Final report

Pilot Wireless Charging - Rotterdam

ROTTERDAM INDUCTIELADEN

Gemeente Rotterdam

Elaadnl

EVCONSULT

HEVO POWER

Rotterdam elektrisch

ENGIE

Colophon

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Executive Summary

The main goal of this pilot was to show the world that it is possible to wirelessly charge a car in public space. Assisted by ElaadNL and EVConsult, the City of Rotterdam contracted ENGIE to achieve this goal, which they accomplished in conjunction with these parties and EV-Box, HEVO Power and ANWB. In order to share the lessons learned during the pilot, the project team hosted a wireless charging event in 2016, bringing together the majority of stakeholders within the field of wireless charging in the Netherlands. This final report is part of this project group's desire to share all knowledge gained during this pilot.

A Nissan Leaf was successfully equipped with a wireless charging receiver, while the test site in Rotterdam was adapted so that the car could be driven over a wireless charging transmitter in the ground, providing 3 kilowatts of charging power. This type of charging system works in a manner similar to an electric toothbrush.

In order to launch the user phase, the system needed to work safely and in a stable manner without malfunctioning too often. Stability proved to be a challenge and the system required regular hardware and software upgrades to overcome this challenge. This, together with the safety analysis, took up most of the project time.

So, is it safe? Yes. Even more so, the electromagnetic field in and around the car is lower than the exposure from an induction cooker, exposing humans to a maximum of 5.24 μT (micro tesla). Based on (Dutch) Council Recommendation 1999/519/EC, the exposure limit for the general population is 6.25 μT. The field intensity was measured in accordance with the SAE J2954 standard.

A lack of standardization is one of the reasons why wireless charging technology is not available more widely. However, much standardization work is currently in progress. Within the IEC, the TC69 committee has been working on Wireless Charging or Wireless Power Transfer (WPT) since 1996 and the first versions of the IEC61980 will be released in 2017, covering three main elements: General Requirements, Communication and Magnetic Field Power Transfer.

One of the most frequently mentioned benefits of wireless charging is its user-friendliness. User experiments were set up at the start of the pilot, aimed at learning about the experiences of users with the wireless charging system. The usage period lasted until May 2017. While aligning the car over the wireless charging power transmitter was perceived as challenging (due to the lack of a software-based guidance system), not having to connect a charging cable was perceived as a positive development. There were more than 150 user transactions during the pilot.

During the pilot preparation, implementation and research phases, numerous new insights were gained by the project team. Although this pilot exceeded the intended time period and budget, the consortium is proud of the milestones achieved and the knowledge that it can now share with the public. Although after-market systems will be prevalent in coming years, a mass rollout depends on standardization support by OEMs. ENGIE is currently reviewing the experiences gained with this pilot. Two ENGIE Infra & Mobility departments - E-Mobility and Smart Mobility - are working jointly on a deployment plan for a continuation of the project. The City of Rotterdam has also expressed an interest in following up on the pilot and a new project will be launched in 2018.

1. Introduction

The City of Rotterdam plays a leading role in the electric mobility segment. To facilitate electric transport in the future and give e-mobility a special role in the energy network, it is important to overcome as many obstacles as possible. One major technical and practical obstacle is the charging cable. The city is convinced that wireless charging is a viable solution. Wireless charging is not expected to act as a substitute to traditional charging in the near future. However, it can enhance the existing charging solutions. This is not only for the benefit and convenience of the user, but also due to the visual and technical advantages this solution provides. In a future in which autonomous vehicles will be commonplace, the consortium believes that autonomous wireless charging will be the only way to charge. This report describes lessons learned and challenges that had or will have to be overcome in order to implement the first public wireless charging system in the City of Rotterdam, paving the way for a larger scale adoption of inductive charging techniques in the future.

1.1 Current developments

The development of the wireless charging technique is at the start of the implementation cycle, a status where electric mobility was roughly seven years ago. The number of charging points for electric cars in the Netherlands is increasing exponentially. Around 30,000 public and semi-public charging points are currently installed in the Netherlands (not including private charging points)[1].

Laadpunten (exclusief private laadpunten)

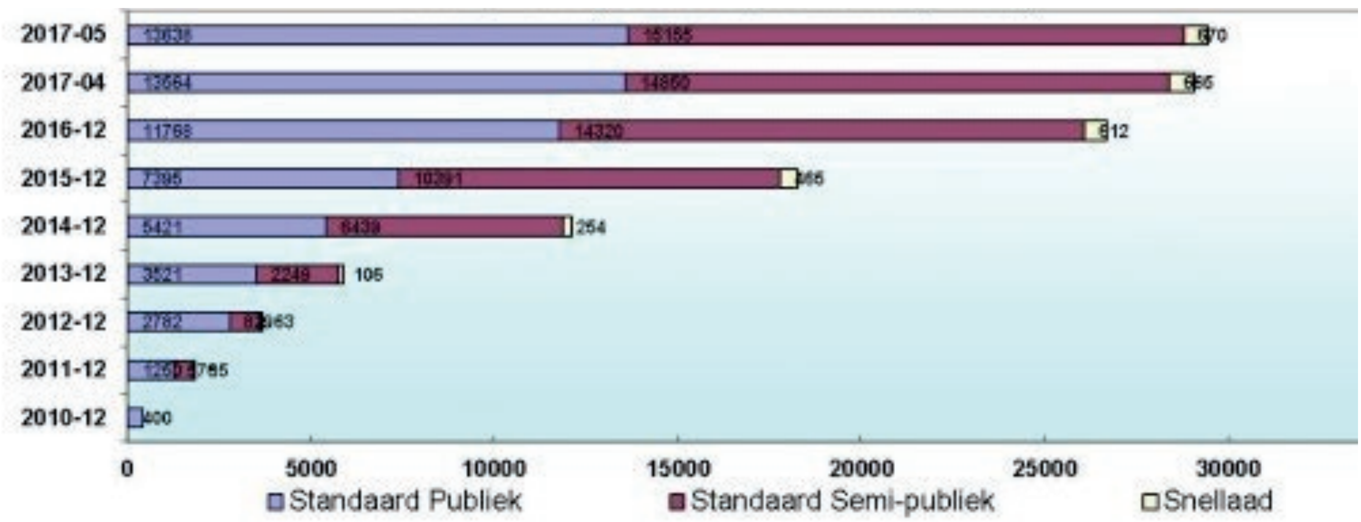


Figure 1: Charging points in the Netherlands

[1] http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/energie-en-milieu-innovaties/elektrisch-rijden/stand-van-zaken/cijfers

More than 115,000 electric vehicles (PHEV and FEV) are currently used for transportation in the Netherlands. PHEVs are experiencing a decline in growth - mainly due to decreased financial tax benefits - whereas positive growth can be seen for FEVs. Developments in the automotive industry are stimulating the market for electric vehicles, as each of the manufacturers aims to offer at least one type of car with an electric drive train. Multiple new and better developed car models will be available in the market from 2018 onwards.

Figure 2: Electric vehicles in the Netherlands

2. Project Description

2.1 Project goals

The objective of the City of Rotterdam and project partners is to identify the technical, organizational and environmental implications of wireless charging in real life. This pilot provides valuable information that can be used for the further development of wireless charging capabilities, standards and a possible expansion.

Testing the usability of a wireless charging system in the public space with real users instead of an experimental indoor set-up was another objective of this pilot. The current conductive charging infrastructure has reached an advanced stage in terms of technical, management, interoperability and back office development. In order to use wireless charging in the public space, it is important that the system progress to an advanced stage and not be limited to a single type of electric vehicle, but can be used for different makes and types.

2.2 Vision on working method

Development and flexibility are key to this pilot, as are monitoring and allowing the possibility for adjustments to the charging system. This requires continuous consultation with the client and partners. To carry out this pilot, ENGIE has chosen to collaborate with partners with proven experience in construction and development within the EV market and with every stakeholder contributing value based on its competencies.

2.3 Scope of the project

The project entails:

- Delivering a working wireless charging system for two vehicles;
- Mounting and installing hardware on to two types of cars;
- Installing the base charging system and connecting it to the electricity grid;
- Testing the wireless charging system during installation and on-site during the pilot period;
- Monitoring user experiences;
- Managing and maintaining the wireless charging system during the pilot period.

The consortium has agreed that the methods and learnings from all stakeholders in this pilot will be shared publicly.

2.4 Pilot-specific goals

The aim of this project is to gain experience with the implementation and use of wireless charging solutions within public space. Answers to the following questions were learning goals for the pilot:

- What are the technical aspects of a wireless charging system?
- What standards are applicable or need to be developed?
- How does wireless charging integrate with the energy grid?
- How can interoperability be achieved?
- Which security aspects are covered?
- How will the user experience wireless charging?
- How can wireless charging be used in public space?
- What is the most viable business case?

2.5 Learning objectives

At the start of the project, six learning objectives were drawn up in cooperation with the client. These learning objectives are:

1. From conductive to inductive;
2. Technical possibilities, standards and limitations;
3. Monitoring and transactions;
4. Safety;
5. User experiences;
6. Inductive charging business case.

2.6 Work package responsibility

For purposes of the pilot scope and manageability of the pilot, the various activities and phases have been divided into work packages. Each work package has an owner, lead time and delivery goal (installation or delivery document).

WPK no.	WPK name	Owner
WPK-100-001	Project Management	ENGIE
WPK-100-002	Communication	ENGIE
WPK-200-001	Design Hardware	ANWB
WPK-200-002	Design Software	EV-Box
WPK-300-001	Supplier Management	ENGIE
WPK-400-001	EV Conversion Hardware	ANWB
WPK-400-002	EV Conversion Software	ANWB
WPK-400-003	Implementation in Rotterdam	ENGIE
WPK-500-001	FAT Testing	ENGIE
WPK-500-002	Integration Testing	ENGIE
WPK-500-003	SAT Testing	ENGIE
WPK-600-001	Pilot	ENGIE

2.7 Planning

The pilot was launched in June 2015. The implementation phase was completed at the end September 2015. Due to the necessity to upgrade and replace parts of the system, the usage period of the induction system started in October 2016 and continued until November 2016. The pilot ended in June 2017.

2.8 Location management

The pilot was conducted in the City of Rotterdam. The charger was placed in a public area at Groene Kruisweg 36 in Rotterdam. The site is one of Rotterdam's municipal working areas for city logistics.

2.9 Consortium

City of Rotterdam

Rotterdam offers business specialized in zero-emission transport and the possibility to conduct pilot projects in real life. The Rotterdam energy grid, with its fast expanding charging system for electric cars, is one of the most advanced in Europe.

Pilot client with responsibility for both project management and location management, carried out in collaboration with EVConsult, a Dutch company with vast knowledge of the e-mobility market.

ENGIE Infra & Mobility

One of the Netherlands' largest technical solutions partners, specializing in sustainability and serving as the contractor and project manager for the entire pilot project. Responsible for installation and servicing of the wireless charging system.

