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Public Wireless Charging in the City of Rotterdam

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Abstract

This paper provides an overview of the Pilot Wireless Charging in the City of Rotterdam, The Netherlands. From early 2016 until mid-2017, the City of Rotterdam and multiple partners performed research on a semi-public installed wireless charging system for shared electric vehicles. This paper covers the challenges that were faced by finding the right technical solution, the installation of the system and the test results of the safety tests. Since interoperability and standardization is an important topic in the success of EV charging infrastructure and thus also in the Wireless Charging pilot, two different electric vehicles were prepared for wireless charging: a Nissan Leaf and a Peugeot iOn. The charging system can deliver 3.3 kW max. During the pilot, the efficiency of the energy transmission between the coils are tested, as well as safety and EMC. The efficiency of the system is estimated on 90% with an air gap of about 12 cm. the system was used by normal drivers who used the vehicle for work-related trips. Their feedback on the use is also an important part of the conclusion of the pilot.

Keywords: wireless charging, wireless power transfer, electric vehicle, charging infrastructure

1 Proof of Concept: Wireless Charging in Rotterdam, The Netherlands

Rotterdam's clean air strategy already resulted in over 2.000 public charging stations in the city. However, streets are already filled with lanterns, energy distribution boxes and other sometimes disturbing objects.

Besides the wish for more invisible charging stations, the City believes in a future of autonomous vehicles. And autonomous vehicles are only fully autonomous, if they can charge themselves. Therefore, the expected charging technology for autonomous vehicles is wireless charging [1].

Besides the advantages of less visual impact in the street and the possibility of autonomous charging, the more convenient way of charging and therefore the expectation that more (PH)EV drivers will charge their vehicles, Rotterdam had a clear wish to explore the possibilities of Wireless Charging. [2]

To determine the current (then: 2015) state of development in wireless charging infrastructure, the city of Rotterdam, together with ElaadNL and EVConsult, sent a 'Request For Information' (RFI) to parties that focus on EV Charging technology. From the results of the RFI, it seemed that there are a handful of suppliers that already had experience with outdoor-wireless charging, despite the technology being available for many years.

The resulting information has been used as input for the tendering request of delivering a wireless charging system for two vehicles from the cities' fleet. In 2015 the municipality awarded the pilot to the most promising supplier: ENGIE Infra & Mobility in collaboration with ANWB, EV box and wireless charging system supplier HEVO Power.

In collaboration with these partners, the City of Rotterdam wants to identify the technical, organizational, environmental and financial implications of wireless EV charging in practice. In addition, the parties must investigate the options for developing a business case for wireless charging. This pilot provides valuable information that can be used for the further development and possible expansion of the project at a later stage.

1.1 The pilot

The development of the current charging infrastructure is well-advanced. It is essential that innovative new charging systems - such as Wireless Charging - are suitable within the current standards and interoperability requirements. Therefore, considering the application in public spaces, it is for example important that the system is not limited to one type of electrical vehicle, but adaptable for multiple brands and types.

The pilot location is an outdoor public parking area for employees of the City.

1.1.1 Retrofitting

The Rotterdam pilot set up combines a normal charging point with a wireless charger. The used cars can be charged with both a cable and with the induction system. The choice of keeping the cable-option is to be able to charge the vehicles at multiple locations instead of only one wireless charging location. When more public wireless charging points are available, it is expected that a secondary charging possibility is no longer necessary.

To prepare the vehicles of the City (a Nissan Leaf and a Peugeot iOn) the wireless charging system was connected to the ChaDeMo outlet, which means that the standard AC Type 1 socket remains available for normal charging. Fast charging is not possible on the pilot-vehicles anymore. Extra electrical components could provide a solution where the vehicles could charge wireless, AC level 2 and DC but the DC charging option was not necessary on the vehicles since their operation area was always within the cities' borders.

Minor differences in the implementation and structure of the Battery Management Systems in the vehicles required customisation to integrate the charging system in both vehicle chargers. The lessons learned from this process are regarded as valuable output of the pilot. When the pilot started, still no wireless charging from OEM's can be found on vehicles' option lists when purchasing a new car [3]. This means that for wireless charging, after-market solutions will remain the most important technique the coming period.

Another important action on the vehicles was protecting the components under the vehicle against obstacles that may cause damage, such as speed bumps.

