Deliverable D3.3 – Economic feasibility of en-route charging technical report

Project acronym & number:	UNPLUGGED
Project Number	314 126
Project title:	Wireless charging for Electric Vehicles
Status:	Final
Authors:	UNIFI
Contributors:	CONTI, CRF, ENDESA, ENEL, HELLA, VTEC
Due date of deliverable:	30/06/2014
Document identifier:	UNPLUGGED-D3.3 Economic feasibility of en-route charging technical report APP v150728.01.docx
Revision:	V2.1
Date:	24/07/2015

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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Dissemination Level

PU	Public	X
PP	Restricted to other program participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Change History

Version	Notes	Date
v0.1	Creation of the document (All partners)	20.05.2014
v0.2	Harmonization and first review of the complete document (UNIFI)	24.06.2014
v1.0	Internal peer review (TFL - ENIDE)	03.07.2014
V2.0	Final version (UNIFI)	10.07.2014
V2.1	Updated with conclusion section	24.07.2015

Abbreviations

AC	Alternating Current
BEV	Battery Electric Vehicle
CBP	Circuit Braker Panel
CISPR	Comité International Spécial des Perturbations Radioélectriques
CPM	Charging Point Manager
CSC	Charging System Provider Cost
CSP	Charging System Provider
DC	Direct Current
DoD	Depth of Discharge
DSO	Distribution System Operator
ECU	Electronic Control Unit
E/E	Electro/Electronic
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
eP+R	Electric Park and Ride
ES	Electric Services
ER-EV	Extended Range Electric Vehicle
EV	Electric Vehicle
EVSP	Electric Vehicle Service Provider
EVSE	Electric Vehicle Supply Equipment
FEV	Full Electric Vehicle
HMI	Human Machine Interface
ICE	Internal Combustion Engine
ICNIRP	International Commission for Non Ionized Radiation
ICT	Information and Communication Technology
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IPT	Inductive Power Transfer
ISO	International Organization for Standardization
LF	Low Frequency
LV	Low Voltage
PHEV	Plug-in Hybrid Electric Vehicle
PP	Parallel – Parallel
PS	Parallel – Serial
PTP	Public Transport Provider
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
TRA	Energy Trading Revenues
TSO	Transmission System Operator
V2G	Vehicle to Grid

WPT Wireless Power Transfer

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1 Executive Summary (UNIFI)

The mass introduction of electric vehicles is strictly related to economic model that will be developed for these vehicles. Within this report have been studied the economic issues of both vehicle and infrastructure. From this study it is evident that the major issue for the mass introduction of EVs is related to the availability of infrastructure and how the cost of these will be managed by the service providers. This is not only an economic problem because the electric mobility appeal to final customer has a direct correlation with easiness for the driver to find all the facilities needed and with cost savings from economies of scale. Besides, the facilities diffusion is strictly related to the possible revenues enabled by the new technology. In this classical “chicken-egg” problem, cost understanding and business model developing are key tools to understand the feasibility of this technology and to define how it will be possible to create a virtuous market, able to produce revenues, for wireless recharge of EVs. This step is fundamental to prove the technology profitability and so to encourage investments.

More in details, this document will focus on:

1. The vehicle point of view: an analysis of possible solutions and relative costs needed to enable wireless charging technology has been developed. In particular, this part is divided in two sub-parts, firstly a detailed analysis for the vehicles and then for the E/E and communication systems. For this analysis also the effect of mass production has been considered in order to evaluate the effect of the future diffusion of such technology within the market. For both public and private vehicles the increase of cost due to new hardware and solutions needed is more than covered by the reduction of the battery cost so the inductive charging technology could be considered sustainable from the vehicle point of view.
2. Infrastructure needs and costs. In this chapter an analysis of the recharge infrastructure has been carried out in order to assess the general cost considering different scenarios (public transportation system, taxi transportation system and private mobility) and penetration levels.
3. Business model for an inductive charging mobility system. The above data has been merged together in order to create a business model to evaluate the general sustainability of this technology. In order to evaluate the real life application of this business model the city of Firenze has been used as test case. Within the business model has been considered also the accounting strategies and the possibility to implement smart grid solutions, such as grid to vehicle energy storage. The general result has been that such technology could be profitable in the long period and with public support to create the first core of infrastructure. Considering only the public transportation system for short range buses the break-even point could be reached after 20 years.

It is important to notice that this document is public and so most of the cost information are reported as a percentage normalized on a specific value in order to protect the core business of the involved partners.

2 Vehicle solutions and associated costs for en-route inductive charging (CRF, VTEC)

2.1 On-vehicle solution to enable en-route charging (CRF)

In this chapter a description of the solutions to be developed for on-vehicle architectures to enable inductive stationary and en-route static charging is presented.

Use cases are, for example, charging when the vehicle is in a garage or in a semi-private environment (e.g. supermarket parking), but also on the roads, for example at stop lights.

An evaluation and some hypotheses of associated costs investments necessary for the development and introduction of this technology will be carried on.

En-route dynamic charging will be handled in task 3.5.

2.1.1 Vehicle costs for Stationary/Static en-route charging

Costs related to the development and integration of new technologies, applied to a standard EV, can be divided in two main streams:

- R&D/Engineering Costs
- Component/Device Costs

According to the applied approach for vehicle architecture development and the integration of the new technologies, two main scenarios can be considered:

- Installation on an existing EV vehicle without a specific EV platform (retrofitted EV)
- Installation on a new EV vehicle with a specific EV platform

Furthermore, it is possible to define two scenarios on power levels:

- Low Power Charging Systems: about 3-3,7 kW
- High Power Charging Systems: over 20 kW

On a standard vehicle passenger car, a 3,7 kW system can be compared to a conductive on-board charger, which, while strictly necessary for home application, is limited for enabling a charging time reduction.

For enabling en-route and dynamic charging, an increased power level should be considered in order to attain a consistently high energy level.

As already discussed in deliverable D3.1, an increased power level can be a good solution for en-route charging, allowing a reduction of battery capacity and related costs.

Of course, this implies additional modification to the vehicle architecture.

From the mechanical point of view, the larger dimensions of the charging infrastructure require new solutions to enable integration with the vehicle chassis, also taking into account the crash test constraints.

From the electrical point of view, integration with the existing High Voltage Systems must be evaluated and supplementary safety mechanisms on the vehicle side can be added.

Therefore, costs for high power systems could be much higher than for low power systems, and may be strictly related to an integrated approach that takes into consideration also the infrastructure. In particular, higher development and component costs could be reduced, at least partially, if a battery capacity reduction is possible.

In terms of automotive development, the costs analysis associated with each vehicle modification, additional R&D or engineering costs or each additional component is deeply evaluated and contributes to the definition of a business case, taking into account the production volume estimation.

Depending on the forecasts related to the market, the additional costs for the vehicle integration can vary widely.

In the short-term, the market penetration of EVs seems to remain fairly low compared to conventional vehicles, and different scenarios are more optimistic than others.

Considering government announcements, industry capacities and exploitation and research projects, three possible scenarios can be defined, as described by the study “Impacts of Electric Vehicles – Summary report”, Delft.

In these three possible EV diffusion scenarios various types of EVs are considered, Full Electric Vehicles (FEVs), Plug-in Hybrid Electric Vehicle (PHEVs) and Extended Range Electric Vehicle (ER-EVs):

- Scenario 1: a “most realistic” scenario with 3,3 million EVs in the EU in 2020; hypothesis is based on current technologies and related costs.
- Scenario 2: a “less optimistic” or “niche” scenario, with 2 million EVs in the EU in 2020; hypothesis is based on strong improvements in fuel efficiency of ICEs.
- Scenario 3: an “optimistic scenario” with 5,5 million EVs in 2020; hypothesis is based on the assumption of a breakthrough technologies in batteries.

It is not easy to define how many electric vehicles will be equipped with a wireless charging system, even if it can be considered an enabling technology for the widespread diffusion of EV.

Another favorable aspect is that premium class EVs seems to be a possible starting point for the EV diffusion, at least in the next years, and wireless solution could be a plus for this niche market.

The main application of wireless charging system is the FEV, but it can be a plus also for PHEVs and ER-EVs.

2.1.2 Common costs for all the scenarios

Independently from the scenarios, there are common costs associated with vehicle modifications for enabling en-route static charging.

Additional components must be installed on a vehicle:

- secondary coil and related power electronics unit
- additional high voltage connectors
- communication module
- additional fuses/relays and high voltage safety system (e.g. braking resistors)
- positioning system and HMI
- …

2.1.3 Installation on existing EV

Considering the installation on an existing architecture, costs related to the R&D and engineering modifications, the following items must be considered:

- Low Voltage Cables
- High Voltage Cables
- Additional fuses/relays and high voltage safety systems integration
- Mechanical installation analysis
- Electrical integration analysis
- Vehicle Management SW integration
- Positioning system + HMI Integration
- …

2.1.4 Installation on new EV

Considering a development for a new EV, therefore a new architecture, part of the costs associated with the integration of the new technology can be comprised into the R&D and Engineering charges, but the investment for the development of a new platform is very big and can be planned only over a long-term period.