EV-Box

Market leader in charging stations for electric vehicles. Also plays a leading role in interoperability in the Netherlands. In this pilot, EV-Box was responsible for the delivery and operation of the wireless charging system. The producer and supplier of this system is the American company HEVO Power.

Technical Expertise Centre ANWB

In the Netherlands, the ANWB is the authority on vehicles and mobility. Its technical expertise center performs R&D activities and is a knowledge center for the technical aspects of vehicles. For this pilot, the ANWB was responsible for vehicle adaptation, considering the necessary activities to be incorporated into the wireless charging system.

ElaadNL

As a co-client, ElaadNL participated in this pilot to investigate whether the wireless charging technology was suitable for public space. ElaadNL conducts research into how this technique complies with the existing standards in the field of smart public charging infrastructure and interoperability.

EVConsult

EVConsult supports companies and authorities by launching innovative projects and pilots and other activities. In this pilot, EVConsult acted as project manager on behalf of the City of Rotterdam.

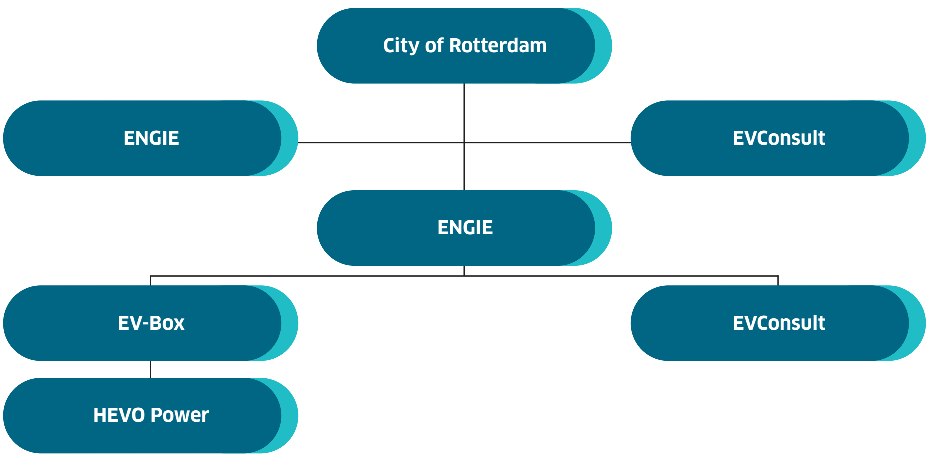


Figure 3: Organizational chart of the project team

3. Challenges

In order to share what the consortium has learned from this pilot, the team wants to be transparent, not only in what it has achieved, but also what the greatest hurdles were. The pilot was extended by a year due to the numerous technical challenges faced. While having learned a considerable amount from the implementation and testing, these challenges also prevented the team from being able to answer all of the learning objectives. The activity timeline is shown below, followed by a summary of the most relevant challenges.

3.1 Timeline

Start of technical preparations: software, on-site and vehicle-wise	August	2015
1st PRE-integration testing	September	2015
1st EMC/EMF testing and challenges	September	2015
1st technical communication challenges	September	2015
Inverter (hardware) replaced	November	2015
2nd PRE-integration test	November	2015
Switch for disconnecting integrated Bluetooth (due to 12V battery problems)	December	2015
Inverter (hardware) replaced	December	2015
3rd PRE-integration test	December	2015
Inverter (hardware replaced) + testing with limited functional stability	January	2016
Researching alternative solutions	February	2016
Decision to continue with the current hardware supplier	March	2016
Attending the AVERE E-Mobility Conference	April	2016
Installation of new and more stable charging system	June	2016
2nd EMC/EMF testing	July	2016
On-site testing of system (hardware failure due to inverter temperature)	July	2016
Realignment of system on-site, software upgrades	August	2016
Solved: Hardware failure due to inverter temperature	September	2016
System is now up and running	September	2016
Hardware failure due to power shortage	October	2016
Inverter (hardware) replaced	October	2016
System is now up and running again	October	2016
Wireless charging event in Rotterdam	October	2016
Hardware failure	November	2016
EMC/standards session with Dutch Telecom Agency	November	2016
Research on upgraded wireless charging system	January	2017
Delivery of final report	June	2017

3.2 Most relevant challenges

The first implementation activities went according to plan, through the on-site installation in Rotterdam and vehicle adaption at the ANWB. During the FAT (Factory Acceptance Test) at the ANWB, the system charged as expected. While integrating the complete system on-site during the SAT (Site Acceptance Test), the consortium ran into hardware, software and EMC issues. For the duration of the pilot, positive testing experiences alternated with planning adjustments in order to repair and/or upgrade the system.
The most relevant challenges are described below.

Hardware: maturity of the product

At the start of the pilot, HEVO was contracted as a supplier with a plug-and-play (after-market) wireless charging system. However, while integrating the system on-site, it turned out that the product was still in the product development phase. This caused both exciting (technical) insight into the system, as well as near-constant repair activities, which caused planning delays. This also had a major effect on the tests at the end of the pilot, including fewer user experiences, no official efficiency test and no energy grid testing.

Software back office integration

One objective was to research how interoperability could be achieved, as well as to provide monitoring and enable transactions. In order to achieve this, EV-Box and HEVO worked together on integrating the HEVO system with the EV-Box back office. Due to difficulties with integration protocols and variables on the part of both parties, resulting in transactions not being delivered, the HEVO system was separated from the EV-Box back office. From 2016 onwards, HEVO further developed its own back office in which transactions were monitored. OCPP (Open Charge Point Protocol), which enables interoperable charging, was not implemented.

Uncertainty regarding EMC/EMF

During the first EMC (Electromagnetic Compatibility) and EMF (Electromagnetic Fields) tests performed by DARE, the consortium was not sure whether the system could be used safely. While charging, the system emitted conducted emissions, leading to a possible disturbance in systems in the vicinity. After more research and testing by the emissions authorities (DNV-GL), these conducted emissions seemed to have little to no effect on systems in the area. As regards EMF, in which the electromagnetic exposure to humans is measured, the Peugeot iOn in particular proved to be a challenge. The magnetic field exposure between the transmitter in the ground and the receiver in the car was above the threshold, with exposure at the front of the car while charging. In order to try and resolve this issue, the inside of the car was shielded further and the hardware repositioned. However, this did not properly solve the problem.

Communication between the charger and multiple cars

The charger connects to the car by means of a Bluetooth communication module. While this worked one at a time while charging either the Nissan Leaf or Peugeot iOn, it would not properly alternate charging sessions when trying to charge the two different makes of cars consecutively. This issue, together with the uncertainty regarding EMC/EMF, forced the consortium to focus on getting the charging system to work with the Nissan Leaf alone first.

12 volt battery dead after not being charged for several days

While a normal charging system should keep the car's 12 volt battery at full capacity, the rectifier in the car drained the battery at a higher rate than normal. This resulted in the 12V battery dying after a few days of not charging or driving the car. A fix, entailing adding a manual switch to the car dashboard to turn the rectifier off and on, only slightly prolonged the capacity of the battery. This seems to be a common problem for EVs with a rectifier installed for these charging purposes.

Overheating of the system

The charging system, more specifically the on-site inverter, would overheat at 65 C after charging for around 45 minutes. The wireless charger used in this pilot depended on passive cooling only. After active cooling by means of ventilators, thermal management was brought under control.

Implementation in public space

From the perspective of the City of Rotterdam, the wireless charging system meets the ultimate objective of clutter-free streets and not having to install charging posts. The findings of this pilot were that inverter, rectifier and identification methods still need to be installed above the ground to ensure easy access for service and proper cooling. Identification through a mobile application and the development of better underground casings could ensure a completely invisible charging station.

4. Wireless Charging: how does it work?

In 2015, there were only a handful of suppliers testing wireless EV charging technology, including Qualcomm, WiTricity, Evatran and Proov. Though testing phases seemed to be developed at quite a mature stage, it was hard to find a supplier that could actually supply a fully functional wireless charging system and install it outside in a public area. At the start of this pilot, the consortium decided to contract the American company HEVO Power, one of the few that seemed to meet the requirements of the pilot.

4.1 HEVO Power: Wireless charging system

The principles behind HEVO Power's wireless charging technology were identified and proven by Nikolai Tesla over 100 years ago. The innovative technology provides a non-radiative, magnetic field mode for energy transfer, which is called the HEVO Wireless Power Transfer (WPT). Utilizing magnetic resonance, HEVO Power's technology matches the resonant coupling of the HEVO transmitter in the ground and the vehicle receiver to permit the transfer of wireless power to take place with the highest efficiency possible. Imagine it like an FM radio, where the transmitting antenna relays a radio frequency signal for a specific radio station.

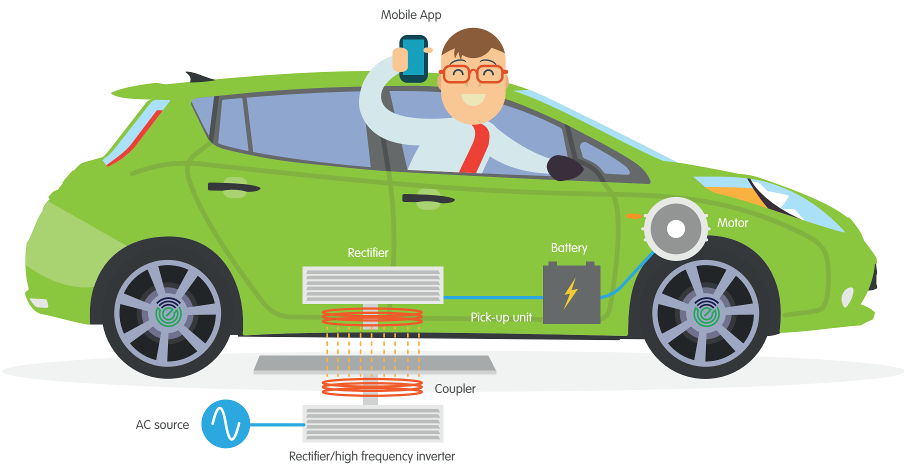


Figure 4: The concept of wireless charging

4.2 PFC inverter

The inverter converts AC voltage from the grid to DC and uses Power Factor Correction to reduce the harmonics to the grid, making it significantly more efficient for the grid operator. The Inverter then converts the DC voltage into high frequency AC and initiates the wireless power transfer process.