1.1.2 Users

The pilot is not only about technical research. The vehicles will be used by a various group of employees of the city. They all work in the city of Rotterdam and use the cars for their daily activities. All ten of them already have experience with charging electric cars. Before and during the pilot they will share their experiences with Wireless Charging. Those experiences will be very valuable since normal usage of a wireless charging system is still rare.

2 Technology

To enable Wireless transfer of electrical energy, two magnetic coils are necessary. Between these coils, the energy transfer will take place. One of the coils is located in the ground and is connected to a power source. The other coil is installed in the vehicle and is connected to the charging system and the battery of the vehicle. Energy is transferred through a magnetic field between the two coils.

The set up in Rotterdam was as follows [4]:

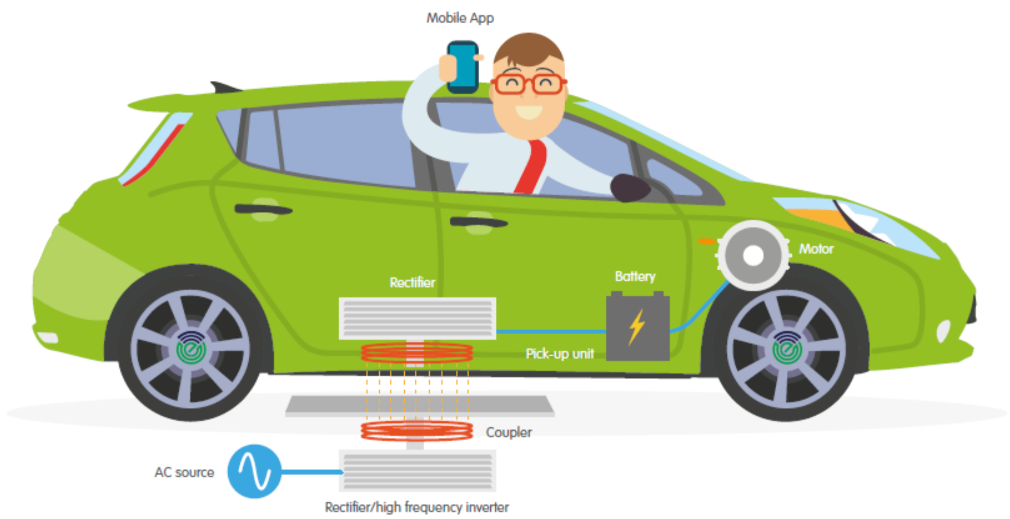

Figure 1: System Overview

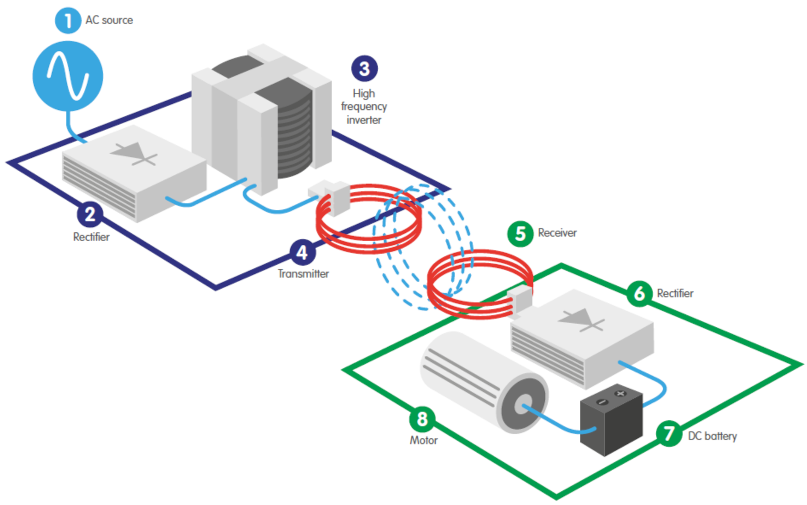

Figure 2: System Components

2.1 Efficiency, Airgap and Positioning

The AC grid current must be converted to a higher frequency to be transferred to the vehicle through the two coils as efficiently as possible. Therefore, a rectifier and converter are needed. Together these provide a conversion to direct current (DC) and back to high-frequency AC. In the vehicle, a rectifier converts this current to DC again, to charge the battery. Multiple conversions are necessary to achieve the most efficient energy transfer. However, those conversions have the highest impact on the overall efficiency, while one would expect that the ‘air gap’ has the most influence on the efficiency.

In the first tests the efficiency was approximately 90%, with an airgap of 12cm. Compared to other known projects [5], this is a very promising number.

