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UNPLUGGED: Wireless charging for Electric Vehicles

UNPLUGGED project aims to investigate how the use of inductive charging of Electric Vehicles (EV) in urban environments improves the convenience and sustainability of car-based mobility. In particular, it will be investigated how smart inductive charging infrastructure can facilitate full EV integration in the urban road systems while improving customer acceptance and perceived practicality. UNPLUGGED will achieve these goals by examining in detail the technical feasibility, practical issues, interoperability, user perception and socio-economic impacts of inductive charging. As one special variant, inductive en-route charging will be investigated thoroughly.

As part of the project, two smart inductive charging systems will be built, taking into consideration requirements from OEMs, energy utilities and end users. The systems will be innovative and will go beyond the current state of the art in terms of high power transfer, allowing for smart communication between the vehicle and the grid, as well as being in line with the latest inductive charging standards and considering interoperability. These innovative inductive charging systems designed and built as part of the project will then be tested and assessed in order to understand their potential impacts on urban mobility and the acceptance of e-mobility. Application in an en-route charging scenario in particular will be examined for different vehicle types, ranging from cars to buses.

It is anticipated that UNPLUGGED will provide clear evidence on and demonstrate whether the use of smart inductive charging infrastructure can overcome some of the perceived barriers for e-mobility, such as range and size of on-board energy storage, and practical difficulties associated with installing traditional charging post infrastructure.

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Change History

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Abbreviations

AC	Alternating Current
CAN	Controller Area Network
CAPEX	Capital Expenditure
CBP	Circuit Breaker Panel
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CISPR	Comité International Spécial des Perturbations Radioélectriques
DC	Direct Current
DSO	Distribution Service Operator
ECU	Electronic Control Unit
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
HMI	Human Machine Interface
ICNIRP	International Commission for Non Ionized Radiation
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
IPT	Inductive Power Transfer
ITU	International Telecommunications Union
ISO	International Organization for Standardization
kHz	Kilo-Hertz
kW	Kilo-Watt(s)
kWh	Kilo-Watt Hours
LF	Low Frequency
LTPH	London Taxi and Private Hire
LV	Low Voltage
OPEX	Operating Expenditure
PHEV	Plug-in Hybrid Electric Vehicle
PP	Parallel – Parallel
PS	Parallel – Serial
PWM	Pulse-Width Modulation
RE-EV	Range Extended Electric Vehicle
RFID	Radio Frequency Identification
SAE	Society of Automotive Engineers
SECC	Supply Equipment Communication Controller
SOC	State of Charge
SP	Serial – Parallel
SS	Serial – Serial
WPT	Wireless Power Transfer

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Figures & Tables

1 Executive Summary

This task 2.3 of the UNPLUGGED project is concerned with the issues around interoperability, the aim of which is to ensure that any vehicle can use any charging site. This requires that:

- Communications interoperability – The vehicle and power transfer infrastructure are able to communicate.
- Financial interoperability – There is a mechanism allowing the user to pay for the use of the power transfer infrastructure –(this is outside the scope of this task, and this type of payment interoperability is well established in other industries, e.g. energy service providers, mobile phone networks etc.)
- Physical interoperability – the vehicle can be parked in such a way that the primary coils of the charging station and (secondary) pickup coils align with sufficient accuracy. This also includes ensuring the any guidance system for optimising alignment is interoperable.
- Electrical interoperability – the pickup coil is able to receive the wireless power from the power transfer coil efficiently and safely. This therefore requires the charging and pickup coils to be compatible in terms of technology, power transfer rate, frequency, spacing requirements etc. This is also the area of largest risk as it requires that all WPT systems work, or at least fall back to, a common standard, which could severely affect new entrants to the market who may have incompatible but innovative solutions.

The challenge of this Task is to achieve a WPT system that allows charging of different secondary devices using the same primary coil and to demonstrate it in the wireless power transfer station built in Zaragoza Demosite.

The task is divided into 3 sub-tasks:

- Assess possible methods of integration with road infrastructure, including the transfer of power
- Assess interoperability of charging “bay” designs with different vehicles and locations for installations
- Provision of driver information (signage / road markings, etc.).

The research undertaken for this task has concluded that interoperability with the power transfer infrastructure is feasible, even where equipment from different suppliers operates at different frequencies. As long as both sides of the power transfer equipment are aware of the requirements of the other, and there is an agreed strategy regarding which side (primary of secondary) adapts to the other, rapid adaptation is possible. This results has been shown both in simulation and experimentally.

For interoperability between the vehicle and the power transfer infrastructure, a standardised interoperable communications link needs to exist. The technology to achieve this exists, and the standards used for communication in conductive charging solutions are, with some adaptation, suitable for wireless power transfer solutions. The required changes are already being addressed by the standardisation bodies. The communications required for billing purposes was not specifically addressed, but the technology to achieve this is well established, for example in the mobile phone industry.

Two significant studies were undertaken, one each in Barcelona and London, to investigate the integration of power transfer infrastructure into the urban environment. These found that public taxis and delivery vans would be most likely to benefit from the introduction of wireless charging infrastructure. Both vehicle types tend to stop for short periods where the use of plug-in charging would be time consuming and inconvenient.

Taxi ranks and queuing areas would be a prime candidate for infrastructure. Because of the short time taxis tend to spend in these locations, higher power infrastructure would be most suitable.

Delivery vans on the other hand would benefit most from charging infrastructure in shopping centres and logistics premises. As they tend to be stationary for longer periods of time at these locations, lower power systems would most likely be sufficient for these. The installation of wireless charge system in loading/unloading bays makes sense for short duration stops (up to 30 minutes stop time). For longer duration stops the plug-in charge system fully covers the driver’s needs.

Additional areas where infrastructure should be considered include commercial parking, tourism zones, connectivity with other transport modes, services for citizens (hospitals, schools, etc.) and deliveries to residential streets.

Citizens' perception is a key factor for the wireless charging system installation success. The information should emphasize the benefits of the wireless system, should not be intrusive and should indicate the safety of the installation. This was illustrated by a survey of London taxi drivers, whose chief concern about electric vehicles was range and the possibility of running out of charge.

A review of technical standards identified that significant standardisation effort is already underway in the IEC, ISO, CEN, CENELEC and the ITU. Creation and adoption of standards provide a strong incentive to interoperability.

Another important area of interoperability is the provision of information to drivers. Three aspects of this are addressed in this report, namely the in-vehicle Human-Machine Interface (HMI), the overall charging HMI, and the provision of signage.

Guidelines for the clear and unambiguous provision of information to the driver are addressed in the in-vehicle HMI. As an illustration, an initial HMI design is analysed, shortcomings identified and an improved version presented. The adoption of a standard set of symbols and HMI design elements enhances interoperability as users move between vehicles.

The HMI at the charging station is also discussed, identifying the different methods that the power transfer process may be initiated and controlled. The choice of the type of method of control used is based on the type of contract that the user has, and also has to cope with users without a contract. Interoperability between these different processes requires standardisation of message interfaces between EVSEs and in-vehicle systems.

Finally the issue of signage is investigated. It has been found that many countries are already adopting signage to cope with the introduction of electric vehicle and charging infrastructure. Unfortunately most countries are adopting their own signage, with little evidence of standardisation, although some countries are adopting the same or similar signage to other, mostly neighbouring countries.

2 Introduction

This task 2.3 of the UNPLUGGED project is concerned with the issues around interoperability, where according to IEC 61980-1 (Committee Draft for Vote))

> Interoperability describes the state of the primary and the secondary device enabling wireless power transfer (WPT) (sometimes referred to as inductive power transfer or wireless charging) in a safe and efficient manner based on compliance with the regarding specification.
>
> Interoperability can only be achieved by a WPT system, when the primary and secondary devices are of the same technology.
>
> Interoperability of WPT systems between different power levels within the same technology is desired but not required.

The aim of interoperability is to ensure the any vehicle can use any charging site to charge their vehicle. This requires that:

- The vehicle and charging infrastructure are able to communicate – communications interoperability.
- There is a mechanism allowing the user to pay for the use of the charging infrastructure – financial interoperability (which is not a major focus of this task, as this type of payment interoperability is already well established in other industries, e.g. the mobile phone networks).
- Physical interoperability – the vehicle can be parked in such a way that the charging and pickup coils align with sufficient accuracy. This also includes ensuring the any guidance system for optimising alignment is interoperable.
- Electrical interoperability – the pickup coil is able to receive the wireless power from the charging coil efficiently and safely. This therefore requires the charging and pickup coils to be compatible in terms of technology, power transfer rate, frequency, spacing requirements etc. This is also the area of largest risk as it requires that all WPT systems work, or at least fall back to, a common standard, which could severely affect new entrants to the market who may have incompatible but innovative solutions.

The challenge of this Task is to achieve a WPT system that allows charging of different secondary devices using the same primary coil and to demonstrate it in the wireless charging station built in Zaragoza Demosite.

The task is divided into 3 sub-tasks:

- Assess possible methods of integration with road infrastructure, including the transfer of power
- Assess interoperability of charging “bay” designs with different vehicles and locations for installations
- Provision of driver information (signage / road markings, etc.)

The following sections will look at each sub-task in turn.

3 Assess possible methods of integration with road infrastructure

3.1 Power Transfer issues

Interoperability between the power transfer elements of different providers of equipment is dependent on the primary and secondary parts of power transfer equipment working to the same technical specifications. The most important aspects of these are:

- Using the same fundamental technology. In the case of systems investigated in UNPLUGGED, these are all based on resonant inductive coupling.
- Using compatible architecture. Resonant inductive coupling systems can produce constant voltage or constant current secondary outputs, and it is important that at least the secondary side is aware of what the primary side is expecting. This aspect is investigated in the UNPLUGGED trials and simulations.
- Coil topology. Different systems may use different shapes and numbers of coils. Coupling between different shapes and sizes of primary vs. secondary coils may be compromised and lead to unacceptable levels of EMC. This aspect is investigated in UNPLUGGED.
- Agreement on the frequency of operation. Being a resonant system, it is important that both the primary and secondary sides operate at the same frequency. Where systems which normally operate at different frequencies wish to be interoperable, at least one of the systems needs to be able to switch its operating frequency to match the other. This aspect is investigated in UNPLUGGED.
- Alignment issues. Different systems have different requirements with respect to maximum allowed misalignment between the primary and secondary parts. How the misalignment between systems from different suppliers is handled is investigated in UNPLUGGED.

3.2 Results of power transfer simulations

This chapter studies the possibility of charging the 3.7 kW prototype developed by FKA with the primary coil developed by CIRCE.

Since the CIRCE 50 kW system is formed by two 25 kW units, only one of them is considered regarding the possibility of interoperability between both prototypes. The final dimensions for each coil are given in Figure 1. Note that the images represent a section through the coil, where the red dots are the coil windings.

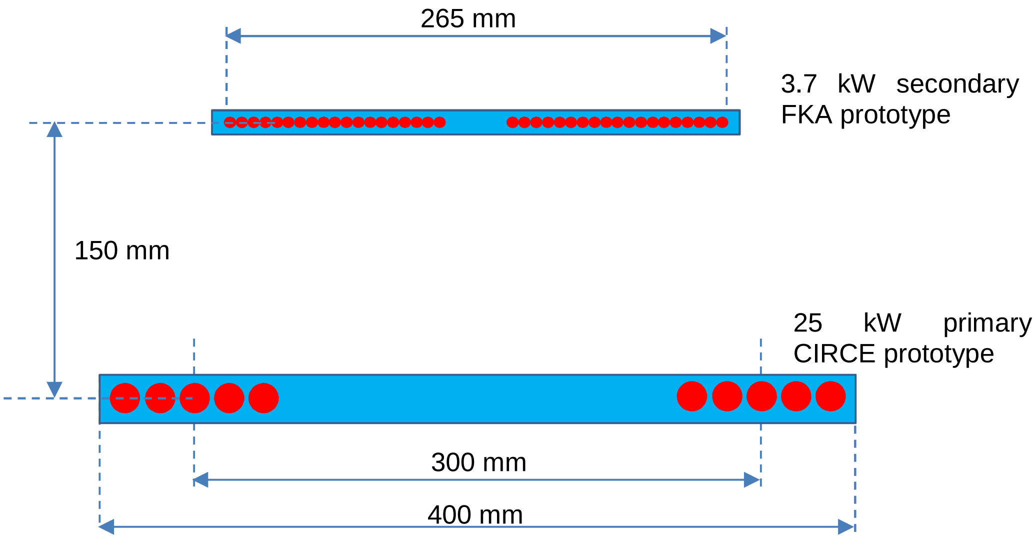


Figure 1: Schematic of the interoperability configuration

3.2.1 Main Parameters of the coils

Primary Coil (CIRCE)

The circuit topology of the CIRCE power transfer system is shown in Figure 2. The circuit to the left of the IPT transformer is the 25kW CIRCE primary part, up to and including the transformer primary coil. The secondary part is substituted by the FKA secondary (see below).

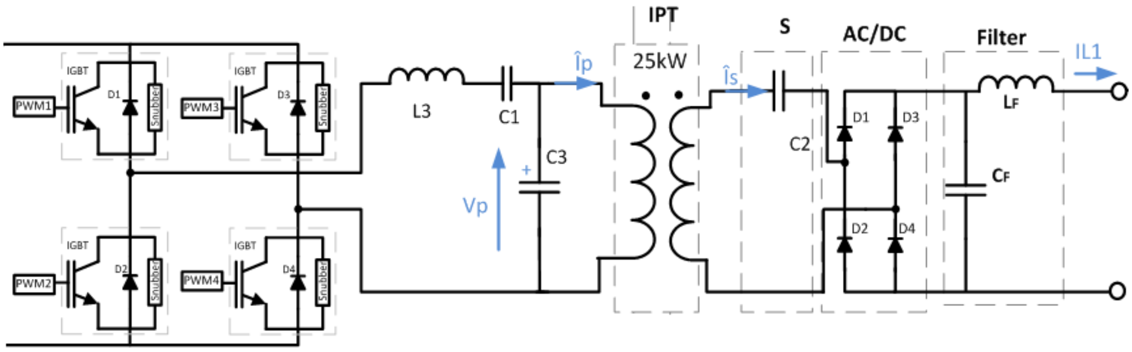


Figure 2: Main 25 kW UNPLUGGED topology

The main primary coil parameters are:

N1 (number of turns) = 5 turns of 125 mm2

Size = 0.3 * 0.4 m (outer dimensions of 0.4 * 0.5 m)

L1 = 15 e-6 H (Self- inductance of the primary coil with ferrites)

Operating frequency = 25800 Hz

Primary resonance capacitor: It is formed by two capacitors according to Figure 2

C1= 0.135 e-6 F

C3= 2.24 e-6 F

Secondary coil (FKA)

The circuit topology of the FKA secondary part is shown below in Figure 3. The secondary part is everything to the right of the transformer, including the secondary coil of the transformer (Ls)

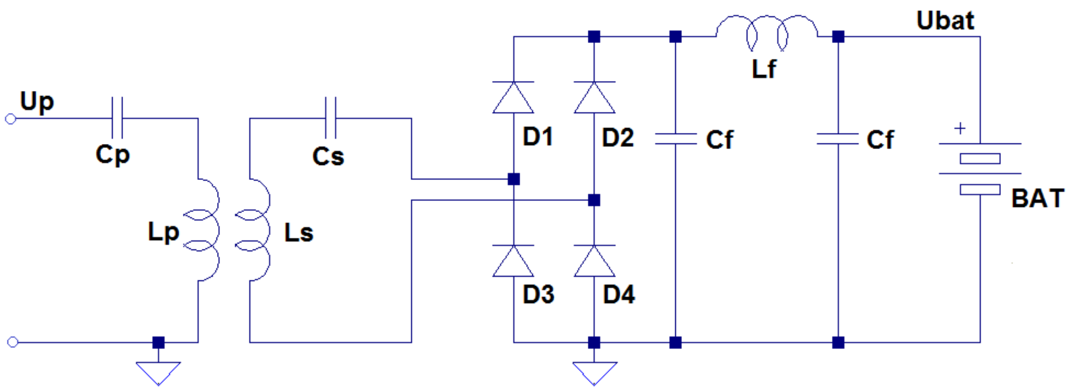


Figure 3: Main 3.7 kW UNPLUGGED topology

The latest secondary 3.7 kW coil data provided by FKA according to D1.2 are:

N2 = 19 turns of 14.4 mm2

Size = 0.21 * 0.25 m (outer dimensions 0.265 * 0.31 m)

L2 = 215 e-6 H (Self- inductance of the secondary coil with ferrites)

Working frequency= 140000 Hz

Secondary resonance capacitor: It is formed by one capacitor Cs connected in serial with the coil according to Figure 3

CS= 6 e-9 F

Both prototypes are currently working under different physical and electrical conditions: resonance frequency, distance between coils, battery voltage and rated charge current, as shown in Table 1.

Table 1: Differences between 3.7 kW and 25 kW prototypes

Parameter	3.7 kW prototype	25 kW prototype
Resonance frequency	140 kHz	25.8 kHz
Rated distance	0.15 m	0.2 m
Vbat (battery voltage)	220-250 V	300-355-400 V
Distance range	0.1 -0.17 m	0.15-0.22 m
Ibat (battery charging current)	10 A	70 A

3.2.2 New Circuit Topology

The new configuration using the primary side from CIRCE prototype and the secondary side from FKA prototype is shown in Figure 4.

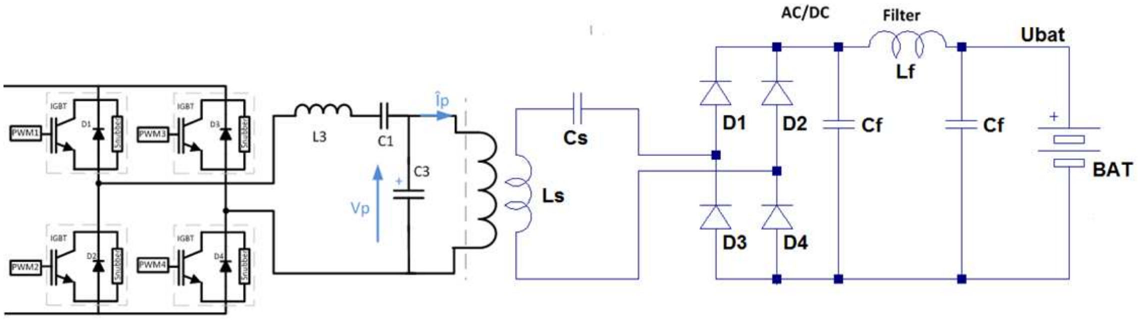


Figure 4: New topology created by the combination of the 3.7 and 25 kW prototypes

Taking into account that the working frequencies in both prototypes are very different, it is necessary to select a new frequency for interoperability.

First, it is impossible for CIRCE inverter to work at 140 kHz, since it is composed of IGBTs and this frequency is too high for them.

Second, if the selected frequency is the one used in CIRCE prototype, the secondary capacitor in FKA prototype is not tuned at this frequency, so it would be impossible to capture any power.

Finally, the only way to use the secondary from FKA with the primary from CIRCE is to find a new frequency that can be handled by the IGBT inverter, and change the secondary capacitor in order to achieve resonance at this frequency.

The distance between coils is set to the same value as that of the 3.7 kW prototype, that is 0.15 m, as this is a distance that is common to both prototypes (Table 1).

Using the frequency set in CIRCE prototype and with the dimensions and number of turns already selected in the previous prototypes, the parameters that need to be found are the resonance capacitor in the secondary side “CS” at this frequency, and the suitable primary voltage able to charge a 250 V battery voltage with a current of 10 A.

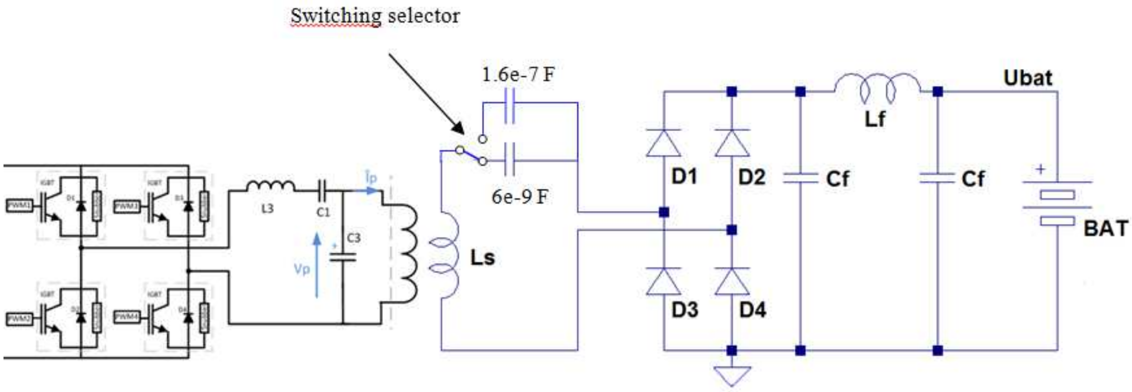


Figure 5: New capacitor CS, able to tune the secondary to the new resonance frequency

With a capacitor of CS = 1.6 e-7 F and a primary voltage of 140 V, the system is able to charge the battery (Figure 5) correctly. Table 2 lists the main electrical values for the new interoperable system.

Table 2: Electrical Parameters of interoperable system

Parameter	Description	Value
Vbus	Power supply voltage	140 V
Frequency	Operating frequency	25800 Hz
I1	Primary current	25 A
I2	Secondary current	11.2 A
Ibat	Battery charging current	10 A
Vbat	Battery voltage	250 V

The behaviour of the new system has been studied in different situations when the rated parameters change, e.g. variations in battery voltage, distance between coils due to the weight, position between coils not centred or variations in the frequency in order to be able to work at resonance.

3.2.3 Simulations

Several mathematical models using the commercial software Simulink® have been carried out to analyse the possibility of interoperability between prototypes and to study the behaviour in different working conditions.

3.2.3.1 Battery voltage variations

This study is necessary to test the ability to charge in different levels of voltage depending on the SOC of the battery at the moment that the charge process starts. The system is designed to work at resonance in a specific situation of battery voltage, but if this voltage is higher or lower, the primary current will not work in resonance, so a suitable control will be necessary to correct these deviations.

The next table shows the main electrical parameters with three different battery voltages, with the suitable frequency to work in resonance.

Table 3: Electrical Parameters at three battery voltages

Parameter	Min value	Nominal	Max value
Vbat [V]	**200**	**250**	**300**
Vbus [V]	140	140	140
I1 [A]	18	25	28
Ibat [A]	10.3	10.2	9.5
Freq [Hz]	25850	25800	25700
Pabsorbed [W]	2240	3075	3450
Pbattery [W]	2010	2570	2870
Efficiency [%]	88	84	83

It can be seen that with a slight change in the resonance frequency, the system is able to work at resonance with almost the same charging current (Figure 6).

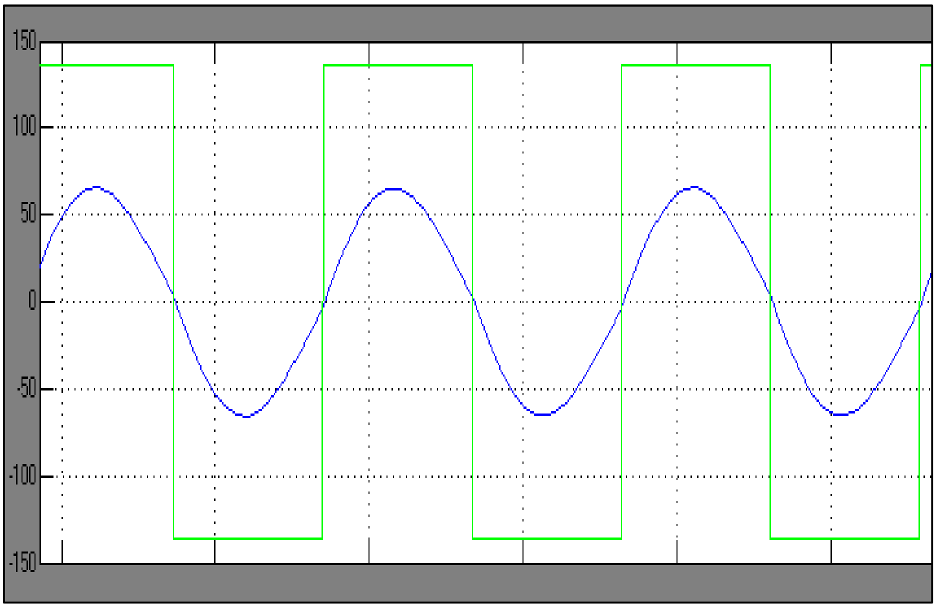


Figure 6: Primary current (blue) and voltage (green) working at resonance

3.2.3.2 Distance variations

Figure 7 shows the behaviour of the main electric parameters of the system when the distance between coils varies from 10 to 17 cm, considering the coils centred and a battery voltage of 250 V.