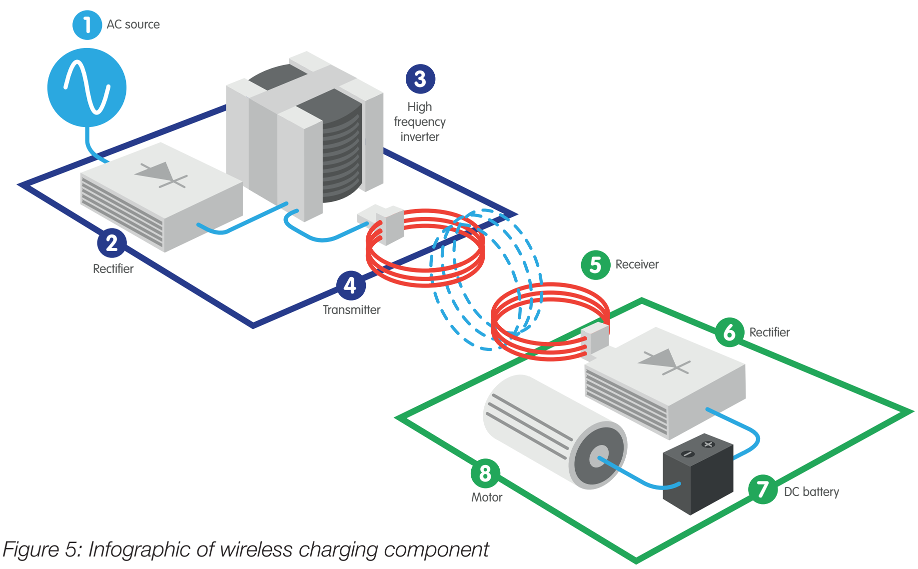


Figure 5: Infographic of wireless charging component

4.3 Transmitter

The HEVO Power transmitter is connected to the inverter and can be either surface-mounted or embedded flush into the pavement. The technology is able to withstand tough urban environments and is even submersible. The transmitter is a large coil.

Figure 6: Wireless charging system as implemented in Rotterdam

4.4 Vehicle receiver

Installed along the chassis of an electric vehicle. The driver can visually align the HEVO vehicle receiver with the transmitter. Once optimally aligned, the transmitter and receiver form a “handshake” that initiates the process of wireless power transfer to the batteries. The receiver can be manufactured in multiple standard sizes, but can also be custom designed as requested. HEVO is currently testing alignment of the system through their mobile app.

4.5 Rectifier

The HEVO rectifier, which is also mounted under the vehicle, supplies power to the batteries by converting the high frequency AC voltage to DC. It also interfaces with the battery management system (BMS) through the entire charging process and makes Current corrections as required by the BMS. The rectifier (combined with the inverter, transmitter and receiver) can deliver efficiencies of 85-92%.

5. Results

5.1 From conductive to inductive

Enabling the vehicle to charge wirelessly

Two vehicles were selected for this pilot, a Nissan Leaf and a Peugeot iOn. Both are fully electric (no ICE assistance) with AC and fast DC charging possibilities. A requirement was that the cars could charge wirelessly, as well as by cable, during the pilot. In order to make wireless charging possible, three main components needed to be installed on the vehicles: the secondary coil, rectifier and a communication module. The secondary coil receives AC power transmitted from the primary coil, which is placed in the ground, while the rectifier transforms this AC power into suitable DC power for the vehicle's battery and the Bluetooth establishes communication between the rectifier on the vehicle and charging station inverter.

One critical aspect of the conversion is the positioning of the secondary coil under the vehicle. Its placement should allow for easy alignment with the primary coil and protection against road obstacles that could damage it, such as speed bumps. For this reason, and with the use of a properly designed mounting plate (by ANWB), the secondary coil is placed right behind the front axle.

Figure 7: Mounting bracket and position of secondary coil under the vehicle

Using a similar method, the rectifier is placed in series with and behind the secondary coil, with a respective mounting plate. The output of the secondary coil is connected to the rectifier power input. The rectifier output is connected to the battery, replacing the DC fast charging input, which has been disconnected on the socket outlet side. The DC fast charging socket remains in its original position, but is no longer functional. If desired, it can be adjusted. The necessary communication between the rectifier and onboard charger is established through the already available wiring loom by matching the respective signal I/Os of the charger with the ones from the rectifier. This matching process requires the communication protocol of the charger in order to maintain an overview of I/O functionalities, signal codes, reaction times, etc. This communication line was wrapped around a ferrite core to eliminate noise signals from the induction system. The rectifier control system is powered by the 12V system of the vehicle by directly connecting it to the 12V battery through a 5-10A fuse.

The Bluetooth communication device, also safely placed on the underside of the vehicle, is connected to the rectifier's communication system with the inverter of the charging station.

Necessary information for this conversion was the dimensional characteristics of the HEVO system components, as well as the communication and behavioral protocol of the onboard battery charger.

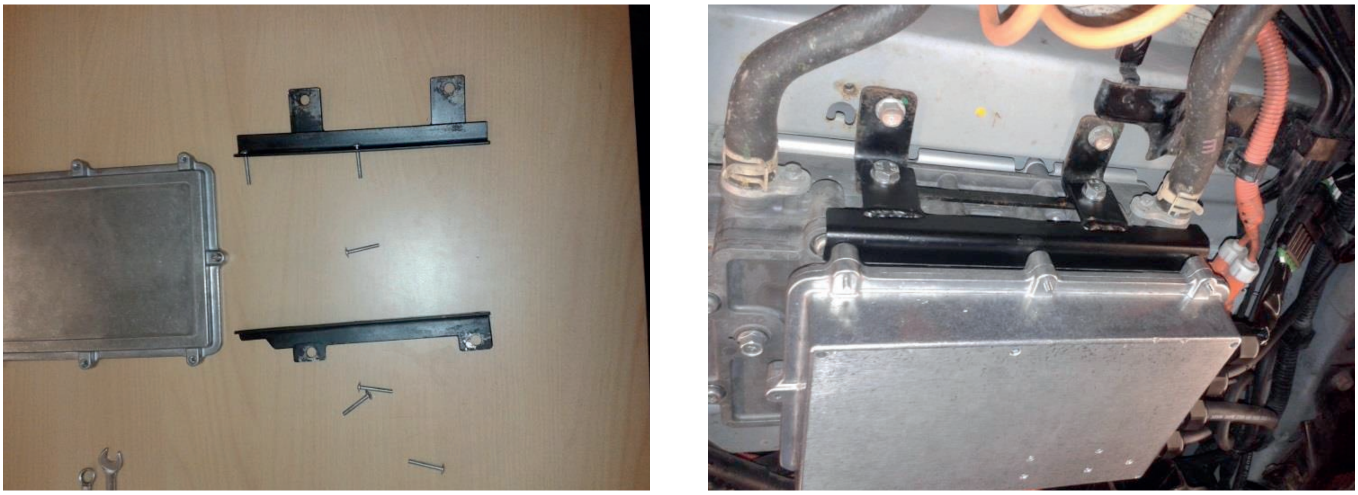


Figure 8: Mounting bracket and position of rectifier under the vehicle

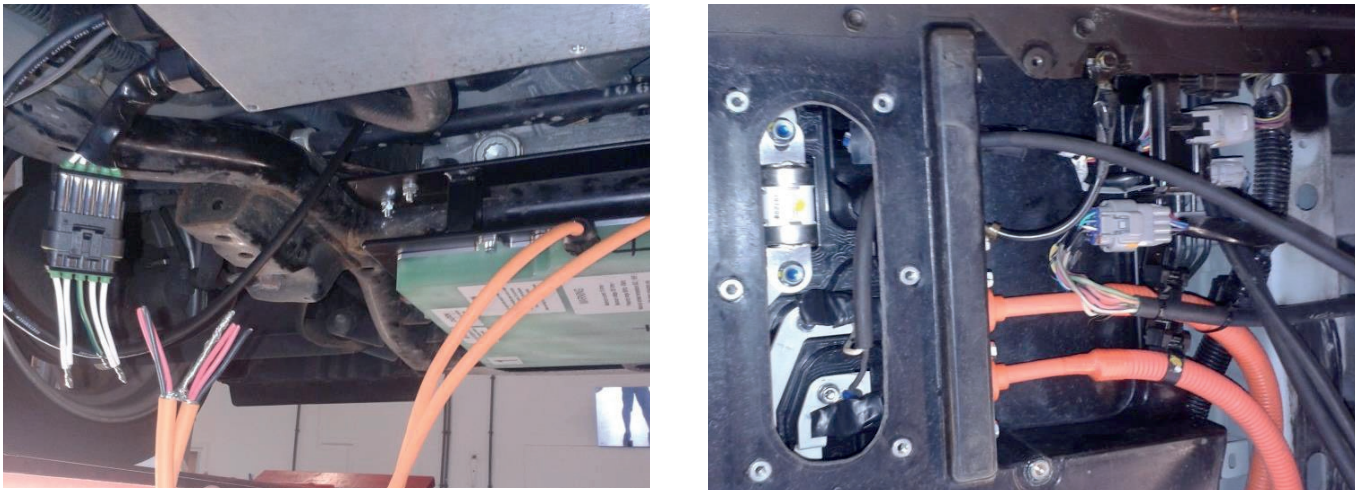


Figure 9: Connecting output of secondary coil with input of rectifier (left) and output of rectifier with input of onboard charger (right). Orange DC fast charging cables disconnected and tape wrapped

Figure 10: Plugging new communication line of rectifier into the existing one in the onboard charger (left). Wrapping communication line around a ferrite core (right)

Challenges in vehicle homologation

When one or more aspects of a vehicle are adjusted, new approval must be obtained from the Department for Transportation (Rijksdienst voor Wegverkeer in the Netherlands). If these changes take place before the registration of the vehicle, the original approval is affected and the vehicle must pass an individual assessment. The department responsible for such inspections is the Product Assessment of the Admission and Supervision Vehicles. Since the original vehicles are already registered and therefore deemed road legal, Chapter 6 of the Vehicles Regulation applies .

The RDW was consulted during this pilot. Due to the limited impact of adjustments to the vehicle, no new approval was needed. The conversion of the vehicles concerns only the charging system and has no effect on driving behavior. Also, the extra weight was not enough to require a new approval. Only the charging system itself needed to be assessed, along with compliance with regulations on Electrical Safety (VN/ECE-regulation no. 100) and Electromagnetic Compatibility (VN/ECE-regulation no. 10 conducted by DARE and DNV-GL).

Maintaining the standard (cable) charging function

The two vehicles are normally equipped with two charging sockets, one normal AC and one fast DC inlet. To enable wireless charging, the fast DC charge connection is eliminated temporarily. However, the normal AC charge remains fully functional, so that charging with a Level 2 charging station remains an option. When both options -cable and wireless charging, i.e. when parked at a wireless charging station but also with a cable inserted - are offered to the vehicle, the onboard charger will prioritize the cable charging option.

Enabling multiple vehicles to use one and the same transmitter

The difference between the two vehicles in terms of charging systems is found from the onboard charger backwards. The added components, namely secondary coil, rectifier and 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 the power supply has not yet reached the desired level within this time window, 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 behavioral difference was identified and the controller of the inverter 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 rapidly rising current. The respective time window for the Nissan Leaf is longer, so this requirement is met by default. As a result, both vehicles can be charged through the same station. At a later stage of the pilot, it was decided to focus on one vehicle because the Bluetooth communication module would not let the two cars charge consecutively in a stable manner, as the two rectifiers were identical and the charging device would chose a rectifier at random.