Another aspect that influences the efficiency is the alignment between the vehicle and the ground coil. When parking precisely above the coil (with a margin of 10cm X and Y direction), the efficiency can be increased. The coil must be mounted under the car in such a way that the driver can easily park over the coil in the ground.

During the pilot project the driver is directed to the correct position with a threshold and markings on the parking surface. A correct position helps significant in the efficiency of power transfer. Moreover, the coils have different sizes, to easily reach a larger ‘contact surface’.

Figure 3: The wireless charging station in Rotterdam

2.2 Monitoring and Transactions

To monitor the system, the wireless charging station was connected to a normal charging station. This station contained the necessary components for communication with a backend. The station was monitored 24/7 with an active connection. During charging, the Power Factor and efficiency are measured and calculated and monitored permanently. An in-house protocol was used, since available standardized communication like OCPP does not support wireless charging yet. However, for public use, open standards are essential for success.

To start a transaction, users simply had to drive on the parking spot and the system would start a transaction. The transaction was ended when charging stopped, mainly when the battery was fully charged.

During the pilot, HEVO presented an application where transactions could be started and stopped via an application. The charging process can be followed via this application, and also other charging stations can be found and activated (if the vehicle is within range). The application also provides alignment-assist.

3 Results and Conclusions

3.1 Safety and EMC

One of the main learning objectives was to find out and how to control safety related challenges that might come with wireless charging [6]. To analyse the impact of electromagnetic interference (EMI) and electromagnetic fields (EMF), tests were performed by certified measuring companies.

3.1.1 Electromagnetic interference (EMI)

EMI tests were performed to test radiated and conducted EMI.

A quick scan was performed to get a better insight into the electromagnetic challenges. Norms EN55022 and EN55011 were used as reference.

To get a more pilot-specific insight into EMI, in depth tests were performed to get a more realistic insight into where the charger stood in regard to emissions and electromagnetic fields.

Radiated emissions

The magnetic field while charging was measured by means of a magnetic field meter at a distance of 10 meters from the charging station. The conclusion was that disturbance of other radio receivers like air traffic, FM, P2000 and DAB+ is non-existent.

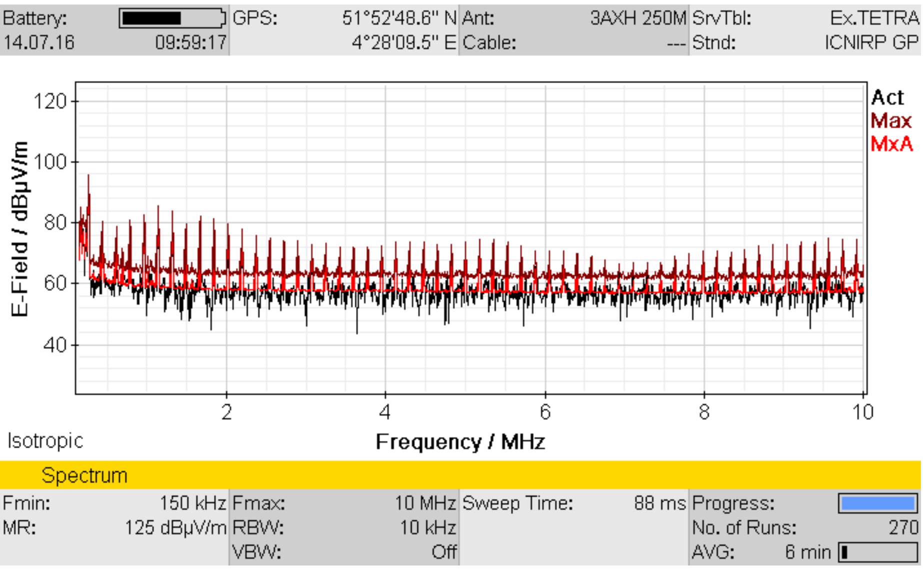

Figure 4: Radiated emissions

Conducted emissions

The conducted emission was measured with a current clamp. The results were similar to the radiated emissions.