Some benefits arise from this approach and opportunity:

- possibility to consider the secondary coil installation constraints since the early phases of the project: high power system integration easier
- integration of power electronics components inside other units: optimization of power electronics integration
- design of a specific chassis both for battery pack and secondary coil integration: reduction of wires length and connectors
- …

2.1.5 Scenarios on power levels

From the power levels scenarios, passenger car applications are addressed to Low Power Systems that can be compared to a standard conductive charger:

- easy vehicle mechanical installation due to small dimensions
- easy E/E integration with the existing HV subsystems
- easy communication integration on CAN bus

Even for low power systems, for example in domestic applications, the costs for a wireless charging system (comprised of the infrastructure pad) is higher than a standard on-board conductive charger (even considering the wall-box infrastructure) and cannot be considered as an alternative in the near future without adequate infrastructure and interoperability among different systems.[1]

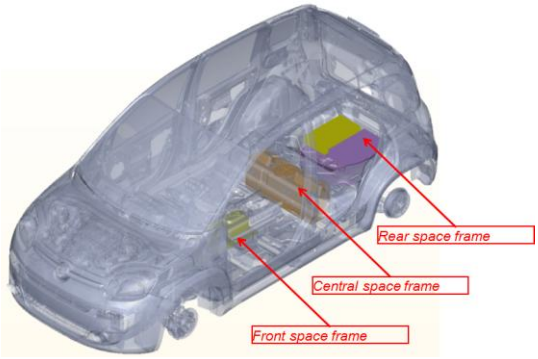

Figure 1 - Space frames in a passengers car

The installation of High Power Systems, especially in passenger cars, require additional costs for a strong integration into/with the vehicle chassis.

Prototype integration analysis for the projects has highlighted these aspects.

On a Light Commercial Vehicle, such as the Iveco Daily, the integration requires a high effort for the mechanical installation, due to the large dimensions of the coil, and for the integration of the power electronics unit, as demonstrated in the image below.

For a series production, with high volumes, integration and optimization activities are necessary-

[1] At around $3,000, including the Parking Pad, control panel, hardware, and installation—the Parking Pad is more expensive than a plug-in Level 2 charger, some of which cost well below $1,000. The comparatively higher price makes the standard even more important, Lisa Jerram, a senior analyst at Navigant Research, told PluginCars.com [1].

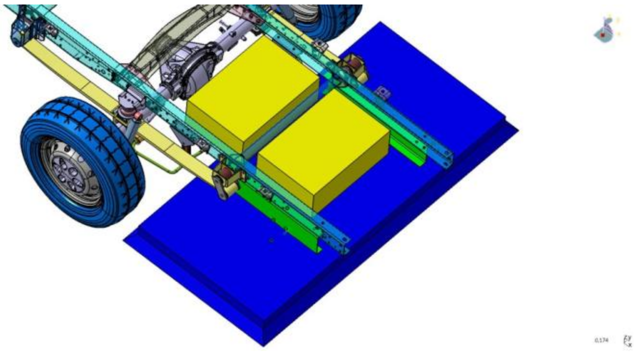

Figure 2 - Iveco Daily integration proposal

2.1.6 Auxiliary systems and HMI solutions

The adoption of auxiliary systems and HMI solutions must be evaluated because they are necessary to guarantee the driver gets the best performance from the wireless charging system.

In particular, as described in deliverable D3.1, the adoption of auxiliary driving systems for drivers, such as Parking Assist, helps the driver with parking maneuvers and allows the best alignment of primary coil with secondary one.

Furthermore, integration with existing or ‘under development’ HMI solutions are useful to offer user auxiliary services, as, for example:

- charging place booking
- vehicle/driver authentication
- billing
- …

2.1.7 Vehicle technical solution table estimation

Table 1 summarizes solutions and considerations described in the previous paragraphs.

Costs reduction should be considered if the vehicle is equipped only with a wireless charging system and the conductive on board charger can be removed.

Table 1 - Cost % estimation for E/E architecture

Item	Cost % Estimation
Secondary coil + Power Electronics Unit	? - CIRCE/HELLA *1
Additional HV connectors	-10/+10 *2
Communication module	? – Conti
Additional Fuses/Relays and HV Safety Systems	0/+15 *2
Positioning System + HMI	?- FKA
Low Voltage Cables Modifications	+5
High Voltage Cables Modifications	+10
Additional Fuses/Relays and HV Safety Systems Integration	+15
Mechanical Installation analysis	+5/+20 *3

Electrical Integration analysis	+10
Vehicle Management SW Integration	+5
Positioning System + HMI Integration	+10
ADAS System as Parking Assist	0/+100 *4
HMI and auxiliary services	0/+100 *4
Battery Size Reduction	0/-30 *5

Cost% Estimation is derived from general considerations and from the activities for the integration of the secondary coil on the prototypes.

Additional notes:

*1: cost for aftermarket systems are at the moment about US$3000, not including installation of the pad (which must be carried out by a certified technician) or the additional on-vehicle components [2, 3, 4].

*2 The adoption of a wireless charging solution should provide the opportunity of eliminating the HV standardized charging connector and on-board traditional conductive charger (not in the first market phases).

Additional fuses/relays may be necessary to protect and allow separation between new system and standard components present on HV DC bus, as in the prototype version.

*3 Costs for mechanical integration depends on the power level (and dimensions) of the system.

*4 Regarding the HMI and auxiliary services, costs can be considered similar to the current system already installed or optional on standard ICE or EV vehicles, but very different depending on the vehicle and the level of the services, for example:

- Rear Park Sensors (Fiat 500L): 310€
- Rear Park Camera (Fiat 500L): 260€
- Connected drive services package (BMW i3): 710€
- Park Assistant Package (BMW i3): 1020€

The system used for the parking/positioning tests of Deliverable D3.1, on the Mazda CX-5, costs 1350€ (optional or series pack depending on the vehicle version) comprises: Navigator system 5,8" Touch Screen, Front and Rear Park Sensors, Rear Vehicle Monitoring System (RVM).

*5 Battery Pack reduction depends on the integration with the infrastructure. For the en-route system, a reduction of about 30% can be evaluated, while if wireless charging is considered only an alternative to conductive (for example for home charging), no capacity reduction is possible.

2.2 Commercial vehicle solution to enable en-route charging (VTEC)

In an HEV the battery management system (including cooling/heating of the battery) is turned off when the vehicle is turned off. When charging of the battery is needed these systems need to be enabled hence the electrical architecture for the low voltage power net needs to be adopted when considering stationary charging. In contrast, en-route static charging is supposed to be carried out when on the go, i.e. when the vehicle is turned on so the same change of the electrical architecture is not needed. Still there may have to be restrictions in what is allowed and what is not, e.g. for safety reasons the movement of the vehicle could be restricted while the charging is ongoing, but this could be solved with changes in software.

2.2.1 Cost reference

In chapter 2.2.2 and 2.2.3 we will elaborate on the additional[2] cost for having en-route static inductive charging capabilities instead of conductive charging with the same power level. But first we need to define a reference application to be able to state the difference in cost.

We could distinguish between two different conductive technologies to compare with:

- Stationary or en-route static conductive charging as possible with pantograph plugin technology[3]
- Stationary charging with traditional cable plug in technology

There is no mature plug or pantograph standard for DC charging of commercial vehicles. The standard used for passenger vehicles could not be used, mainly due to higher voltage level (e.g. 500-750V) than cars and also higher power levels in general. The first PHEV applications of Volvo group are heavy duty buses and these applications require 100 - 200 kW charging at terminal stop hence only pantograph solutions could be considered for conductive charging. The Volvo 7900 Plug-in Hybrid, see Figure 3, will therefore be our reference vehicle.

Figure 3 Volvo 7900 Plug-in Hybrid

2.2.2 Pantograph vs. inductive charging

In principal the same electrical architecture used for conductive charging could also be used for inductive charging, see Figure 4. However there are some areas that could differ more or less:

- Mechanically
- Communication
- Alignment requirement
- HMI
- Batteries

[2] As decided in a task 3.3 meeting 6th of June 2014 the BEV or PHEV with conductive charging at the same power level is the reference vehicle.

[3] The technology is now tested in service in three buses in Gothenburg in the plug-in-hybrid project in corporation with Göteborg Energi, Business Region Göteborg, Trafikkontoret and Västtrafik [5].

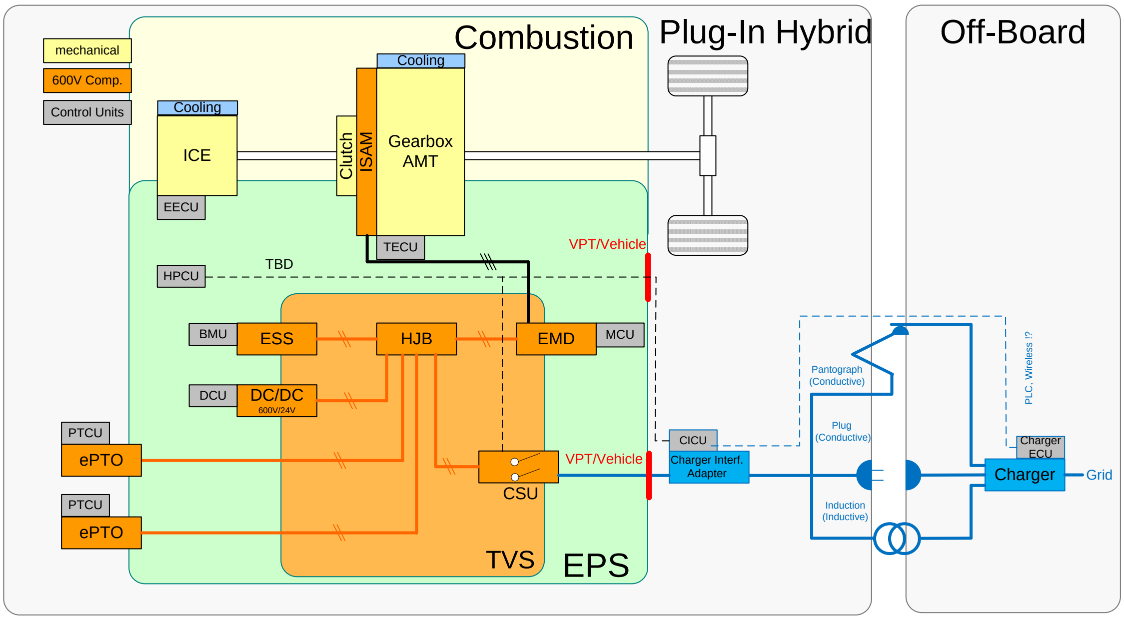

Figure 4 Conductive charging and inductive charging with the same principal electrical architecture

Communication

For conductive charging with pantograph the vehicle-to-charger communication is likely to be either wireless (i.e. RF) or power line communication. For inductive charging the vehicle-to-charger communication is likely to be wireless (i.e. RF) only, even though it may be possible to also modulate the magnetic coupling to pass information on to the vehicle. Since communication with RF technology could be used for both conductive charging with pantograph and inductive charging, no extra hardware costs for communication are considered. However, more parameters need to be communicated for inductive charging so changes to the communication protocol (SW) are needed.