Which (technical) information is required by the car manufacturer?

To carry out the conversion, information from the OEM is needed regarding the original BMS. This includes communication, operation and functionality protocols to ensure a smooth operation of the inductive system, as well as an I/O pins/signals wiring diagram for a safe and correct integration of the systems. ANWB, together with HEVO, provided the information needed for this pilot. However, it is possible to integrate after-market wireless charging systems without the intervention of the car manufacturer through reversed engineering.

How does the conversion from AC to DC work?

For this report, the analysis of the inductive charging system is provided at a higher level to ensure understanding of the basic principles of its operation.

The vehicle battery pack is a DC power component that acts as both storage and source. The inductive charging system operates with AC power from the grid and is connected to the DC fast charge input of the onboard charger. As a result, an AC-DC conversion is necessary to transfer power from one end of the system (AC grid) to the other (DC Battery).

[2] http://wetten.overheid.nl/BWBR0025798/Hoofdstuk6/geldigheidsdatum_26-04-2015

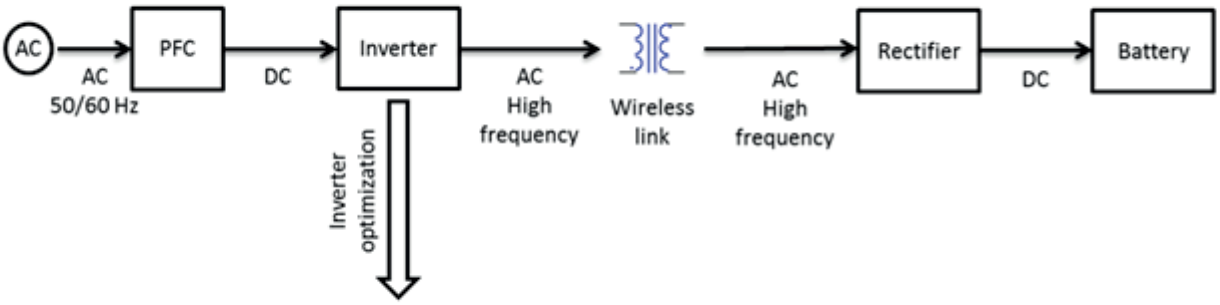


Figure 11: Typical diagram of wireless battery charger

The AC voltage of the grid is fed to a full bridge rectifier (in the PFC block in the figure above) in order to transform it into DC voltage and reduce the inductance and capacitance of the system. This is done through diodes that are activated in the proper order by the natural flow of the AC current. In order to keep the voltage output of this rectifier stable, a large capacitor is installed after the bridge. However, this capacitor creates harmonics and a reactive power flow to the grid, lowering the power factor at the connection point. Corrective actions are taken with an active Power Factor Correction module in the form of a controlled DC-DC boost converter that adjusts the power factor to values close to 1.

The DC output of these two components is the input of the inverter. This inverter is similar to a full bridge inverter, composed of diodes and semiconductor devices (Mosfet). The Mosfets are fast-acting controlled switches that, in combination with the diodes, manipulate and reform the DC input current into an AC of desired magnitude and frequency. In order to ensure minimal fatigue and loss during the switching action of the Mosfets, the zero voltage crossing principle is implemented. This means that the switches only open and close when there is no voltage at their terminals. This is primarily achieved through the phase control of the switches and to a lesser degree using the frequency control. The phase control also manipulates the power flow of the entire system, i.e. the power received by the battery.

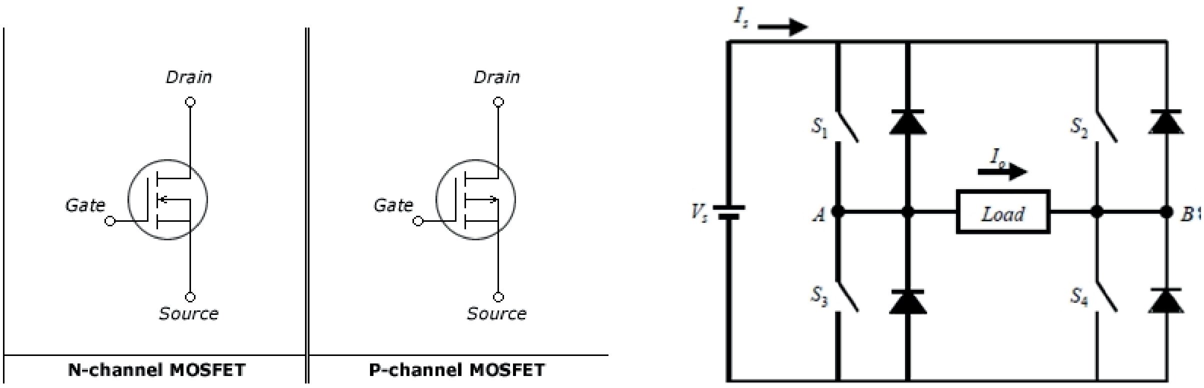


Figure 12: Mosfet semiconductors (left). Bridge inverter with Mosfet and diodes (right)

The result of this complex control process is an AC high frequency sinusoidal current that feeds the wireless link. This component, similar to an air-core transformer, consists of two coils: one in the ground (primary) and one on the car (secondary). In series with each coil and using SS topology, a capacitor is connected in order to create a resonance system. Every inductor/capacitor set has a specific resonance frequency defined by its inductance and capacitance, respectively. When operated at that frequency, the capacitance and inductance are mutually eliminated and the system experiences minimum loss and maximum power transfer. In our application, due to the need for relatively compact and cost-effective components with low copper losses, the current delivered by the inverter to the wireless link was chosen at a (resonance) frequency of 85 kHz. The wireless power transfer is based on the principles of electromagnetism. The current output of the inverter runs through the primary coil, creating a magnetic field around it. This magnetic field passes through the secondary coil, creating in turn a current of the same frequency and of a magnitude proportional to the ratio of the turns of the two coils.

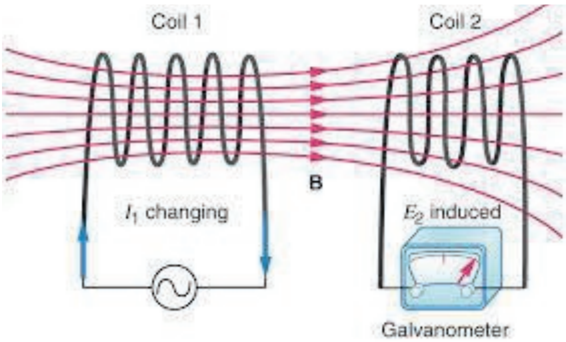


Figure 13: Electromagnetic principle of coupling

A topology inverse to the inverter is used on the secondary side. Here, the AC output of the secondary coil is fed to a rectifier, which transforms the AC signal into DC. The DC signal is then received by the vehicle's onboard charger and used to charge the battery. It is worth mentioning that a matching impedance topology is utilized to ensure maximum power transfer by equalizing the impedance of the secondary coil to the impedance of the battery.

5.2 Technical possibilities and limitations

What are the standards in wireless charging?

When it comes to standardization, the wireless charging of electric vehicles is quite a challenge. Although the technique has been available for decades, there are still only after-market systems for wireless charging available in 2017. No vehicle OEM offers an EV with wireless charging technology. Press releases promise factory-fitted systems by the end of 2017, such as on premium models like the Mercedes-Benz S500e Plugin Hybrid and BMW 5 series. In July 2017, Audi announced that its high-end A8, to become available in the market in December 2017, will have an optional wireless charging system.
A lack of standardization is one of the reasons for the wireless charging technology not being available more widely. However, much standardization work is in progress. Within the IEC, the TC69 committee has been working on Wireless Charging or Wireless Power Transfer (WPT) since 1996 and the first versions of the IEC61980 will be released in 2017, covering three main parts: General Requirements, Communication and Magnetic Fields Power Transfer.
The IEC 61980-1 covers, for instance, Safety Requirements and Positioning and is compatible with various types of systems, including after-market systems and systems with the coil(s) on the roof or front bumper of the vehicle. Different energy transfer techniques for Wireless Charging are also 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 14: Standards for power and air gap classes

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

The system used in Rotterdam meets the standardization requirements known at the start of the pilot in 2015, i.e. a WPT1 system with Z2 clearance. However, these specifications alone provide no guarantee that future vehicles can charge at this location. Also, the frequency of 85 kHz used is a standardized value.

Communication between the vehicle and the ground system is one of the more challenging aspects of interoperability. Every vehicle must have the same communication method as the ground assembly. Initial steps for WPT communication are expected soon.

What efficiency can be achieved during charging with the HEVO system?

During the first tests following vehicle adaptation, efficiency rates between 85-92% were measured. Unfortunately, due to a system failure at the end of the pilot, scientific on-site efficiency tests could not be performed. However, HEVO has carried out lab measurements:

Efficiency & Accuracy

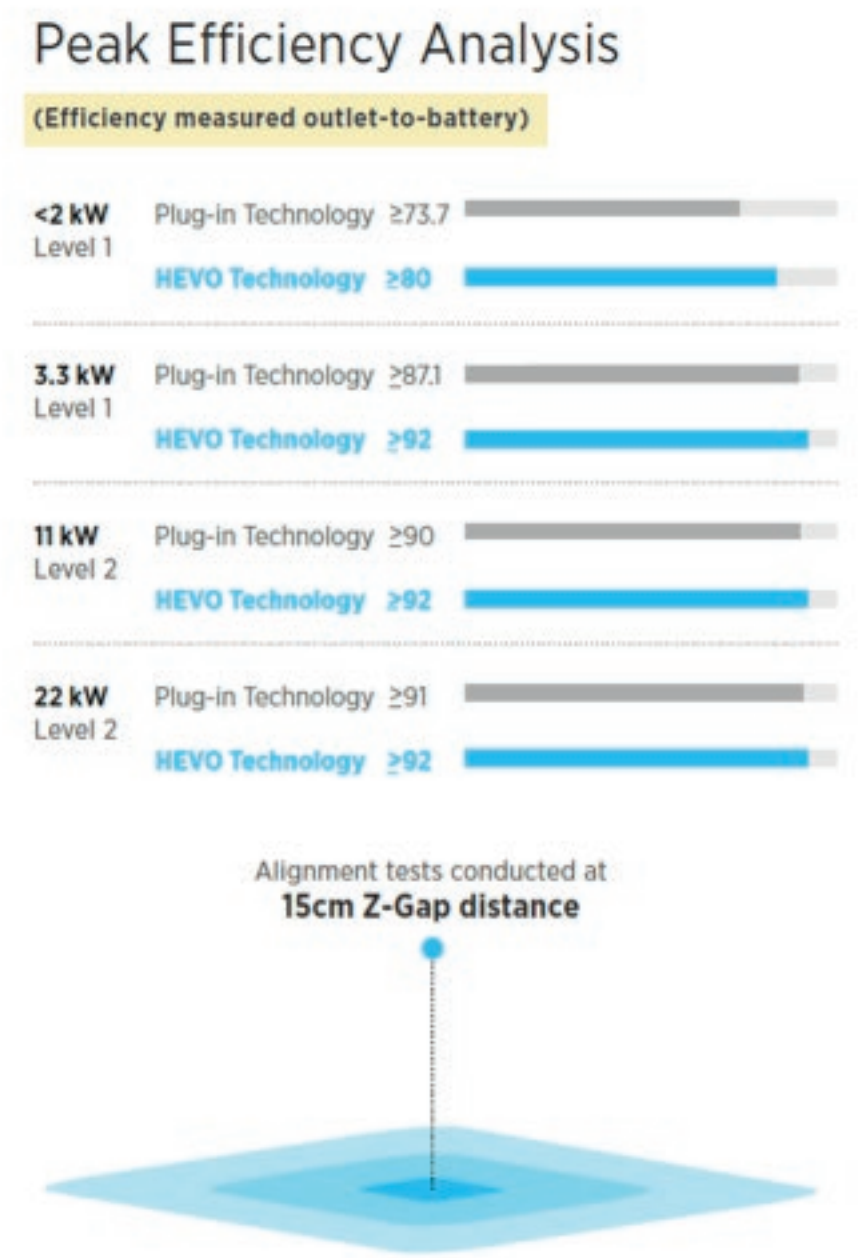


Figure 15: Peak efficiency analysis

How does power efficiency compare to plug-in charging technology?