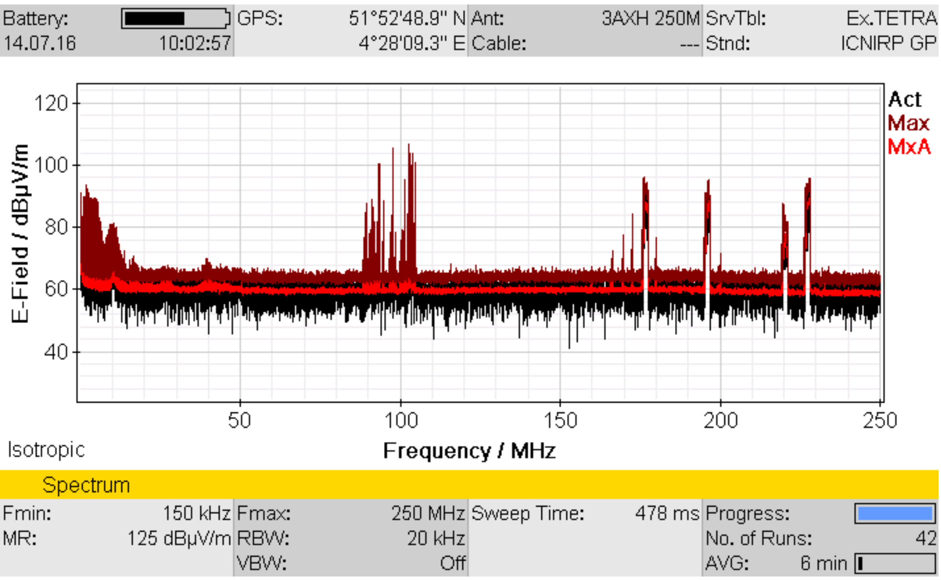

Figure 5: conducted emissions

Both radiated and conducted emissions were higher than allowed for public use. Therefore, to extend this pilot, a solution has to be developed. For pilot use, the test organizations advised that the situation was acceptable.

3.1.2 Electromagnetic fields (EMF)

A very important aspect of wireless charging is EMF.

The field intensity has been measured conform the norm SAE J2954, in and around the car while charging. Two car positions have been measured: the car being perfectly aligned, and the car being positioned 12 centimeters away from the center of the transmitter. The field intensity is measured in microTesla. The following spots have been taken into account:

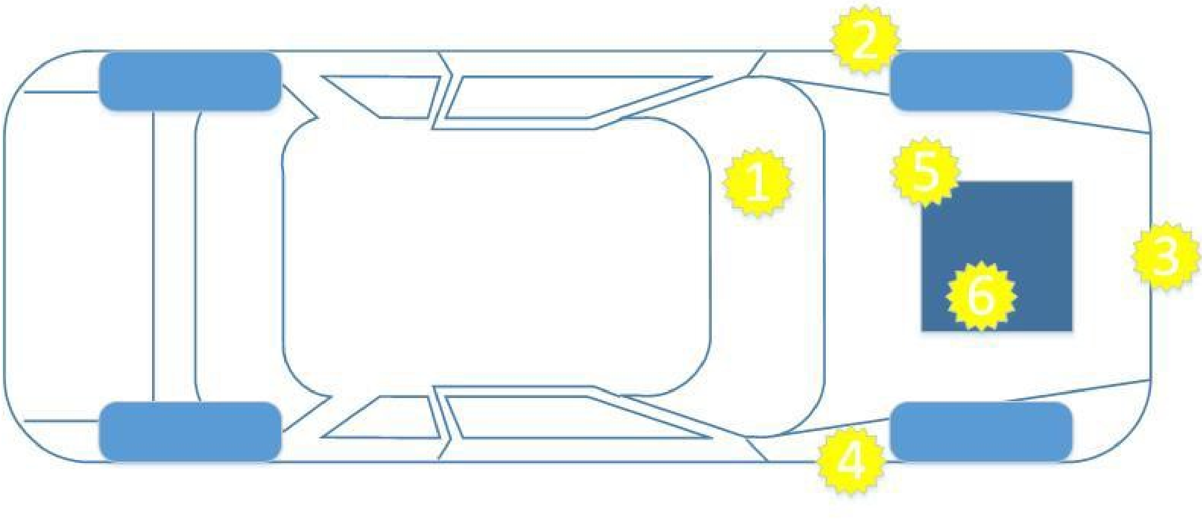

Figure 6: EMF measurement locations

Position	Magnetic field intensity (µT)	Magnetic field intensity (µT) with 12cm offset	Remark
1	0,03	0,04	Inside the car at the feet of the driver
2	1,08	1,65	Left front wheel near the door
3	3,00	2,89	Under the license plate
4	2,05	5,24	Right front wheel near the door
5	100	100	Under the car, next to the transmitter
6	810	306	Under the car, between the transmitter and the receiver

Figure 7: EMF test results

Conclusion:

The guideline 2013/35/EU describes that for a regular working space situation, the limit for the human body is 100 µT. For arms and legs, the limit is 300 µT. Between the transmitter and receiver, this limit is exceeded. It is currently not possible to reduce the intensity of the magnetic field, however it is not likely that a human being will get between the two coils on the specific pilot location. Therefore this is a situation that is acceptable for this pilot.