Mechanically

There are of course major differences both in design and integration challenges when it comes to conductive charging with pantographs vs. inductive charging. The most obvious difference is that the pantograph is mounted on top of the roof, see Figure 5, and that the inductive charging secondary side is mounted under the floor (not essential, but most common and practical).

In a bus application many of the high voltage components e.g. batteries (including cooling system) and sometimes converters are mounted on top of the roof. This means that the length of the high voltage wiring harness could be substantially longer in an inductively charged bus compared to a one with pantograph.

Figure 5 Pantograph from Opbrid on a Volvo bus (Hyperbus project)

Alignment requirements

In the first generation PHEV bus (Hyperbus, with charging solution from Opbrid [6]) the bus positioning beneath the charging pole required an alignment tolerance of +/- 40 cm sideways, +/- 70 cm lengthways. In principle all professional drivers could park with this precision. For most inductive chargers the alignment tolerance is tighter (e.g. +/- 20 cm both sideways and lengthways) and some guidance may be needed. Also there is an extra driver for trying to park with high precision as both maximum power and efficiency are coupled to the alignment of the primary and secondary sides of the inductive charger. Hence we foresee additional costs for some kind of parking aid.

The parking aid could be as simple as used by the inductively charged electric bus used in Torino since 2004, see Figure 6. The bus driver can find the properly aligned position using a camera at the underfloor of the bus, which “looks down” to cross-hairs painted on the road surface. The small monitor is inside the bus, next to the steering wheel:

Figure 6 Parking aid for electric bus in Torino 2004.
(The driver is watching the monitor)

Conductix Wampfler is also using a (much simpler) variant of this kind of optical positioning system in their bus trial in Hertogenbosch Netherlands. This version even works without camera/monitor; the driver just keeps an eye on the passenger door, until he sees both yellow bars, see Figure 7.

Figure 7 Conductix Wampfler bus trial in Hertogenbosch Netherlands

The last example does not add cost to the vehicle but it is not perfect e.g. in snowy conditions. Also since we in the Unplugged project have developed a solution for alignment suitable for both passenger cars and commercial vehicles we will use that solution for the cost estimation.

HMI

The first generation Volvo PHEV bus (Hyperbus project) has a very simple HMI. One press of a button starts charging. Another press of button if charging needs to be interrupted before completion.
This simple HMI could in principle also be used for inductive charging but we believe that the Unplugged alignment system will drive further costs for a suitable driver HMI.

Batteries

Since the same power level is assumed for both the conductive charging with pantograph and the inductive charging one may think there are no differences. However the conductive charging with pantograph is rather slow in comparison to what could be achieved with inductive charging. At end stops (5-10 minutes) this does not matter much but if you would like to charge at every bus stop (10-60 s) the time it takes to position the pantograph takes up time of the possible charging time. Time to engage the pantograph is about 6 seconds. Hence there is a theoretical[4] chance to reduce the battery capacity in the inductively charged bus compared to the conductively charged one.

2.2.3 Estimation of cost for commercial vehicle solution

The reference vehicle, Volvo 7900 Plug-in Hybrid, was decided in 2.2.1. For the first generation PHEV bus (Hyperbus project) the investment in a complete charging station, including certain development costs was about SEK 3 million. Likely market price in large-scale production was under SEK 1 million. However this first generation will not be commercialized instead Volvo Buses expects to commence commercial manufacturing of the second generation plug-in hybrids in a couple of years.

Since the second generation is under development there is no official cost and no final unofficial cost either. Of course this is even more so for a theoretical PHEV with inductive charging. Nonetheless, in Table 2 we will estimate the additional cost for a PHEV bus with inductive charging compared with the reference vehicle with pantograph charging.

Table 2 Estimation of cost for inductively charged PHEV bus compared with a pantograph charged ones.

Item	Additional cost [%]
Alignment system	*
HMI	*
Secondary side + power electronics	*
HV connectors	20
Communication unit	*
Fuses/relays (HV safety)	-15
HV cable modifications	30
Low voltage cable modifications	-10
Fuses/relays (HV safety) integration	-50
Mechanical installation analysis	25
Electrical integration analysis	10
Vehicle SW integration	2
Alignment system integration	300
HMI and aux services (additional features)	1000
[5]* Battery size reduction	0 to -35

Disclaimer: Volvo is not part of the integration work package and only limited knowledge about this area has been gained, hence this estimation does not claim to take all necessary details into consideration.

[4] Since the charger is expensive and the amount of energy transferred is rather low the business case is not obvious and needs to be assessed.

[5] * It is just the integration/installation cost we consider in chapter 2.1 since the cost for HW developed within Unplugged is estimated in chapter 3

3 E/E components need and production cost (HELLA, CONTI)

3.1 General note (HELLA)

For cost evaluation we requested feedback from different sources including auto manufacturer. The German OEMs have difficulties with a request higher than 20k pieces per year and focus on lower quantities. The main concern regarding automotive inductive power transfer is the lack of standardization. Without regulation, reliable cost estimation is difficult, since many assumptions have to be made.

This fact was reflected in the discussion with several OEMs for the 3,7kW application. Some have minor activities in inductive charging, but are still waiting for a standard. Other OEMs force a regulation to an uniform transfer frequency of 85 kHz and will start a series production in 2015/2016.

Other important parameters, such as coil shapes and sizes i.e. topology (to ensure interoperability), etc. are currently not in the main focus of the standardization process. These boundary conditions will directly determine the construction area, the component weight and consequently the (system) prize.

In the meetings with several OEMs we have discussed different specification and considered them in our design. An interesting feedback of the meetings was the request to minimize the cost on the vehicle (secondary) side and transfer the major cost to the primary side. Obviously the car manufacture differs between vehicle cost and system cost at all. Desired are 80% of the system costs on primary (infrastructure) and 20% on secondary side (vehicle). For the controlled strategy this result in a primary controlled systems with a simple car electronic (no DCDC converter on the car side) like shown in Figure 8.

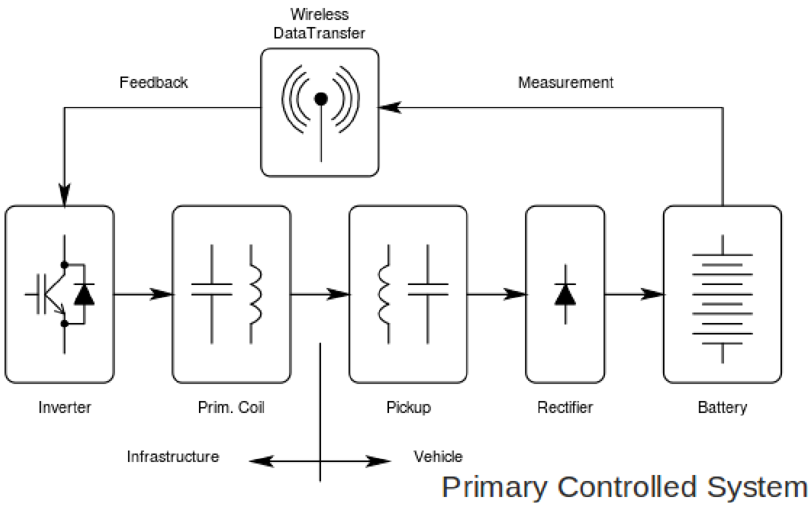

Figure 8: Control Strategies based on low cost on the vehicle side

With market introduction the OEMs are expected to provide both parts of the system, as a garage solution. Some of them aim on a uniform solution with 3,7 kW power and target a system prize of 1.200€. Others like to provide more customized solutions in separated categories like convenient, standard and reduced power with system prize in the range between 800 bis 1.800€.

3.2 SMS survey during the Euroforum Conference (February 2014)

An easy and unconventional way to get a first prize orientation for inductive charging system is to interview electronic experts. During the Euroforum Conference “Elektronik-Systeme im Automobil” in February 2014 in Munich the organizer conducted a SMS survey during a contribution of inductive charging. About 60 experts were asked about their acceptance of an additional price for inductive charging as comfort feature.

Question: “Which additional price will you pay for the comfort benefit of inductive charging?”