Power efficiency tests performed by HEVO show that wireless charging is more efficient than plug-in charging technology.

Power Efficiency tests

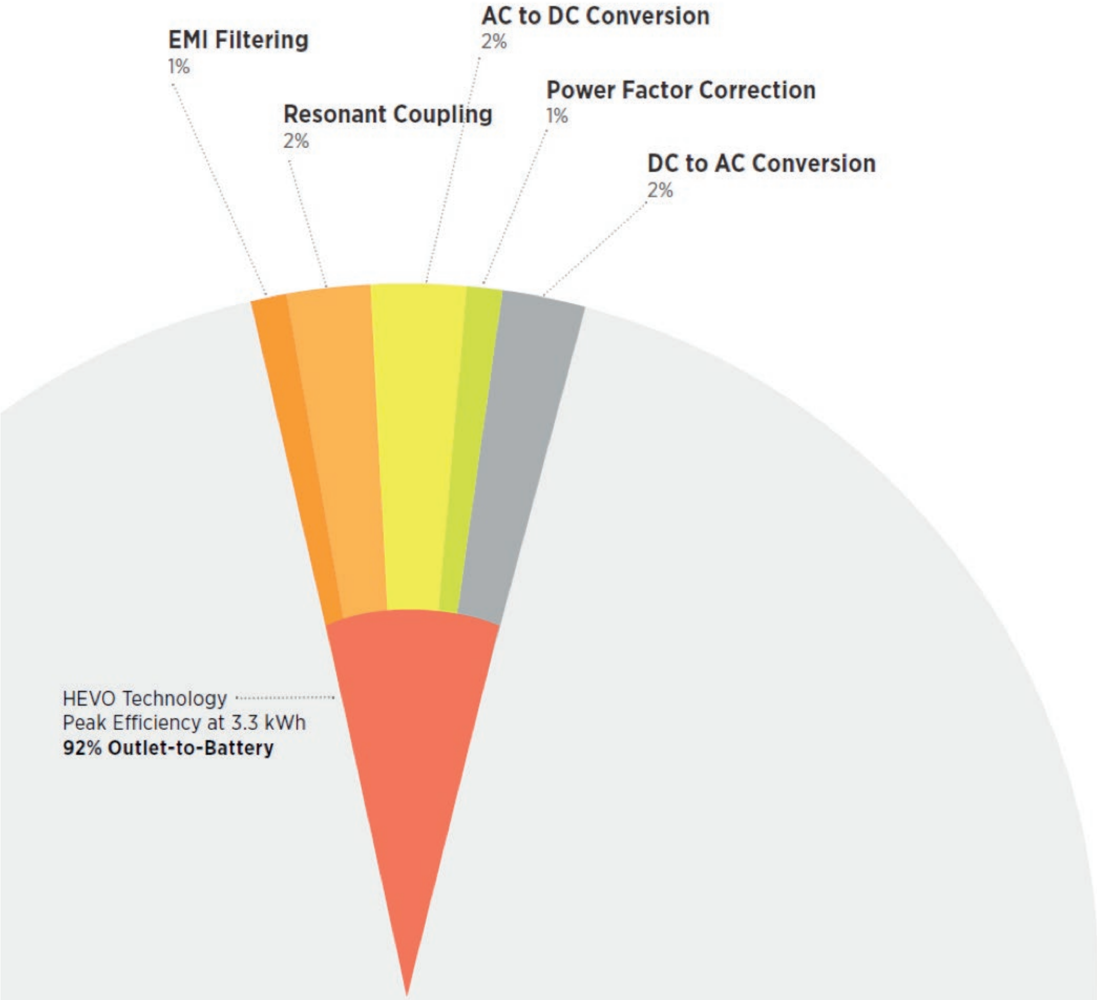
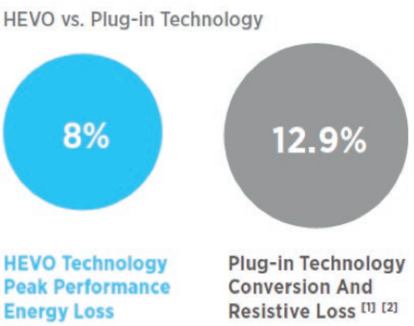


Figure 16: Power efficiency tests

Sources of Losses



Sources of plug-in technology efficiency analysis:

1) A Study of 6.6kW On board Charger for Electric Vehicle ... Author Y.S.DOW, H.H.KIM1. Y.I.KWON1. B.Y.KIM1, J.C.KIM1Hyundai Mobis, 80-9 Mabook-dong Giheung-gu Yongin-shi Kyounggi-do, 446-912, Korea ... EVS28 KINTEX, Korea, May 3-6, 2015.

2) An Assessment of Level 1 and Level 2 Electric Vehicle Charging Efficiency ... TO INVESTIGATE POTENTIAL APPLICATIONS OF EFFICIENCY MEASURES TO VARIOUS ELECTRIC VEHICLES AND TH EIR SU PPLY EQU I PM ENT ... PRE PAR ED BY Vermant Energy Investment Corporation Transportation Efficiency Group ... Evan Forward, Karen Glitman, and David Roberts ... March 20, 2013 (Revised)

How does the “air gap” affect efficiency?

The “air gap”, or distance between the centers of the primary and secondary coil, has a significant impact on the power efficiency of the system. This distance virtually changes the load seen from the primary coil and, consequently, the current flowing through the inverter also changes. As the zero voltage switching control of the inverter is not dynamic (the switching frequency and sequence are set for a specific load), this altered current can cancel its effect and increase losses to the point where the inverter shuts off for protection. Decreasing the distance between the coils has a more prominent effect on switching losses than increasing it. When the distance increases, the efficiency and power transfer decrease, mainly due to weaker coupling between the coils (smaller part of the primary magnetic field passes through the secondary coil). At some point, the charging session stops. During the conversion of the vehicles, the optimal perpendicular distance of the two coils for maximum power transfer with the highest possible efficiency was set to 15 cm.

Horizontal margins

In terms of aligning the vehicle over the transmitter, power transfer continued up to 5 centimeters from the center of the transmitter. Exact losses were not measured, but a rough estimate and monitoring of the power flow while charging showed that efficiency dropped in the range of 1-10% while moving away from the center.

Misalignment has an effect similar to increased distance between the coils. However, since the distance of the centers is now measured on a diagonal plain, the impact on efficiency loss per centimeter is much higher. Therefore, an accurate and user-friendly alignment system is important for maximum utilization of the system. Any metal, such as objects with ferrite qualities, set between the two coils would affect the efficiency of the system by distorting the magnetic field lines and coupling of the coils, leading to system shut-off. Moreover, these objects will be heated to high temperatures.

HEVO performed parking alignment accuracy tests in their lab:

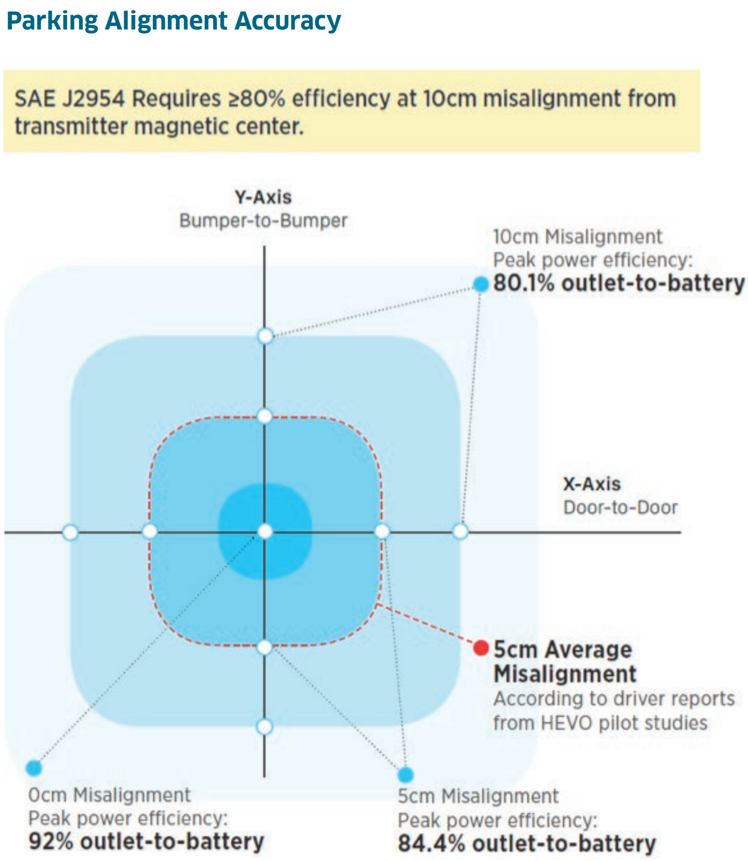


Figure 17: Parking alignment accuracy

What is the maximum charging power the system can produce?

When operated under optimal conditions of temperature, state of charge, alignment and perpendicular distance, the maximum power that can be transferred through HEVO's currently installed system is 3 kW. HEVO is already in the design stage of an 11 kW system. The efficiency of these systems cannot yet be accurately predicted, as this depends strongly on the quality of the design, control and materials used. The efficiency is expected to be at least similar if not better.