It can be seen that the system is stable when the coils get closer, as the parameters are lower than their rated values, and it will be possible to return to them with a suitable frequency control. However, the system is unstable if the coils are moving apart. In this case, an increase in the working frequency returns the system to proper operation.

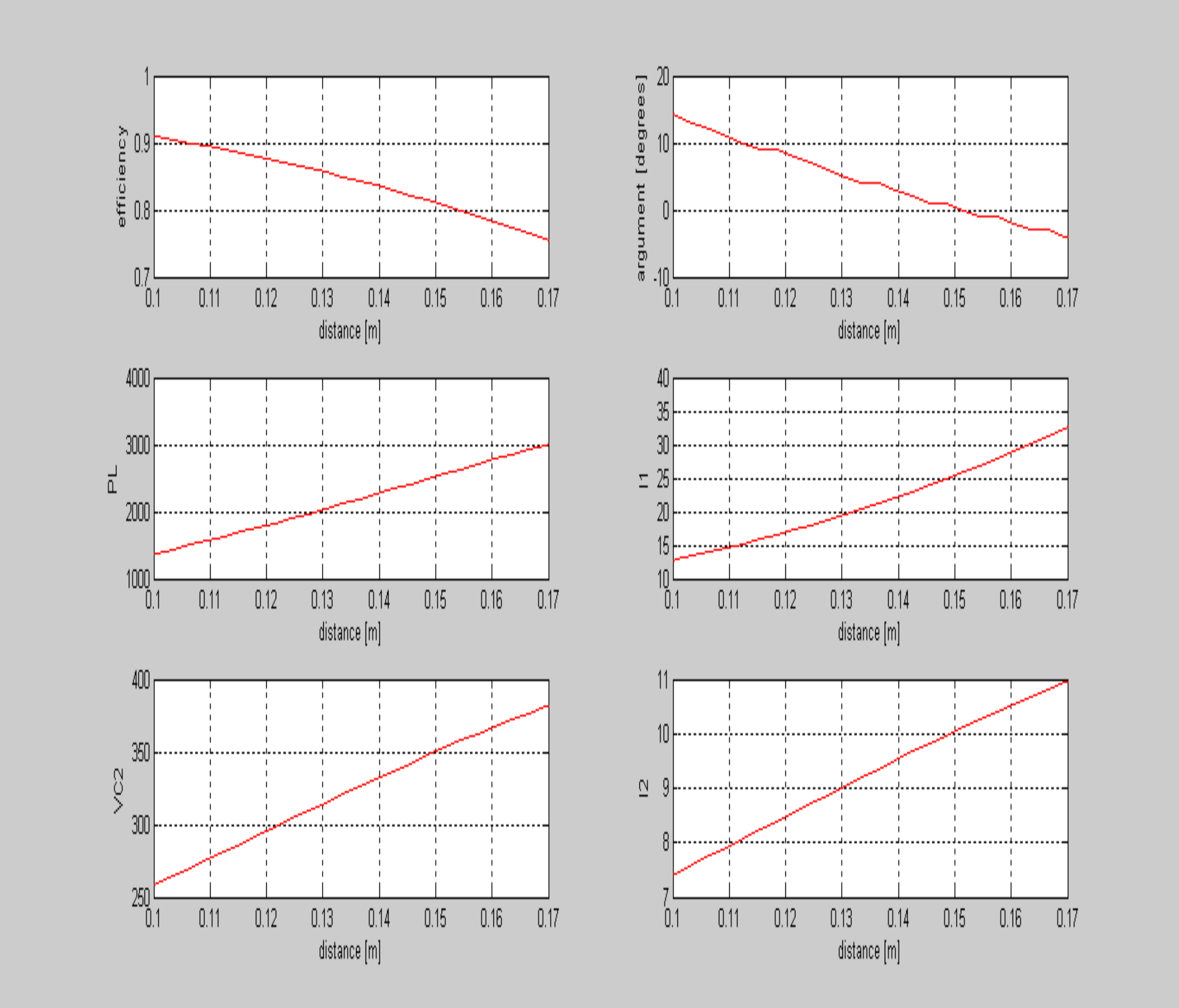


Figure 7: Main electrical parameters vs distance

3.2.3.3 Misalignment

Another important aspect to consider related to the interoperability is the behaviour of the main electric parameters when the coils are not perfectly aligned, as shown in Figure 8.

The results shown in Figure 9, correspond to the case of ± 0.3 m misalignment in lateral direction and ±0.3 m in longitudinal direction with Vbat = 250 V and rated distance of h = 0.15 m.

In fact, 0.3 m misalignment is too much and it is not a normal situation. The system should be able to charge with a maximum misalignment of around 0.1 - 0.15 m

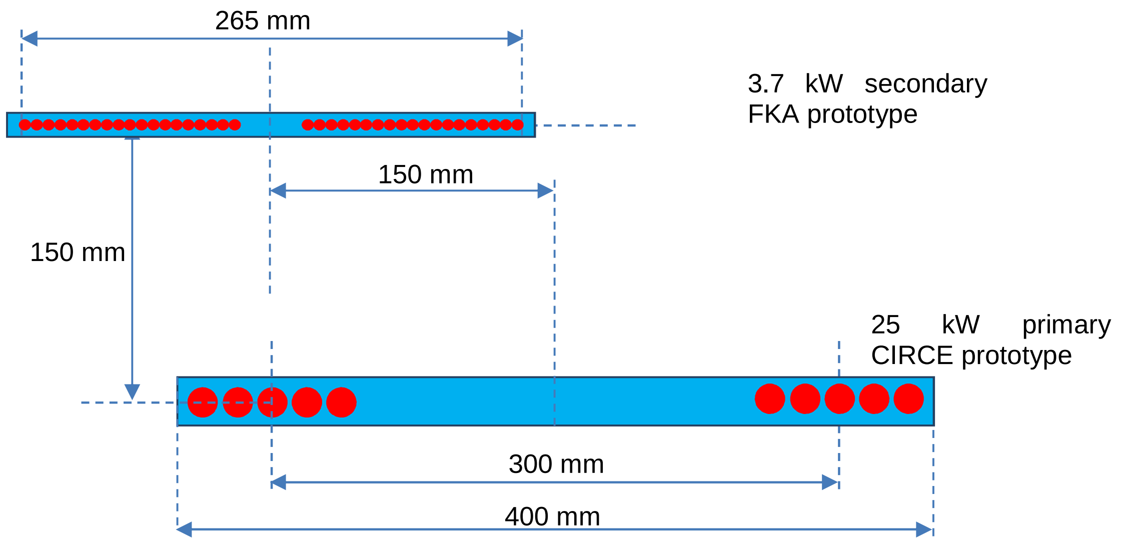


Figure 8: 0.15 m misalignment between coils

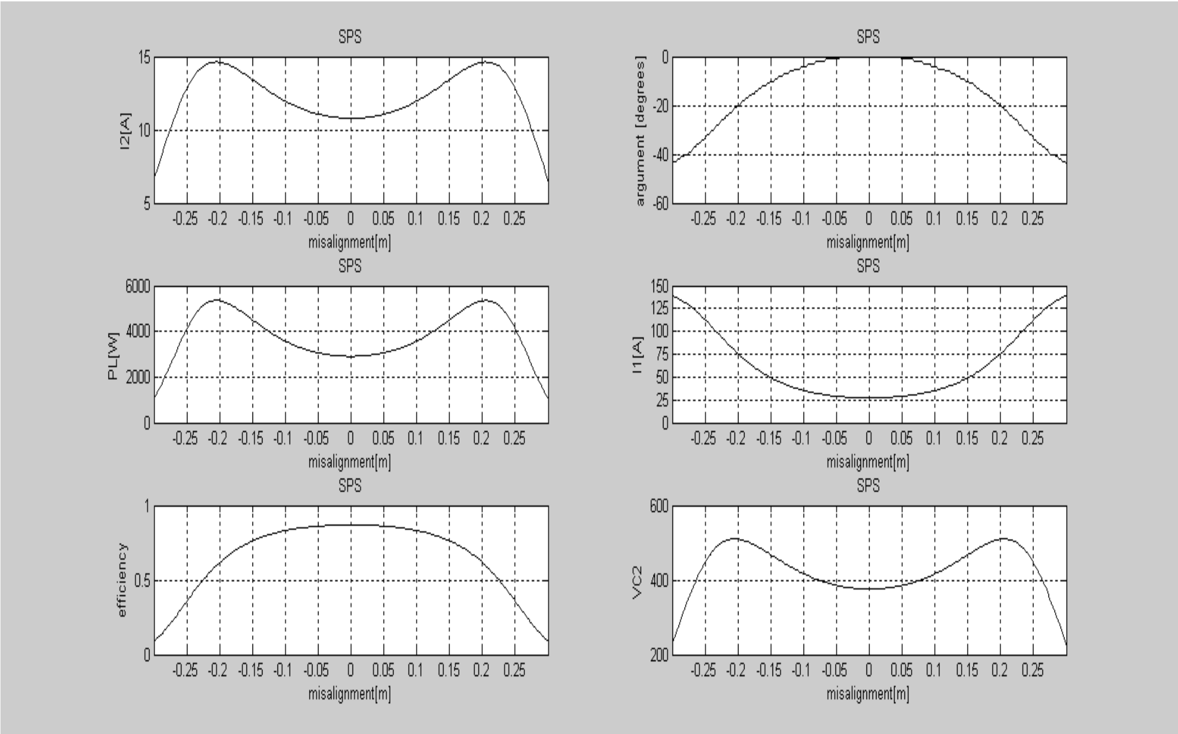


Figure 9: Main electrical parameters vs misalignment

The system presents a poor behaviour when the coils are not perfectly aligned, since all the electric parameters increase dangerously above their rated values. E.g. the primary current “I1” could be twice the rated one with a misalignment of 0.15 m (Figure 9).

Thus, a suitable control mechanism must be developed in order to keep the system safe when the car is positioned in such a way that the coils are misaligned.

3.2.3.4 Frequency variations

Regarding the controllability of the system, it is necessary to know how variations in the frequency affect the electric parameters.

Figure 10 shows that the behaviour of the system with ± 5 % variations around the rated frequency is very stable, and predictable. If the frequency increases, current lags the voltage, and in the case that the frequency decreases, current leads with respect to the voltage. In both cases, the primary current and the rest of electrical parameters are below their rated values.

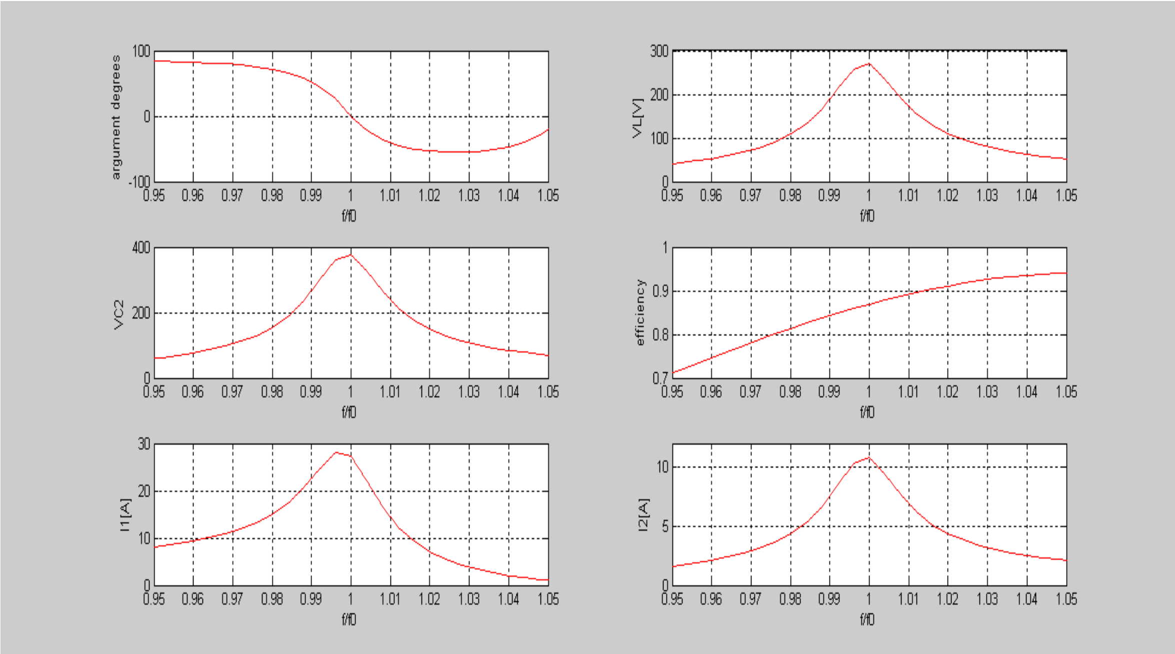


Figure 10: Electric parameters vs frequency

3.2.3.5 *Controllability*

To maintain the primary current in resonance when the coil position is out of alignment, a control is needed, not only of the frequency but also of the primary voltage. In Figure 11 this control process is shown, when the secondary coil is e.g. 0.1 m misalignment, to keep the system in resonance and with the primary current in its rated value, it is necessary to decrease the frequency down to 25750 Hz and the voltage to 80 V. In this case, the power transferred to the battery is lower than the rated one.

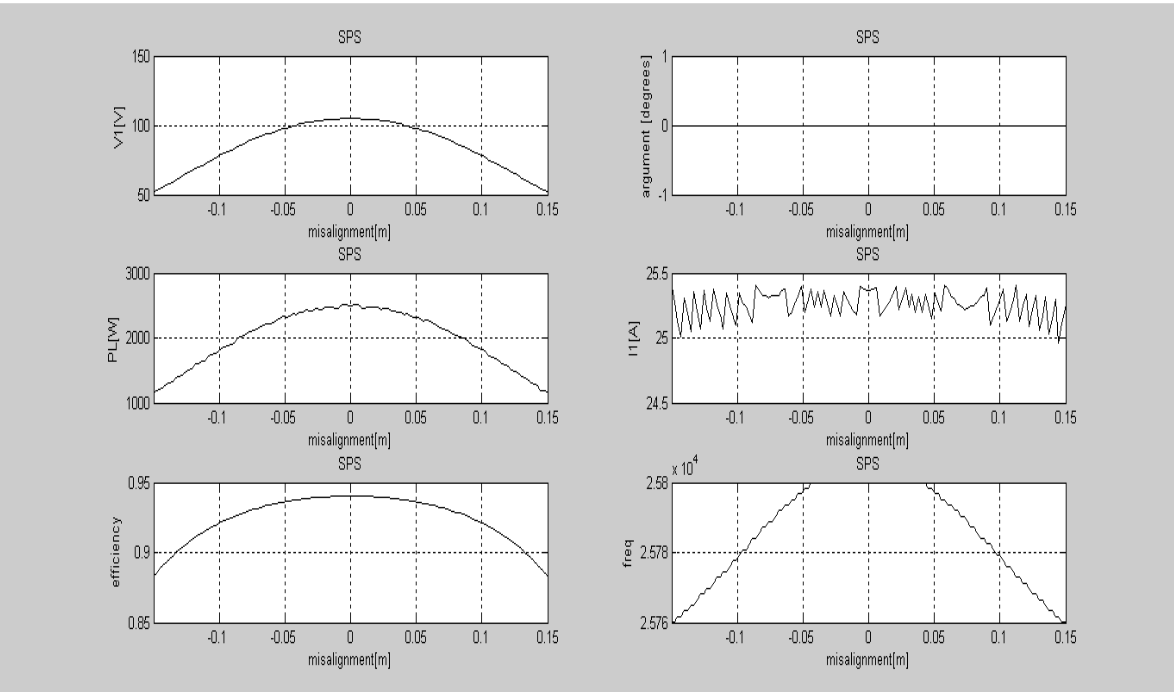


Figure 11: Suitable control to keep the system in resonance

3.2.4 Conclusions to simulation study

This study demonstrates that it is theoretically possible to charge a 250 V battery voltage electric vehicle with a 3.7 kW secondary coil mounted at the bottom of the vehicle and separated from the road around 0.15 m, with a different primary coil than the one it was originally designed.

The results show that interoperability between inductive chargers always will be possible, if the secondary side is tuned to the primary frequency with a suitable capacitor.

In this case, if the car has two different capacitor sets, it could charge in primary stations, in slow charge and fast charge. The communication between the charger and the vehicle would establish the suitable capacitor. A further enhancement would be to use a variable capacitor in the vehicle in order to be able to charge in any inductive charging station.

3.3 Power Transfer issues, experimental results

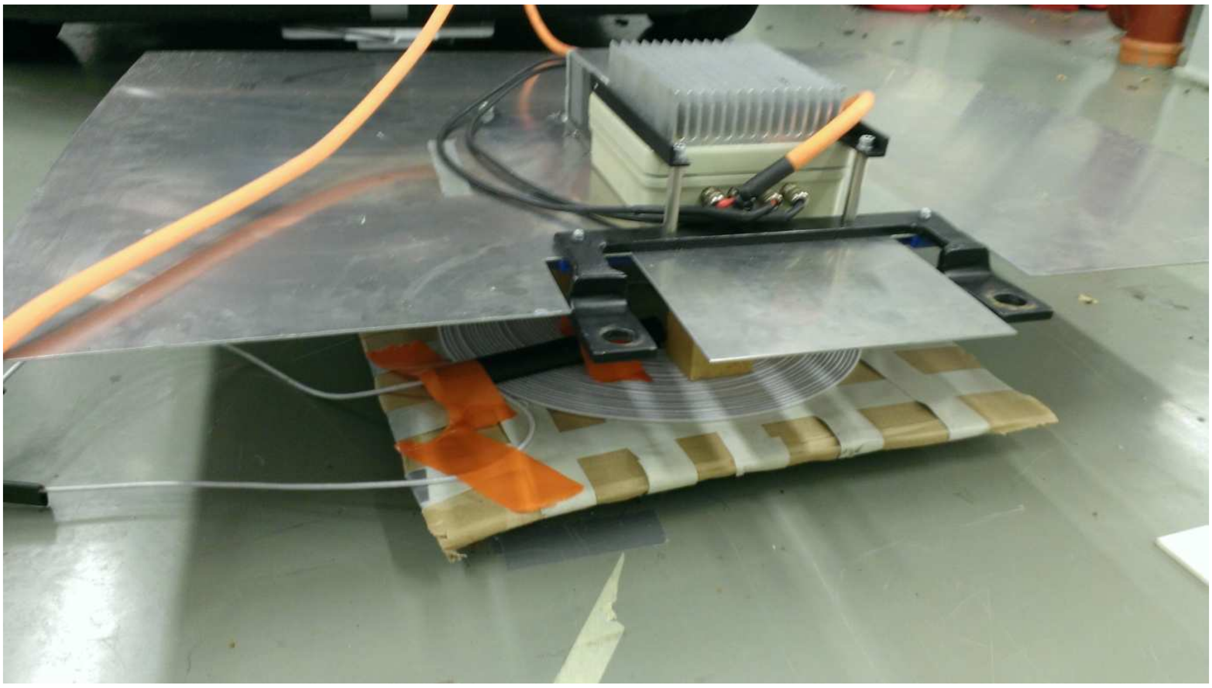
Normal inductive charging systems have their specific frequency range for power transfer. The unplugged project developed two different inductive charging system one 25 kHz with 50 kW power and a 3,5 kW system at 145kHz. One vehicle is equipped with the 25 kHz system and the other one with the 145 kHz pick-up. The following analyses are made to establish if there exists a possibility to charge the vehicle at both inductive charging stations. For these experiments, a lower frequency of 21 kHz was user rather than 25 kHz. This was done for convenience. The results remain valid as the object is to show two systems designed for different operating frequencies interoperating. 4 scenarios are tested.

3.3.1 Normal 145 kHz charging system

To have a reference the normal 3,5 kW system is used. During charging the following measurement indicators are relevant. The maximum current into the vehicle is rated up to 9 A and the normal battery voltage is 250 V. The voltage and current into the inverter are taken as input information. In this normal case the input voltage is 350 V and corresponding current is 9,1 A at a coil gap of 8 cm.

3.3.2 21 kHz primary system moved up to 145 kHz

For this test the 21 kHz primary coil is connected to the 145 kHz inverter and the capacitor of the 21 kHz is modified to get resonance at 146 kHz. The pick-up in the car has no modifications. The following figure shows the 145 kHz pick-up with the quickly build primary coil.



With this scenario it was not possible to reach the full 9 A output current due to the fact that the maximum inverter voltage was reached by 450 V. The input values are 5,4 A at 450 V and the output values 8,5 A at 250 V with an air gap of 12 cm.

3.3.3 21 kHz primary system with 145 kHz Pickup

This scenario handles the typical use case that the 145 kHz vehicle parks on a 20 kHz charging station. That means no adaptations are made. In this test no power transfer was possible. This is shown in the following diagram. The orange trace shows the primary current drawn by the system while the red trace shows the no secondary current is drawn, hence no power is transferred.

Figure 12: Power transfer graph - 20 kHz primary, 145 kHz secondary

3.3.4 21 kHz primary system with modified 145 kHz Pickup

For the last test the pick-up capacitor is replaced to reach the resonant frequency of 21 kHz. This is realized by direct wiring but can also be done by relay switch or similar. See the replaced capacitors in figure below.

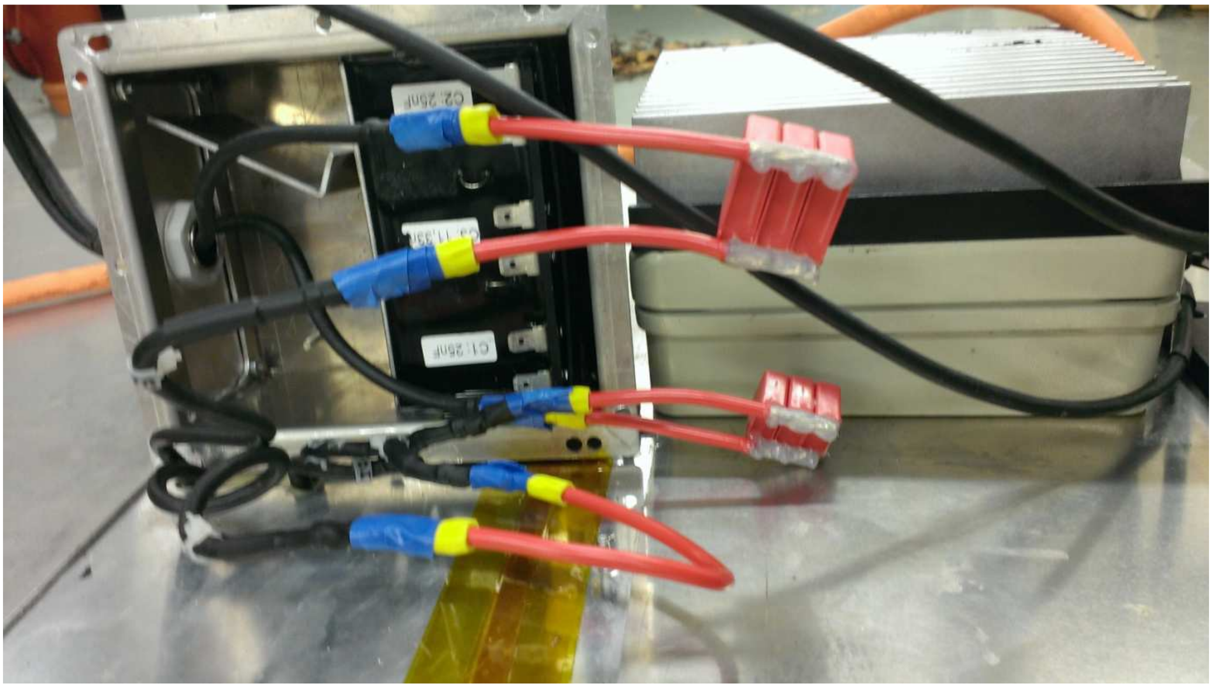


Figure 13: Compensation capacitors

The cables are made quite short to get no influences. The result of this test is that the system works fine with a bit lower efficiency as shown below. The input values are 26,2 A primary current (pink trace) at a primary voltage of 118 V (purple trace) and the output values are 9 A (red trace) at 250 V with an air gap of 10 cm between the coils. This shows that power has been successfully transferred by switching the secondary compensation capacitors.