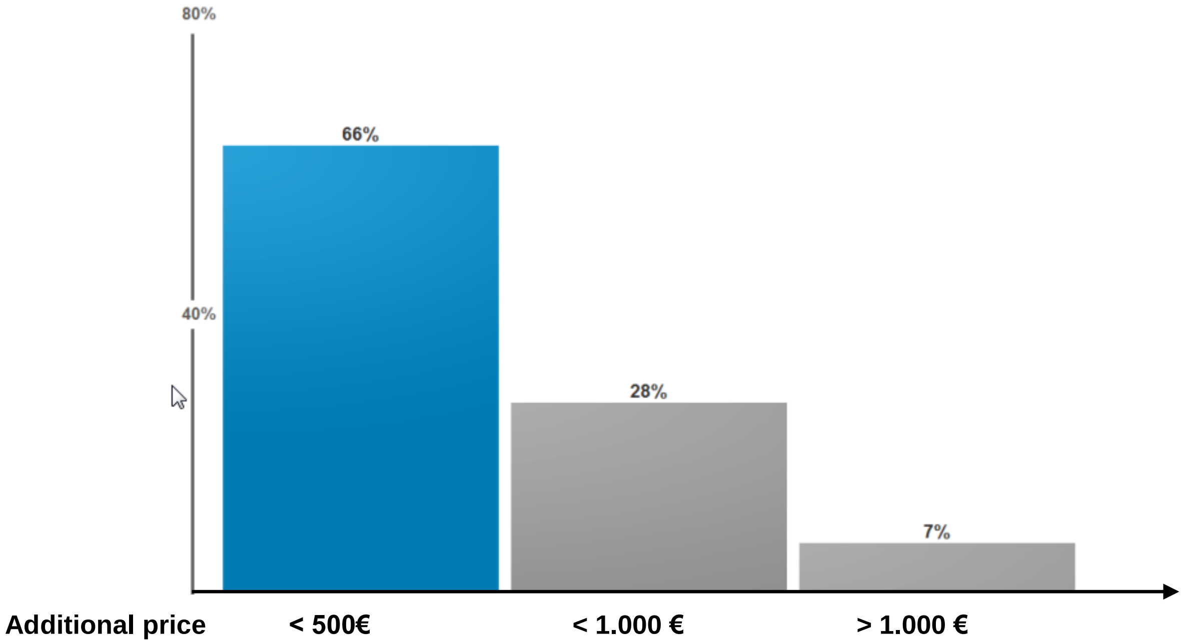

Figure 9: Acceptance of an additional price for inductive charging (system price)

In Figure 9 the result is shown. Under the experts, which have the technical background of such a system, most of them see the additional prize for inductive charging below 500 €.

3.3 Pickup – vehicle side

The pickup design on the vehicle side is shown in Figure 10. The electronic parts are placed in a box on the backside of the secondary coil device.

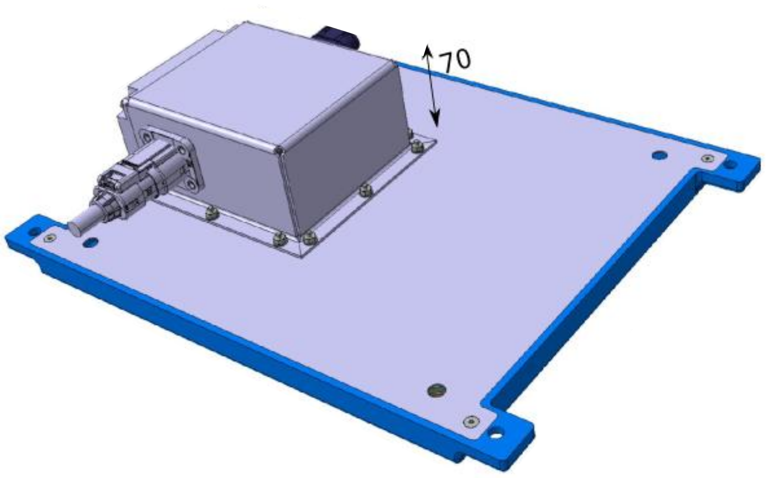

Figure 10: Complete pickup design: coil and electronic

Since the primary side includes the power transfer control the electronic components of the secondary side are reduced to a rectifier, compensations capacitors, filter elements and a µController with a RF interface for the control loop.

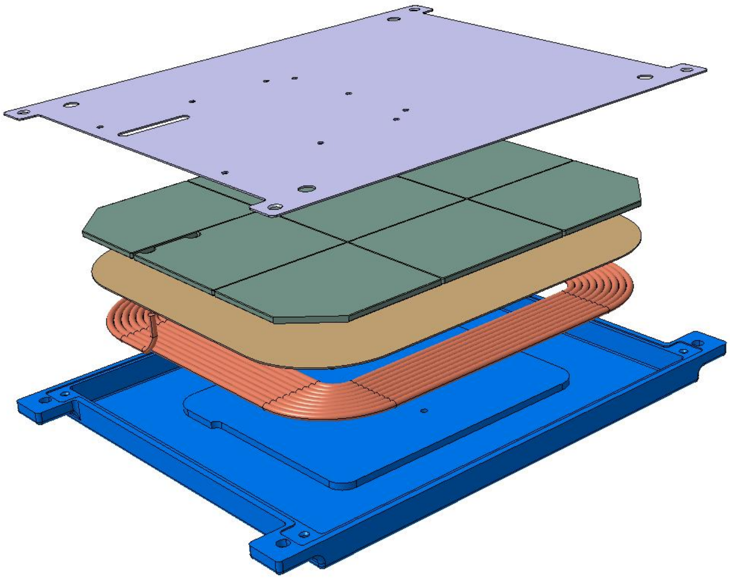

Figure 11: Principle design of secondary coil (top to bottom: alu plate, ferrite, bobbin (glue), coil, housing)

The coil structure itself can be seen in Figure 11. It includes the housing, the coil with bobbin, the ferrite for shaping the magnetic field and an aluminum plate for the shielding. The complete design will be finally glued together to achieve the necessary robustness.

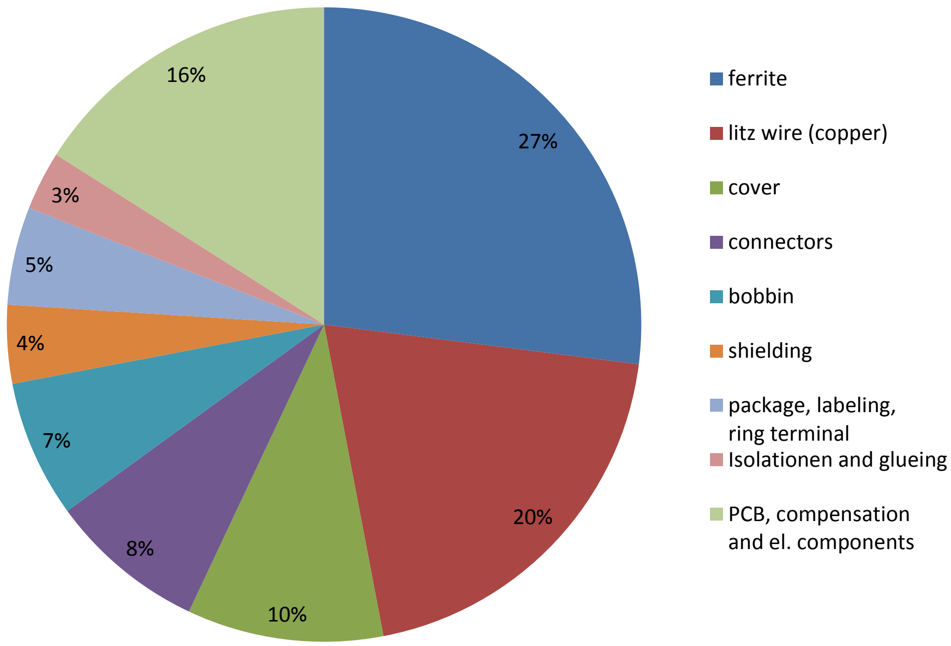

Figure 12: Detailing of the cost of the vehicle side

Figure 12 gives an overview about the cost allocation for the pickup. The costs are mainly driven by the ferrite material, the copper coils and the housing.

3.4 Infrastructure side – bottom plate and wallbox

As already mentioned the current tendency is that OEMs will provide a garage solution including both parts of the inductive charging system. Nevertheless, it is still unclear, if the primary as well as secondary side needs to comply with automotive standard. Especially, the primary infrastructure will be installed in garages or other fixed places and therefore it seems to be possible to equip it with electronics which fulfill industrial standards. In the end, this will influence the total system cost.

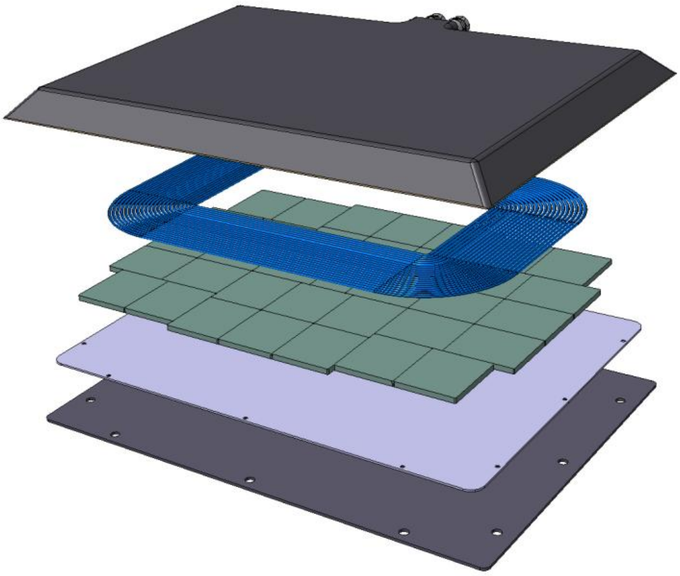

Figure 13: principle design of bottom plate (top to bottom: housing, coil, ferrite, alu plate, housing)

A further benefit for saving cost is the integration of the power electronics in the in the bottom plate, which makes the additional wallbox unnecessary. For the installation in a car garage or outside for public use such a device has to be driven over with a load of approximate 1000kg.