The secondary coil should be mounted so that the driver can easily place it above the primary coil in the ground. It is important that the coil and rectifier under the vehicle cannot sustain damage

Figure 18: Installation of the wireless charger in Rotterdam

Important to note for future reference is the use of hardware filters in the system. A higher power output of a wireless charging system also comes with higher conducted and radiated emissions. This means that an increase in power should go hand in hand with the use of better/larger filters.

How can "smart charging" be used for wireless charging systems?

Smart charging means dividing the available charging capacity to reduce the impact on the power grid or to ensure efficient use of renewable energy sources like solar and wind. Explained from a technical perspective, smart charging can be achieved through a variable charging profile, which can be controlled by the back office of the charging station and carried out by the charging station and wireless charging system.

The HEVO wireless charging system used for this pilot has certain technological restrictions that make smart charging operation unworkable. As mentioned above, the induction system inverter is programmed to work with zero voltage switching under certain load conditions for close to nominal current. If the power delivery varies, so will the current flow, which will ultimately cause increased losses and system shut-off. The system can only transmit nominal power to the load with slight adjustments according to the state of charge of the vehicle's battery.

In order to achieve variable charging power levels, a dynamic or adjustable control algorithm of the inverter is needed in order to be able to handle different values of current flowing through the system without compromising the zero voltage switching.

HEVO is working on a version that can be charged with 11 kW, as well as developing the requirements necessary for smart charging.

How does communication between the transmitter and receiver work?

The parts of the system that need to communicate with each other can be divided into three parts. On the vehicle itself, there is direct communication through the battery charger cable with the induction system rectifier. Depending on the condition of the battery and the state of charge, the onboard charger sends signals to the rectifier for the required power transfer in terms of voltage and current.

The rectifier then communicates these requirements through the onboard Bluetooth module to the Bluetooth of the charging station connected to the inverter controller. The controller then adjusts the switching pattern accordingly to achieve the required power level.

The initial goal of communication management was to connect the HEVO system to the EV-Box system. This goal was not achieved due to a communication failure between the two systems. In order to maintain progress in the pilot, the communication line between HEVO and EV-Box was eliminated. The wireless charging system worked stand-alone. This resulted in not being able to achieve interoperability and will be an important requirement for a future wireless charging pilot.

How are Foreign Object Detection (FOD) and Living Object Detection (LOD) used within the system?

Sensors can be integrated into the charging system in order to actively monitor the surrounding area for both living and foreign objects. If either is detected, the system safely halts operation and alerts the driver or fleet manager to clear the area. The system used in this pilot was not equipped with these sensors, as there were no safety concerns for living objects such as humans or animals. For the sake of safety, the consortium placed an audio device in front of the transmitter to detect movement. When detected, the device emits high frequency sounds, which scare away animals.

HEVO is currently including the FOD and LOD system in their new generation of chargers.

Which grid connection categories are suitable for wireless charging?

This is currently “limited” to 240V 16A Single Phase with max 3.7 kW charging. Technically, a 3-phase 16A is possible in the future to support 11 kW charging.

Is it possible to re-supply energy through wireless charging?

This is possible in theory, but the current system as installed in Rotterdam does not support this. Wireless charging focuses on specific users and vehicle groups (e.g. taxis). It remains a question if, in these situations, V2G will be a requirement. As long as V2G through a cable is still being discussed as to if, how and in which situations, it is unlikely that manufacturers of inductive charging systems will support this within the near future.

Grid connection and other components: above or underground?

An important advantage of wireless charging systems from the viewpoint of municipalities is the fact that there are multiple components located under the ground surface. Normal charging stations are often considered as having an impact on the visual aspect of the environment. Also, in “protected village view” areas for example, assets like charging stations are potentially unwanted because they do not “fit” in the environment. Using wireless charging systems enables components to be located on or underground.

Since this pilot was carried out in a public environment, the inductive charging system was connected (through a normal charging station) to the grid connection of the Roteb building. Theoretically, no extra components have to be placed above the ground. However, due to specific goals at the start of this pilot, there were several reasons to choose a connection through a normal charging station:

• **User identification**
The approach used was to connect the EV-Box system to the HEVO charger. The user has to swipe an RFID card at the EV-Box RFID reader in order to initiate a transaction. The adjustment to make the HEVO charger stand-alone eliminated this functionality. At the end of the pilot, the HEVO app could successfully be used to initiate a transaction.

• **The inverter**
The inverter is placed above the ground to ensure fast and easy access for troubleshooting. Apart from that, experience has taught that certain components require air cooling and detailed temperature management, which was not fully assessed for underground use at this time. Installing those components in a controlled environment above ground was therefore more relevant. However, a more advanced system could result in having all components located under the ground surface. Correctly defining the requirements and/or restrictions in accordance with the inverter's operation is an important aspect of this, apart from the necessity for the underground "box" to have the proper IP specifications of water-resistance, air flow for cooling the inverter and communication with the vehicle and charging station.

There are multiple possibilities to locate more components underground in order to reduce the visual impact on the environment. This is a significant advantage of inductive charging versus conductive charging.

• **Option for normal conductive charging**
Since an inductive charging system is used in a pilot/testing situation, an alternative charging option through a charging cable was needed, which is why a normal charging station was also installed at the pilot location.

In order to take full advantage of the fact that no charging station and/or cable is used, and therefore no components of the charging system other than the coil are visible, it is necessary to develop three aspects:
1. Alternative identification using, for example, a mobile phone application;
2. An underground compartment that is easily accessible and provides enough cooling for proper functioning of the inductive charging system components;
3. An underground grid connection in public environments.

For the latter, multiple studies have been conducted by Dutch grid operators in cooperation with ElaadNL. No standard or regulated underground connections are currently available. However, there are multiple examples of pilot situations in which a grid connection is installed underground. The greatest challenges are the accessibility of this underground compartment for maintenance (fuses, calibration) and reading the (smart) meter. Normally, meter readings from smart meters in a grid connection are done wirelessly. With a meter located underground, there is a risk of signal weakness. ElaadNL is currently conducting further research into the underground grid connection together with the grid operators in order to find a standardized solution that fits in the grid operator's processes. The consortium is monitoring the progress of this research in order to learn and benefit from the outcomes and possible usage in public wireless charging.

Connecting multiple transmitters

Every transmitter requires its own inverter. The possibility to connect multiple transmitters to a single inverter has not yet been developed. For future load balancing, it will be possible to connect multiple inverters to one charge control system in a satellite/hub situation.

5.3 Monitoring and transactions

How will the charging system be monitored?

As mentioned above, the goal was to monitor the transactions through the EV-Box back office. After eliminating the connection between the EV-Box and HEVO system, HEVO's back office took over the monitoring of the transactions. A user ID will be provided to the user through the HEVO app. A user account enables transactions to be logged wirelessly. Billing was not included in this pilot, but will not be difficult to include in the future compared to current monitoring and transaction systems for charge points.

How can existing protocols (OCPP) be applied to the wireless charging system?

One of the pilot's goals was to explore possibilities for interoperability between charging systems: Is it possible to manage a wireless charging system through different back office systems? To achieve this, the OCPP protocol can be used. During the pilot, more and more was learned about the set-up of communication for wireless charging systems. Smooth operation requires a permanent data connection with the system. The power factor and efficiency are measured in real time and continuously. Apart from that, very specific wireless charging-related messages, such as the coupling factor, are also monitored. OCPP was not suitable during the pilot for the system used in Rotterdam. Future research should include a more specific gap analysis for wireless charging systems in OCPP.

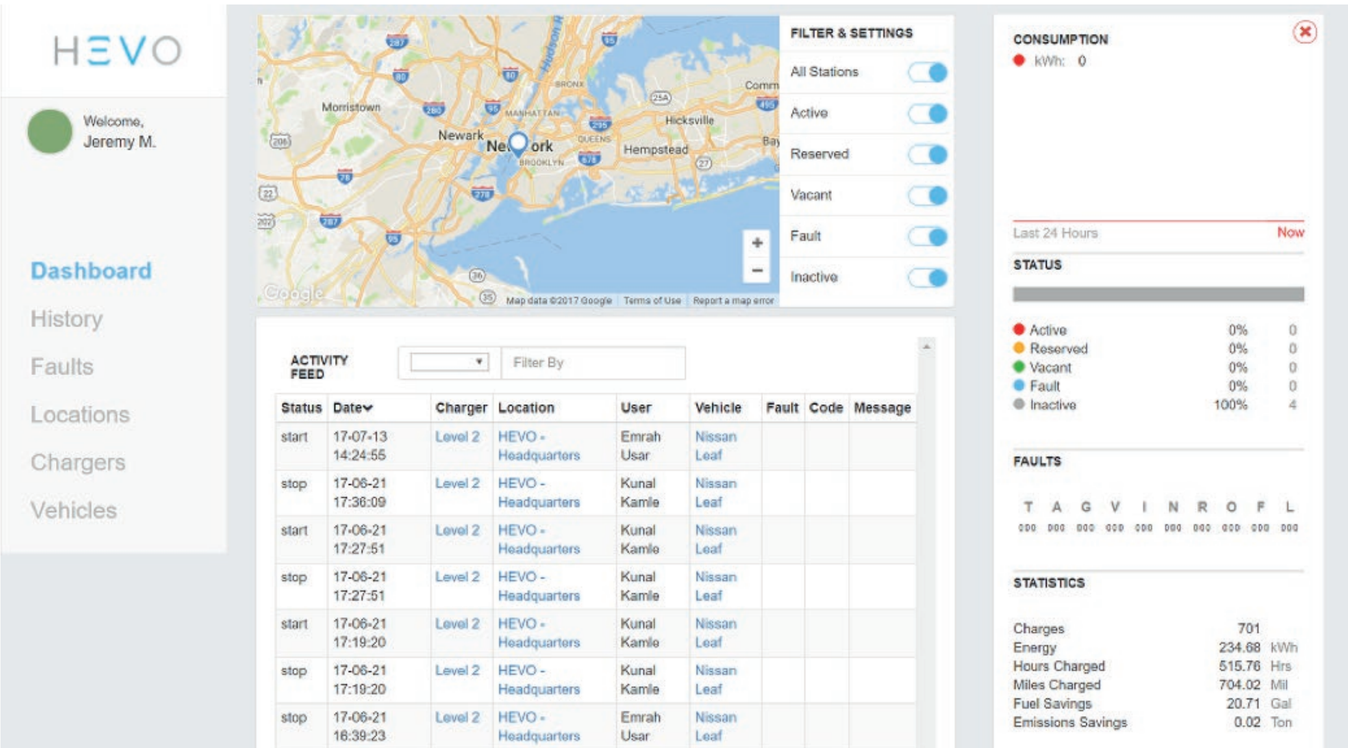


Figure 19: HEVO online back office

5.4 Safety & EMC

One of the main learning objectives was to establish how to control safety-related challenges that might arise with wireless charging. To analyze the impact of electromagnetic interference (EMI) and electromagnetic fields (EMF), tests were performed by certified measuring companies. The consortium consulted ANWB, one of the project partners, with regard to vehicle safety aspects.

