are investigating what the impact of large scale EV usage would be, we will assume for this pilot that all cars in our neighborhoods have switched to EV.

Naam	verbruik	aantal	percentage	totaal
Tesla Model S	0,191	9661	0,330	0,063
Nissan Leaf	0,158	3351	0,114	0,018
Renault Zoe	0,148	2993	0,102	0,015
Tesla Model X	0,224	2706	0,092	0,021
BMW I3	0,163	2449	0,083	0,014
Volkswagen Golf	0,160	2422	0,082	0,013
Hyundai IONIQ	0,144	1765	0,060	0,009
Opel Ampera	0,168	759	0,025	0,004
Overig	0,176	3104	0,106	0,019
Totaal	| 29210	1	0,176	

We multiplied the number of cars with the average usage of cars per day. In total in the Netherlands we drive an average of 13.269 kilometers per year per car, or 36,35 kilometers per car per day. To translate range into electricity demand, we noted that, like with combustion vehicles, not every EV is equally efficient in turning electricity into mileage. We've used information from ev-database.nl to look up the most used cars and their effectiveness. Taking into account the various models and market shares, the average EV-kilometer will cost about 0,176 kWh. Finally we made a correction for the fact that the effective energy need is higher since charging a car is not 100% efficient. In the best case, an onboard charging unit in the car has an efficiency of 0.9. That means the actual energy demand is higher.

CPO: Controlling Charge Transactions – on Grid Connection level

We encountered that delivering charging profiles in near-time to real-world charging stations through existing systems introduces challenges beyond the correct determination of available grid capacity. One example is the increased message volume to and from the remote charging stations. Since these charging stations are connected over GPRS data connections, data transmission speed and latency is a real factor. In practice, when sending hundreds of charging profiles at once, the charge point management system (CPMS) must be able to cope with these rates, even when dealing with unreliable and variable response times from the charging stations.

Originally, the charging stations were to be given exact set points for charging speed and time intervals. These were updated whenever the number of running sessions in the pool changed, or whenever a new grid capacity limit was introduced. For example, if 99 sessions were running in pool A, and a new vehicle arrived and started charging, all 100 running sessions would get an updated charging profile that distributed the available current equally among them. During peak hours, this situation could occur many times per minute, resulting in hundreds of charging profiles being set every minute.

In our case, the existing interface on the CPMS for applying charging profile was only ever designed to handle 10 in-flight messages at a time. This required the messages to be queued before being sent to the CPMS.

This required a three-step solution:

- Reduce the charging speed resolution (rounding the ampere value to the nearest integer) to increase the odds that the previously set value would still be valid. In many cases, the one extra vehicle added to the pool did nothing to the other charging vehicles, negating the need to set new charging profiles for them;
- Introduce a queuing mechanism before sending out the profiles, ensuring that no more than 10 charging profiles are in-flight at any given time, so as not to overload the CPMS. This did result in charging profiles arriving many minutes after they are generated;
- Reserving a safe amount of current in case the charging stations could not be reached in time to reduce their charging rates.

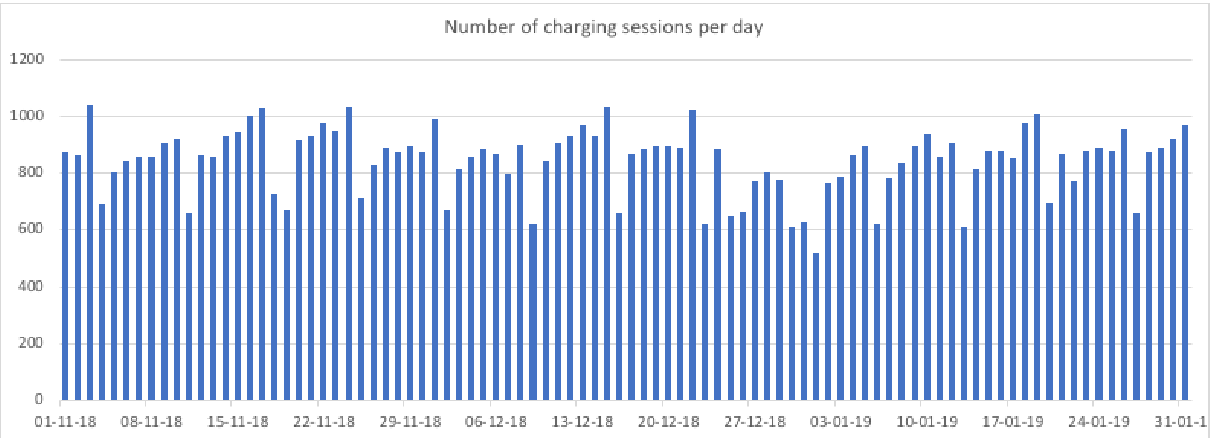
Further measures for optimizing message delivery in rate-constrained settings could be:

- Recording the response times of the individual charging stations, and prioritizing the charging stations that respond the fastest (which would hold up the queue the least);
- Introduce an express-lane for large changes in charging current over small corrections; these messages could be pushed to the front of the queue and get priority service.
- Introducing a mechanism for replacing charging profiles that are waiting in the queue. If, for instance, a profile for charging station A is generated at 11:00:00 with a limit value of 14A, and an updated charging profile with limit value 13A is generated at 11:02:00 while the earlier profile is still queued, the new profile should replace the old profile before being sent out;

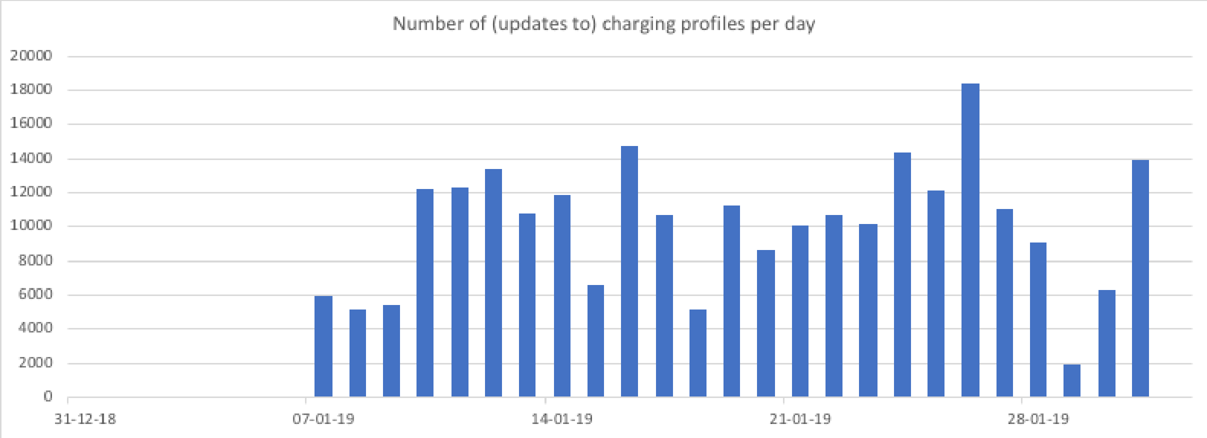
Mostly, this rate constraint was related to the original system design and updating that system to a more capable implementation was outside the scope of the INVADE project. The lessons learned from this, however, might be applicable in many real-world cases where the delivery of messages is constrained by existing systems.

1.3 Demontration results

For a typical week during the operations of this pilot, we've around 600-1000 charging sessions per day:



Each day, we are sending out around around 10.000 charging profiles (and updates to charging profiles). This means that each charging session is updated about 10 times to optimize the charging rate. This can be further optimized at a later time by using different control strategies.



In the project, in certain circumstances, the speed of charging sessions can be reduced to ensure grid stability. As ElaadNL is neither an e-mobility service provider, nor a charge point operator, this means that we have no direct relation with the EV driver. EVnetNL validates a user at a charging station directly with the e-mobility service providers, get a simple yes/no in return and start or refuse the charging session accordingly. Consequently, EV drivers participating do this without explicitly choosing to.