3.5 Cost estimation with several assumptions

To give any kind of cost estimation the following constraints have to be considered in the overview (see Table 4).

1) Estimation is basing on 20k pieces per year
2) Uniform solution in the power range of 3,7 kW
3) Low cost on the vehicle side → a primary controlled systems with a simple car electronic (breakdown wish of 80% infrastructure to 20% vehicle cost)
4) Fixing of an operation frequency of 85 kHz → other parameter are chosen reasonable due to the missing standard. For example coil shape and size supports interoperability.
5) FOD, LOD, Keyless entry compliance, Isolation monitoring, positioning and a WLAN (Car2X) communication for identification, certification, payment etc. are reflected on the experiences from other projects.
6) No consideration of development and standardization costs.
7) An isolation monitoring system on the vehicle side is available

Table 3 - System prize estimation for 3.7 kW inductive charger

System	Cost for 20 k units
Vehicle side incl. power electronic	200€
Positioning, Car2X,	N.N.
Bottom plate (with primary coil and power electronic)	900€
Isolation monitoring	60€.
FOD, LOD	250€
Electronic components to ensure Keyless Entry functionality	300€

3.6 Cost estimation for communication devices

As already mentioned in D3.1 for wireless charging it is evident that communication between the vehicle and the infrastructure has to be wireless, too. Thus a wireless communication system in the EV (and also on infrastructure side) is required to play the role of communication link (gateway) between charging management and other vehicle systems on the one side and the infrastructure on the other side.

The same communication system (hardware and procedure) should be used for all wireless charging possibilities (e.g. stationary or en-route charging). That means the wireless communication system should be designed to support all these charging possibilities.

This should be possible, as we see for the communication system:

- no significant difference between stationary charging and static or dynamic en-route charging and;
- no difference between different power levels (e.g. 3.7 and 50 kW systems).

Furthermore no significant technical or financial difference between cars and commercial vehicles for the communication system could be seen.

Today wireless communication is a common technology in almost all fields of everyday life and in vehicles as well. In the near future all new cars and commercial vehicles (particularly EVs) will be equipped with short and long range wireless communication system(s) anyway. These communication systems will be used for different use cases (e.g. navigation, infotainment, communication, and internet) and can obviously be used for wireless charging too.

This leads to following conclusions:

The wireless communication system does not necessarily need an additional part of wireless charging system, as it already exists in the vehicle for other use cases. But it's necessary to connect (directly or indirectly) the communication system to all systems involved in the wireless charging of the EV. This can be done by extending existing vehicle buses (e.g. CAN, Flexray, Ethernet) or by implementing new connections. Furthermore the communication system must contain some software modules to support the protocols and all other requirements of wireless charging. Maybe some of these software modules will be placed in other ECUs (e.g. charging management unit) of the vehicle.

For all other requirements regarding wireless communication system please refer to D3.1.

Using above statements to estimate costs for a wireless communication system we can deduce following:

- There are none or few additional costs for hardware on the vehicle side (e.g. only cable and connectors). On infrastructure side full hardware costs have to be considered.
- Software development costs have to be considered on vehicle and on infrastructure side.
- We don't need to differentiate stationary charging and static or dynamic en-route charging.
- We don't need to differentiate different power levels (e.g. 3.7 and 50 kW systems).
- We mustn't differentiate cars and commercial vehicles.

Table 4 shows the result of cost estimation of communication system for wireless charging. In principle cost estimation includes costs for software and hardware development and material and production costs for the hardware.

Table 4: Cost estimation for communication system

System	Installation Cost	Cost for 50 k Units	Cost for 200 k Units	Cost for 1M Units	Maintenance Reliability
Vehicle: Communication system (EVCC) with minimal H/W costs	<1	21	6	2	0
Vehicle: Communication system (EVCC) with full H/W costs	<1	36	17	12	0
Infrastructure: Communication system (SECC)	10	43	28	24	0

For the vehicle there are two rows. In the first row only minimal hardware costs are included. This follows the scenario described above – wireless communication system already exists in the vehicle for other use cases. In the second row full hardware costs are estimated. This would apply in cases where no wireless communication system exists in the vehicle for other use cases. On infrastructure side full hardware costs have to be considered anyway.

4 Analysis of the infrastructure needs and costs for the implementation of en-route charging in an urban environment (ENEL, UNIFI)

The main objective of this chapter is to present a methodology for the infrastructure sizing when a switch from internal combustion engines mobility to a wirelessly recharged electric mobility will be carried out.

The analysis provided below refers to the three most common mobility solutions available in the city of Firenze, chosen as case study. These are: public transportation services operating with busses, taxi service and private mobility.

Another important feature to be considered for this analysis is the market penetration. All the analysis provided investigates different levels of electric vehicle penetration: the analysis underlines how pros and cons of electric mobility vary with the increasing number of electric vehicles involved.

4.1 Scenario and service level for the introduction of en-route charging within the city of Firenze

4.1.1 Bus scenario

The bus lines of the city of Firenze have been divided in three main categories according to the route they run each day. The categories are short range buses, medium range buses and long range buses. Each bus line has been analyzed and the "range" attribute is given following two possible criteria: the district crossing criterion and the route length criterion:

- Solution A: District crossing criterion
    - Short: the bus serves only a district
    - Medium: the bus crosses a district border
    - Long: the bus crosses the municipality border
- Solution B: Route length criterion
    - Short: if the bus drives less than 8 km, the average maximum length of a district
    - Medium: if the bus drives more than 8 km, but less than 13 km the maximum length of the Firenze municipality
    - Long: if the bus drives more than 13 km, the maximum length of the Firenze municipality.

In Figure 14 it is possible to visualize Firenze municipality borders, the five districts, their borders and the bus terminal stops of the public transportation system in Firenze. In the small image in the bottom right-hand corner, names of the Firenze districts are provided. This data comes from the deliverable 3.2 analysis, Annex III:

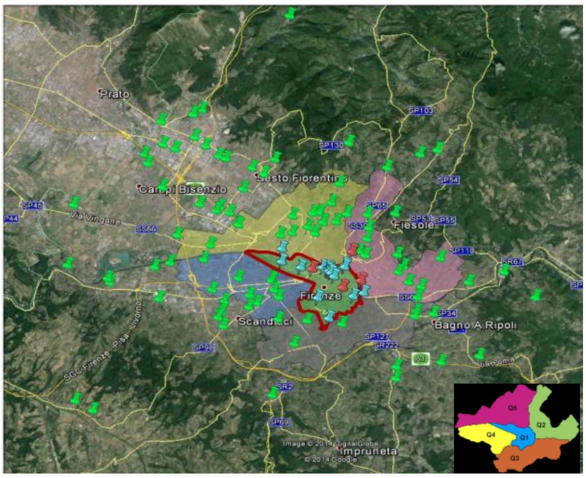

Figure 14 - Map of Firenze and its district borders

The range attribution of the bus lines is reported in the Annex I – Bus lines characteristics, Table 34 of the deliverable. The results are summarized in Table 5:

Table 5 - Summary of bus lines classification

	No. of bus lines	
	Solution A	Solution B
Short range	17	21
Medium Range	20	25
Long Range	18	9

It is possible to see that the trend of the Solution A is to favour the higher class and the Solution B the lower. Assuming that the long range is the most challenging when concerning the recharging infrastructure size, Solution A has been chosen for the analysis as the infrastructure challenges presented will provide for a more precautionary model.

One bus line per range has been chosen and used as a stereotype to describe the average behavior of the entire class. The chosen lines are:

- Line C1 for short range attribute.
- Line 4 for medium range attribute.
- Line 23 for long range attribute.

Concerning the data for line C1, results have been presented in the deliverable 3.2. Please refer to that document for detailed analysis.

For the other two lines, a data collection campaign has been carried out with a GPS tool and a set of drive cycles have been recorded and post processed. In addition, also the following information has been collected:

- The geo-localization of the terminal stops:
- The geo-localization of the intermediate stops along the line:
- Length of the route:
- How many vehicles serve each line in the day peak, Table 6:

Table 6 - Number of vehicles contemporary driving in the peak hour

Line	Number of vehicles running contemporarily
C1	5
4	6
23	14

Once the data has been collected, the post processing algorithm , as reported in the deliverable 3.2 Annex III, has been used. The information collected is:

- Average stop time of the buses stop at the terminal stops.
- Average stop time of the buses stop at each of the intermediate stops.

From this data, it is possible to say that the timespan between two consecutive buses is on average 510 seconds for line C1, 362 seconds for line 4 and 480 seconds for line 23. So this is the starting point to evaluate if any difference in the service level would occur when the electric mobility paradigm will be introduced.

4.2 Scenario development and infrastructure analysis

In this part the three scenarios presented in the above chapter will be closely investigated in order to understand the possible infrastructure/battery dimension for different levels of technology implementation.