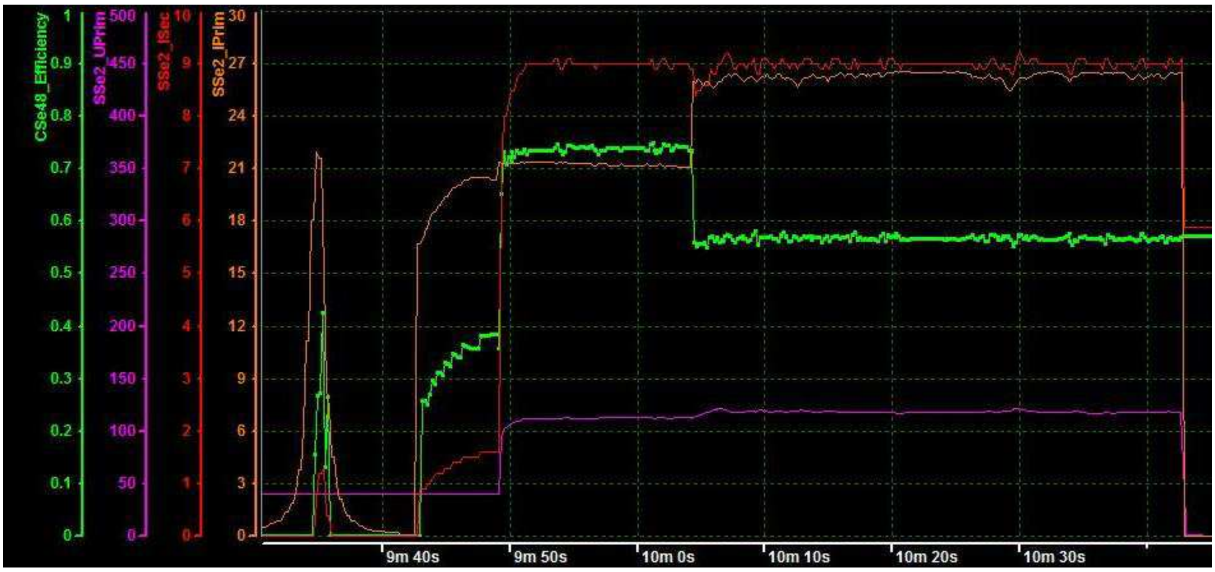


Figure 14: Power transfer graph - 20 kHz primary, modified 145 kHz secondary

3.3.5 Conclusions to experimental study

This test shows that both systems are working together after certain change. That means to make the inductive charging stations compatible the resonant circuit has to be adapted to the relevant frequency. It does not matter if this is made on car side or on station side. But it is easier to make this change at the pick-up side than on primary, because in this case the inverter can work at his normal frequency. In the other case the 21 kHz inverter has to handle the 145 kHz and it cannot be certain that it will be designed for this frequency. The efficiency in these scenarios depends on coil design, and reactive power due to different coil currents and capacitors, air gap etc.

Table 4: Summary of power transfer performance

Air gap	Upri	Ipri	Usec	Isec	Ppri	Psec	Eff	
8 cm	350	9,1	250	9	3185	2250	70,64%	Hella @ 145 kHz
12 cm	450	5,4	250	8,5	2430	2125	87,45%	Hella Pickup/fka coil @ 145 kHz
10 cm	108	15,8	150	9	1703	1350	79,26%	Modif. Hella Pickup/fka coil @ 22 khz
10 cm	114	18	180	9	2052	1620	78,95%	Modif. Hella Pickup/fka coil @ 22 khz
10 cm	117	22,8	220	9	2668	1980	74,22%	Modif. Hella Pickup/fka coil @ 22 khz
10 cm	118	26,2	250	9	3092	2250	72,78%	Modif. Hella Pickup/fka coil @ 22 khz

3.4 Communications

In all situations where a WPT service is being provided, a communication needs to take place between the vehicle's charging system and the infrastructure. This communication is required for two reasons:

1. Identification of the user for billing purposes. While some current installations do not bill for charging, or use a pre-pay system which does not require the setting up of an account, in future installation it is expected that users will have accounts for billing purposes and hence the user will need to be reliably identified prior to commencement of power transfer.
2. Technical support before and during the power transfer process. This will assist in ensuring the alignment between the primary and secondary systems is within limits, that the primary and secondary systems are compatible, negotiation of power transfer levels and monitoring of the power transfer process.

While it is possible that the identification for billing purposes could be done without a communications link between the vehicle and the infrastructure, for example identifying the vehicle using automatic number plate recognition (ANPR), this is considered sub-optimal. Likewise it is possible to envisage a WPT system which works without a link providing technical support to the power transfer process, most trial systems do envisage a communications capability.

In addition to the communications between the vehicle and the infrastructure, a link needs to exist between the infrastructure and the billing back office. The definition of this link is considered out of scope for this study.

For systems integrated into vehicles, an internal communications mechanism needs to be implemented within the vehicle for transferring information from the power transfer system to the vehicle systems and the HMI. This communications system is considered the domain of the vehicle manufacturer, and its definition is outside the scope of this project.

For communications to take place between the vehicle and the infrastructure, the signals and protocols used for the communications need to be agreed and standardised.

As the whole charging procedure in UNPLUGGED is fully dependent on the wireless data exchange, all EVs and EVSEs communications need to be compatible to each other – independent from their charging power (in this case 3.7 and 50 kW). Otherwise charging would not work at all. Therefore a common data exchange mechanism was created for both passenger and commercial vehicle, using the same communication controllers and the same data flow.

The requirement was to use an already standardised wireless link, which is able (e.g. in terms of speed and data length) to support this. After an investigation of several wireless data busses (among others Bluetooth), it was decided to specify a Wi-Fi/Ethernet system making use of ISO 15118 (which specifies the communication between Electric Vehicles (EV), including Battery Electric Vehicles and Plug-In Hybrid Electric Vehicles, and the Electric Vehicle Supply Equipment (EVSE)) protocols. ISO15118 was originally designed for conductive charging only, but in principle the requirements for conductive and wireless power transfer are similar. This configuration is also under discussion in wireless charging transmission international standardisation groups.

(Special) wireless charging data like current electrical battery values, maximum values, current power on primary and secondary side, some mutual diagnostic statuses and other data like start of charging information were collected and put into new ISO 15118 data protocols. These are fed by CAN messages. Both EV/truck and charging stations were programmed to accept the same incoming data via the communication controllers, so they are fully interoperable in terms of data communication.

During implementation, several rounds of debugging and updating were required to achieve the interoperability desired. The amount of effort required to achieve this is indicative of the importance of clear and well formulated specifications.

The inherent non-deterministic nature of wireless communications means that additional error handling is required to ensure reliable communications can be achieved between the EV and the EVSE.

The experience of this project has shown that communications interoperability is possible, but will require robust standards which take into account the strengths and weaknesses inherent in wireless communications.

For future compatibility, these standards should also seek to support dynamic wireless power transfer system, as being investigated in the FABRIC project. These systems have far more stringent timing requirements.

3.5 Grid connections

Interoperability is one of the main factors to reach for the DSO and to avoid a reinforcement of the grid: instead of installing one inductive station for system at 50 kW and another for system at 3,7 kW (or 20 kW for example) it is possible to install just one station. Moreover interoperability is needed to guarantee a service for the customers.

Suppliers wishing to sell into multiple countries have to comply with local regulations regarding the connections to the national supply grid. Three issues need to be considered:

- Regulations regarding the different supply levels in different countries, mainly voltage and current limits
- Connection and safety requirements
- Effect on the grid of the EVSE.

The first issue is not significant in the EC as it is relatively easy to comply with most jurisdictions because of the very similar standards for voltage and current levels, particularly the low voltage grid. The typical specifications of a low voltage grid are given below, in this case for Italy, as an example:

- Voltage= 230/400 V (single/3-phase)
- Frequency= 50 Hz
- Active user[1]: up to 6 kW in single phase
- Passive user: up to 10 kW in single phase
- Power up to 100 kW (3-phase)

The voltage and frequency are standard across the EU, although the power limits may vary.

The maximum power that can be drawn may vary somewhat between countries, although the voltage and frequency limits are the same throughout the EC. As the systems being considered in UNPLUGGED all operate from the LV grid. There should not be a significant interoperability issue.

Connection requirements are more significant. In Appendix 1, the grid connection requirements for Spain are given as an example of the types of regulations all suppliers will need to comply with. Each jurisdiction will have its own requirements and regulations which must be complied with.

The safety requirements for connection to the grid are set in individual jurisdictions, but again these are well understood by suppliers and should not cause interoperability issues.

The overall load on the grid from EVSE is driven by the overall number of vehicle connected, and the amount of power be transferred by each charger. The University of Firenze has done some simulation studies to quantify the effect on the grid of different types of loads in city centres. These results are shown in Appendix 4. Whether or not these additional loads present a problem for the DSOs really depends on the installed capacity and is not an interoperability issues as such.

[1] An Active User is one who supplies power into the grid, e.g. photovoltaic generator, whereas a passive user only draws power

4 Assess interoperability of charging "bay" designs with different vehicles and locations for installations

4.1 Methodology

Two studies were undertaken by members of the project team:

- ENIDE investigated the integration of inductive charging systems with road infrastructure and with vehicles in Barcelona. The full report from this study is presented in Appendix 2.
- TfL undertook a study of needs and boundary conditions for the implementation of inductive charging infrastructure for EVs within London. The full report from this study is presented in Appendix 3.

Both studies took a wide ranging look at the needs and requirements of electric vehicle in the respective locations, and investigated how charging infrastructure could be incorporated into the road infrastructure in the two cities. Further, both studies concentrated no two specific user groups – taxis and light delivery vehicles, as these have been identified as the most likely initial users of dynamic charging in cities.

4.2 Results

UNPLUGGED vision, and particularly the implantation of inductive spots in urban areas, will produce relevant benefits for businesses and society.

Public taxis and delivery vans drivers will benefit from the installation of inductive spots in terms of usability in their daily workday routines while giving a considerable saving in energy cost.

Taxi businesses depend on maximising driving time. According to their needs, it can be concluded that taxis need higher power (e.g. 7.3 kWh) inductive charge stations. On the other hand, van delivery businesses spent significant time stationary while drivers make deliveries, so in this case lower power charging stations (3.7kWh) are enough to cover delivery vans daily business needs.

The traditional taxi rank where vehicles move forward slowly till they reach the front of the queue are somewhat less suitable for wireless power transfer due to the uncertainty in the stopping position of the vehicle in the rank. It is possible however that this could be addressed by a change in design and driver behaviour while on the rank. The feeder park concept found at Heathrow and London City Airports (where taxis wait in stationary queues until called forward to the taxi rank), and the collaboration between the Westfield Group shopping centres and Source London are the most pertinent examples of these.

Addressing the potentially large user base of London taxi drivers (and this is likely true of taxi drivers everywhere), on an economic level, taxi drivers are very aware of fuel costs per mile/km, far more so than normal consumers. If a clear reduction in cost for electric charging can be demonstrated, enforcement of a new set of behaviours would be a non-issue.

However, over 60% of taxi drivers polled for a recent TfL survey on the feasibility of EV taxis indicated that they cannot afford to lose out on productivity due to charging time, and many travel long distances from outside/Outer London to work within central London, calling for infrastructure investment at their home locations. Over 80% expressed the opinion that there was insufficient range between charges for electric vehicles and had concerns about running out of charge. However, it was found that they cover an average of 71 mile (114 km) per day and 98 miles (157 km) including commuting. This would indicate that a modern electric vehicle is feasible for a day's working, particularly if there is an opportunity to "top up" charge during the day.

The global distribution of the inductive charging stations in the whole municipality should consider coverage of commercial areas, tourism zones, connectivity with other transport modes, services for citizens (hospitals, schools, etc.) and neighbourhood streets distribution.

The installation of inductive charge system in loading/unloading bays makes sense for short time stops (up to 30 minutes stop time). For longer time stops the plug-in charge system fully covers the driver's needs.

Citizens' perception is a key factor for the inductive charging system installation success. The information should emphasize the benefits of the inductive system, should not be intrusive and should indicate the safeness of the installation.

New signalization should ease the guidance to the charge stations and should ease the EV positioning in the taxi rank as the car positioning is a key challenge. Additionally the signalization should regularize the usage of the inductive spots and define fine rules.

Consideration has also been given to specific boundary conditions and limitations that need to be addressed within the London region, demonstrating the multi-stakeholder nature of infrastructural development within the urban realm, and the benefits that can be gained from working with private sector organisations and assets.

This last point has been particularly well illustrated in a January 2015 press release from UK-based charge point supplier Chargemaster.

> Chargemaster, based in Luton, UK, designs, develops, manufactures and operates charging points for electric vehicles. It has produced over 27,000 charging points for use in public, workplace and domestic locations and operates POLAR, the UK's largest network of public charging points. The company has already installed more than 10,000 'wireless ready' public and workplace charging points in the UK and Europe, which can be easily adapted to include Qualcomm Halo's Wireless Electric Vehicle Charging (WEVC) system.
>
> David Martell, CEO of Chargemaster said, "We have been working with Qualcomm for several years now and this investment is a natural progression. We are very excited about helping to bring the next major evolution in electric motoring to the market, making the electric driving experience even more enjoyable and practical for daily use".
>
> With the benefit of progressive strategising and fruitful collaboration between the public and private sectors, Chargemaster's extensive WPT-ready infrastructure clearly has the reach and potential to elevate this nascent technology into the mainstream.

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5 Standards

5.1 Relevant Standardisation Bodies

There are an extensive number of standards focused on electric vehicles (EVs), their relationships to the infrastructure and to their users. These standards and regulations are developed at different levels (such as International, European and National) in a number of different organizations. At the international level, the standardization is mainly dealt with by two institutions: the International Electrotechnical Commission (IEC) and International Organization for Standardization (ISO). IEC, founded in 1906, deals with all electrical technologies, while ISO, founded in 1948, deals with all other technologies. In the IEC committees, many of the delegated experts are electricians or component manufacturers, while in ISO committees there is a much stronger input from vehicle manufacturers.

In addition, the International Telecommunication Union (ITU) is a specialized agency for communications and information technology which develops the technical standards to ensure networks and technologies meet consistent standards. The main objective is to enable growth, to sustain the development of telecommunications and information networks and to facilitate universal access so that people everywhere can participate in, and benefit from, the emerging information society and global economy.

Within Europe, CENELEC and CEN operate as the European counterparts of IEC and ISO. Both have been active in electric vehicle standardization in the 1990s, through their technical committees CENELEC TC69X and CEN TC301. However, much of this work was parallel to the global standardization work, with the European standards created superseded by international standards when these became available (such as EN50275 vs. IEC61851, and EN1987 vs. ISO6469). The CEN and CENELEC electric vehicle committees have been reactivated in 2010, aiming principally at expediting the European adoption of international standards rather than drafting own standards.

5.2 Addressed concerns of inductive EV charging

For long term interoperability of all electric vehicles with all charging stations, a wireless inductive charging standard is required. But if the market has not yet developed, it is not known which requirements are important, and what the best route to eventual interoperability is. So the standards are developed along the way, with the first wireless electric vehicle charging systems leading the way.

The major concerns for EV inductive charging systems regarding their interoperability can be listed;

- Safety and Security
    - Electrical safety, supply-side
    - Electrical safety, vehicle-side
- Magnetic fields
- Electromagnetic compatibility (EMC)
- Communications
- Reliability
- Performance & efficiency

Within this task of the UNPLUGGED project these topics are partially considered and the content of the standards development and standards, as described in the next section are respected

5.3 International standardisation work done by ISO/IEC and their current status

Currently, the following Standard is under development by IEC-TC69:

IEC 61890-1/Ed.1: Electric vehicle wireless power transfer systems (WPT) Part 1: General requirements (corresponding to IEC 61851 for conductive charging). This standard is of interest for the ISO TC22 SC21. It was started a year ago with the objective to fulfil requirements related to inductive charge, while the development has brought to cover all the wireless charge technologies.

Two other ongoing standards are in the state of Committee Draft (CD):

- IEC 61980-2: Electric vehicle wireless power transfer (WPT) systems - Part 2 specific requirements for communication between electric road vehicle (EV) and infrastructure with respect to wireless power transfer (WPT) systems
- IEC 61980-3: Electric vehicle wireless power transfer (WPT) systems - Part 3 specific requirements for magnetic field power transfer systems.

All parts of IEC 61980 will be developed in a Joint Working Group (JWG) between IEC-TC69 and ISO TC22/SC21. Pending publication of the international standard, they will be circulated as Technical Specification. Figure 15resents the main parts of the IEC-TC69-PT61980.

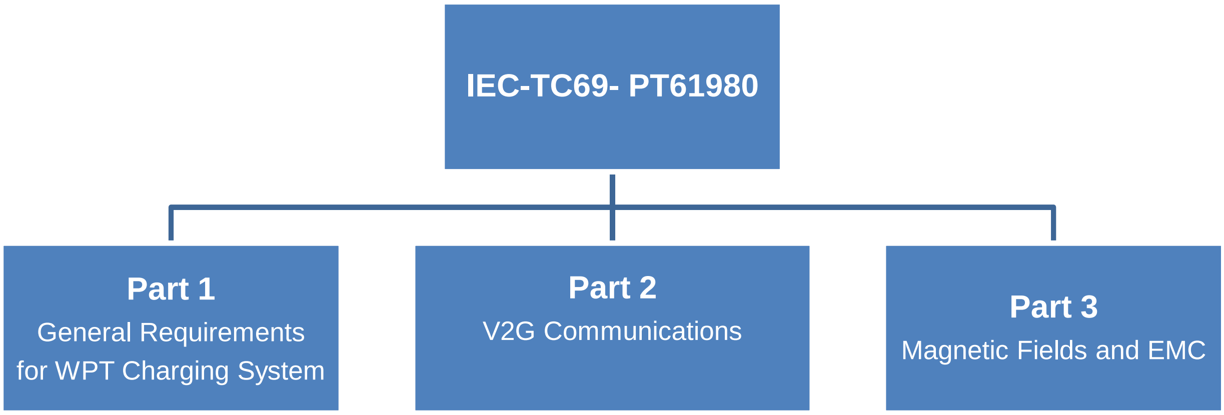


Figure 15: The main parts of the new IEC-TC69-PT61980 standard

According to IEC 60038 standard, the standard ac supply voltage is up to 1000V (ac), while the dc supply voltage is up to 1.5 kV (dc). These supply voltage standards are considered in IEC-TC69-PT61980/1. Furthermore, the rated frequency of the ac supply is 50 Hz ± 1% or 60 Hz ± 1% (IEC60038, Ed. 6.2, July 2002). However, the internal voltages in the WPT charging system (such as the resonance voltages) are currently not available in this standard.

There is a joint working group drafting a family of standards called ISO/IEC 15118 to describe the communication, in terms of data format and message content, between the electric vehicle (this term refers to battery electric vehicles as well as plug-in hybrid electric vehicles) and the electric vehicle supply equipment (charging post). This also includes the message content and data structure to enable billing communication and grid management. Provisions for additional communication aspects (like vehicle charge status information and configuration) can be considered to allow for interoperability of all vehicles with all charging stations. The main communication-parts of the generic equipment are the electric vehicle communication controller (EVCC) and the supply equipment communication controller (SECC). Therefore, this standard describes the communication between these components. All connections beyond the EVCC and how the messages can be exchanged are considered to be out of the scope as specific use cases. ISO/IEC 15118 standard is oriented on the charging of electric road vehicles (ISO/IEC15118, DIS, 2011), dealing specifically with the communication link between vehicle and charging post. The major concerns of ISO/IEC 15118 are illustrated in Figure 16

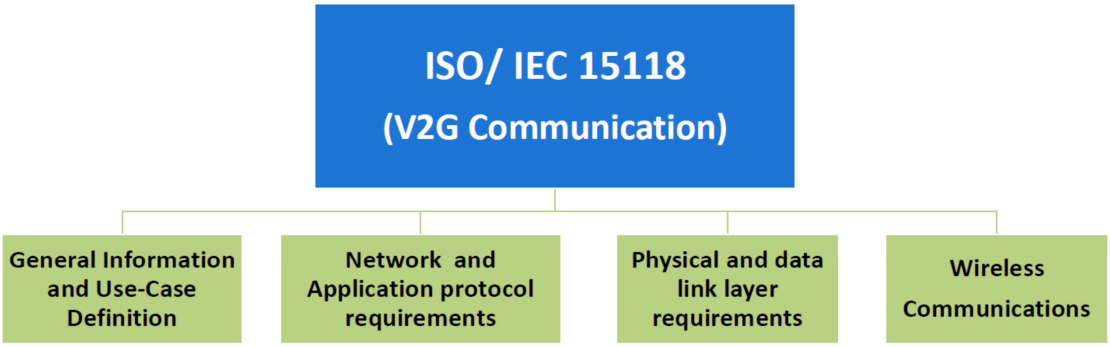


Figure 16: The main scope of ISO/IEC 15118

It should be pointed out that SC3 has the responsibility for the charging communication aspects. At the moment, V2G communication interface has been developed for conductive charging only. Currently, the ISO/IEC 15118 standards family is composed of the three items applicable for the conductive electric vehicle charging process:

- ISO/IEC DIS 15118-1: Road vehicles - Vehicle to grid communication interface - Part 1: General information and use-case definition. This standard can be used for WPT charging system.
- ISO/IEC DIS 15118-2: Road vehicles - Vehicle to grid communication interface - Part 2: Network and application protocol requirements
- ISO/DIS 15118-3: Road vehicles - Vehicle to grid Communication Interface - Part 3: Physical and data link layer requirements

These three standards are currently at the stage of Draft International Standard (DIS).

A further 6 parts of this standard are under development, these being:

- Part 4: Network and application protocol conformance test
- Part 5: Physical layer and data link layer conformance test
- Part 6: General information and use-case definition for wireless communication
- Part 7: Network and application protocol requirements for wireless communication
- Part 8: Physical layer and data link layer requirements for wireless communication

When developed, parts 6-8 will be of particular relevance to WPT systems.

6 Provision of driver information

It is important that users are confident in their ability to use any new system installed in a vehicle. As users do not generally receive formal training in the use of new systems in vehicle, or indeed in new signage introduced on the roads, it is imperative that the HMI is clear and easy to understand. This can be further enhanced by ensuring that all manufacturers use a consistent set of symbols and layouts in their HMI, and that standard signage is used in different countries.

6.1 The In-vehicle Human Machine Interface (HMI)

In order to evaluate the usability of the interface that will lead the interaction between the user and the charging system, a study has been carried out on the system architecture. First of all, an overview on usability has been provided in order to clarify the second part of the study, the HMI usability analysis. In the analysis, a first version of a charging system HMI was evaluated and improvements suggested.

6.1.1 An introduction to usability

In ISO 9241, usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [8]. This means that usability defines the user degree of ease and satisfaction when interacting with a tool.

Starting from its definition, usability is not an intrinsic feature of an instrument, but it is the result of the interaction process between the user, the tool, the environment, the manner and the purpose of use.

A usability tool evaluation is performed to make sure that the mental model of who designed the instrument (design model), from which the tool derives their real functions, corresponds as closely as possible to the mental model of who uses the tool (user model). The problem arises when design and the user model do not match.