Electromagnetic interference (EMI)

In terms of EMI, the following two types of emissions were analyzed as part of this pilot:

- Radiated emissions;
- Conducted emissions.

Both emissions were first analyzed by DARE. A quick scan was performed to gain better insight into the electromagnetic challenges. The results of the quick scan showed that the wireless charging system needed further development before it could meet emissions standards. Standards EN55022 and EN55011 were used for this activity.

DARE provided the consortium with important insight. The conclusion, however, could not be fully applied to the pilot, as the team was looking for more specific learning points and risks. DARE specializes in product certification, advice regarding pilots.

To gain more pilot-specific insight into EMI, the consortium contracted DNV-GL to perform EMI tests in order to provide more realistic insight into the status of the charger with regard to emissions and electromagnetic fields.

Radiated emissions

The magnetic field was measured while charging wirelessly by means of a magnetic field meter at a distance of 10 meters from the charging station. In a frequency band of 148.5-5000 kHz, the system had a radiated emission of 43.29 dBµA/m. The emission in this frequency band is 58 dB higher than allowed. The emission was also above the limit within other bands up to 10 MHZ. The conclusion by DNV-GL: disturbance of other radio receivers like air traffic, FM, P2000 and DAB+ is non-existent.

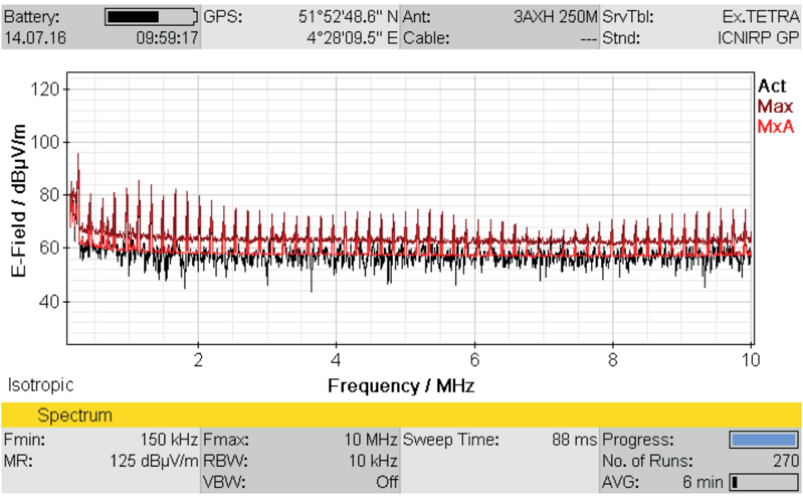


Figure 20: Radiated emissions: measurements conducted using a magnetic field meter

Conducted emissions

The conducted emissions were measured using a current clamp. The results were similar to the radiated emissions, in that the emissions were around 50 dB higher than allowed.

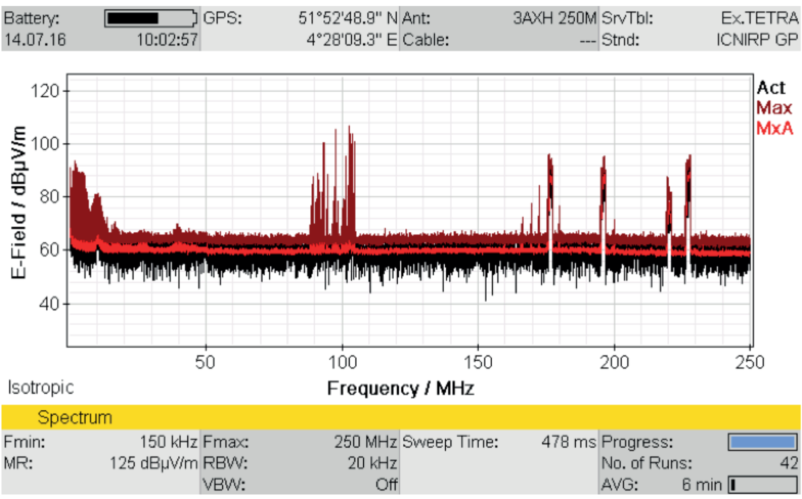


Figure 21: Conducted emissions: measurements conducted using a current clamp

Electromagnetic fields (EMF)

A very important aspect of wireless charging is the electromagnetic field. This is the term for the magnetic field that influences or could influence human beings. The social aspects of these fields are not to be underestimated, as the public is generally unaware of the effects of EMF.

The field intensity was measured in accordance with standard SAE J2954 in and around the car while charging. Two car positions were measured: with the car in perfect alignment and with the car positioned 12 centimeters away from the center of the transmitter. The field intensity was measured in micro tesla. The following spots were taken into account:

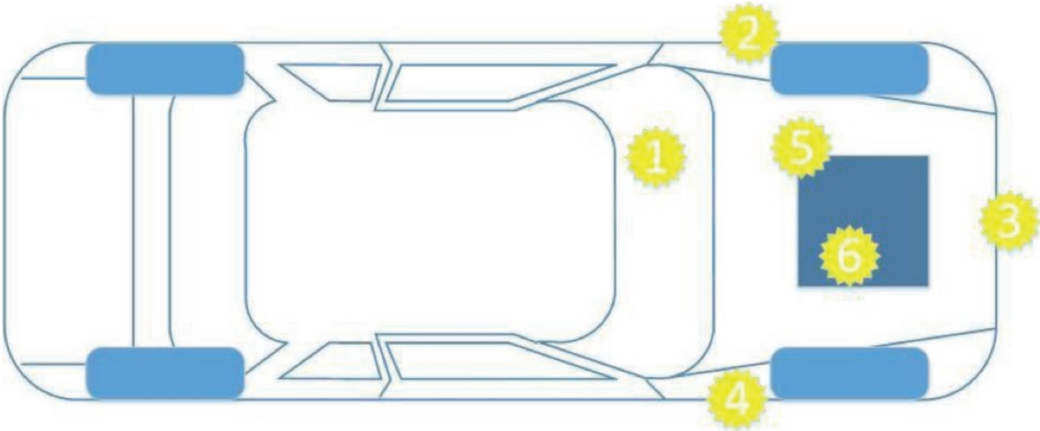


Figure 22: Points of measurement for measuring the electromagnetic field

Measurement 1: With the car perfectly aligned above the transmitter

Position	Magnetic field intensity (μT)	Comment
1	0.03	Inside the car at the driver's feet
2	1.08	Left front wheel near the door
3	3.00	Under the license plate
4	2.05	Right front wheel near the door
5	100	Under the car next to the transmitter
6	810	Under the car between the transmitter and receiver

Measurement 2: With the car misaligned by 12 centimeters

Position	Magnetic field intensity (μT)	Comment
1	0.04	Inside the car at the driver's feet
2	1.65	Left front wheel near the door
3	2.89	Under the license plate
4	5.24	Right front wheel near the door
5	100	Under the car next to the transmitter
6	306	Under the car between the transmitter and receiver

Conclusion

The 2013/35/EU guideline prescribes 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, nor is it likely that a human being will come between the two coils, making this an acceptable situation for this pilot.

Based on (Dutch) Council Recommendation 1999/519/EC, the exposure limit for the general population is 6.25 μT. In and around the car, the electromagnetic field is lower than the exposure from an induction cooker.

DNV-GL comments that the risks for people with a pacemaker or ICD are minimal. During charging, however, this group of people should not attempt to position themselves under the car.

Public acceptance
The effects of EMC and emissions are generally unknown to the public. One of the objectives was to delve deeper into the risks of these emissions and this topic was addressed by several stakeholders during the pilot. To create greater awareness and knowledge, it is 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 wireless charging is not in any way dangerous. While charging, sitting in or standing next to the vehicle, the magnetic field exposure to the human body is comparable to or lower than the exposure while cooking with an induction cooker.

Can the vehicle participate in traffic?

The Dutch transport authority was consulted through the ANWB to learn whether a car with built-in equipment for wireless charging would be permitted on the road and in traffic. There were no issues regarding participation on the road or in traffic. The greatest concern regarding participation in normal traffic and roads was to ensure that the vehicle could still drive over speed and other bumps. Thanks the assembly constructed by ANWB and the standard ground clearance from Nissan, this was not an issue, nor were rain or driving through a carwash.

Impact of wireless charging system on the energy grid

This was not properly tested. Wireless charging, however, is not likely to (negatively) impact the energy grid.

5.5 User experiments

User experiences

One of the most frequently mentioned benefits of wireless charging is user-friendliness. User experiments were set up at the start of the pilot, aimed at learning about the experiences of users with the wireless charging system. The usage period was originally from September 2015 to March 2016 but, due to a number of technical setbacks, the pilot was ultimately extended until May 2017. Chapter 3 describes the challenges faced by the pilot.

There was no extended period of use without technical malfunctions. Users were often unable to use the system, resulting in the absence of an objective analysis of user-friendliness. A baseline measurement was performed at the start of the pilot. This baseline measured user expectations of the wireless charging system. During the pilot, the user group was an important source of information on technical malfunction, the user-friendliness of the system and possible improvements.

Baseline measurement in August 2015

A fixed group of seven users was selected for the user survey. Apart from understanding user expectations of wireless charging, the survey also gathered information on current views on standard (cabled) charging.

The group of users completed a survey before the pilot started. Since there were only seven users for conducting the user experiments, these tests aimed to provide the consortium with insight on the differences between standard and wireless charging as opposed to conducting scientific research.

An overview of the questions and answers can be found in the following table:

Questions and indicators as baseline measurement
Appearance
What do you think of the appearance of standard charge points?
• Cluttered.
• Too many objects in public space.
• Visually less attractive than parking meters.
• Too big.
What should a wireless charging system look like in your opinion?
• The system should not be visible.
• The system should be placed underground. No objects should be visible.
Usage
What are your major complaints about the current charging method?
• The cable (getting your hands dirty, takes up space in the car).
• ICE (internal combustion engine) cars that take up charging spots.
• Malfunctions regarding the cable (not being able to remove the cable).
In your opinion, how should wireless charging work?
• Just park and start charging.
• It should be really simple without any RFID cards.
• It should be easy to use without extra objects in public space.
How should feedback be given regarding positioning and when charging starts?
• Through an indicator in the car.
• Through a display in the car.
What are the advantages of wireless charging in your opinion?
• No more cable.
• No more objects in public space.
How would you like to pay?
• Automatically from inside the car.
• The same as a normal electric car, i.e. RFID.
Uncertainties
What are your uncertainties regarding wireless charging?
• Safety (EMC/EMF).
• Influences of the weather.
• User-friendliness (parking the car directly over the ground system).
What would you like to know about wireless charging?
• How safe it is.
• Is it faster than standard charging?
• The costs.
• How does it work in general?