Based on the Dutch council recommendation 1999/519/EC, the limit for exposure for the general population is 6,25 µT. In and around the car, the electromagnetic field is lower than the exposure of an induction cooker.

The risks for people with a pacemaker or ICD are minimal. During charging, this group of people should not attempt to position themselves under the car.

Since the location is in a public environment, there is a chance of animals between the two coils. Though there are no guidelines for animal exposure, a device to prevent animals from coming close to the system was installed. Rabbits and cats are scared by using ultrasonic soundwaves.

3.1.3 Public Acceptance

The effects of EMC and emissions are a generally unknown subject to the public. One of the objectives was to delve deeper into the risks of these emissions, and this topic was addressed again by several people during the pilot. To create more awareness and knowledge it is very important to share the results of the measurements and conclusion from the authorities on this subject.

Based on the test results, the conclusion is that public wireless charging in this pilot is not in any way dangerous to use. Being in the vehicle, or standing outside of it while charging does not expose the human body to a weaker magnetic field compared to using an induction cooker.

3.2 Standardization and Interoperability

When it comes to standardization, wireless charging of electric vehicles is quite a challenge. While the technique is already available for decades, anno 2017 there are still only after-market systems for wireless charging. No vehicle OEM does already offer an EV with wireless charging technology. Press releases are promising factory-fitted systems coming by the end of 2017, for example on premium models like the Mercedes-Benz S500e Plugin Hybrid and BMW 5 series [7]. In July 2017, Audi announced that its high-end A8 which will enter the market in December 2017 will have an optional wireless charging system [8].

A lack of standardization is one of the reasons for the wireless charging technology not to be available more broadly [9]. However, a lot of standardization work is in progress [1]. Within the IEC, the TC69 committee is working on Wireless Charging or Wireless Power Transfer (WPT) since 1996 and the first editions of the IEC 61980 will be released in 2017, covering three main parts: General Requirements, Communication and Magnetic Fields Power Transfer [10].

The IEC 61980-1 covers for instance Safety Requirements and Positioning and is applicable for different kinds of systems, including after-market systems and systems with the coil(s) on the roof or front bumper of the vehicle. Furthermore, different energy transfer techniques of Wireless Charging are described in the standard.

The defined power classes and air gap classes in the standard are as follows:

Power Classes

	WPT1	WPT2	WPT3	WPT4
Power from Mains	3.7 kW	7.7 kW	11.1 kW	22 kW

Z Classes

Class	Ground Clearance [mm]
Z1	100 -150
Z2	140-210
Z3	170-250

Figure 8: Power and Air Gap (Z) classes

3.2.1 Interoperability

Another important goal of the pilot was to investigate interoperability and show how charging two different types of cars with one charging system will function.

To ensure interoperability between ground and vehicle assemblies, it is important that both support the same Power and Z classes. That means that the vehicle's system as well as the ground-mounted system should support the same technique. Only then, multiple vehicle brands and types can charge at the same wireless charging station [11].

The system used in Rotterdam meets the standardization requirements that were known at the beginning of the pilot in 2015, being a WPT1 system with Z2 clearance. Only these specifications however give no guarantee that future vehicles can charge at this location. Also the used frequency of 85kHz is a standardized value.

Communication between the Vehicle and the ground system are one of the more challenging parts for interoperability. Every vehicle must have the same communication method as the ground assembly has. First steps for WPT communication are expected soon.

Practical interoperability challenge in Rotterdam

The Rotterdam pilot used an in-house technology from HEVO and is a Bluetooth-based communication module. The difference of the two vehicles regarding their charging systems lies from the onboard charger backwards. The added components, namely the secondary coil, the rectifier and the Bluetooth module are identical. The onboard chargers are designed with different operation and functionality protocols by the OEMs and as a result their interaction with the wireless charging system differs. More specifically, the onboard charger of the Peugeot iOn has a shorter time-window for the power supply to reach its nominal value when a charging session starts. If within this time-window the power supply has not reached yet the desired level the car goes into stand-by mode terminating the charging session. This means that the charging system must be able to increase the supplied current from zero to a high enough level within this timeframe. During the conversion process, this behavioural difference has been noticed and the controller of the inverter has been programmed to give small power bursts during charge start up, in order to keep the car from terminating the session and protecting the wireless charging system from a too fast rising current. The respective time-window for the Nissan Leaf is longer, thus this demand is fulfilled by default. As a result, both vehicles can be charged through the same station. In a later stadium of the pilot, it was decided to focus on one vehicle because the Bluetooth communication module would not let the two different cars charge after each other in a stable way, as the two rectifiers were identical, and the charging would choose a rectifier at random.