The usability is not concerned with the tool “engine”, but only with its interface. What lies under the interface is considered a black box on which there is no intention to make any assessment. It may happen in some cases that an intervention to improve usability involves a consequent revaluation of the operating modes of the instrument, but that is not the purpose.

The ISO standard was first published in ‘90s and it refers to computer products in general. However, usability is an older concept, dating from the '60s as part of ergonomics in relation to human artefacts.

Nowadays usability found the major applications on software/web tools and in the field of cognitive ergonomics, but the concept is rapidly extending to many fields, particularly those potentially risky, such as electro medical equipment, power generation tools (nuclear energy) and transportation (aeronautics).

The standard evolution for usability is shown in Figure 17, with a focus on one of the previous fields: electro medical equipment.

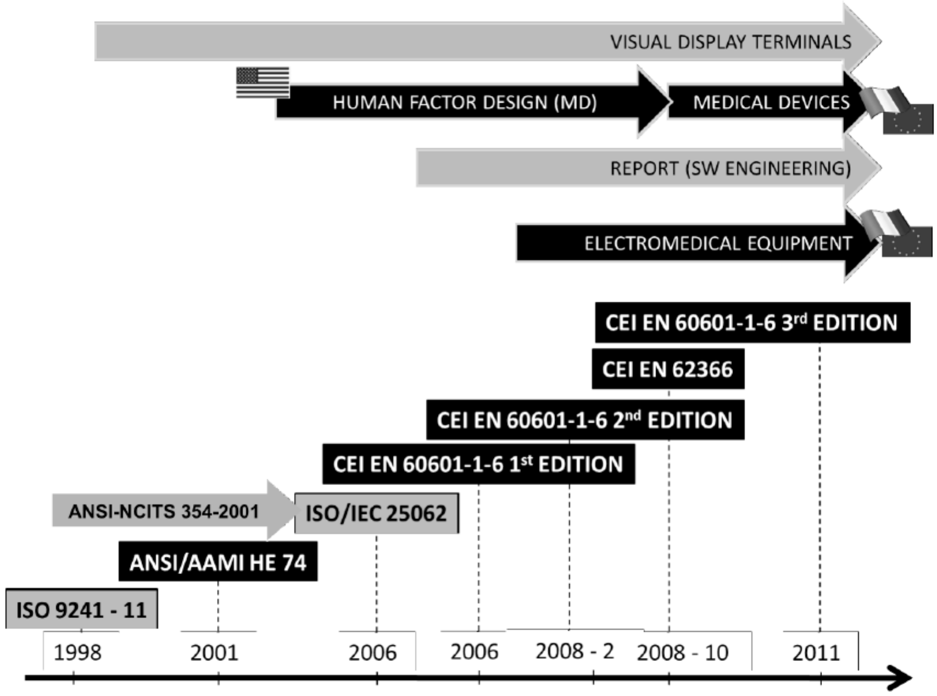


Figure 17 - Usability standard evolution

6.1.1.1 How to evaluate usability

A usability analysis can be carried out in various ways, such as users feedback analysis (using questionnaires, interviews and focus groups) or an experts evaluation (the so called heuristic analysis), but the best way to investigate usability is to perform an usability test: a laboratory simulation or a field test followed by a task analysis. At the end of the usability analysis, a usability report, which contains analysis results and proposals, is written.

Following the requirements of the ISO, the main metrics to measure usability are:

- **Effectiveness:** measures accuracy and completeness with which users achieve specified goals.
- **Efficiency:** measures resources expended in relation to accuracy and completeness with which users achieve goals; efficiency in context of usability is related to “productivity”.
- **Satisfaction:** measures freedom from discomfort and positive attitudes towards the use of the product.
- **Learnability:** measures how easy it is for users to accomplish goals the first time they encounter the tool.

The ISO 9241 usability framework is presented in Figure 18:

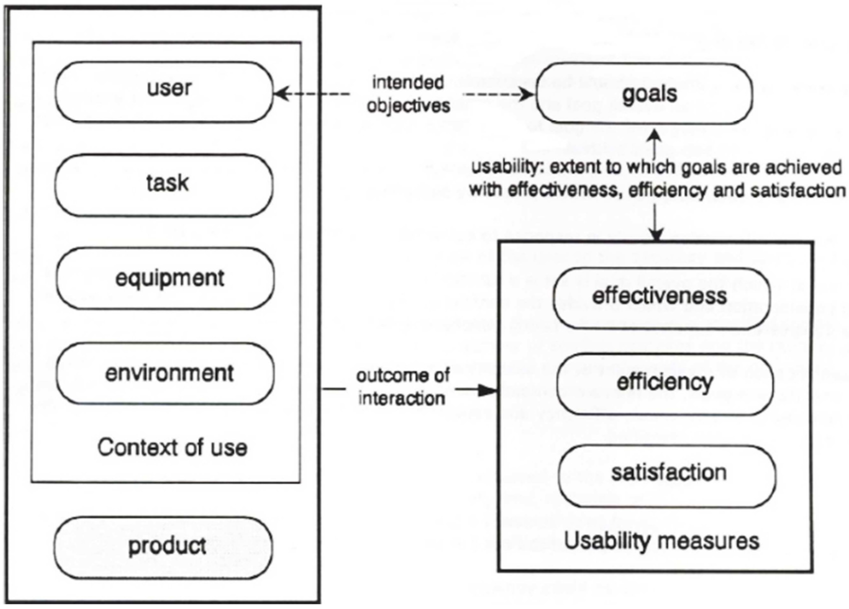


Figure 18 - ISO 9241 usability framework

Usability tests can be performed while developing a new tool (i.e. using mock-up, starting from the interfaces of similar instruments, also from competitors), for a new version of an existing tool (starting from the old interface) or to compare different interface versions for the same tool.

6.1.1.2 Design for Usability

A design that uses usability criteria is able to meet the following requirements:

- Speaking the language of the user;
- Facilitate recognition rather than the memory;
- Provide feedback in order to make visible the state of the system;
- Create a consistent and regular interface structure;
- Simplify tasks;
- Facilitate use flexibility;
- Help users to recognize and solve errors;
- Provide usable help and manuals.

A usable design of a tool can bring the following benefits for producers:

- Lower costs of product development;
- Increase the degree of customer acceptance;
- Increase in sales;
- Reduction in user support.

In addition, for users:

- Reduction of the number of errors;
- Reduction of training time;
- Reduction in use of manuals and/or assistance;
- Increase of safety.

6.1.2 HMI Usability analysis

Starting from the first version of the charging application, a heuristic evaluation of HMI has been performed. The University of Florence usability team did the analysis and proposed the new version.

Only the HMI was evaluated, since the procedures (the “engine” of the tool) have no significance for the usability approach.

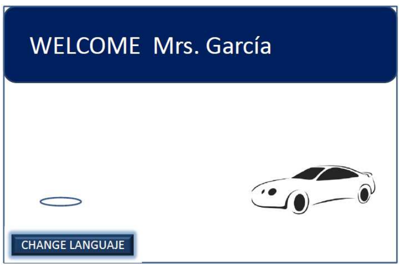
Basing on the HMI received file, the following assumptions were made:

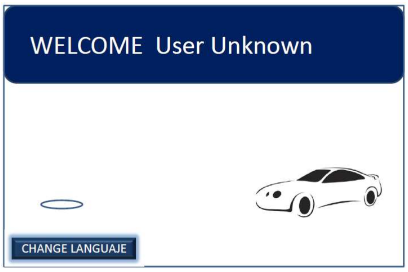
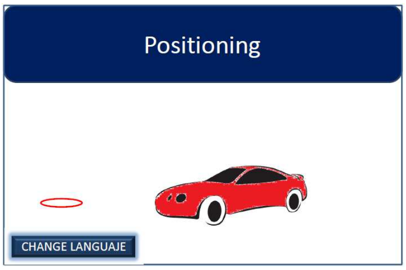
- HMI size (4:3) have been kept unmodified
- For each screen, information provided to users have not been modified

Considering the HMI mock-up received it has been judged consistent to divide the information provided to users in 3 areas:

- Title area, with the main feedback to user
- Main area, with content feedback to user
- Help & Action area, with press buttons and language change option

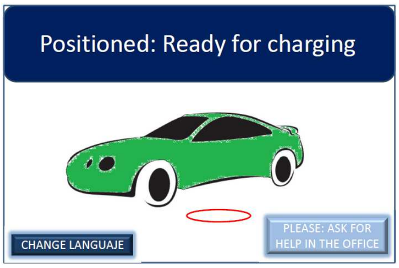
The results of the heuristic evaluation and the proposed HMI version are displayed in the following table. It has to be considered that the proposed HMI is a mock-up preliminary usable version: colours, fonts type, fonts dimension has to be considered as archetypes. To define a more advanced version, the real context of use has to be taken into consideration to verify if brightness, contrast, visual and audio feedback, etc.

Previous version	Comments & suggestions	New version
Screen 0 	Flags should be conventionally ordered (English is expected to be the first, etc.). Languages should be written (to avoid problems in case of colour blindness). Selectable options should be coloured in blue (conventional colour for link).	
Screen 1 	More emphasis on the recognized user (should be written in green and capital letters). 2D instead of 3D for a more clear iconic identification. Approaching displayed on screen should be from left to right, with an arrow (conventional). Language selection should be iconic.	

Scree 1.1 	The unknown user should be written in capital letters and in yellow.	
Screen 2 	Two different screens for both known (green) and unknown (yellow) driver. The arrow change colour from red to yellow. Car and target icons are closer, the arrow is smaller.	
Screen 3/3.1 	Two different screens for both known and unknown driver. Car icon is superimposed to target icon. The «Positioned & ready for charging» message should be written in green. Information on following action should be displayed in the main area.	

<table>
<tr>
<td>

Screen 3.2



</td>
<td>

Two different screens for both known and unknown driver.

Car icon is superimposed to target icon.

The «Positioned & ready for charging» message should be written in green.

Information on following action should be displayed in the main area.

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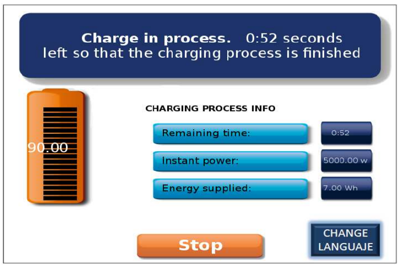
Screen 4



</td>
<td>

“Charge in progress” should be written in capital letters and in green.

“Remaining time” is the main information and should be larger.

Information on following action should be displayed in the main area.

The «stop charging process» button should be filled in red (abortion process convention).

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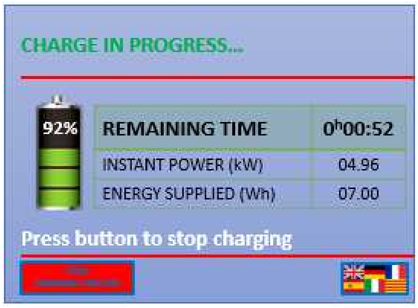

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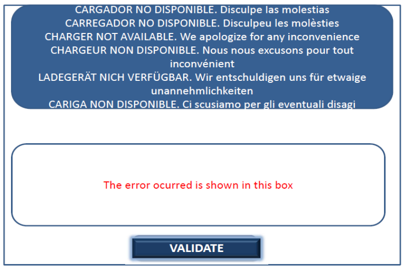
Screen 5



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The error message should be only written in the chosen language.

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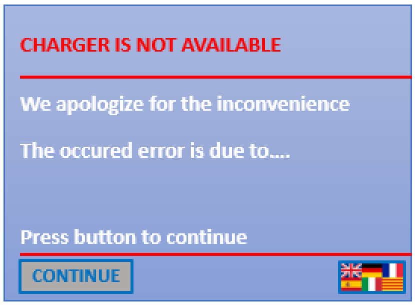

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Screen 6

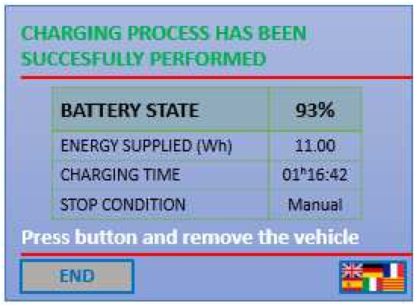
</td>
<td>

“Charging progress…” should be written in capital letters and in green.

“Battery state” is the main information and should be larger.

Information on following action should be displayed in the main area.

</td>
<td>



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</table>

6.2 Interoperability of HMI at the charging station

Beside a consistent and easy to use interface, even by different car manufacturers as mentioned above, an important challenge is to provide a HMI concept that has the ability to work even when different vehicles from different manufactures encounter different charging stations. The challenge is not only that the driver needs to understand the interface on a foreign charging station but that the HMI has to be able to adapt to different situations regarding identification and authentication, payment process and potentially the procedure to start the charging process.

In general it is the charging station that defines the boundary conditions for the process. Depending on the business model for the particular charging point different scenarios are possible:

6.2.1 Charging without any restrictions:

This, sometimes called “exhibition mode”, is the easiest mode. No identification, authentication or payment is needed. This is e.g. the case for charging stations at private spots at home or on company grounds or maybe a supermarket uses free charging for promotion issues (although any of these situations may require authentication for other reasons, for example contractual limitations). The HMI only needs to help the driver with vehicle positioning.

6.2.2 Charging starts from within the vehicle:

In this scenario the driver needs to identify himself within the vehicle. The identification can be carried out just once with the association with the customer kept in the charging station, or drivers can identify themselves each time upon presenting at charging station. The charging station allows the customer to charge after authentication. The HMI provides the driver all information of the process, from the identification to authentication.

An example of this scenario is where a user charges at the charging station of a company where the user is a customer.

6.2.3 Charging starts from the charging station:

This mode requires the driver to go to the terminal of the charging station and identify himself or make a payment. The terminal may be at the parking spot or, for example, inside the mall where the charging station is located. In this mode the HMI needs to tell the driver that he has to leave the car to start the charging process.

6.2.4 Charging is started from inside the car and the station (both mandatory):

The driver has to confirm or identify himself inside the vehicle and additionally is required to go to the terminal of the charging station. This may be the case if identification is needed but for any reason the driver needs to pay at the station or the owner wants the driver to come to the terminal for promotion reasons.

6.2.5 Charging is started from within the vehicle or the charging station.

The driver may decide to start the charging process from within the vehicle or at the charging station.

Depending on the appropriate mode from the charging station the HMI has to show different screens and information and has to ask for different interactions with the driver. Additionally there are various ways to terminate or interrupt the charging process.

One solution would be to allow the charging station to transfer images, text and information to the HMI inside the vehicle to adapt it to the special scenario at this particular charging station. On one hand this would allow a lot of different solutions but on the other hand this requires a lot of predefined standards to make sure that the technical equipment within the vehicle is able to show every possible input from the station and it would in some cases need to transfer a lot of data between the vehicle and the station.

The better solution is to define and standardize the possible modes as mentioned above as it has been implemented in the UNPLUGGED project. As a result the HMI of the vehicle and the charging station need to hold available suitable screens, text messages and ways to give input. During the approach of the vehicle to the charging station the vehicle is told which mode is relevant. Thus the Information exchange is reduced to a minimum and fits in the communication standard.

Additionally the screens and text will be customized for the driver even if in the charging station a special language is not implemented.

6.3 Provision of driver information though signage

6.3.1 Introduction

With an increase in the availability of electric vehicles across the EU, road signs have been developed and are being introduced in a number of EU countries to inform motorists where they are able to re-charge their electric vehicles (EVs) at designated charging points or stations. A review has been made of the signage adopted by some of these countries.

6.3.2 United Kingdom

The Traffic Signs (Amendment) (No.2) [10] Regulations and General Directions 2011 prescribed the use of a new road sign (Figure 19) that enables motorists to park at designated electric vehicle charging points.

Figure 19: UK Electric vehicle charging point parking sign

The sign shown in Figure 19 incorporates the authorised ‘Parking place for electric vehicles symbol’ (Figure 20).

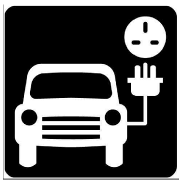

Figure 20: Symbol for parking place for EVs

The Traffic Signs Regulations and General Directions 2015 [11] (due to be published in the spring of 2015) prescribes the use of an alternative symbol to designate a parking place reserved for the recharging of electric solo motorcycles (Figure 21):

Figure 21: Symbol for parking place for electric solo motorcycles

6.3.3 Sweden

In 2009, Sweden adopted road signs (Figure 22), to indicate the location of charging stations for electric vehicles. [9].

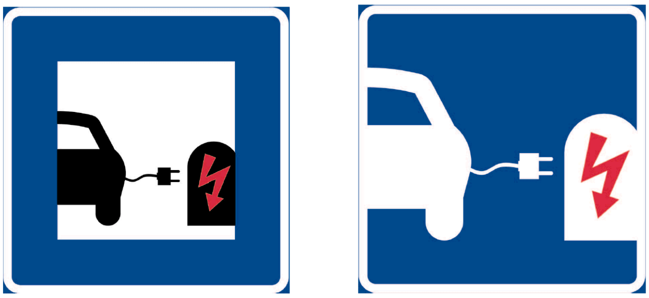

Figure 22: Swedish road signs for EV charging stations

Sweden and Norway co-submitted these designs of EV sign designs as a formal joint proposal to the Economic Commission in 2011 [13].

For the left hand sign, the colour of the electrical symbol (arrow) could be varied to white or yellow. The red coloured electrical symbol arrow was subsequently rejected by the Commission, as red is an emergency colour and is not suitable for EV signs [9].

6.3.4 Norway

Norway has adopted the Swedish EV charging station sign designs as shown in Figure 22.

6.3.5 Belgium

In Belgium, a road sign (see Figure 23) has been developed for EV charging stations where there are reserved parking places. The design of this signage is in line with the design approach undertaken for the adopted United Nations traffic signs for liquefied petroleum gas (LPG), compressed natural gas (CNG), liquefied natural gas (LNG) and hydrogen fuelling stations.

In addition, another sign have been designed for charging parking spaces, to be installed directly below a larger informational type sign. These charging parking space signs, see Figure 24, can also be shown with a text legend in Dutch or French (two of the official languages of Belgium) [9].

Figure 23: Belgium - EV charging station sign

Figure 24: Belgium signs for charging parking spaces

6.3.6 Denmark

Denmark has developed a road sign to indicate the location of charging stations for electric vehicles, see Figure 25. The charging station sign shown in Figure 25 is similar in design to the equivalent sign proposed by Belgium.

Figure 25: Denmark - EV charging station sign

The sign shown in Figure 27 is an EV charge parking sign and is intended to be used as an additional panel, mounted directly below to the prescribed Vienna Convention parking sign E, 14[a] (Figure 26).

Figure 26: Parking sign

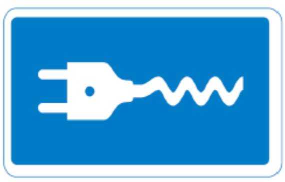

Figure 27: Denmark - EV charge parking sign

Both the Belgium and Danish sign designs for EV charging stations have been designated as UN recommended road signs to indicate the locations of refuelling points for electric vehicles [14].

6.3.7 France

The French have developed a sign design for an EV charging station, see Figure 28.

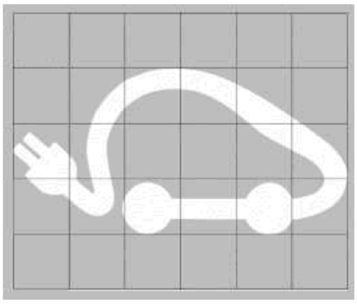

Figure 28: France - EV charging station sign design

This particular sign can be shown on a blue background, see Figure 29, and the text legend ‘recharge véhicules électriques’ can be added to the sign.

This sign has already been installed on roads in France. This blue background sign has also been installed in conjunction with the parking sign (shown in Figure 26).

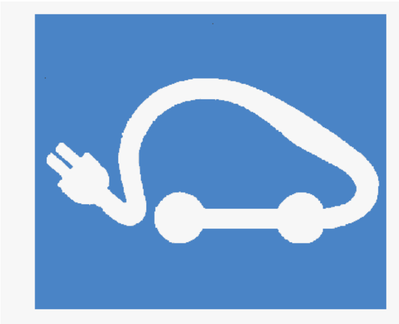

Figure 29: France- EV charging station sign (with a blue background)

An electric vehicle charging parking sign design was submitted to the Economic Commission for Europe [12]. This sign design shows the EV charging station sign in combination with the prescribed Vienna Convention ‘No waiting’ sign C, 18, see Figure 30Figure 30.

Figure 30: France - EV charge parking sign plus ‘No waiting’ sign

There is a lack of evidence to show that this particular sign combination has actually been introduced in France for electric vehicle charging parking. It appears that the P’ parking sign / blue EV charging station sign combination has been adopted for vehicle charge parking.

6.3.8 Portugal

Portugal has developed EV charging station signage based on the French design, see Figure 31. In addition, they have proposed a sign design for dedicated EV charge parking signs, see Figure 32.

Figure 31: Portugal - EV charging station sign

Figure 32: Portugal - dedicated EV charge parking signs

6.3.9 Other countries

Some countries have signage which is determined regionally rather than nationally. An example for this would be Italy, where different regions use different signage conventions and rules, making standardisation difficult.

At the time of writing no standardised signage for electric vehicle was found in Germany of Spain.

6.3.10 Conclusion to signage investigation

Following this review of road signage for electric vehicle (EV) charging points, it has been established that there is no single harmonization standard in the EU for road signage for EV charging points. As a result of this lack of a harmonization standard, some EU countries have already developed their own EV road signage, or for example, in the case of Norway, have adopted EV road signage from another country.

There is a lack of photographic evidence to establish whether the EV charge parking signs have actually been introduced on the road network in EU countries which have developed sign designs.

7 Overall Conclusions

The research undertaken for this task has concluded that interoperability with the power transfer infrastructure is feasible, even where equipment from different suppliers operates at different frequencies. As long as both sides of the power transfer equipment are aware of the requirements of the other, and there is an agreed strategy regarding which side (primary of secondary) adapts to the other, rapid adaptation is possible. This results has been shown both in simulation and experimentally.

For interoperability between the vehicle and the power transfer infrastructure, a standardised interoperable communications link needs to exist. The technology to achieve this exists, and the standards used for communication in conductive charging solutions are, with some adaptation, suitable for wireless power transfer solutions. The required changes are already being addressed by the standardisation bodies. The communications required for billing purposes was not specifically addressed, but the technology to achieve this is well established, for example in the mobile phone industry.

Two significant studies were undertaken, one each in Barcelona and London, to investigate the integration of power transfer infrastructure into the urban environment. These found that public taxis and delivery vans would be most likely to benefit from the introduction of wireless charging infrastructure. Both vehicle types tend to stop for short periods where the use of plug-in charging would be time consuming and inconvenient.

Taxi ranks and queuing areas would be a prime candidate for infrastructure. Because of the short time taxis tend to spend in these locations, higher power infrastructure would be most suitable.

Delivery vans on the other hand would benefit most from charging infrastructure in shopping centres and logistics premises. As they tend to be stationary for longer periods of time at these locations, lower power systems would most likely be sufficient for these. The installation of wireless charge system in loading/unloading bays makes sense for short duration stops (up to 30 minutes stop time). For longer duration stops the plug-in charge system fully covers the driver’s needs.

Additional areas where infrastructure should be considered include commercial parking, tourism zones, connectivity with other transport modes, services for citizens (hospitals, schools, etc.) and deliveries to residential streets.

Citizens’ perception is a key factor for the wireless charging system installation success. The information should emphasize the benefits of the wireless system, should not be intrusive and should indicate the safety of the installation. This was illustrated by a survey of London taxi drivers, whose chief concern about electric vehicles was range and the possibility of running out of charge.

A review of technical standards identified that significant standardisation effort is already underway in the IEC, ISO, CEN, CENELEC and the ITU. Creation and adoption of standards provide a strong incentive to interoperability.

Another important area of interoperability is the provision of information to drivers. Three aspects of this are addressed in this report, namely the in-vehicle Human-Machine Interface (HMI), the overall charging HMI, and the provision of signage.