Impact on the EV driver

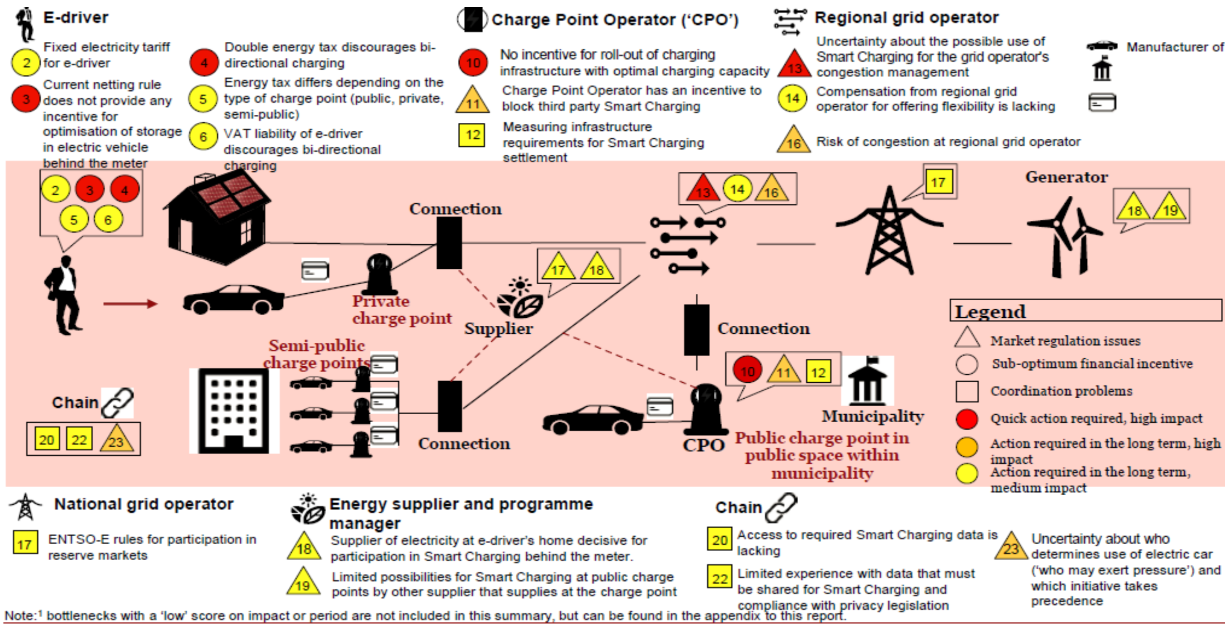
The actual impact on the EV driver experience is very limited. Most cars are connected to a charging station for much longer than just the time spent charging. Slight adjustments of the charging speed therefore go unnoticed in most cases. In cases where the effect can be noticed, because the EV driver leaves before charging is complete, the effect is always still within the boundaries the EV driver is familiar with. Dual socket charging stations are very common. They often have a grid connection that cannot support both sockets at full power so when the second charging starts, the first one is throttled a bit. Initially, the thresholds stay within the same boundaries of throttling, to minimize the actual impact on the EV driver experience. So, if a car was charging for instance at 15 Ampere, the session may be throttle to 12 Ampere (about 20 percent).

Privacy

For the regular business of exploiting charging infrastructure, there is no knowledge of the EV driver identity and no information is handled that could lead to his/her identity. Although this project may impact the charging speed, it has no other business impact. We don't engage with the EV driver directly and do not collect additional information about any driver or car. Therefore, there are no additional privacy concerns to be addressed within this project.

1.4 Institutional bottlenecks that impede the development of the Smart Charging

We have identified over a dozen possible regulatory bottleneck for Smart Charging. In this abstract we have illustrate a few.



The netting rule also discourages optimal use of electricity in the Netherlands. This rule has stimulated the purchase of solar panels because low-volume consumers only pay for the balance of kWh that they consume from the grid on an annual basis. This arrangement actually allows low-volume consumers to 'virtually' store electricity that they generate themselves on the grid. No costs are charged for this. As a result, low- volume consumers (with a private charge point) have no incentive to optimise the self-generated electricity behind the meter, for example by storing it in their electric car for later use. This may cause a double peak in the grid: supply peak due to the generation of solar energy that is not used immediately and a demand peak if the electric vehicle is charging.

Uncertainty about the possibility of using Smart Charging for congestion management grid operator. The core task of the grid operator is the transmission of electricity to the consumer: they may not trade, generate or supply. Under current legislation (group prohibition and rules for congestion management from the Electricity Act and Grid Code), it is unclear whether they may purchase flexibility from third parties. The question is whether this is in line with the statutory duties of the grid operators. As a result, it is unclear whether they may deploy Smart Charging. Under current regulations, grid operators may only temporarily apply congestion management. They are obliged to eliminate situations of transmission scarcity as quickly as possible by investing in grid upgrades. Grid operators are not allowed to own batteries themselves, nor are they allowed to give compensation for offering flexibility in the Netherlands.

There is no incentive to roll out charging infrastructure with optimum charging capacity. Charge point connections can have different capacities, such as: 3 x 25, 3 x 35 or 3 x 63 amps. The higher the capacity of the connection, the faster a car can be charged and the more flexibility is generated for the use of the car for Smart Charging. If charging is temporarily stopped, for example, the car can be charged on time by speeding up the charging (according to the e-driver's wishes).

A high capacity connection is significantly more expensive than a lower capacity connection. One of the reasons for this is the difference in capacity that must be reserved on the grid in order to meet the peak load of the connection. The tariffs for the connection are determined by national administrative boards. Because of these higher costs, mostly low-capacity connections are installed in the (semi-)public domain.

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Authors

Frank Geerts is Digital Innovator eMobility at Alliander and program manager Smart Charging at ElaadNL. He realizes IT innovations and solutions to facilitate and accelerate eMobility. He is currently engaged in the development of several Smart Charging solutions, fe in Amsterdam testing a new Grid Connection with flexible capacities and in the Utrecht area with Smart Solar Charging based on V2G. Before, Frank was project leader within the Mobi Europe project, which among other things has realized a smart charging plaza in the Amsterdam ArenA. At that time he was also IT manager at Allego. Frank plays an active role in the open standardization of e-mobility at national and international level. He is regular speaker on conferences throughout the world. He has more than 15 years in the energy sector, in different roles and for several energy companies in the Netherlands.