The analysis of the following chapters is based on some cost assumptions. Firstly, battery costs:

- 0.15 €/Wh of capacity.
- 1000 discharge/recharge cycles (precautionary assumption).
- Unit cost of battery swapping: 450€ for bus/freight and 250€ for car/taxi.

The first two assumptions come from battery vendors market research and the third is an estimation based on how many person hours of work and equipment utilization could be necessary.

On the other hand, recharging infrastructure costs have been evaluated starting from the prototype costs. The help of CIRCE, as they are the 50 kW infrastructure developer, has been fundamental to define this analysis. The costs of the prototype elements, as long as they are applicable for more than one of the involved partners, are only reported as a percentage of total cost.

Table 7 - Cost for the installation of a 50 kW recharging station

Material	Percentage cost
Resonant coil	69%
Capacitors	13%
Mounting cabinets	13%
Civil works	5%
Litz cable (5 meters)	N/A
Total	100%

The industrialized cost of Litz cable is estimable in 2.40$/foot. It means that 5 meters of Litz cable (50 € with rounding up for all the excesses) necessary to connect the cabinet to the resonant coil are not influencing the final cost. Litz wire cost will have a heavier weight when dynamic charging infrastructure will be investigated.

From the prototype, costs after the industrialization have been qualitatively forecasted: ENEL kindly provides the prototype cost vs. the industrialized cost of plug-in recharging infrastructure. The average cost savings from economies of scale are in the order of 30% of the prototype total. So, infrastructure recharging facility will be assumed as the 70% of the prototype.

4.2.1 Bus scenario

In this chapter, the “as-is” situation of the bus scenario is reported. The data comes, as said before, from a data collection campaign and a post processing phase carried out with the algorithms described in deliverable 3.2, Annex III.

4.2.1.1 **Short range bus case - Line C1**

Analysis for short range vehicles comes from deliverable 3.2, Annex III. Detailed analysis of line C1 has already been carried out and this paragraph goal is to determine costs and to extend the results to the entire city of Firenze.

The average stop time at terminal stop coming from the data collection is 644 seconds and the average consumption per round is 5.213 kWh. 5 buses are simultaneously driving along the C1 route.

With a power inverter capacity of 50 kW, it is possible to transfer 8.9 kWh during the terminal stop time, that is enough to complete the entire route cycle. Battery equipped on board can be oversized of 20% to be sure avoid empty battery issues and it will be sized to 11 kWh capacity.

Therefore, a 20-years’ scenario for line C1 can determine the following costs. Cost of infrastructure is a percentage of line 4 costs presented below:

Table 8 - Cost for bus scenario

Cost voice	Cost
Battery cost	420750€
Battery swapping cost	114975€
Infrastructure cost	5%

The scaled results for the entire city of Firenze for a 20 year period are reported in Table 9. infrastructure costs are a percentage of the line 4 total cost:

Table 9 - Total cost for solution A and B

	Solution A	Solution B
Battery cost	7152750€	8835750€
Battery swapping cost	1954575€	2414475€
Infrastructure cost	4%	4%

4.2.1.2 **Medium range bus case - Line 4**

In Annex I – Bus lines characteristics, Table 35, are reported the station name, station id, latitude, longitude and average stop time of each of the stops of line 4. “Stazione Mercato Centrale” is the terminal stop of line 4.

The total average stop time is 325.5 seconds per route cycle. With a recharging facility of 50 kW power, full efficiency, it’s possible to transfer only 4.83 kWh per round with 23 recharging platforms, one per stop. It is possible to conclude that it is not sufficient to enable wireless recharged public transport service

Line 4 is a “circular” line that starts from a terminal stop and ends its route at the same terminal stop. Each of the vehicles has to provide 12 route cycles per day. In Annex I – Bus lines characteristics, Table 38, is reported the average crossing time from one station to the next, the distance travelled from one station to the next, the average speed of the bus in a certain route segment and the average consumption per segment.

So, to switch to electric mobility the “as-is” situation with only recharging facility at the stops it is required that each vehicle mounts an on board battery of 170 kWh (as a result of (19.013-4.83)*12) available (the battery’s total dimensions should be 170*1.2=204 kWh to avoid deep discharge issues). In addition, each of the batteries has to be fully charged at the beginning of the working day.

Cost for the “as-is” scenario for a 20 years period for line 4 will be as reported in Table 10. The infrastructure cost is forecasted with the industrialized facility cost and its cost has been set at 100%:

Table 10 - "As Is" cost for EVs servicing line 4

Cost voice	Cost
Battery cost	3213000€
Battery swapping cost	47250€
Infrastructure cost	100%

Scaling these costs to the entire city of Firenze it is possible to forecast the total cost of the two solutions for 20 years utilization:

Table 11 - Total cost for EVs servicing medium range lines

	Solution A	Solution B
Battery cost	64260000€	80325000€
Battery swapping cost	945000€	1181250€

Infrastructure cost	100%	125%

As it is possible to directly see from data, this solution is very expensive and the equipped on board battery is huge. So it is not possible to directly switch from traditional combustion engine mobility to electric wireless recharging mobility with any modification to the service itself.

An optimization problem has been realized in order to understand how the service could be dimensioned by increasing either the number of circulating vehicles and/or the waiting time at the terminal and the normal stops. The objective function is the total cost of batteries, considering material and swapping cost.

Some assumptions have been made:

- The payback time considered is 20 years.
- The maximum time at terminal stop is set at 600 seconds.
- The maximum time at normal stop is set at 50 seconds.
- The minimum battery size is 24 kWh to be sure to avoid “out of energy” stops.
- Battery size has to be at least 1.2 times (to avoid deep discharge issues in the battery).
- One recharging infrastructure station has to be mounted in each stop. As it has been proved in deliverable 3.1, it does not seem feasible to recharge vehicles while stopped at a traffic light: the average stop time is too low.

Subjects are:

- Number of vehicles has to be integer.
- Average waiting time at each of the stations have to be at least the same of the “as-is” situation.
- Total discharge during the day has necessarily to be equal to total charge + initial battery.

The used solver algorithm is the generalized reduced gradient one with the “Multistart” option selected, because one of the subjects was not linear.

In Table 12 is reported data for the optimized line 4 scenario. In this scenario, the battery equipped on board is only 27 kWh capacity, the waiting time at terminal stop is 600 seconds and 41 for each of the normal stops:

Table 12 - Optimized solution for line 4 bus

Cost voice	Cost
Battery cost	1938524€
Battery swapping cost	215392€
Infrastructure cost	100%
Number of vehicles	7

In this scenario an additional vehicle is needed to ensure an average waiting time that is only 20% (434 seconds) than the “as-is” situation. Assumed a total cost of 100000€ per vehicle and a 25 years vehicle life, the cost to be added is 80000€ more. If it possible to increase the average waiting time of 40% more than the “as-is” solution (506 seconds), no extra vehicles or battery extra costs are needed.

And so, scaled for the all the medium range lines of the city of Firenze:

Table 13 - Medium range buses total cost

	Solution A	Solution B
Battery cost	38770480€	48463100€
Battery swapping cost	4307840€	5384800€
Extra vehicle cost	1600000€	2000000€

Infrastructure cost	100%	125%

4.2.1.3 **Long range bus case - Line 23**

The same analysis has been carried out also for line 23, the stereotype for long range vehicles.

The table with the data related to localization and average crossing time for this line has been moved to Annex I – Bus lines characteristics, Table 36. In this table is reported the station name, station id, latitude, longitude and average stop time of each of the stops of line 23. The terminal stops of line 23 are “Sorgane” and “Nuovo Pignone”.

It is interesting to notice that some of the stations have a zero seconds average stop time. It means that, during the drive cycle data collection, the vehicle never stopped to these stops. These intermediate stops have not been considered in the analysis because it has been assumed that are “optional” stops and so not often used.

Total average stop time is 1577.1 seconds per round and the transferrable energy is 21.9 kWh within 75 recharging infrastructure, one per “active” stop.

Line 23 is a circular line with two terminal stops. Each of the vehicles has to provide 7 route cycles per day.

In Annex I – Bus lines characteristics, Table 38, is reported the average crossing time from a station to the next, the distance travelled from a station to the next, the average speed of the bus in a certain route segment and the average consumption per segment. Due to the fact that consumption estimation is a key issue, the analysis has been kindly provided by CIRCE by using a more precise absorption algorithm.

So, to switch to electric mobility the “as-is” situation with only a recharging facility at the “active” stops it is required that each vehicle mounts an on board battery of 155 kWh (as a result of (43.9404-21.9)*7) available (the battery’s total dimensions should be 155*1.2=186 kWh to avoid deep discharge issues). In addition, each of the batteries has to be fully charged at the beginning of the working day.

As in the above analysis, the cost for the “as-is” scenario, 20-years period for line 23 is reported in Table 14. The infrastructure cost is forecasted at the industrialized facility cost and it is set to a percentage of line 4 cost.

Table 14 - Total cost for long range buses for the long range scenario

Cost voice	Cost
Battery cost	8593200€
Battery swapping cost	138600€
Infrastructure cost	326%

Scaling these costs to the entire city of Firenze it is possible to forecast the total cost of the two solutions for 20 years utilization:

Table 15 - Total cost for long range busses

	Solution A	Solution B
Battery cost	154677600€	77338800€
Battery swapping cost	2494800€	1247400€
Infrastructure cost	293%	173%

Also in this case costs are very high and the on board required battery is huge. Optimization is needed also for this scenario.

The optimization algorithm settings are exactly the same as those for the previous analysis.