Guidelines for the clear and unambiguous provision of information to the driver are addressed in the in-vehicle HMI. As an illustration, an initial HMI design is analysed, shortcomings identified and an improved version presented. The adoption of a standard set of symbols and HMI design elements enhances interoperability as users move between vehicles.

The HMI at the charging station is also discussed, identifying the different methods that the power transfer process may be initiated and controlled. The choice of the type of method of control used is based on the type of contract that the user has, and also has to cope with users without a contract. Interoperability between these different processes requires standardisation of message interfaces between EVSEs and in-vehicle systems.

Finally the issue of signage is investigated. It has been found that many countries are already adopting signage to cope with the introduction of electric vehicle and charging infrastructure. Unfortunately most countries are adopting their own signage, with little evidence of standardisation, although some countries are adopting the same or similar signage to other, mostly neighbouring countries.

8 References

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9 Appendix 1: Grid requirements in Spain

9.1 Introduction

This appendix describes the connection requirements for Electric Vehicle Supply Equipment (EVSE) in Spain. These conditions should be adapted to the current regulations in each country.

Currently all EVSE must be supplied from the 400V AC low voltage system. According with the Spanish REBT (Electric Low Voltage Code, Reglamento Electrotécnico de Baja Tensión in Spanish and REBT abbreviated), an AC voltage lower or equal to 1000 V, and a DC voltage lower or equal to 1500 V are considered as low voltage. Their connection to the medium voltage grid must be performed using transformation centres complying with the corresponding regulation and the particular technical regulations of the area distribution company.

It is possible that in the future there will be EVSE which can be connected directly to the medium voltage grid, or small transformation centres specially designed to feed EVSE devices. All those devices and their components will need to comply with the requirements established in the regulation for transformation centres and the particular technical regulations of the area distribution company.

For the connection to a low voltage grid, the main components to be placed between the grid and the charging point are:

1. Disconnection box (DB)
2. Connection
3. Circuit breaker panel (CBP)
4. Meters
5. Power control switch (PCS)
6. Control and protection device concentration.

Figure 33 shows an example of a connection to the low voltage grid (400/230 V AC).

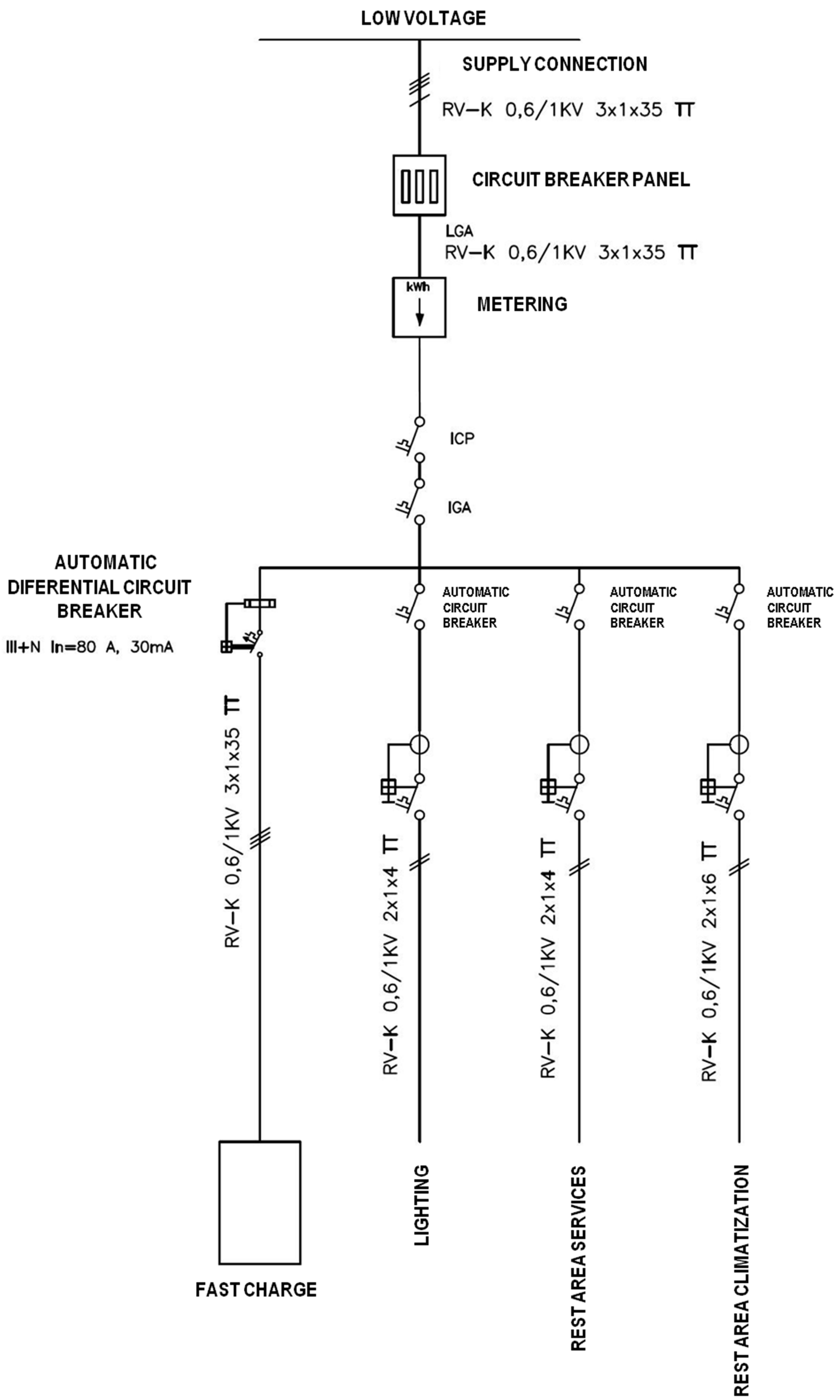

Figure 33: Typical low-voltage mains connection in Spain

9.2 Disconnection box

If the supply is performed from an underground grid, the installation of a disconnection box is necessary. The boxes will be embedded or mounted against the wall, just below the CBP of the charging point. They will be installed in those lines where, according to the exploitation, it is considered necessary to include disconnection points.

9.3 Connection

As a general rule, the connection must follow the indications included in complementary technical instruction 11, ITC-BT-11 (Electric energy distribution grids: Connections), of the low voltage electrotechnic regulations. Conductors will be isolated aluminium, and the materials used and the installation conditions will comply with prescriptions shown in ITC-BT-06 and ITC-BT-07 for aerial and underground electric energy distribution lines, respectively.

The connection will be dimensioned taking into account the following aspects:

- Maximum expected load, according to ITC-BT-10
- Supply voltage
- Maximum allowed currents for the conductor type and installation conditions
- Maximum allowed voltage drop. This voltage drops will be the one established by the distribution company, on its voltage drop sharing in the elements that constitute the grid, so that in the general protection box it is within the limits established by the Electric Verification and Energy Supply Regularity Regulation

Connections should always comply with the general conditions for crossing, proximity and parallelism set by ITC-BT-7.

In underground connections conductors to be used will be Aluminium, single-pole, type RV, rated voltage 0,6/1 kV, with reticulate polyethylene insulation and PVC cover. Connection conductors will be the ones shown in Table 5.

Table 5: Recommended conductors for the construction of LV connections

Conductor (mm^2)	Maximum allowable current at 25ºC		Resistance Ω / km	Reactance Ω / km
	Direct-Buried	Tubed	At 25ºC	
4x1x50 Al	180	144	0,64	0,09
3x1x95+1x50 Al	260	208	0,32	0,08
3x1x150+1x95	330	264	0,21	0,08
3x1x240 + 1x150 Al	430	344	0,13	0,08

9.4 Circuit Breaker Panel (CBP)

As a general rule, a CBP must comply with the indications shown in ITC-BT-13 (Connection installations. Circuit Breaker Panels). Circuit Breaker Panels are the boxes where protection elements for the main supply lines are placed, and they signal the beginning of the part of the installation own by the client.

CBP will be preferably placed on the exterior facades of the buildings, in places with free and permanent access. Their location will be set in agreement between the property and the supplying company. If the connection is underground, it will always be installed a niche in the wall, which will be closed with a door, preferably metallic, with protection level IK 10 according to UNE-EN 50.102, externally covered according to the environmental characteristics and protected against corrosion, having a standardized ENDESA lock. The lower part of the door will be located at a minimum of 30 cm from the ground. If the facade is not public, the CBP will be placed in the limit between public en private properties.

Only two boxes can be located in the same niche, having a box for every general supply line. If more than two boxes are required, other technical solutions could be used, with prior agreement between the property and the supply company.

CBPs to be used will belong to one of the types included in the technical specifications of the supply company that have been approved by the competent public administration. Inside it there must be fuses in all the phase conductors, with breaking power at least equal to the expected shot-circuit current on the point of installation. The neutral conductor will consist of a mobile connection located to the left of the phases, being the CBP in service position, and will also have a terminal for ground connection if required.

CBPs will comply with all the points indicated in regulation UNE-EN 60439 -1, will have flammability degree according to UNE-EN 60439 -3, once installed will have protection level IP43 according to UNE 20324 and IK 08 according to UNE-EN 50102 and must be sealable.

9.5 Protection and measurement box

If supplying a single client, CBP and measurement devices can be concentrated in a single element. This element is called Protection and Measurement Box (PMB) and it is also analysed in ITC-BT-13 (Connection installation. CBPs).

For the installation of the PMB the same indication must be followed as in the CBs, except no superficial installation will be allowed. Besides, reading devices from the measurement equipment must be located at a height between 0,7 and 1,80 m. PMBs will comply with all the applicable points of UNE-EN 60439 -1, will have flammability degree according to UNE-EN 60439 -3, once installed will have protection level IP43 according to UNE 20324 and IK 08 according to UNE-EN 50102 and must be sealable.

9.6 Meters

Meters and other devices used to measure the energy consumed by the EVSE should comply with the indications of ITC-BT-16 (Linkage installations. Meters: Location and installation systems). Meters and other devices used to measure the electric energy could be located in:

- Modules (boxes with sealed lids)
- Panels
- Electric cabinets

All of them will constitute groups that should comply with regulation UNE-EN 60.439 parts 1, 2 and 3. The minimum protection level that those groups have to possess, according to UNE 20.324 and UNE-EN 50.102, respectively are:

- Indoors installations: IP40; IK 09
- Outdoors installations: IP43; IK 09

They must allow the direct Reading of the meters and time switches, and to the rest of metering devices when needed. Transparent parts allowing those direct readings must be UV resistant. When modules or cabinets are used, they must have inner ventilation to avoid condensation without diminishing their protection level.

Meters will be installed in outdoors modules or cabinets, having free and permanent access. Those cabinets will be embedded in civil work, and their walls should be at least 15 cm thick; or in a prefabricated concrete box, having walls 5 cm thick. The box will be closed with a door, preferable metallic, with protection level IK 10 according to UNE-EN 50102, externally covered according to the environmental characteristics and protected against corrosion, having a standardized ENDESA lock. It will be located at such a height that metering devices are located between 0,7 m and 1,8 m from the ground.

Cables should have a rated voltage of 450/750 V , made of copper, class 2 according to UNE 21.022, with dry insulation, extruded based on thermostable or thermoplastic mixtures, identified according to the colours described in ITC MIE-BT-26. Cables should be non-fire propagators, with low opacity and smoke generation. Cables with characteristics similar to UNE 21.027 –9 (thermostable mixtures) or UNE 21.1002 (thermoplastic mixtures) comply with this description. Moreover, it must have the required wiring for control circuits in order to satisfy current tariff conditions. The cable should have the aforementioned characteristics, its identification colour will be red and it will have a 1,5 mm^2 section. Connection will be direct and conductors will not require special preparation or terminals.

Meters recommended by the supplier companies on their particular technical regulations should be used.

9.7 Concentration of control and protection devices

The concentration of control and protection devices of the installation must comply with the indications reflected in ITC 17, 22, 23 and 24. The housings will comply with UNE 20.451 and UNE-EN 60.439 -3, with a minimum IP 30 protection level according to UNE 20.324 and IK07 according to UNE-EN 50.102. The housing for the power control switch should be sealable and its dimensions will be adequate to the supply type and the applicable tariff. Its characteristics and type correspond to an officially approved model.

Control and protection devices will be, at least:

- One power control switch (PCS)
- One automatic general switch (AGS) breaking all poles, having manual operation and provided with overload and short-circuit protection. This switch should be independent from the power control switch.
- One general differential switch, destined to the protection from indirect contacts in all circuits, except if this protection is achieved using other devices, according to ITC-BT-24.
- All-pole breakers, destined to the protection from overloads and short circuits of every inner circuit.
- One overvoltage protection device, according to ITC-BT 23, if required.

For operational and safety reasons, it is convenient to install the charging points in independent circuits where the only load is the charging point itself. Thus, every circuit and every charge point will be protected by an automatic switch and a differential switch, besides the general PCS and AGS. Automatic switches will have a rated current of 160 A, regulated to 100 A, and will be able to break three phases and neutral. Differential switches form the charge point circuit should have a sensitivity of 30 mA an 125 A rated current The automatic switch and the differential switch con be implemented in the same device.

10 Appendix 2: Assessing integration of inductive charging systems with road infrastructure and with vehicles in Barcelona

10.1 Introduction

This document will assess the possible integration of en-route static charging systems with road infrastructure and with vehicles in the city of Barcelona.

The assessment considers the best approach in order to do a smart and gradual integration, selecting public taxis and delivery vans for a first implantation, analyzing the reasons why these vehicle types are selected, focusing in the main characteristics of the selected vehicles fleet and studying the needs of the involved drivers. The current scenario in the city of Barcelona is analyzed in order to check the present situation, and also future scenarios are examined in detail considering the overall municipality characteristics and the specific parking spots distribution. In order to achieve these goals the impact in the citizens' perception is a key factor for the inductive systems implantation success and for this reason a detailed analysis of the citizens' needs and the signalization needed in order to reach the final objective is fully analyzed.

Including private cars in this initial integration is not part of the main focus. However, whenever appropriate, the benefits/issues of sharing the infrastructure under certain circumstances will be considered.

- *Public taxi*

  At this stage, in Barcelona there are only 2 homologated electric vehicles to operate as taxi, the Nissan e-NV200 and the BYD E6. Additionally, the usage of the public taxi is a very controlled market as it is regulated by the IMT (Institut Metropolità del Taxi), part of AMB (Area Metropolitana de Barcelona). This makes the homologation of the installation of inductive infrastructure in the car easier to implement, as well as the interoperability between vehicles and infrastructure much simplified. The installation of inductive spots dedicated to taxis would be limited to the taxi stops. One of the challenges will be represented by the different lengths of the vehicles, particularly once there will be more variety of EVs homologated as taxi.

- *Delivery van*

  The delivery vans main activity is doing short stops in order to deliver the goods. The process of getting the cable and plug it in is quite slow and annoying for the drivers. In this situation, it makes a lot of sense installing inductive system in the loading/unloading spots. When the driver performs a short stop, the delivery van is partially charging. If in each stop the van can be partially charged, it can be enough in order to complete the working day.

In order to do this assessment, some key features will be analysed. They will be mentioned below and fully analysed in this document:

Location of the charge spots – General study

A general study of the spots localization in the city will be done considering different factors. In general, the starting point will be the adaption of the plug-in charging spots, making them "hybrid spots", able to work both by cable and inductively. The full analysis can be found in section 10.2.

Location of charge spots by vehicle type

The location of the charge spots will depend on the **vehicle types** included in this assessment, as taxi ranks and loading/unloading spots have different particularities. The full analysis can be found in section 10.3.

Charge power stations

The needed charge type power stations should be studied considering different aspects, like waiting patterns of taxis and delivery vans, EV battery capacity and consumption, or cost and maintenance of the installation. The full analysis can be found in section 10.4.

User perception

The installation of new inductive system will impact the citizens (mobility, visual perception and concerns). The full analysis can be found in section 10.5.

Signalization

New signalization should be included in the city in order to identify the position of the inductive charge points. The full analysis can be found in section 10.6.

Maintenance

As the inductive system is installed in the pavement, any pavement replacement should consider the inclusion of these coils. The full analysis can be found in section 10.7.

Payment method

The inductive charge spots will be wireless. This solution opens new possibilities to implement a more efficient payment system. The full analysis can be found in section 10.8.

Policies

The fact of performing new installations in the street implies that new policies should be accomplished. The full analysis can be found in section 10.9.

10.2 General location of the charge spots

In any urban area, there are some key factors that should be considered for the installation of charge spots. This social/economic factors and geographical factors should benefit the citizens' and the drivers' needs.

- Commercial spots coverage.
- Tourism zones.
- Connectivity with other transports (train main stations, bus stations, etc.).
- Services (hospitals, schools, etc.).
- Neighbourhood streets distribution.

This study will be done for each vehicle type included in the assessment.

The airport will also be included in this study, but will be detailed in a specific section as this is a very particular scenario.

10.2.1 Current scenario

In the last semester of 2014 Barcelona municipality is installing plug-in charge spots for taxis and delivery vans. The actual scenario is analyzed due to its importance for future implantation of inductive charge spots.

10.2.1.1 Public taxi

In Barcelona there are 207 taxi stops, and 64 additional ones in the metropolitan area. These taxi stops do not have plug-in charge spots installed (available electric vehicle charging stations do not include taxi stops).

In the last semester of 2014 new 7 plug-in system charge stations for taxis are being installed. These stops have been chosen considering the social/economic factors identified above. These spots are located in the following addresses:

1. *"Villarroel" street – "Diagonal" avenue corner*: this is identified as a commercial zone.
2. "*Paral.lel" avenue – "Llançà*" street corner: this is a spot near expositions and conventions.
3. "*Plaça del Mar" square – "Escar*" street crossing: this is identified as a touristic zone.
4. "*Hospital de Sant Pau*": services for citizens.
5. "*Estació del Nord*": connection with bus station.
6. "*Plaça Universitat*": city center, this is a very crowded spot.
7. "Garcia Faria" avenue – "Josep Pla" street crossing – commercial zone, next to the beach.

These plug-in charge points will be low power spots (7kWh).

10.2.1.2 Delivery van

The city of Barcelona is located in an area limited by the Collserola Mountains and the Mediterranean Sea. Its central area is flat, but there are several streets and avenues with significant slopes due to the presence of several hills. This makes that some districts have a very limited mobility due to the presence of very narrow streets, pedestrian streets, etc. Some examples are *Gràcia*, *Sarrià* or *Ciutat Vella* districts.

Figure 34: Districts with limited mobility in Barcelona

The loading/unloading spots have a limited time of 30 minutes. Currently the ICE delivery vans, in the districts specified above, are going around these areas, without going inside. They park 30 minutes in one spot next to the area, deliver some goods and then move to another location surrounding the same area, deliver a new set of goods and go on with the process. This is not a smart solution.

In order to improve this process, additional plug-in charge spots will be installed just in the border of these neighborhoods. The delivery vans will be allowed to use these spots during 2 hours (when the usual maximum time allowed is 30 minutes in loading/unloading spots). In these 2 hours the driver can deliver all the goods inside the neighborhood and can have some refreshment if desired. When the driver goes back to take the van, the EV has been charged enough to complete the working day.

6 plug-in spots of this type will be installed in Barcelona during the end of 2014.

The plug-in charge solution is good in the above scenario, when the driver is allowed to use the spot 2 hours in these specific neighborhoods, but it is not in common loading/unloading spots with a maximum allowed time of 30 minutes (usual spots in the central area of the city of Barcelona). In this scenario, after parking the van and in the next 30 minutes the driver should:

- Get the cable from the trunk.
- Plug-in the cable from the charging post to the EV.
- Get the payment card, insert it in the post and perform the payment.
- Start the charging process.

- Deliver the goods.
- Go back to car.
- Unplug the cable and place it again in the trunk.

As can be seen, the driver spends around 5-10 minutes of the 30 allowed loading/unloading minutes in the charging process. Usually these drivers are in a hurry and in most situations they will not do this process.

In these spots is where the inductive wireless charging process makes a lot of sense. In an ideal situation (with wireless payment process included) the driver should only park the van in the inductive spot and accept the inductive charging process. These 5-10 minutes used for the plug-in charging process can be used here for the delivery of goods process.

10.2.1.3 General charge spots

Currently in Barcelona municipality there are around 170 plug-in charge spots.

Additionally to these spots, 23 new charge spots will be installed in the city and in the metropolitan area. These spots will be able to be used by all private and public transport and will be fast charge spots (CHAdeMO+Menneke+CCS).

The installation cost of one of these spots is around €50.000 at the time of writing.

The ones in the city will be installed during summer of 2014 and will be these ones:

1. *"Gaudí" avenue* – Touristic zone.
2. *"Passeig de Gracia" street* – City center.
3. *"Diagonal" avenue (between "Casanova" and "Muntaner" streets)* – Commercial zone.
4. *"Viriat" street 25-35 and "Guitard" street 2* – next to "*Sants*" train station (the most important one in the city).
5. *"Mercabarna"* – Logistic zone, next to the port.
6. *"Paral·lel" avenue* – next to expositions and forums.
7. *Parking "Hort de la Vila" street 29-37 and "Via Augusta" street 323* – residential zone.
8. *Parking "Isaac Newton" street 26-28 (Cosmocaixa)* – next to "Ronda de Dalt" – high traffic volume.
9. *"Torrent de l'Olla" street 203* – in the border of Gracia neighborhood.
10. *Parking "Mas Casanovas" street 71* – next to Sant Pau Hospital.
11. *Parking "Via Favència" street 21*– next to "Ronda de Dalt" – high traffic volume.
12. *"Meridiana" avenue 408* – next to "Sant Andreu Arenal" train station.
13. *Exit 23 of "Ronda Litoral" (McDonalds - Vila Olimpica)* – already installed and working.

Figure 35: 13 fast charge spots in the city of Barcelona

The 10 ones to be installed in the metropolitan area will be next to these spots:

1. *El Prat del Llobregat (Mas Blau):* the nearest to the airport
2. *Gavà (Barnasud sector)*
3. *L'Hospitalet de Llobregat (Granvia economic district)*
4. *Cornellà de Llobregat (Almeda Polygon)*
5. *St. Joan Despí (next to TV3 – TV channel)*
6. *Pallejà (Camps d'en Ricard Polygon)*
7. *Sant Cugat del Vallès (Mall)*
8. *Barberà del Vallès (Baricentro)*
9. *Moncada i Reixac ("Pla d'en Coll" Polygon)*
10. *Badalona (Montigalà Mall)*

In the future, these fast charge spots should allow reservation in order to:

- Increase the productivity of the spot.
- Increase the quality of service (drivers will avoid waiting for other user charge).
- Promote discounts for specific time range.

In a first phase reservation would be only for "commercial vehicles" (delivery vans and taxis), not for private cars. But private cars can charge in these spots, and they should be informed when the spot is available or not.

These spots will be particularly useful for taxis in very busy working days, when they cannot spend time in taxi ranks to do partial charge. The taxi driver would be able to do a 30 minutes pre-reservation in the fast charge spot. With this, he/she only needs 30 minutes of the working day to fully charge the EV.

10.2.2 Expected situation for inductive charge

The installation of inductive charge spots will consider the below factors:

- Same **social/economic factors** than for plug-in charge can be considered (commerce, tourism, services, etc.)
- It should be considered if there are urban logistics operators' specific routes in order to place the inductive spots mainly in these routes for delivery vans.

- **Waiting patterns** of the vehicle types studied.
- **Cost** of the implantation: the number of inductive charge spots will depend on the cost of implantation. The cost highly depends on the power type charge system. It will be fully analysed in section 10.4.

10.2.3 Airport specific scenario

Barcelona Airport is located 12 km southwest of the centre of Barcelona lying in the municipalities of El Prat de Llobregat, Viladecans and Sant Boi.

Due to its high importance in the mobility in the city it is a strategic stop for Barcelona public taxis.

10.2.3.1 Current scenario

Currently there is not specific conductive charge spot in the airport; the nearest one will be installed in El Prat de Llobregat – Mas Blau (around 3km from the airport taxis stops).