3.3 Invisible Charging Station

Wireless charging can be a solution for situations where charging stations are not desirable in the street, because of limited space next to parking lots or because it has a negative effect on the looks of the environment. However, wireless charging systems use large components like invertors and rectifiers that are necessary to feed the coils. In the Rotterdam pilot, important research is done how these components, including the grid connection, can fit in the ground of inside already existing objects in the public street. The biggest challenge is creating an underground box that fits the needed components and can deliver as much cooling as needed and is fully water resistant. Another solution could be to centralize or combine the components for multiple charging stations on a remote location and then work with underground cables to the actual coil(s). However, the distance of these cables is limited and each coil needs its own rectifier. Also for maintenance, it is recommended to not work with underground boxes.

3.3.1 User Experience

The most important lesson learned from the user group is that reliability is more important than charging convenience (cable vs wireless). Since this was a pilot, with tests and technical challenges, malfunctions of the system were faced. This influenced the user group and their experience. Therefore, the user feedback is not an objective examination of the use case. The feedback from the users is not seen as scientific prove but definitely as valuable information for the pilot.

The lessons learned from the user group:

- Reliability is more important than the advantage not having to use a cable. Users prefer to use the cable because this ‘always works’. It takes time to trust a new charging system, especially when the vehicle is used very frequently for business purposes.
- Though the vehicle alignment seemed easy (good coupling factor at bad alignment), users asked for a more advanced parking support system. The markings on the parking spot are not enough and hard to see in bad weather conditions. An in-vehicle system is desired.
- A confirmation that the vehicle is parked well and charging is started is important. The Nissan offered this by 3 flashing blue lights on the dashboard. This is very important for users; they would not leave the vehicle without the confirmation that is was charging properly.
  Therefore, after a charging session being able to just step in the car and drive away is considered as most valuable. Especially in bad weather conditions, coming from a dry house of office and not having to unplug was experienced as very convenient.

4 Continuation and future research

The pilot ended in May 2017 and received a lot of Media attention. Looking at the amount of attention and requests from people who would like to buy or use a system, one would say that there is already a market for wireless charging. To improve this market and make a business case for wireless charging, the following aspects are relevant but require future research or pilots:

- The use of OEM-installed wireless charging systems
- Charging parks with multiple wireless charging spots, used by Taxi fleets
- Adaption of smart charging technology
- High Power Wireless charging

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Authors

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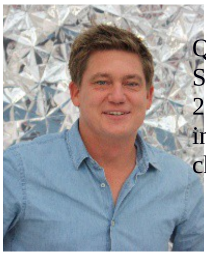
Roland Steinmetz (MSc) has a degree in civil Engineering from TU Delft and has worked on EV infrastructure strategies for OEM's, Utilities and national and international governments. Roland has a broad experience in the field of consultancy at (non)-profit sector in energy, infrastructure and spatial planning. Managerial experience with organisation, financing and planning on large scale projects. Often involved in innovative projects to connect goals of public parties to feasible solutions from commercial parties.



Quirijn Oudshoorn is urban planner at the department of transportation of the city of Rotterdam. Since 2011 Quirijn is involved in the program Rotterdam Electric where he created a network of 2.000 public chargepoints. Besides the pilot wireless charging, Quirijn is responsible for the innovation agenda Smart Charging which has the goal to experience new methods and technics of charging, so Rotterdam will be able to integrate electric mobility in the urban environment.

Stef Pierik followed a management traineeship at ENGIE Services Nederland after finishing his studies in Business Administration at the University of Amsterdam. He currently functions as project manager for the E-Mobility sector of ENGIE in the Netherlands. Connecting customer demands with solutions within the private and public sector of E-Mobility is his main goal. Besides upholding the vast market position of ENGIE in charging solutions, innovative projects such as Vehicle 2 Grid and Inductive Charging conclude his portfolio.