In Table 16 is reported the data for optimized line 23 scenario. On board battery capacity is 33 kWh, the waiting time at terminal stops is 600 each terminal and 30.8 for each of the normal stops:

Table 16 - Optimized solution for line 23

Cost voice	Cost
Battery cost	5148864€
Battery swapping cost	468078€
Infrastructure cost	326%
Number of vehicles	19

In this scenario 4 more vehicles are needed for a cost of 320000€ for the considered period. To not have extra vehicles, it is mandatory to accept a 634 seconds of average waiting time, 32%more than the "as-is" situation.

Last step, evaluation of the cost over the entire Firenze city:

Table 17 - Total optimized cost for the long range buses

	Solution A	Solution B
Battery cost	92679552€	46339776€
Battery swapping cost	8425404€	4212702€
Extra vehicle cost	57600000€	28800000€
Infrastructure cost	293%	173%

4.2.2 Taxi scenario

This paragraph will describe the wireless recharged electric taxi. The analysis of taxi service (number of vehicles, geo-localization of taxi stands, number of taxi stands, etc.) has already been provided in deliverable 3.2, paragraph 3.2. Within this chapter, a forecast of the cost of electric device and installation of the recharging infrastructure in 4 different market penetration hypotheses will be given.

4.2.2.1 Recharging device cost forecast

The goal of the Unplugged project is to design and realize two test sites where wireless recharging can be provided to electric vehicles with 3.7 kW and 50 kW power capacity. For the purposes of an electric car, there are two main issues related with these powers:

- 3.7 kW power inverter capacity: in this case, the power transferrable to the vehicle is very low, not usable for city taxi service. In fact, the assumed energy consumption per day of a taxi is 33.25 kWh (deliverable 3.2), that means 8 hours recharging per day. It is not feasible with taxi working conditions.
- 50 kW power inverter capacity: in this case, power inverter capacity is more than enough, but car technology cannot sustain these high currents.

For cars, a 20 kW power inverter capacity has been hypothesized, so proving a power comparable with the ChaDeMo solution [7]. However, to evaluate the cost, prototype costs are not available and so the analysis comes from the 50 kW power inverter scaling.

Table 18 - Forecast cost for 20 kW recharging station

Material	Percentage cost
Resonant coil	55%
Capacitors	16%
Mounting cabinets	22%
Civil works	7%

Litz cable (5 meters)	N/A
Total	60%

Some of the costs are exactly the same, such as the Litz cable cost, which bears no influence on the cost. This is also the case with the civil work needed to install the device into the street concrete and the cost to mount the cabinet device. The resonant coil and the capacitors costs have instead been scaled by using the power inverter capacity as weight. Resonant coil cost and capacitors costs have been scaled with a 20% safety coefficient. The total cost is given as a percentage of the 50 kW power inverter cost.

From the estimation of the prototype cost for a 20 kW power device, the industrialized cost of the device has been forecasted by using the same weight of the 50 kW power device cost: the industrialized cost will be the 70% of the prototype and so the cost expressed as a percentage of 50 kW prototype is 41.3%.

4.2.2.2 **Firenze taxi scenario analysis**

To define which could be the number of devices required at the lower cost for Firenze taxi infrastructure, the data of taxi service has been taken into account:

- In Firenze there are two taxi companies.
- 654 taxi are circulating within the city of Firenze. 196 are labeled as ecological (methane and LPG fueled or hybrid) of which 80 are hybrid electric vehicles.
- No full electric vehicles are used within Firenze.
- Average waiting time at taxi stand is very variable and depends on the month of the year. In high season periods the average waiting time is 10 minutes, but for the remaining 6 months it is also possible to have 60 minutes waiting. This data comes from a direct interview with the president of a taxi service company.

The relevant hypotheses for this study are:

- Power of each charging station set at 20 kW as passive users.
- The charging profile is steady during all the day.
- The charging just occurs in dedicated taxi parking slots.

In addition, the taxi stands within the city have been investigated and geo-localized. For the complete list, please refer toAnnex II – Taxi characteristics, Table 39.

In this table it is also reported the total power needed if all the stands will be equipped with a 20 kW power recharging device.

To create a consistent analysis, 4 market penetration levels have been hypothesized. The penetration percentages are 5%, 10%, 15% and 25%. A safety coefficient of 20% on the total number of electric vehicles for each of the penetration levels has been also taken into account in order to be sure to assure a parking slot available to each of the electric taxi.

Calculation of the number of charging stations necessary for each terminal is difficult to make through an algorithm based on the elapsed time at the terminal or time of arrival at the terminal due to the random behavior of the taxi, which is also influenced by the season. For this reason a proportional calculation is applied on available parking slots for each station.

The available data are detailed below:

- $ParkingSlots_{tot}$ amount of all taxi parking slots located in Firenze
- $ParkingSlots_i$ amount of available parking slots for each station
- $Stations_{tot}$ amount of all charging stations for the 4 different cases.

Therefore, the number of required charging stations, $Stations_i$, for the i-th taxi terminal stop is described from equation below

$$Stations_i = \frac{ParkingSlots_i * Stations_{tot}}{ParkingSlots_{tot}}$$

In Annex II – Taxi characteristics, Table 40, the electrified taxi slots are reported. To decide which of the taxi slots have the priority for the electrification, the chosen weight is the total number of parking spaces.

As for the deliverable 3.2, the analysis has been performed using Atlante software, an Enel internal software.

From this data, it is possible to determine the infrastructure cost for the taxi service of the city of Firenze. It is reported in Table 19. Costs are given as a percentage of 5% hypothesis considered 100%:

Table 19 - Total cost for taxi scenario

	5% Hypothesis	10% Hypothesis	15% Hypothesis	25% Hypothesis
Resonant coil	100%	195%	295%	492%
Capacitors	100%	195%	295%	492%
Mounting cabinets	100%	195%	295%	492%
Civil works	100%	195%	295%	492%
Total	100%	195%	295%	492%

4.2.3 Private mobility scenario

In this paragraph, the analysis of private mobility will be taken into account. The main goal of this analysis is to provide both a forecasted cost for electric recharging device introduction and a methodology to assess the optimal geo-localization of the recharging infrastructure. Private mobility is the most difficult scenario, because any parameter could be a fixed one: for example, the public mobility service is the simpler scenario because routes, speeds, stop places, stop times and so on are both fixed and manageable. Taxi, on the other hand, is an intermediate scenario, where taxi stand places and the average annual mileage are known quantities. The optimal geo-localization of the recharging infrastructure has to be based on other parameters than geo-localization of existing infrastructure. Two different approaches are described within this paragraph: one qualitative based on analysis of the most frequented places and parking within the city and another quantitative based on a set of significant drive cycles.

In order to have a “closer to reality” analysis for the private e-mobility, a preliminary study has been conducted to evaluate the number of the private EVs. There are about 300,000 cars that run in Firenze, and it is hard to assume and freeze a percentage without any preliminary analysis. In fact, with respect to the bus and taxi service where the number of the circulating EVs is known a priori, and the assumptions just regard the number of charging stations, for the private e-mobility this data is not available. So, thanks to historical data available in UNRAE website [8] concerning the EVs sold in Italy from 2010 to 2013 yearly, it has been possible to forecast the number of the EVs that will be sold over 2014, hypothesizing comparable behavior in the market. Moreover, another assumption refers to consider all EVs in Italy run in Firenze, where this analysis takes place. Details of this assumption are explained later in this chapter.

Table 20 reports the data available on UNRAE web site regarding the sold EVs in Italy in the last four years.

Table 20 - Data from UNRAE site

Year	EVs sold
2010	116
2011	307
2012	524
2013	864

Starting from these values, linear regression has been built:

$$y = 246.1x - 494577$$

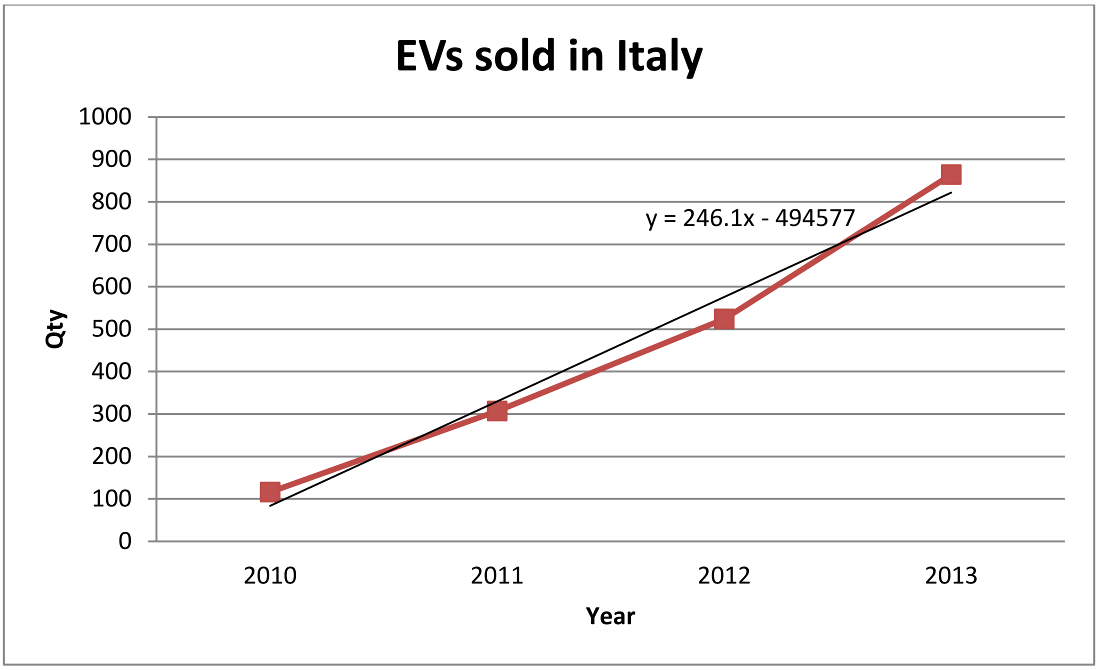

Figure 15 EVs sold in Italy from 2010 to 2013

In order to evaluate the number of hypothetical EVs that will be sold during the 2014, the linear regression equation has been used, and for which the EVs will be 1068, for a total of 2879 of EVs.