Figure 36: Airport plug-in charge station

10.2.3.2 Inductive charge

In the future the installation of inductive charge spots in the airport Terminal 1 and Terminal 2 taxi stops should be studied.

It should consider that currently the taxi ranks in the airport are a complex grid, as we can see in the below image.

Figure 37: Airport taxi rank

The taxi driver goes to the taxi rank (a grid with multiple files) and has some refreshment/relaxation waiting for his/her turn. This is a long process that can take a couple of hours.

The installation of the charging stations in the airport involves the participation of AENA (Aeropuertos Españoles y Navegación Aerea), specific policies should be discussed with them.

Including the EV in the taxi fleet would need some changes in the current solution. These are the ones proposed:

- Do not change the existing taxi rank. The EV taxi driver would park in the rank and would wait for the next taxi to arrive. With a taxi covering the position behind, the taxi driver has his/her turn and can go to the charge spot (no inductive charging necessary). Obviously the next driver should respect the positions and do not move his/her taxi to the spot covered by the electric taxi that has gone to the charging station. When the EV is charged, it will go back to its position in the queue. A new fast charge plug-in spot should be installed in the airport, as the current one is installed 3 km far from the airport terminals.
- To include a separate new taxi rank for inductive charging, then 2 different taxi ranks would coexist in the airport, the current one and a new one for electric vehicles with charging needs. This solution would need a new software system to assign turns merging the traditional taxi rank with the inductive charge taxi rank, assigning turns when a new taxi arrives to any of the two ranks. This solution would have a high installation cost and additionally taxi drivers should be educated to follow the new procedure to get his/her turn.

10.3 Specific location of the charge spots

Public taxis and delivery vans have different stop stations with specific characteristics. Some of these taxi ranks and loading/unloading bays are including plug-in charge spots. Additionally the assessment is analyzing the possible options for inductive charge spots inclusion.

10.3.1 Public taxi

There are several reasons why the taxi is the best vehicle type in order to do the first approach of inductive charge systems:

- There are only 2 EV models homologated for taxi usage: Nissan e-NV200 and BYD E6; this makes an easier homologation that can guarantee interoperability.

Figure 38: Nissan e-NV200 and BYD E6

- In order to concede the homologation, a European standard charging system can be requested to the EV a wireless charging system can be requested, then.
- This is a very controlled market, as these taxis will only be used in Barcelona metropolitan area.
- The taxi queue is a perfect place to install inductive charge spots.

10.3.1.1 Current scenario

In Barcelona there are 207 taxi stops, and 64 additional ones in the metropolitan area. In 7 of them, plug-in charge stops are being installed during this 2014.

In this 7 plug-in charge spots, the spot is outside the queue, right in front of it, to guarantee extra visibility for Electric Taxis and to assure a certain charging time. The process is the following for taxi drivers:

- The electric taxi arrives at the taxi stop.

- The electric taxi gets his turn.
- The electric taxi goes to the charge spot.
- The electric taxi stays in the charge spot until its turn arrives (does not go back to its position in the queue). If the desired charge is not completed, he can bring his turn to the next taxi in the queue.

There is some regulation (IMT: Institut Metropolità del Taxi) for passengers where they can select the desired taxi, and this regulation will probably include the user to select an EV if desired.

Figure 39: Taxi rank in the city of Barcelona

10.3.1.2 Inductive charge

The introduction of inductive charge spots can consider 2 different scenarios for the coil positioning:

Specific spot outside the queue

This is the same solution than the one described for the plug-in charging.

Advantages:

- Great visibility of the spot. Easy identification and opportunity for promotion.
- If the inductive system is down, the plug-in system can be used for charge.

Constraints:

- Only one taxi can be using the charging system at the same time. In this situation a reservation system should be introduced.

Different spots in the taxi queue

The inductive charge spots would be installed in different positions in the taxi queue and not in a specific spot outside the queue.

The first position of the rank should not have a coil. The passenger gets into the taxi in the first position and any sensation of danger that can be avoided the better.

Advantages:

- This system takes advantage of the taxi queue in order to install the inductive system there. While the taxi is advancing in the queue, the charge goes on (if next spot has charge system available).
- This solution allows doing a quick charge in each different taxi stop. In a common working day, this can be enough in order to cover the day. In a busy working day, when the driver cannot stop (e.g. Mobile World Congress in Barcelona) the driver should use one of the fast charge spots in the city to load 100% the car in one shot.

Constraints:

- Queue positions should be clearly identified. Electric and non-electric taxis should coexist, and now the queue does not have specific positions. The taxi drivers always try to minimize the space between taxis in the queue. With this new solution, some respect rules should be inculcated to the drivers, as if the EV is not placed in the correct position, the inductive charge system will not work as desired.

Specific considerations for this second solution should be:

- The average time in the same position without moving on in the queue.
- Specific placing in the queue (EV will coexist with common vehicles). It should be studied if it is better to place the inductive spots in alternate positions or if they are placed together.
- In this solution the charge power of the station is divided between the different coils. These smart charging points should respond to the criteria selected for the energy division (prioritize the car with lowest charge; prioritize the first car in the queue, etc.).

In a final implementation, probably if low power spots are installed, more spots will be necessary. Then an economic study should be done considering the power of the spot and the number of the spots necessary to fit the driver's needs. It will be fully analysed in section 10.4.

10.3.2 Delivery van

The implantation of inductive system in delivery vans would be more difficult than for taxis for the below constraints:

- More variety of existing EV fleet.
- No regulation for inductive system installation in a wide variety of vehicle types currently exists.

This makes more difficult to find guidelines for inductive charge.

In Barcelona study, medium size delivery vans are considered. These are some considered models, with a volume around 700kg:

- *Nissan e-NV200*
- *Peugeot Partner*
- *Renault Kangoo ZE*
- *Citroen Berlingo*
- *Mercedes Vito*
- *Fiat Fiorino*

Figure 40: Delivery vans considered in this assessment

In an eventual first phase, the inductive charge spots will be installed in the same plug-in charge spots. In this scenario, if there is a specific issue in the wireless charge, the driver can use the plug-in charge.

The implantation of the inductive system should be done in the loading/unloading parking spots where the drivers will do short stops (not more than 30 minutes). In this situation, and considering that usually the drivers are in a hurry to deliver some packages, plug-in charging with the requirement to handle the charging cable would not fit with their needs .

This would be a perfect scenario to install inductive charge spots, allowing these drivers to do quick charges with a very low effort.

In Barcelona, the loading/unloading parking spots are placed in:

- Common street parking spots with loading / unloading signalization: the signalization of the specific spots should be changed to clearly separate the positions, as currently there is only a yellow line identifying the whole loading/unloading spot, see Figure 41.

Figure 41: Loading/unloading area in the city of Barcelona

- In the corner between streets (Barcelona "Example" streets distribution have 4 different corners in the streets crossing used for loading/unloading purposes, Figure 42 should clarify this distribution).

Figure 42: Barcelona 'Example' streets distribution

The inductive charge spots should be clearly signalled in order to be used primarily by the EV, so they should be easily identified.

Some regulations should be set up for the usage of the common loading/unloading parking spots by the ICE delivery vans and the inductive charge spots by the EV delivery vans.

10.4 Charge power stations

The implantation of the inductive charge system should study the most efficient power to be installed in the spots. The needed charge type power stations are studied considering different factors that can be grouped mainly in 2 groups:

- Cost of installation and maintenance of the spots
- Electric vehicles main features and specific business needs for public taxis and delivery vans

A specific charge column would be available that would be shared between all the inductive spots, dividing the power between all the spots used at that moment.

Installation and maintenance

The main features to be considered regarding the installation and maintenance of the spots are summarized below:

- Single-phase (from 3.7kWh to 15kWh) or three-phase (from 22kWh to 100 kWh) installation.
- Equipment cost: higher if high power installations. It should also depend on the number of coils to be installed in the spot.
- Installation cost: cheaper if next to the transformer, higher for high power installations.
- Energy cost: This is a yearly quota of 80€/kWh/year (lower power, lower maintenance price).

- Equipment maintenance costs: a 10% of the equipment cost each year might be considered.
- Pavement maintenance costs: a 10% of the coil cost each year might be considered.

EV main features

The selected power should consider different parameters that can differ between taxis and delivery vans. The autonomy of the car for a whole working day should be guaranteed.

These are the main characteristics to be considered.

- Vehicle battery full capacity: this will determine the autonomy at the day start. It will depend on the EV model.
- Consumption: the EV consumption will also impact on the needed energy to complete the working day.
- Mileage per day: this is the whole mileage for a working day, including also the way back home if the taxi driver lives in the outskirts of the city.
- Average stop time: the stop time may be very variable; an average value will be determined in order to do the calculations.
- Number of stops: the number of stops needed to charge the EV should not be higher than the current values for taxis and delivery vans.

10.4.1 Workday autonomy – Quantitative analysis

The first goal of the installation of inductive spots is the drivers' to complete their working day using this charging system. Public taxis and delivery vans have different business, so the power needed for each vehicle type should be studied separately.

10.4.1.1 Public taxi

The below values will be calculated considering different charge power types (3.7kWh, 7.3kWh and 50kWh):

- Total stop time: this time should not be higher than current total stop time. In a common working day, the taxi driver is stopped between 2-3 hours. This time can be used for EV charging.
- Number of stops: with the total stop time and the average stop time, the number of stops needed to charge the car will be calculated.
- Stop Time / Total Time ratio: a percentage of stop time against total working time will be calculated.

In order to calculate the 3 above parameters, the below main values will be used:

- Specific battery capacity and autonomy in the car model specification (the BYD E6 has a battery capacity that would allow the driver to complete the working day without charging if the driver starts the day with almost full battery). An autonomy correction factor of 0.75 will be applied as commonly the consumption is a bit higher than the one provided in the car specification.
- Mileage: 200 km/day
- Driving Time: 10 hours
- Average stop time: 20 minutes

The calculations are done considering that the car starts the day with full battery capacity, as charging the car at home during the night has a very low cost.

Table 6: Conventional charge taxi workday autonomy values (3.7 kWh)

	Nissan e-NV200	BYD E6
Station Charge Power (kWh)	**3,70**	**3,70**
EV Battery capacity (kWh)	24	75
EV Autonomy	170	280
Autonomy Correction factor	0,75	0,75
EV Consumption (each 100Km)	18,82	35,71
Mileage (Km each day)	200	200
Total Energy needed (kWh)	37,65	71,43
Energy at the day beggining (kWh)	24,00	71,43
Daily charge needed (kWh)	13,65	0,00
Average speed (Km/h)	20	20
Total Driving Time (hours)	10,00	10,00
Average Stop Time (minutes)	20	20
Total Stop Time (hours)	**3,69**	**0,00**
Number of Stops needed (each day)	**11,07**	**0,00**
Total Daily Work Time (hours)	**13,69**	**10,00**
Stop Time / Total Time ratio	**26,95%**	**0,00%**

Charging the Nissan e-NV200 at 3.7kWh brings a stop time a bit higher than 3 and a half hours. This time is higher than current values, so this solution would not be accepted by the taxi drivers as they would spend too much time stopped.

Table 7: Semi-fast charge taxi workday autonomy values (7.3 kWh)

	Nissan e-NV200	BYD E6
Station Charge Power (kWh)	**7,30**	**7,30**
EV Battery capacity (kWh)	24	75
EV Autonomy	170	280
Autonomy Correction factor	0,75	0,75
EV Consumption (each 100Km)	18,82	35,71
Mileage (Km each day)	200	200
Total Energy needed (kWh)	37,65	71,43
Energy at the day beggining (kWh)	24,00	71,43
Daily charge needed (kWh)	13,65	0,00
Average speed (Km/h)	20	20
Total Driving Time (hours)	10,00	10,00
Average Stop Time (minutes)	20	20
Total Stop Time (hours)	**1,87**	**0,00**
Number of Stops needed (each day)	**5,61**	**0,00**
Total Daily Work Time (hours)	**11,87**	**10,00**
Stop Time / Total Time ratio	**15,75%**	**0,00%**

The total stop time needed to charge the EV in order to complete the whole working day is a bit less than 2 hours, this value is in the current stop patterns of diesel taxis.

For busy days where the driver should do extra mileage, a fast plug-in charge spot should be used.

Table 8: Fast charge taxi workday autonomy values (3.7 kWh)

	Nissan e-NV200	BYD E6
Station Charge Power (kWh)	**50,00**	**50,00**
EV Battery capacity (kWh)	24	75
EV Autonomy	170	280
Autonomy Correction factor	0,75	0,75
EV Consumption (each 100Km)	18,82	35,71
Mileage (Km each day)	200	200
Total Energy needed (kWh)	37,65	71,43
Energy at the day beggining (kWh)	24,00	71,43
Daily charge needed (kWh)	13,65	0,00
Average speed (Km/h)	20	20
Total Driving Time (hours)	10,00	10,00
Average Stop Time (minutes)	20	20
Total Stop Time (hours)	**0,27**	**0,00**
Number of Stops needed (each day)	**0,82**	**0,00**
Total Daily Work Time (hours)	**10,27**	**10,00**
Stop Time / Total Time ratio	**2,66%**	**0,00%**

Only one stop would be necessary in order to charge Nissan e-NV200 to cover the working day. These values do not correspond with the reality, as taxi drivers do more stops during their working day.

This solution is discarded as lower power posts may be enough to cover the existing scenario.

10.4.1.2 General conclusions:

- Conventional charge is not enough for e-NV200, as the stop time needed is around 4 hours. Conventional charge spots would need EV with higher battery capacity than Nissan e-NV200 and/or better consumption values.
- Semi-fast charge would be enough to cover the working day for e-NV200 model.
- Fast charge does not apply in this scenario due to installation costs.
- If we consider installing a taxi rank with 3 coils, an installation of 22kWh would bring 7.3kWh to each vehicle. This would be a three-phase installation that would allow to easily upgrading to higher power transfer.
- The business of a taxi depends on the driving time. The power should be at least 7.3kWh in order to cover the driving needs.

10.4.1.3 Delivery van

In this assessment, we have defined 2 different scenarios for delivery vans, one for limited mobility districts with 2 hours charge spots, and the 2nd one with common charge spots, where the stop time is limited to 30 minutes.

The 2 hour charge spots will use the plug-in charging system, so calculations will only be done for the spots limited to 30 minutes.

The fleet of delivery vans included in the study are the ones with pre-defined routes, the freelance drivers trying to cover as much work as possible are not included in these calculations.

The below parameters will be calculated considering different charge power types (3.7kWh, 7.3kWh and 50kWh):

- Total stop time: this time should not be higher than current total stop time. In a common working day, the van performs several stops in order to deliver the values. This time can be used for EV charging.
- Number of stops: with the total stop time and the average stop time, the number of stops needed to charge the car will be calculated.
- Stop Time / Total Time ratio: a percentage of stop time against total working time will be calculated.

In order to calculate the 3 above parameters, the below main figures will be used:

- Specific battery capacity and autonomy in the car model specification. An autonomy correction factor of 0.75 will be applied as commonly the consumption is a bit higher than the one provided in the car specification. The models included in the assessment are the 6 more commonly used in Barcelona.
- Mileage: 150 km/day (the mileage is lower than taxis mileage, considering delivery vans with pre-defined routes)
- Driving Time: Around 8 hours, common workday.
- Average stop time: 20 minutes (considering that the maximum stop time is 30 minutes, the average stop time will be a bit lower).

The calculations are done considering that the car starts the day with full battery capacity, as charging the car at home during the night has a very low cost.

Table 9: Conventional charge delivery van workday autonomy values (3.7 kWh)

	Nissan e-NV200	Peugeot Partner	Renault Kangoo ZE	Citroen Berlingo	Mercedes VITO	Fiat Fiorino
Station Charge Power (kWh)	**3,70**	**3,70**	**3,70**	**3,70**	**3,70**	**3,70**
EV Battery capacity (kWh)	24	22,50	24,00	22,50	36,00	26,00
EV Autonomy	170	170	170	170	130	100
Autonomy Correction factor	0,75	0,75	0,75	0,75	0,75	0,75
EV Consumption (each 100Km)	18,82	17,65	18,82	17,65	36,92	34,67
Mileage (Km each day)	150	150	150	150	150	150
Total Energy needed (kWh)	28,24	26	28	26	55	52
Energy at the day beggining (kWh)	24,00	22,50	24,00	22,50	36,00	26,00
Daily charge needed (kWh)	4,24	3,97	4,24	3,97	19,38	26,00
Average speed (Km/h)	18	18	18	18	18	18
Total Driving Time (hours)	8,33	8,33	8,33	8,33	8,33	8,33
Average Stop Time (minutes)	20	20	20	20	20	20
Total Stop Time (hours)	**1,14**	**1,07**	**1,14**	**1,07**	**5,24**	**7,03**
Number of Stops needed (each day)	**3,43**	**3,22**	**3,43**	**3,22**	**15,72**	**21,08**
Total Daily Work Time (hours)	**9,48**	**9,41**	**9,48**	**9,41**	**13,57**	**15,36**
Stop Time / Total Time ratio	**12,08%**	**11,41%**	**12,08%**	**11,41%**	**38,60%**	**45,75%**

The total stop time needed to charge the EV in order to complete the whole working day is a bit more than 1 hour for 4 of the 6 models, this value is lower than current stop patterns of delivery vans, so this power charge is enough to cover the workday.

Table 10: Semi-fast charge delivery van workday autonomy values (7.3 kWh)

	Nissan e-NV200	Peugeot Partner	Renault Kangoo ZE	Citroen Berlingo	Mercedes VITO	Fiat Fiorino
Station Charge Power (kWh)	**7,30**	**7,30**	**7,30**	**7,30**	**7,30**	**7,30**
EV Battery capacity (kWh)	24	22,50	24,00	22,50	36,00	26,00
EV Autonomy	170	170	170	170	130	100
Autonomy Correction factor	0,75	0,75	0,75	0,75	0,75	0,75
EV Consumption (each 100Km)	18,82	17,65	18,82	17,65	36,92	34,67
Mileage (Km each day)	150	150	150	150	150	150
Total Energy needed (kWh)	28,24	26	28	26	55	52
Energy at the day beggining (kWh)	24,00	22,50	24,00	22,50	36,00	26,00
Daily charge needed (kWh)	4,24	4	4	4	19	26
Average speed (Km/h)	18	18	18	18	18	18
Total Driving Time (hours)	8,33	8,33	8,33	8,33	8,33	8,33
Average Stop Time (minutes)	20	20	20	20	20	20
Total Stop Time (hours)	**0,58**	**0,54**	**0,58**	**0,54**	**2,66**	**3,56**
Number of Stops needed (each day)	**1,74**	**1,63**	**1,74**	**1,63**	**7,97**	**10,68**
Total Daily Work Time (hours)	**8,91**	**8,88**	**8,91**	**8,88**	**10,99**	**11,89**
Stop Time / Total Time ratio	**6,51%**	**6,13%**	**6,51%**	**6,13%**	**24,16%**	**29,94%**

The total stop time needed to charge the EV in order to complete the whole working day for the 2 models not covered by 3.7kWh solution is still higher than an acceptable value (ratio should be under 20%). So installing 7.3kWh spots do not have an added value, and these 2 models with very low autonomy should consider fast recharge plug-in spots instead of inductive charge.

Table 11: Fast charge delivery van workday autonomy values (50 kWh)

	Nissan e-NV200	Peugeot Partner	Renault Kangoo ZE	Citroen Berlingo	Mercedes VITO	Fiat Fiorino
Station Charge Power (kWh)	**50,00**	**50,00**	**50,00**	**50,00**	**50,00**	**50,00**
EV Battery capacity (kWh)	24	22,50	24,00	22,50	36,00	26,00
EV Autonomy	170	170	170	170	130	100
Autonomy Correction factor	0,75	0,75	0,75	0,75	0,75	0,75
EV Consumption (each 100Km)	18,82	17,65	18,82	17,65	36,92	34,67
Mileage (Km each day)	150	150	150	150	150	150
Total Energy needed (kWh)	28,24	26	28	26	55	52
Energy at the day beggining (kWh)	24,00	22,50	24,00	22,50	36,00	26,00
Daily charge needed (kWh)	4,24	4	4	4	19	26
Average speed (Km/h)	18	18	18	18	18	18
Total Driving Time (hours)	8,33	8,33	8,33	8,33	8,33	8,33
Average Stop Time (minutes)	20	20	20	20	20	20
Total Stop Time (hours)	**0,08**	**0,08**	**0,08**	**0,08**	**0,39**	**0,52**
Number of Stops needed (each day)	**0,25**	**0,24**	**0,25**	**0,24**	**1,16**	**1,56**
Total Daily Work Time (hours)	**8,42**	**8,41**	**8,42**	**8,41**	**8,72**	**8,85**
Stop Time / Total Time ratio	**1,01%**	**0,94%**	**1,01%**	**0,94%**	**4,45%**	**5,87%**

Fast charge would fit the 6 models, but this solution may be discarded due to the high cost of implantation.

10.4.1.4 General conclusions:

- Conventional charge is enough 4 or the 6 models included in the assessment. The other 2 models would need to improve the consumption in order to use the inductive charging system.
- Semi-fast charge does not have an added value in this scenario.
- Fast charge does not apply in this scenario due to installation costs.
- The business of a delivery van is in the stops, not in the driving time. A power of 3.7kWh will be enough in order to cover these business needs.

If we consider installing a spot with 2 coils, an installation of 7.3kWh would bring 3.7kWh to each vehicle.

10.4.2 Costs – Quantitative analysis

The other main focus in this analysis is the cost analysis for 2 different actors in this process:

- **Energy service provider:** the energy service provider will install and maintain the new inductive charge stations. The energy service provider should take benefit of selling the energy to the drivers.
- **Drivers:** the drivers will buy the energy to the service provider. The inductive charge should benefit the drivers comparing to diesel and hybrid vehicles.

This analysis will first focus on the costs for the service provider, and knowing the yearly cost including installation and operational costs, an estimated monthly rate for the drivers can be established.

The information in order to calculate these costs has been provided by deliverable 3.3 (Economic feasibility of en-route charging technical report), section 5.1 (Accounting strategies and feasibility).

The costs for the service provider can be divided in two main areas:

- **CAPEX (Capital Expenditure)**: these are the costs of installation of a new charging station. The below are the costs to be considered:
  - o *Grid connection*: supply connection rights, access and electrical coupling based on the power. In Barcelona it is around 20 € for each kW.
  - o *Charger*: the cost of the en-route inductive charging point. Software and Hardware cost associated with the en-route charging point included.
  - o *Installation*: average costs of civil works, testing and commissioning of the charger described in the previous point (not including work licenses)
  - o *Project management*: the staff costs of a worker that will work two days per month in these activities.
  - o *Engineering*: cost of carrying out the project: technical basis on which the charging station will be installed and economic evaluation of the project.
- **OPEX (Operating Expense)**: these are the operational costs to run a charging station during one year. The below are the costs to be considered:
  - o *Energy costs*: cost of the total energy consumed to charge the EV during a year.
  - o *Power term*: it is the price that the Service Provider will pay for the electrical power installation. Figure depends on consumption.
  - o *Charger maintenance*: cost incurred to maintain the deployed infrastructure per year.
  - o *Space cost*: the cost that the Service Provider will pay to the council in order to install the charging point in the public thoroughfare.
  - o *Commercial system*: cost of the management and control application of the charging point, customers' billing and electro mobility added value.
  - o *Communications*: annual cost of the charging infrastructure communication with the electric vehicle in the charging process and the central management system.
  - o *Back end*: cost of the information system and necessary telecommunications updating to connect the charger to the control center and the management system.

- o *Insurance*: insurance costs of the en-route inductive charging station.
- o *Project management*: staff cost dedicated to the management of the company created as a Service Provider.

Revenue streams: it refers to how the Service Provider can make incomes from each of its customers. The Service Provider will offer a monthly rate to its customer segments in order to get revenues that cover the costs, that is, to obtain benefits defined by its business model.

The installation costs (CAPEX) will be the same both for public taxis and for delivery vans, as the installation of a new charging station does not depend on the vehicle type.