User phase from September 2015 – January 2017

Before the group of seven users took part in the pilot (September 2015), they were informed about the following:

- Goal of the study (explaining that the pilot is also aimed at application in consumer markets);
- Operation/how to use the wireless charging system;
- Safety;
- How to deal with malfunctions/emergencies;
- Duration of the pilot;
- User survey completion dates;
- Dealing with the press/questions from third parties.

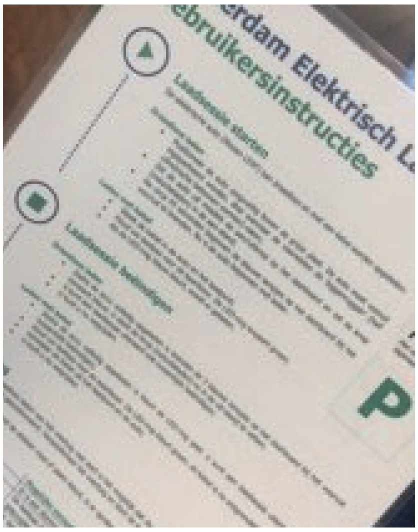


Figure 23: Explaining the pilot to the test users and the instruction leaflet

During the user phase, the consortium remained in close contact with the group of users.

Figure 24: Kick-off of the pilot with the test users

The following questions were asked and answered during the user phase:

Questions and indicators user phase
Usage
How much did the user group use the vehicle? How often did they charge wirelessly? • There were 150+ transactions with a duration of 10 minutes or more.
How did the user group experience the difference with normal charging? • There was a lot of downtime, so wireless charging was not experienced as reliable in general. • When the system worked correctly, the feedback was positive; not having to connect a cable was especially perceived as a positive experience.
How did the user group experience parking the car above the transmitter? • The alignment of the car was difficult in the beginning. So, together with the user group, the correct position of the car was marked on the parking spot.
How did the user group experience feedback from the car? (car charging y / n) • There was no indicator in the car that the car was aligned correctly, so the users had to rely on the markings on the parking spot. An indicator for the right position would have been preferred. • If the car was misaligned while the Bluetooth connection was active, the LED indicators in the car would indicate that the car was charging. In these cases, the users assumed that the car was charging properly, even though it was not.
During the use phase, did you experience any issues regarding use of the car? (if so, what kinds of issues?) • Some issues with the car not charging due to misalignment. • Some issues with the car not charging due to technical malfunctions.
Do you notice any difference between charging through the charge plug and the induction system? • The car actually charged without a cable being plugged in.

5.6 Business case development

How can the system be scaled up?

Collaboration between hardware suppliers and OEMs is an absolute must. Since these car manufacturers will be producing EVs with built-in receivers, the transmitters and communication modules will need to meet a mutual standard. Apart from standards, alignment regarding the amount of kilowatts is also required.

Interesting to note is that each transmitter requires its own inverter. This is important when planning a cluster of, for example, four wireless chargers.

What partners or suppliers need to collaborate?

When it comes to business case development, the realization and implementation of wireless charging is emphasized, while product development is not. The consortium worked on this pilot with the intention of installing and testing a (nearly) plug-and-play system.

Implementing wireless charging requires a hardware supplier and an installing party who preferably can also service the system

Which test results will affect the business case?

The following aspects were taken into account by the consortium in considering a continuation:

- Safety: how to commercialize the system within the limits of EMI standards;
- Functionality and user tests: user-friendliness is determined through user experience. How to initiate a charging transaction and how to align the vehicle are examples of functionalities that dictate the decision-making process for choosing a hardware supplier;
- Interoperability: the Netherlands is a frontrunner in the possibility to charge at any public or semi-public charging station in the country with a single charge card or app. Interoperability was not achieved in this pilot and is a requirement for a follow up project, especially in public space.

What are the costs and benefits of the concept?

As wireless charging is still at an early market stage, this is difficult to answer objectively. Although a pilot charging system is still under development, the cost of a complete system may be anywhere from 5,000 to 50,000. In 2018, however, when the consortium expects wireless charging to take off commercially, a price range equivalent to a normal charging system should be expected.

The benefits and business model also facilitate regular charge points.

How can the system be integrated into the public space?

As concluded above, in order to give the system a visual advantage (i.e. less visible on-site), an underground grid connection is preferred. Otherwise, the system can be integrated into public space like any other charge point.

What is the ideal company for converting the existing EVs?

A professional car dealership with knowledge of electric vehicles should be able to make the adjustments for wireless charging. Car mechanics certified for working on high-voltage vehicles would most probably best fit this job.

6. External Communication

One of the goals of this pilot was to share knowledge about wireless charging, trigger the market and inform the public. From the very start, the consortium aimed to convey a clear and recognizable pilot and message. A recognizable and attractive logo was therefore developed. The logo is a combination of the electric drive, induction and wireless logo and can be used free of charge by for other organizations by simply changing the colors.

Communication activities:

- Creating an abstract of the interim report;
- Wireless charging event organized by the consortium on November 8, 2016;
- Press releases;
- Attendance at several e-mobility-oriented conferences.

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Abstract of the interim report

The interim report was converted into an attractively designed abstract. This report was then shared publicly through the Rotterdam website, by e-mail and included in the invitation to the wireless charging event on November 8, 2016. The current abstract can be found at http://gezonderelucht.nl/wat-gebeurt-er-in-rotterdam/schoon-rijden/inductieladen.

Figure 25: Cover of the interim whitepaper report

Event and press release

Considering the amount of visitors and positive feedback, the event organized on November 8 can be called a success. The press release and official opening at the location took place prior the event. The media attention to the opening was far above expectations:

- 5 newspapers;
- 3 national television reports;
- 3 radio reports;
- Over 500 social media messages.

Figure 26: News articles

Conferences and pilot visits

The consortium shared the gained knowledges by attending and/or presenting at the following conferences:

- The Avere E-Mobility conference – Amsterdam;
- The Innovation Expo – Amsterdam;
- Electric Vehicle Conference – Geneva;
- POLIS Conference – Rotterdam.

The consortium also hosted the wireless working group from the IEA (International Energy Agency) and PIB (Partners in Business) from Germany.

7. Conclusion and Continuation

During the pilot preparation, implementation and research, multiple new insights were gained by the project team. Although this pilot exceeded the intended time period and budget, the consortium is proud of the milestones achieved and knowledge that it can now share with the public.

The most important lessons learned:

- Reliability, convenience and user-friendliness during operation are the most important aspects for users. At this time, public wireless charging does not seem to be ready for market introduction. To accelerate mass adoption, an easy-to-use method of parking alignment is a must. Moreover, systems must be tested thoroughly in different weather conditions and environments before they can be ready to be used in public.
  The supplier of the system, HEVO, introduced an application at the beginning of 2017, supporting users in positioning the vehicle. A new version of the system has also become available in 2017, promising more functional stability. The Rotterdam pilot has therefore marked a major step towards the mass rollout of the public wireless charging station;
- Although after-market systems will be prevalent the coming years, a mass rollout depends on standardization support by OEMs.

7.1 Vision per stakeholder

ENGIE

ENGIE's quest to become a top contributor to the energy transition requires investing in the development and implementation of Green Mobility. Inductive charging is one such innovative mobility solution and a prerequisite for autonomous driving. The technical aspect of wireless charging (inductive and/or magnetic resonance) proved to be very interesting and has significant potential for the increased user-friendliness of electric vehicle charging. The greatest current challenges of wireless charging are the development of charging standards, product maturity (hardware developers and OEMs) and market readiness. Together with partners, ENGIE wishes to continue exploring implementation in public space of these types of systems in the near future.

Rotterdam

This pilot provided the City of Rotterdam with valuable insights into wireless charging. Both at the start of the pilot and afterwards, it was clear to us that wireless charging will be one of the charging solutions for EV in the near future. Major challenges are still faced in terms of standardization, as well as the literal integration of the system into public space. At present, the best opportunities are in taxi applications and the more private spaces. Rotterdam is willing to test newer wireless products in the near future, with the ultimate result facilitating a public space with a minimum of charging objects.

Gemeente Rotterdam

ElaadNL

This pilot has helped Dutch cities, markets and universities learn more about wireless charging in public areas. Although the lessons learned are highly valuable, the technique does not seem to be fully ready for mass adoption. Making wireless charging available from the factory as an optional vehicle feature may improve reliability, but after-market solutions can contribute more to interoperability between brands. To ensure interoperability, there is a strong need for clear standards. Wireless charging is not expected to affect the grid impact of EVs any more than normal charging. However, the frequency of transactions may increase because wireless charging is an easier method of charging. Future research should focus on standardizing communication and smart charging and investigating the actual effects on the environment and grid (i.e. power quality).

EVConsult

Wireless charging will first be available in the top segment of private EVs, so that drivers can enjoy the convenience of wireless charging at home. The additional cost will have a relatively minor impact on the overall cost of the vehicle. Once full standardization is achieved, the price tag will be even lower. Additional applications are expected, although conductive charging will remain the dominant standard for some time to come. The greatest impact on market development will be the growth of autonomous e-vehicles, which require automated charging. Different types of automated charging methods will become available and wireless charging has a good chance of becoming the leading method.

HEVO Power

HEVO's vision is based on creating a global wireless charging standard for electric vehicles (EV) that provides users with the charging experience they demand, namely, the ability to simply park and power up. By offering a wireless charging option for electric vehicles, HEVO can offer a safe and effective means to charge EVs without the limitations of plug-in charging. People, planet and power represent the core values of HEVO's business, products and services. Our mission is to provide a fast, safe and affordable wireless charging network that delivers locally resourced, sustainable energy to customers with electric vehicles. In doing so, HEVO and its partners lead the transportation evolution. This evolution will result in greater energy independence and protect the environment and security interests of future generations.

7.2 Continuation

At this point, developing wireless charging solutions requires cooperation between multiple stakeholders. The continuation of wireless charging projects can be approached on multiple levels:

- Finalization of standards for wireless charging to ensure interoperability. Open standards and access to standards are important for consumer-oriented solutions.
- Pilots aimed at after-market charging solutions in public space, with relevant applications like taxi companies in city centers.
- Developing and testing underground grid connections and inverters in order to maximize the value of wireless charging in public space.

To encourage EV adoption in cities, the scaling of conductive slow and fast-charging infrastructure will continue to be of paramount importance.

ENGIE is currently reviewing the experiences gained with this pilot. A combination of the two ENGIE Infra & Mobility departments - E-Mobility and Smart Mobility - are working jointly on a deployment plan for a continuation project. The City of Rotterdam has also expressed interest in following up on the pilot and a new project will be started up in 2018.

A possible new pilot will be initiated within the public charge point concession of "collaborating municipalities of Zuid-Holland", in which Rotterdam acts as concession manager and ENGIE as contractor.

The lessons learned and such business case aspects as safety, functionality and interoperability will be taken into account in any follow-up project.

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EVCONSULT
experts in sustainable mobility

HEVO POWER

Rotterdam elektrisch

engie