On the other hand, the operational costs (OPEX) depend on the vehicle type, as the energy costs are different for each business. In our scenario public taxis will need more energy than delivery vans to complete a workday, so the service provider should have a higher cost in energy for public taxis stations than for delivery vans.

Installation costs (CAPEX – Capital Expenditure)

The installation costs of a new charging station are shown in the below figure.

We are considering a depreciation period of 10 years and an interest rate of 4.25%.

With these values we can calculate the yearly investment needed for a new charge station depending on the power type.

According to the workday autonomy quantitative analysis performed in previous section, we should consider the 22kWh figure for public taxis and the 7.3kWh figure for delivery vans.

Yearly CAPEX expenses for a public taxi charging station: 7762.87€

Yearly CAPEX expenses for a delivery van charging station: 4341.39€

Table 12: Inductive spots installation costs

INDUCTIVE SPOTS INSTALLATION COST (CAPEX)				
Power (kWh)	3,7	7,3	22	50
Grid connection	74,00 €	146,00 €	440,00 €	1.000,00 €
Equipment cost	3.000,00 €	6.000,00 €	30.000,00 €	50.000,00 €
Installation cost	20.000,00 €	20.000,00 €	20.000,00 €	20.000,00 €
Project Management	9.264,00 €	9.264,00 €	9.264,00 €	9.264,00 €
Engineering	2.000,00 €	2.000,00 €	2.000,00 €	2.000,00 €
Number of stations	1	1	1	1
TOTAL	**34.338,00 €**	**37.410,00 €**	**61.704,00 €**	**82.264,00 €**
Depreciation period	10	10	10	10
Interest rate	4,25%	4,25%	4,25%	4,25%
Yearly CAPEX expenses	**3.579,74 €**	**3.899,99 €**	**6.432,64 €**	**8.576,02 €**

10.4.2.1 Public taxi

Operational costs (OPEX – Operating Expense)

The operational costs depend on the needed energy for each business type. Each public taxi will need to charge 15kWh each day in order to complete the workday. We should consider:

- The maintenance costs are considering a 10% of the equipment cost.
- We are considering the service provider pays 0.1€ for each kWh delivered.
- Considering the autonomy calculations performed above, a taxi should be charging the vehicle during 2 hours each day.
- As there are 3 coils installed in the station, 3 taxis will use the 3 coils during 2 hours for charging purposes.
- Considering the charging spot works 12 hours a day, it will cover 18 taxis for a workday (6 blocks of 2 hours x 3 taxis each 2 hours).
- The above scenario would be perfect where the taxis are not overlapping for charging purposes, but the reality is that there will be times when taxis would like to use the spots at the same time.

For this situation, a Quality of Service ratio may be included. In the first calculations we will use a ratio of 2/3. With this ratio a station would cover 12 taxis during a working day instead of the 18 taxis, minimizing the waiting time for charging.

Considering the workday autonomy calculations performed for public taxis, we should consider the result for 22kWh power station, highlighted in green in the below figure.

Table 13: Inductive spots operational costs for public taxis business

INDUCTIVE SPOTS OPERATIONAL COST (OPEX)				
Power (kWh)	3,7	7,3	22	50
Charger maintenance	300,00 €	600,00 €	3.000,00 €	5.000,00 €
Energy costs	4.692,86 €	4.692,86 €	4.692,86 €	4.692,86 €
Power term	1.230,00 €	1.230,00 €	1.230,00 €	1.230,00 €
Space cost	0,00 €	0,00 €	0,00 €	0,00 €
Commercial system	1.440,00 €	1.440,00 €	1.440,00 €	1.440,00 €
Comunications	180,00 €	180,00 €	180,00 €	180,00 €
Back end	1.440,00 €	1.440,00 €	1.440,00 €	1.440,00 €
Insurance	2.000,00 €	2.000,00 €	2.000,00 €	2.000,00 €
Number of stations	1	1	1	1
TOTAL	**11.282,86 €**	**11.582,86 €**	**13.982,86 €**	**15.982,86 €**

Revenue streams

With the previous CAPEX and OPEX calculations, the yearly cost for service provider with a benefit margin of 10%, we can obtain the following revenue stream.

Table 14: Inductive spots yearly costs for public taxis business

INDUCTIVE SPOTS TOTAL YEARLY COST				
Power (kWh)	3,7	7,3	22	50
TOTAL yearly cost	**14.862,59 €**	**15.482,85 €**	**20.415,50 €**	**24.558,88 €**
Service Provider Margin	10%	10%	10%	10%
Revenue stream	**16.348,85 €**	**17.031,13 €**	**22.457,05 €**	**27.014,77 €**
Monthly rate per taxi	**113,53 €**	**118,27 €**	**155,95 €**	**187,60 €**

Considering that one charging station will be installed for 12 public taxis, the drivers will have a monthly rate of 155.95 €.

There should be some charging limitations for the drivers, as this rate considers each taxi needs 15kWh in a working day.

Driver's costs comparison

With the monthly rate calculated above, we should check if the taxi driver has a cost benefit comparing with diesel and hybrid taxis.

Table 15: Vehicle type costs comparison for public taxis

	Consumption	Price	Daily spending	Yearly spending
Diesel Taxi	6,5 l/100km	1,35€/l	17,55 €	4.575,54 €
Hybrid Taxi	4,5 l/100km	1,35€/l	12,15 €	3.167,68 €
EV Taxi	15kWh / day	N/A	N/A	1.871,42 €

With the above results we can conclude that the taxi drivers benefits of using an electric vehicle and using the inductive charge:

Yearly saving against diesel: 2704.11€

Yearly saving against hybrid: 1296.26€

With these results, the taxi drivers should be encouraged in order to change from diesel/hybrid to EV taxi.

10.4.2.2 Delivery van

Operational costs (OPEX – Operating Expense)

The operational costs depend on the needed energy for each business type. Delivery vans will need to charge 4.5kWh each day in order to complete the workday. We should consider:

- The maintenance costs are considering a 10% of the equipment cost.
- We are considering the service provider pays 0.1€ for each kWh delivered.
- An inductive spot of 7.3Wh with 2 coils would bring an average of 3.7kWh to each coil.
- Considering the autonomy calculations performed above, a van should be charging the vehicle during 1.2 hours each day.
- As there are 2 coils installed in the station, 2 vans will use the 2 coils during 1.2 hours for charging purposes.
- Considering the charging spot works 12 hours a day, it will cover 20 vans for a workday (10 blocks of 1.2 hours x 2 vans each 2 hours).
- The above would be a perfect scenario where the vans are not overlapping for charging purposes, but the reality is that the vans would like to use the spots at the same time. Then we may include a Quality of Service ratio. In the first calculations we will use a ratio of 2/3. With this ratio a station would cover 13 vans during a working day instead of the 20 vans, minimizing the waiting time for charging.

Considering the workday autonomy calculations performed for delivery vans, we should consider the result for 7.3kWh power station, highlighted in green in the below figure.

Table 16: Inductive spots operational costs for delivery vans business

INDUCTIVE SPOTS OPERATIONAL COST (OPEX)				
Power (kWh)	3,7	7,3	22	50
Charger maintenance	300,00 €	600,00 €	3.000,00 €	5.000,00 €
Energy costs	1.525,18 €	1.525,18 €	1.525,18 €	1.525,18 €
Power term	1.230,00 €	1.230,00 €	1.230,00 €	1.230,00 €
Space cost	0,00 €	0,00 €	0,00 €	0,00 €
Commercial system	1.440,00 €	1.440,00 €	1.440,00 €	1.440,00 €
Comunications	180,00 €	180,00 €	180,00 €	180,00 €
Back end	1.440,00 €	1.440,00 €	1.440,00 €	1.440,00 €
Insurance	2.000,00 €	2.000,00 €	2.000,00 €	2.000,00 €
Number of stations	1	1	1	1
TOTAL	**8.115,18 €**	**8.415,18 €**	**10.815,18 €**	**12.815,18 €**

Revenue streams

With CAPEX and OPEX previous calculations, we have the yearly cost for service provider.

- Considering that service provider will have a benefit margin of 10%, we can obtain the revenue stream.

Table 17: Inductive spots yearly costs for delivery vans business

INDUCTIVE SPOTS TOTAL YEARLY COST				
Power (kWh)	3,7	7,3	22	50
TOTAL yearly cost	11.694,92 €	12.315,17 €	17.247,82 €	21.391,20 €
Service Provider Margin	10%	10%	10%	10%
Revenue stream	12.864,41 €	13.546,69 €	18.972,60 €	23.530,32 €
Monthly rate per taxi	82,46 €	86,84 €	121,62 €	150,84 €

Considering that one charging station will be installed for 13 delivery vans, the drivers will have a monthly rate of 86.84 €.

There should be some charging limitations for the drivers, as this rate considers each taxi needs 4.5kWh in a working day.

Driver's costs comparison

With the monthly rate calculated above, we should check if the delivery van driver has a cost benefit comparing with diesel and hybrid taxis.

Table 18: Vehicle type costs comparison for delivery vans

	Consumption	Price	Daily spending	Yearly spending
Diesel Van	6,5 l/100km	1,35€/l	13,16 €	3.431,65 €
EV Van	15kWh / day	N/A	N/A	1.042,05 €

With the above results we can conclude that the drivers benefits of using an electric vehicle and using the inductive charge:

Yearly saving against diesel: 2389.60€

With these results, the drivers should be encouraged in order to change from diesel to EV delivery van.

10.5 User perception

A key factor for inductive charging systems' installation success is the citizens' perception. There are 3 main factors to be considered for users' perception analysis:

10.5.1 Citizens' mobility

The first aspect to consider is to check if the mobility of other users of the street is affected by the installation of the new inductive charge spots.

The introduction of inductive charging system should not physically affect the mobility of the pedestrians and the bicycle riders, considering that the maximum height of a new item in the pavement is limited. The new spot with the coil installed in the pavement should accomplish these rules.

10.5.2 Citizens' visual perception

At this stage, with the plug-In cable solution, and in order to promote the EV usage, the charging spots infrastructure has an attractive design. The same should be done for inductive charge spots, where the new infrastructure design should be more user friendly.

10.5.3 Citizens' concerns

The introduction of new inductive charge spots implies the installation of a new electromagnetic system in the street. Usually the population is reticent to changes and especially if they perceive a possible danger on it.

An example is the introduction of Wi-Fi spots all over the city. In this case, the benefits perceived by the citizens overcome the worries of the installation of Wi-Fi spots. A neighbour will not concern about the installation of a Wi-Fi spot next to his house because he/she benefits of this service, but in a first stage a neighbour will be reticent about the installation of inductive charge spots because he/she is not benefiting of it .

Some important considerations regarding the inclusion of a new electromagnetic system are described below:

- The introduction of many signalization of the inductive system should be avoided in order to not alarm the citizens.
- Citizens should know that the inductive system accomplishes all the security rules and does not have negative impacts for them. It should be clearly communicated that inductive charging infrastructure does not negatively impact on health.
- Citizens will be reticent to have a new electromagnetic system, new cables, etc. next to his private parking spot, as initially the citizens do not perceive an improvement for the community. This perception should be changed promoting the benefits of the inductive system.
- Citizens should be clearly informed that the system is only “ON” if there is a car placed over the inductive system and is “OFF” if the connection between the EV inductive infrastructure and the coil has not been accepted.

10.6 Signalization

New signalization should be included in the city in order to inform about the position of the inductive charge points. The following topics should be considered:

- Traffic signal to identify street charge spots.
- Frequency of these signals to ease the spots identification.
- Design of these signals for easy identification.

The signalization will be focused only on delivery vans charging spots, as taxi drivers know exactly where taxi stops are located, and hence will know which of these stops have inductive charge systems available.

A main objective is to have the signalization the most standardized as possible for all the cities.

Traffic signals are divided in 4 main groups, each of which is analysed for the necessity to include new signals for inductive charging spots.

10.6.1 Informative signalization

These are the traffic signals that inform about the localization of city main streets and spots. These signals will not include information about the inductive charge spots, as we are considering these signals to be far enough from the localization of the spot.

Figure 43: Informative signalization in the city of Barcelona

10.6.2 Guidance/Approximation signalization

These are the traffic signals used for final guidance to the user, when the spot is in the next 200 meters. A typical example is the signalization of a parking.

In this situation, traffic signals will be used in order to inform about inductive charging spots. These signals should clearly differentiate between a conductive and an inductive charging spot; even they should identify a hybrid spot.

10.6.3 Regularization signalization

These traffic signals are used in order to regularize something (in this scenario the usage of the spot) and to fine if a driver does not accomplish these rules.

They should include:

- Charge period of time
- Type of vehicle allowed to charge

Figure 44: Plug-in charge regularization signalization in the city of Barcelona

New signalization should be included for inductive charge (in the above examples the plug-in cable is displayed, new symbol for inductive charge should be designed).

10.6.4 Communication signalization

This is signalization used to bring additional information to the drivers. In our specific case of inductive charge, we should study how to help the driver in the car positioning, as the car should be correctly aligned with the inductive system in the floor.

The best approach should be studied, it should mainly paint some lines in the floor to correctly align the car and without using a colour reserved for other objectives (e.g. yellow colour identify loading/unloading spots).

This is an example of communication signalization in Barcelona, identifying a ‘school path’, used to increment the security and autonomy of the children in his way to the school:

Figure 45: Communication regularization signalization in the city of Barcelona

10.7 Maintenance

The introduction of inductive charge system in the pavement will have some implications in the maintenance. In Barcelona, the pavement is changed periodically following some standards. With the introduction of inductive charging additional issues should be considered:

- Cost of pavement replacement in spots with inductive charge system. A common figure is to have some pavement maintenance every 4 years. The coils are installed inside a concrete structure in the pavement. The coils should be extracted and installed in the new concrete structure when the pavement is replaced. Another option would be to install new coils when the pavement is replaced. Any of these two options will not represent a high cost and would be assumed in the general pavement replacement budget.
- Cost of changing the organization of the parking spots (the inductive charging structure should be moved).

10.8 Payment methods

The introduction of inductive charge technologies for electric vehicles opens new possibilities in order to do the vehicle charge payment.

- **Hybrid method**: to use the existing charge spots, using the existing cards for payment, having to “feed the meter”. This solution would be used in an eventual first phase but it should be replaced by the wireless ones. The advantage is that it does not require an implantation cost but the constraint is that it is not efficient for the driver.

Figure 46: EV payment card in the city of Barcelona

- **Contactless**: this solution would install a new smart payment system that detects the car information when the charge is done. This solution should be used in an eventual second phase, where the user would have software installed in the car recognizing the start of the charge and asking for user confirmation. With this solution the driver can stay inside the vehicle and complete all the charge and payment process without going out of the vehicle, but the constraint is that it requires a high implantation cost.

10.9 Policies

The installation of new charge spots in the city should consider that some different policies should be accomplished:

- Permissions to add new charge spots in the public land: this permission depends on the city council; this organism should bring an authorization of public land space reservation. Currently the electric vehicle charge is free in Barcelona; these policies to take an economical benefit of the public land usage should be regularized.
- The new charge spot should follow the existing rules or urban landscape.
- Restrictions of usage of the charge spots for vehicle type. The public administration should define the rules in order to fine the vehicles using the installation spots where they are not allowed. Taxi spots should only be used by taxis and delivery van spots should only be used by vans in the pre-defined timeframe. The signalization should be clear enough, indicating the prohibition of usage of these spots by other vehicle types.
- The taxi ranks should consider a new scenario, the taxi drivers should be educated in order to understand and use the inductive charge spots in an efficient way:
  - Vehicle positioning in the queue spot should be respected.
  - If the inductive charge spots are not installed in the current taxi rank queue, the turns should be managed and respected accordingly. New regulations for EV promotion can be included permitting to choose an electric taxi instead of a diesel one even if it is still not its turn.

10.10 Conclusions

UNPLUGGED vision and particularly the implantation of inductive spots in urban areas will produce relevant benefits for businesses and the society.

- Public taxis and delivery vans drivers will benefit of the installation of inductive spots in terms of usability in their daily workday routines.

- Public taxis business depends on driving time. To minimise their stop time, we can conclude that taxis need 7.3 kWh inductive charge stations. On the other hand, delivery vans business includes significant stop time, so in this case lower power 3.7 kWh charging stations are enough to cover delivery vans daily business needs.

- Public taxis and delivery vans drivers will benefit of the installation of inductive having a considerable saving in energy cost.

- The global distribution of the inductive charging stations in the whole municipality are considering commercial spots coverage, tourism zones, connectivity with other transports, services for citizens (hospitals, schools, etc.) and neighbourhood streets distribution.

- The specific distribution of the inductive charge spots should take advantage of the taxi queue in order to install several coils in the taxi rank allowing that several taxis use the charging system at the same time.

- The installation of inductive charge system in loading/unloading bays makes sense for short time stops (until 30 minutes stop time). For longer time stops the plug-in charge system fully covers the driver's needs.

- Citizens' perception is a key factor for the inductive charging system installation success. The information should insist on the benefits of the inductive system, should not be massive and should indicate the safeness of the installation.

- New signalization should ease the guidance to the charge stations and should ease the EV positioning in the taxi rank as the car positioning is a key challenge. Additionally the signalization should regularize the usage of the inductive spots and define fine rules.

11 Appendix 3: A Study of Needs and Boundary Conditions for the Implementation of Inductive Charging Infrastructure for EVs Within London

11.1 Introduction

This document presents a study of the boundary conditions Transport for London (TfL) considers key to the integration of wireless power transfer (WPT) technology for electric vehicles within the urban realm. Many of the matters discussed here were addressed with London's infrastructure in mind, but the intention is for the concerns and solutions proposed to be transferable to other urban environments. The main body of this draft is based on stakeholder discussions undertaken with parties both internal and external to TfL.

For this study, the vehicle types under consideration are taxis and light goods vehicles, as the usage patterns of these vehicles are in the high utilisation/low stationary time category, which will provide an opportunity to examine scenarios beyond those that can be resolved by overnight plug-in charging.

11.2 Current Scenario

11.2.1 Taxis

There are currently 22,000 'black cab' taxis in the London region. The Private Hire Vehicles (London) Act 1998 provides for the licensing and regulation of private hire operators, drivers and vehicles within the areas of the Great London Authority and the City of London. TfL is the Licensing Authority, the day-to-day licensing function is carried out by London Taxi and Private Hire (LTPH), which is part of TfL. LTPH also has responsibility for licensing London's taxi industry, and has done so for over 150 years.

Taxi rank outside St Pancras International railway station, London

Figure 47 London Taxi Rank

60% of the black cabs in the region are owned and operated by individual drivers, with the remaining 40% shared between 150 companies that either employ drivers or lease the cars to drivers.

In terms of alternative fuel vehicles, there are currently five hydrogen fuel cell EV black cabs being operated in the London region.

11.2.2 Light Goods Vehicles

Current TfL figures estimate that there are more than 220,000 light good vehicles in use in London. The majority of these vehicles are diesel ICE, at 210,000.

In terms of alternative fuel vehicles, there are in the region of 700 LPG and 270 EV vans being operated in the London region.

TfL developed a city-wide network of plug-in electric vehicle charge points branded as Source London. Launched in May 2011, the scheme initially provided 150 charge points, with that number rising to 1,300 by the close of 2014. The scheme has charge points located in residential streets, public car parks, shopping centres and supermarkets. Although not primarily developed for commercial business use, a number of corporate entities established fleet accounts with Source London, such as Enterprise Van Hire.

TfL is working in partnership with a number of UK-based stakeholders on the FREVUE project, which aims to facilitate and improve the awareness and uptake of electric vehicles for commercial fleet purposes.

Other air quality initiatives within London that support the uptake of EV vans include the Zero Emissions Network, a collaboration between the London boroughs of Islington, Hackney and Tower Hamlets, which provides business with free trials of electric vans.

11.2.3 Wireless Charging for EVs and Parking Spot Alignment

As a matter of priority, vehicle manufacturers need to work with WPT technology developers to define a standard for the positioning of secondary coils in vehicle bodies. In many instances, receiver pads are located under the front suspension, but there are exceptions. The technology allows for a degree of misalignment, but a vehicle with secondary coils situated beneath the rear axle might take up two bays where the primary coil charging infrastructure is geared towards vehicles with a front suspension configuration. This could be addressed by having two sets of coils per bay, but this option is not economically viable due to cost of infrastructure/materials.

Interoperability between an array of proprietary infrastructure designs is also necessary. Wireless charging infrastructure providers such as Qualcomm Halo have undertaken research and development into multi-coil primary base pads that are capable of supporting a variety of secondary vehicle pad designs, such as single circular/square and single solenoid coils.

11.2.4 Power Grid and Capacity

One of the major potential issues hindering the development of a wireless charging infrastructure network is the significant demand it will place on an already constrained grid.

In the UK, the connecting customer (in this case the wireless charging network) must pay a proportion of the cost of network upgrade where it is required. The proportion is calculated based on the share of new capacity created that will be used by the connecting customer. The remainder of the cost will be paid by other network users through their electricity tariff.

In addition to reactive network improvements, the distribution network operators (DNOs) can invest ahead of need and recover the cost from its customers through their electricity bills. However, they can only do so when they have demonstrated that the benefits to customers outweigh the cost and will benefit network users. Unless it can be demonstrated that installing a wireless charging network (with necessary network upgrades) is of benefit to other network users, it may be that the wireless charging network operator will be liable for the full cost of upgrades.

DNOs cannot make speculative upgrades of the network unless they have demonstrated that such upgrades will benefit all network users.

11.3 Location of the Recharge Spots – General Study

11.3.1 Taxis: An Overview

A number of locations have been identified as possible trial sites for inductive charged taxis:

- **London City Airport** (this location will be examined in further detail below)
- **Heathrow Airport** (this location will be examined in further detail below)
- **King's Cross and St Pancras International railway stations:** these are the two most frequently attended London terminal railway stations by black cabs.
- "**Cabman's Shelters":** these are small, one-storey cabin-like structures placed on the highway within Central London for use by London taxi drivers for refreshment/relaxation. Drivers are permitted to leave their taxis for up to 45 minutes in the corresponding taxi parking whilst using the shelters. Of the 61 built between 1875 and

A Cabman's Shelter with corresponding taxi parking in Central London.

Figure 48: Cabmans Shelter

1914, only 13 remain at locations around central London, with taxi parking which could be utilised for charging spots.

- **Rest ranks:** There are a further 16 designated taxi rest ranks situated around Central London at which drivers are permitted to leave their taxis for a maximum of one hour. Again, this parking could be utilised for taxi charging spots.

11.3.1.1 Taxis: Airport Scenario

With a traditional taxi rank/stand, taxis take continuous, incremental step-by-step forward movements: they do not move along a rank by whole vehicle lengths at a time, and longitudinal alignment within the rank can differ depending on the make/models of vehicles in the rank at any given time. Clearly this is problematic for the current generation of static wireless charging technologies.

Therefore, behaviour change is a key consideration if wirelessly charged taxis and charging spots are to be introduced. An already existing practice that could be utilised to provide a viable solution as to how the taxis can engage with the charging infrastructure would be to adopt the ‘taxi feeder park’ approach currently used by London’s Heathrow and City Airports to manage taxi traffic.

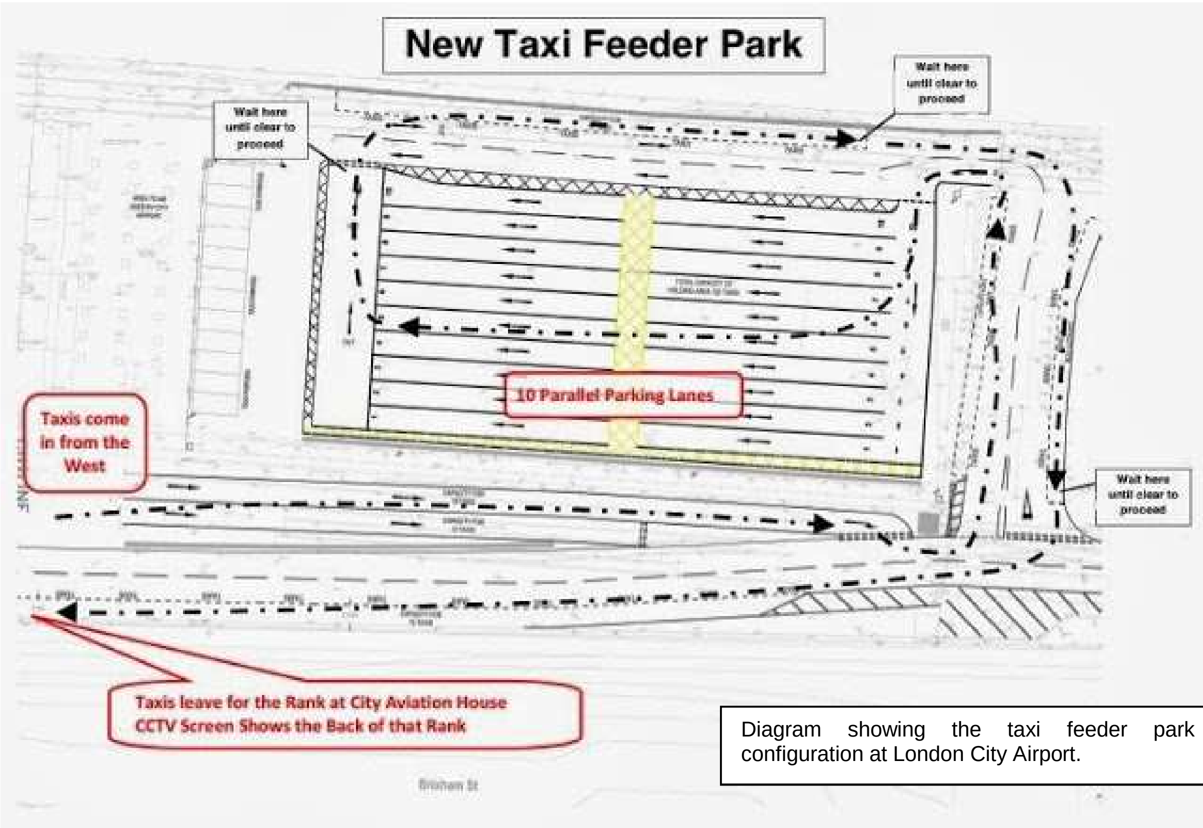

Diagram showing the taxi feeder park configuration at London City Airport.

Figure 49: Taxi feeder park

Black cabs arriving at the airport are required by law to enter a taxi feeder park to queue before being eligible to enter a taxi rank outside the airport’s terminals, where they are permitted to pick up passengers. The taxi drivers are charged a fee for entering the taxi feeder park to cover the administration and maintenance costs of its operation. Drivers are able to switch of their engines and, if they wish, leave their vehicles until it is time for their line to move forward out of the feeder park area.

A ‘holding pen’ arrangement such as this, with blocks of ten clearly defined parking spaces (charging spots) where taxis stay stationary over a charge pad for an extended duration (at peak periods taxis can remain in the feeder park for up to two hours) would encourage a semi-dynamic rank feeding process, allowing taxis to acquire a sufficient charge.

Marshalling, either by manual or electronic means could be used, with vehicles called by number relocate or leave pen and join rank queue once charged. As with Heathrow, this scenario would suit locations such as airports and major train stations. However, this concept would call for a major change to how taxi ranks at this other locations have traditionally operated, and would be contingent on the space available to host the holding pens. The transition to such an approach would also have to consider the integration of diesel taxis during the early stages of EV uptake.

11.3.2 Light Goods Vehicles

For delivery vans, the following types of location have been considered for wireless power transfer technology deployment:

- **Distribution Hubs:** should be considered, enabling the large-scale installation of charge spots to minimise infrastructure costs. Freight company UPS is in the process of deploying 16 EV vans based out of a specially-facilitated logistics hub in north-west London. They will be converting 15-year-old diesel vans for the purpose and installing conductive, plug-in EV charge points to support the fleet. Such an initiative would be a prime candidate for a large-scale inductive charging trial at a later stage, as many of the location-specific concerns encountered during the development of a plug-in fleet, as well as valuable usage and performance data, would inform a strategy for the rolling out of a multi-vehicle wireless charging facility. Further issues to consider may include:
    - o It may be possible to install primary coil infrastructure at 10 loading bays, but have energy distribution infrastructure to power up to any five of these coils at one time, providing flexibility but reducing overall costs.
    - o The optimum location for distribution hubs may be outside of Transport for London's geographical area of influence, so further incentives would need to be explored.
    - o In London there are a number of distribution companies that run 'owner/driver' fleets (e.g. Amazon) with no standard routes, leading to less formal operations and consequently significant economic and behavioural barriers to the uptake of the previously discussed models. An extensive study to profile the make-up of delivery fleets within London would be required.
- **Shopping Centres:** Where shops are clustered together, a single wireless charging-enabled parking spot could be provided to service a collection of shops, meaning the delivery vehicle will spend more time stationary while the delivery operative is walking deliveries to their destinations, giving the vehicle time to receive a charge. In London, shopping centres such as Westfield London and Westfield Stratford City could be prime candidates for such a trial: as part of the Source London network: there are currently 60 plug-in charge points across both sites. This initiative benefitted greatly from the flexibility of having fewer stakeholders to be consulted, as Westfield Group owns both sites. Compare this with the matters addressed in 'Roadside Loading Bays' and 3.3 below.

Figure 50: EV charge points in shopping centre

- **Roadside Loading Bays:** the possibility of providing additional time in public highway loading bays to electric vehicles, giving time to receive a reasonable level of charge requires further investigation. There is also a need to consider alignment issues in loading areas: for example, a solution may be to position charging bays at either end of loading bays, reducing the chance of inductive charge spots being partially obscured by other vehicles. However, an important factor influencing the placement of WPT charge point infrastructure in such locations is the need to gain approval from borough authorities to allocate already limited parking or loading bay space for the exclusive use of EVs, with the acceptance of such schemes being subject to political and socio-economic pressures and trends. However, it is hoped that, with the continued uptake of EVs in general, a more receptive climate for the deployment of an infrastructure that supports this growth will be nurtured.

11.3.3 Location of Charge Spots: Maintenance & Management

- All permit parking activities on the Transport for London's Route Network (TLRN) are agreed with and managed by the 33 London boroughs affected. This includes, for example, electric vehicle bays.
- There are two main legislative mechanisms by which TfL can place infrastructure on the highway. The first requires that TfL accept future maintenance liability for the infrastructure, which in this case, means the assets being placed on the highway will be subject to a Section 8 (Highways Act 1980) agreement. If the maintenance responsibility remains with the wireless charging infrastructure manufacturer or the organisation trialling the technology, the works would be undertaken under a Section 50 (New Roads and Street Works Act 1991) agreement.
- A recent example of a new infrastructure trial taking place on the highway as part of a Section 50 agreement is where TfL are working with Westminster City Council who are trial electronic parking beacons in the carriageway. These are an asset that Westminster will maintain but will be on the TLRN.
- In terms of practical considerations, there is a need to ensure that there is sufficient kerbside space available to allocate to a specific use. TfL also need to ensure that any associated assets on the footway can be accommodated and that there is not an adverse street clutter effect.
- Care must be taken to minimise the visual impact that these devices have on the carriageway – this will be especially critical when planning to place them in conservation areas or areas of historical importance.

11.4 Impact on the Grid: Mitigation Measures

11.4.1 Recommendations

- Consideration should be given to how the peak times when drivers are likely to charge compare with grid load demand profiles. Further work is required in two areas in order to do this:
    - Determine when drivers are most and least likely to access charging infrastructure during the day.
    - Analyse substation load profiles on a site-specific basis once potential chargepoint locations have been determined.
- Consideration should also be given to a pricing incentive to influence charging times. For example, using time of day pricing to encourage drivers to access charging at times of lower electricity demand would help to balance the grid.
- Energy storage, either with dedicated batteries or as a second life for used EV batteries which has two potential benefits:
    - More chargepoints could be installed at a given location without additional network upgrades.
    - As the proportion of renewables like wind and photovoltaic which are susceptible to fluctuations increases in the National Grid, local energy storage can help to smooth out grid supply and demand.
- Locally generated renewable energy can further decarbonise the supply of electricity to taxis. This technology is already in use in the Netherlands, where Fastned charging stations generate electricity using photovoltaic panels. This option may be suitable for larger charging hubs in London.
- Battery swapping technology could also help to balance grid demand but currently this is not a mainstream technology and would be a land intensive solution.
- Grid balancing through a localised smart grid to manage the power delivered by individual chargepoints is advisable; though this must be balanced against drivers' expectations of the time it will take to recharge their vehicles.

- Additionally, to reduce the total cost of network upgrades, charge point network operators should consider either having single points which can be added to the existing network, or installing a cluster or hub of charge points, upgrading the network as required.

11.4.2 Further Considerations

- Currently, the UK's energy supplier's regulatory body, Ofgem, requires customers to pay for the electricity delivered, i.e what leaves the charge pad, not what is received. Therefore, if a primary and secondary coil is poorly matched there will be a loss in efficiency from poor positioning. This is another area where standardisation is key.
- This can be coupled with a need to incentivise more efficient parking at charging spots: users receiving feedback on their parking performance via software application that can provide a visual demonstration of how much energy/cost they have saved to use asset influences by them getting feedback about what they have done e.g. how much they have saved.

11.5 EV Taxi Research and Driver Attitudes

Recent research by TfL into the feasibility of EV taxis in London has ascertained the following:

- London black cab drivers cover an average 71 miles per day while working and 98 miles per day including commuting.
- Wireless charging could present a viable means of allowing taxi drivers to cover the miles they need to drive using either a fully electric vehicle or a rapid charge compatible extended range vehicle.
- Ensuring charging infrastructure is available where drivers work, rank or take breaks will be essential to minimise the impact that EV taxis will have on drivers' schedules.
- 46% of drivers stop for 15 minutes or fewer when they take breaks. Therefore a high power capacity is necessary so that drivers can recharge without additional downtime.
- Strategically locating charging infrastructure is also of critical importance to maximise utilisation rates, increasing revenue for the network operator(s).
- The majority of drivers who acquire any kind of EV taxi will need to install a dedicated home charging point. 70% of London black cab drivers surveyed appear to have the capability to do so as they have access to private parking.

On an economic level, taxi drivers are very aware of fuel costs per mile/km, far more so than normal consumers: if a clear reduction in cost for electric charging can be demonstrated, enforcement of a new set of behaviours would be a non-issue.

However, over 60% of taxi drivers polled for a recent TfL survey on the feasibility of EV taxis indicated that they cannot afford to lose out on productivity due to charging time, and many travel long distances from outside/Outer London to work within central London, calling for infrastructure investment at their home locations.

11.5.1 Driver's Survey

The following dataset is from a survey of 672 licensed black cab drivers who were questioned as to the possible barriers that may exist to the uptake of EV taxis:

Table 19: Results of driver survey

Perceived barrier	Proportion of respondents
Insufficient range (in miles) between charges	83%
Concern about running out of charge	80%
Nowhere to charge during shifts	66%
High lease / purchase cost	64%
Charging would impact on my productive working time	63%
I may have to charge too often during a shift	63%
Nowhere to charge between shifts	63%
The technology is new and unreliable	48%
Needing to know where the chargepoints are	42%
None	2%

11.6 User perception

11.6.1 Effects of Inductive Charging Infrastructure

To date, wireless power transfer trials have largely involved EV buses. As a consequence, human exposure to electromagnetic fields generated by the charging infrastructure during these trials has been limited and controlled due to the location of primary coils being kept to restricted-access areas, such as bus stations and depots. Inductive charging infrastructure for taxis and delivery vans is likely to be more exposed due to the arbitrary nature of these vehicles' duty cycles. In light of this, further development is required to provide technological safeguards and to publicly disseminate assurances as to the secure nature of the technology, including:

- Foreign object/person detection technologies which can detect objects as small as ½ mm thickness to switch off the system are in development. Qualcomm Halo's WEVC Foreign Object Detection is one example of this.
- Physical barriers, such as lowering the secondary coil to within millimetres of the primary coil are already being used on an inductively charged bus trial in Milton Keynes, UK.
- Further test work on electro-magnetic field strengths needs to be carried out, as guidelines and regulations regarding technology are vague: safe limits need to be clearly defined.
- Publication of evidence-based research promoting the position that inductive charging infrastructure does not negatively impact on health is required.

11.7 Conclusion

Whilst this study has been by no means exhaustive, the intention has been to highlight a selection of key areas where the development of a WPT infrastructure network within London can benefit from the knowledge gained from already existing initiatives and solutions. The feeder park concept found at Heathrow and London City Airports, and the collaboration between the Westfield Group shopping centres and Source London are the most pertinent examples of these.

Consideration has also been given to specific boundary conditions and limitations that need to be addressed within the London region, demonstrating the multi-stakeholder nature of infrastructural development within the urban realm, and the benefits that can be gained from working with private sector organisations and assets.

This last point has been particularly well illustrated in a January 2015 press release from UK-based charge point supplier Chargemaster.

Chargemaster, based in Luton, UK, designs, develops, manufactures and operates charging points for electric vehicles. It has produced over 27,000 charging points for use in public, workplace and domestic locations and operates POLAR, the UKs largest network of public charging points. The company has already installed more than 10,000 'wireless ready' public and workplace charging points in the UK and Europe, which can be easily adapted to include Qualcomm Halo's Wireless Electric Vehicle Charging (WEVC) system.

David Martell, CEO of Chargemaster said, "We have been working with Qualcomm for several years now and this investment is a natural progression. We are very excited about helping to bring the next major evolution in electric motoring to the market, making the electric driving experience even more enjoyable and practical for daily use".

With the benefit of progressive strategising and fruitful collaboration between the public and private sectors, Chargemaster's extensive WPT-ready infrastructure clearly has the reach and potential to elevate this nascent technology into the mainstream.

12 Appendix 4: Interoperability impact on electrical grid - The case study of Firenze

Interoperability could affect the electric grid load: in fact, in a scenario where different companies develop primary sides and secondary sides, different coupling yields could be imagined. Consequently, different yields could generate different loads to the electric grid. In this paragraph, a sensitivity analysis will be proposed to give an overview about the importance of this issue.

An assumption is that for the public transportation system this problem could not be taken into account: in fact, for a bus service, both primary and secondary are designed to correctly interact and it is difficult to imagine a different vehicle that circulates on the electrified path. Vice-versa, for taxi and private mobility, it is something that easily could happen until a strong standardization activity will take place.

Data for the taxi and the private mobility scenario are taken from UNPLUGGED deliverable 3.2.

12.1 The taxi scenario

Within the city of Firenze there are two taxi companies with a total of 654 vehicles. In the Deliverable 3.2 it has been assumed four market penetration options of 5-10-15-25% of the total vehicles to reflect possible near future scenarios.

First of all, the worst case of grid impact without interoperability issues with a 20kW power inverters has been analysed. The "worst case" is the case where all of the vehicles are charging at the same time. Results are reported in Table 20

:

Table 20: Worst case grid request

Number of vehicles	Requested kW
33	660
78	1560
118	2360
197	3940

These data has been compared with the yield vector to analyse the sensitivity with this parameter. Results are reported in Figure 51 and Table 21**Error! Reference source not found.**.

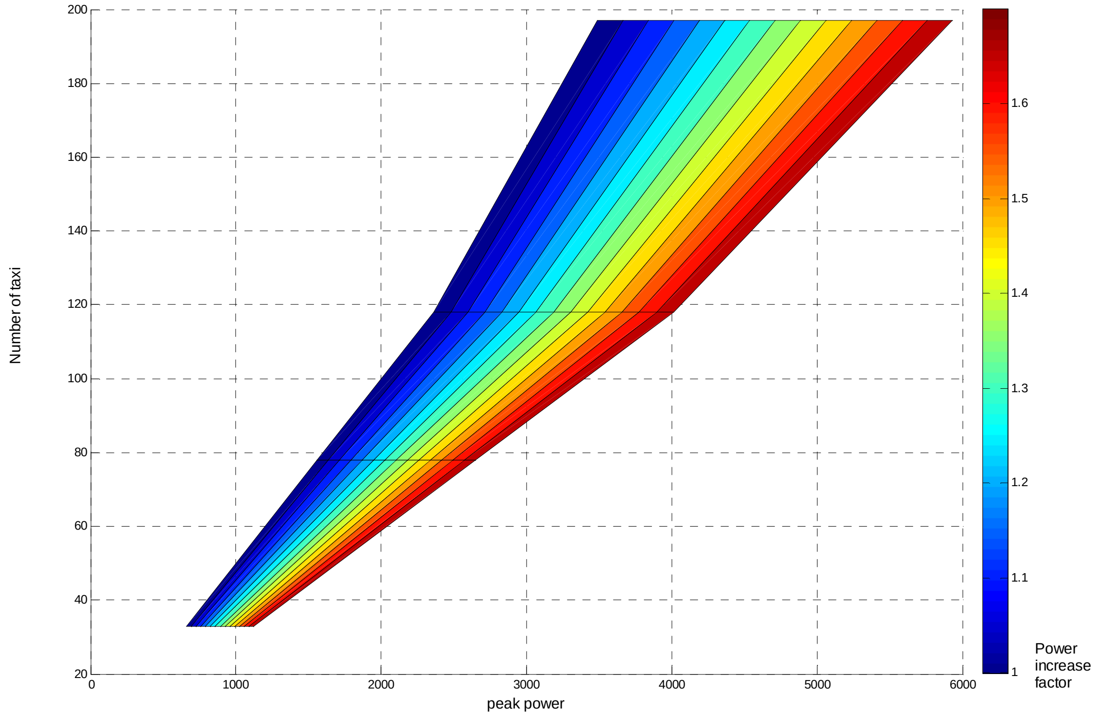

Figure 51- Sensitivity analysis of the power peak requested to the grid

Table 21: Sensitivity analysis of the power peak requested to the grid

Power increase factor	Number of taxi: 33	78	118	197
1	660	1560	2360	3490
1,05	693	1638	2478	3665
1,1	726	1716	2596	3839
1,15	759	1794	2714	4014
1,2	792	1872	2832	4188
1,25	825	1950	2950	4363
1,3	858	2028	3068	4537
1,35	891	2106	3186	4712
1,4	924	2184	3304	4886
1,45	957	2262	3422	5061
1,5	990	2340	3540	5235
1,55	1023	2418	3658	5410
1,6	1056	2496	3776	5584
1,65	1089	2574	3894	5759
1,7	1122	2652	4012	5933

12.2 The private vehicles scenario

Same analysis could be provided also for the total amount of private vehicles that have been hypothesized in Deliverable 3.3. In this case it is important to evaluate both the worst situations with fast charging station (20kW power) and with normal charging (3.7kW power): in fact, for private users, the most probable worst situation is night time when all the vehicles will be charging in domestic areas.

For what concern the 20kW worst case, results are reported in Figure 52 and Table 22:

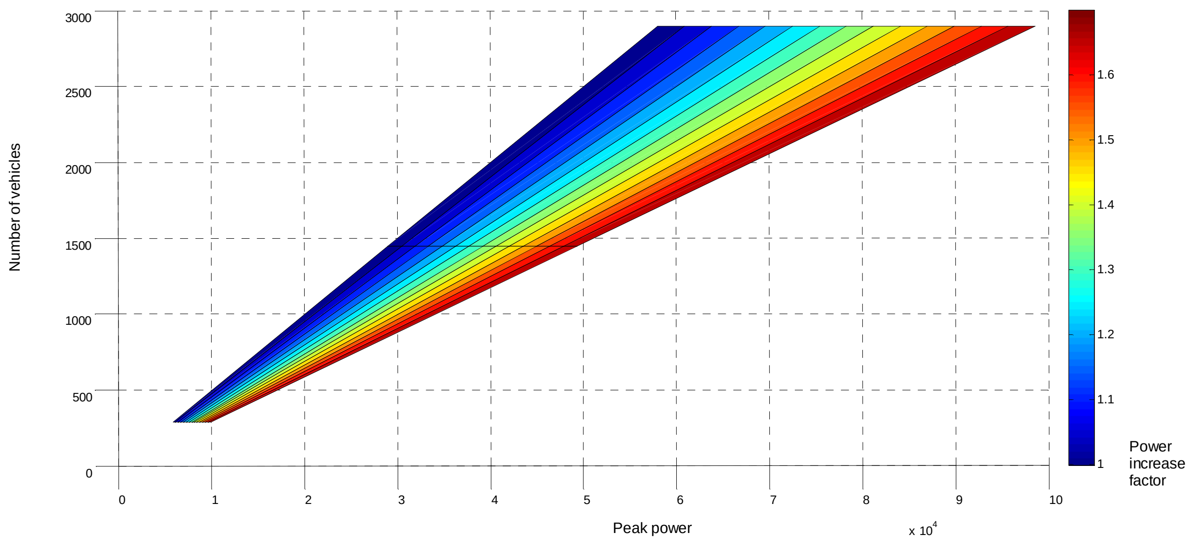

Figure 52 - Sensitivity analysis of the power peak requested to the grid

Table 22: Sensitivity analysis of the power peak requested to the grid

Power increase factor	Number of vehicles: 290	1450	2900
1	5800	29000	58000
1,05	6090	30450	60900
1,1	6380	31900	63800
1,15	6670	33350	66700
1,2	6960	34800	69600
1,25	7250	36250	72500
1,3	7540	37700	75400
1,35	7830	39150	78300
1,4	8120	40600	81200
1,45	8410	42050	84100
1,5	8700	43500	87000
1,55	8990	44950	89900
1,6	9280	46400	92800
1,65	9570	47850	95700
1,7	9860	49300	98600

For the 3.7kW worst case, results are reported in Figure 53 and Table 23:

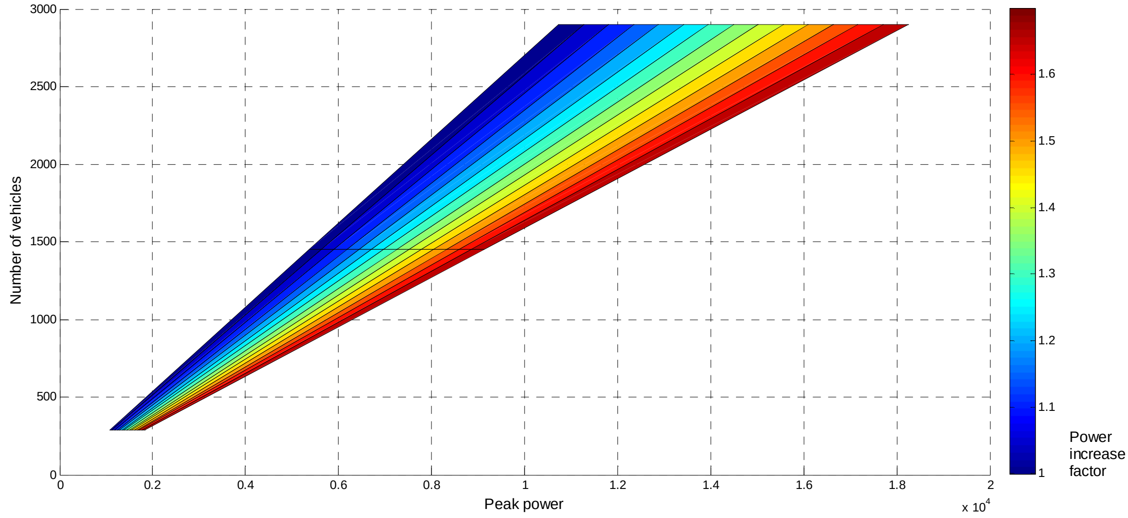

Figure 53 - Sensitivity analysis of the power peak requested to the grid

Table 23: Sensitivity analysis of the power peak requested to the grid

Power increase factor	Number of vehicles: 290	1450	2900
1	1073	5365	10730
1,05	1127	5633	11267
1,1	1180	5902	11803
1,15	1234	6170	12340
1,2	1288	6438	12876
1,25	1341	6706	13413
1,3	1395	6975	13949
1,35	1449	7243	14486
1,4	1502	7511	15022
1,45	1556	7779	15559
1,5	1610	8048	16095
1,55	1663	8316	16632
1,6	1717	8584	17168
1,65	1770	8852	17705
1,7	1824	9121	18241