As already said, in this analysis all EVs in Italy are hypothesized to run in Firenze. This value represents about the 1% of the whole amount of the cars in Firenze, considering a total of 300,000 cars. This assumption fits with the “less optimistic” scenario described by CRF in chapter 2.1.1. In fact Firenze population is the 6‰ of the population of Italy and so the electric vehicles in Firenze in 2020 should be 12,000. The regression analysis forecasts the Italian scenario for 2020 being 10,264 e-vehicles, which is very close to 12,000. So, imagine that all the circulating vehicles are running in Firenze for a long prospective is not a strong assumption.

For the analysis three different cases will be analyzed: Table 21 reports each one with a comparison for the value in respect to all cars circulating in Firenze.

Table 21 - Case studies data

Cases	Number of EVs	Respect to cars circulating in Firenze
10%	290	0,01%
50%	1450	0,05%
100%	2900	0,10%

After calculating the number of the EVs, the number of charging stations dedicated for private mobility needs to be evaluated.

In accordance with the draft of the document for alternative fuels released by European Commission, in 2020 one charging station shall be forecast for every 10 electric cars.

So, for the above, Table 22 summarizes all input data for the further analysis:

Table 22 - Number of charging stations for each of the penetration levels

Cases	Number of charging stations
0,1%	29
0,5%	145
1%	290

Whereas for the bus and taxi analysis the locations for the installation of the charging stations was known a priori (respectively in terminal stops and taxi stations), for private mobility the charging stations have to be installed on public parking slots.

In Italy these parking slots are divided into pay parking slots (blue lines) and free parking (white lines).

In Firenze white lines are dedicated for resident people, so only the pay parking slots have been considered.

4.2.3.1 Method 1: Most frequented places/parking

In Annex III – Private mobility characteristics, Table 41, are reported the most frequented places of Firenze. The table's columns are the name of the station, latitude and longitude of the station, a priority index used to weight the number of electrifiable parking slots and the typology of aggregation point:

By using this priority analysis, the recharging points for each of the market penetration levels hypothesized in Table 22 have been allocated. The results are presented in Annex III – Private mobility characteristics, Table 42:

By assuming the same cost for recharging infrastructure of the taxi scenario analysis, the total cost for private mobility is reported in Table 23. Costs are given as a percentage of taxi scenario 5% penetration hypothesis considered as 100%.

Table 23 - Cost for private mobility implementation with qualitative analysis

5% taxi	0.1% Private Mobility	0.5% Private Mobility	1% Private Mobility
100%	50.75%	253%	1330%

4.2.3.2 Method 2: Drive cycles analysis

Second methodology is to analyze a set of drive cycles. The general idea of this methodology is to understand the power consumption of each trip within the city and the geo-localization of the stop point. The drive cycles are measured on internal combustion engine vehicles, but they are similar to electric vehicles drive cycles. Then an optimization algorithm will define the minimum number of recharging infrastructure stations in order to minimize the distance between each stop point and the recharging infrastructure that has to serve that vehicle. A solution for this case has been obtained and it is reported later on this document.

First of all, the consumption of each trip has to be determined. To do this, the data logged are reported in a table which columns are:

- Record id
- Trip id
- GPS date and time
- Latitude
- Longitude
- GPS quality
- Calculated speed
- GPS heading
- Vehicle type id (car, freight or not specified)

From these data, a set of columns are calculated:

- GPS record time (only hours/minutes/seconds)
- Distance travelled
- Average vehicle consumption (it depends on vehicle id, the typology of the vehicle)
- Segment consumption
- Cumulative consumption

- Total consumption of the trip

At this stage, a table with absorption data and geo-localization has been built. Next step is to find where to put the recharging infrastructure. Some assumptions have been made:

- The recharging infrastructure stations have to be positioned to correspond with one of the car stops. This is to avoid the positioning of an infrastructure station not on the street. For example, if the positioning algorithm puts the infrastructure station in the center of gravity of some stop points, it could be positioned over a building or in a private area.
- Each of the recharging infrastructure stations could not provide more than 120 kWh per day. A parking space, in fact, could be idle or occupied but the car over it fully charged. So the charging time have to be scaled to take into account these possibilities. 120 kWh for a recharging facility of 20 kW means 6 hour of energy transferring per day.
- A 120 meters radius of influence of each recharging infrastructure station has been chosen. The vehicles inside this radius could be expected to move to the recharging infrastructure station, with the vehicles outside the radius prefer to use another recharging infrastructure station.

The steps of the algorithm are:

- The first point is randomly chosen.
- The algorithm puts a recharging infrastructure station in that position.
- The algorithm chooses the closer between the 120 radius distanced vehicles. If the recharging infrastructure station has more energy available, the cars are assigned to that recharging infrastructure station.
- When the energy level of the recharging infrastructure station is exhausted or no more vehicles are inside the 120 radius area, another point is randomly chosen between the available ones.
- If no more stop points are idle, the algorithm stops and the optimal solution is printed.

This algorithm is able to provide a local optimum solution. However it is possible to repeat this algorithm many times with different starting conditions in order to evaluate the convergence to a unique solution.

This kind of procedure is a simplified genetic algorithm. The calculation time is very low and so a lot of simulation could be provided in short time. This method has been chosen because the optimal solution finder algorithm has been proved to be very slow.

For what concerns the Firenze scenario, a mixed approach has been utilized. In fact, the available drive cycle of private mobility was referred to the entire metropolitan area of Firenze, not only the municipality. This area is very widespread and includes other cities such as Prato, Pistoia, Empoli, Sesto Fiorentino and so on. The data available for Firenze municipality was very few and do not allow to reach the minimum number of recharging infrastructure of the market penetration hypothesis. The 16 recharging infrastructure founded with this approach are reported in Figure 16:

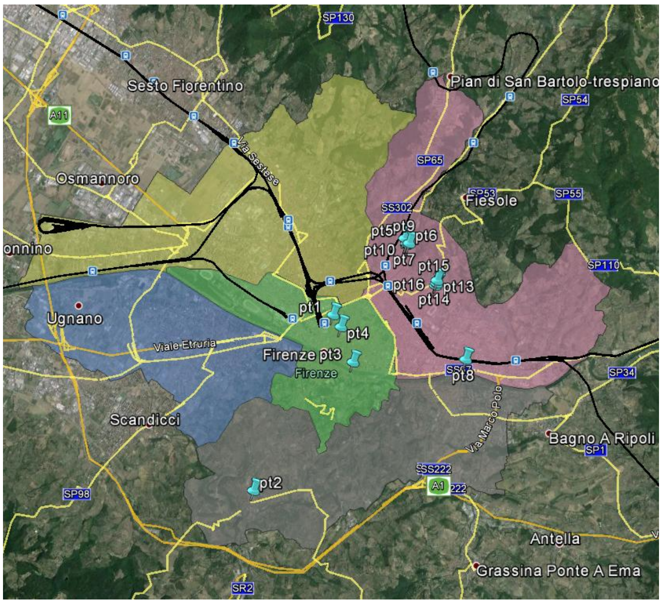

Figure 16 - Map of Firenze city with recharging infrastructure

With this analysis, 16 of the stations with the lower priority index identified with the qualitative algorithm can be replaced with the stations founded with the quantitative algorithm. With this strategy, the total cost could be considered the same and the recharging infrastructure are placed in areas where drivers have effectively stopped their vehicle, in order to be more in touch with the realities of driver behavior.

4.3 Infrastructure costs

In this chapter the main results for taxi mobility and private mobility in Firenze will be reported.

4.1 Taxi mobility

Starting from Annex II – Taxi characteristics, Table 39, a simulation with Atlanta has been carried out to understand if the existing power supply network in Firenze is able to guarantee these hypothetical installations or some reinforcements are needed.

In general, smart charging is foreseen to avoid the reinforcements of the grid, to show that the grid can provide all the power required, but in this case the study knowledge of the cost of the grid is required..

Main results for each case are reported in Table 24:

Table 24 - Recharging infrastructure costs for taxi mobility

Case	Number of charging stations	Power [kW]	Cost [k€]	Note
1	35	700	440	5 new secondary substations
2	82	1640	650	7 new secondary substations
3	116	2320	970	9 new secondary substations and 1 upgrade of transformer
4	195	3900	1148	11 new secondary substations and 2 upgrade of transformers

The costs reported in the Table 24 are referred to civil works, electrical upgrades and new secondary substations installation.

4.2 Private mobility

Starting from Annex III – Private mobility characteristics, Table 41, as already done for the previous analysis, the hypothetical charging stations have been adding in Firenze network with the load flow software Atlante.

As hypothesized for the taxi mobility, the power for each charging station is set at 20 kW and the power is steady during all day.

Table 25 reports the relevant results for each case.

Table 25 - Recharging infrastructure cost for private mobility

Case	Number of charging stations	Power [kW]	Cost [k€]	Note
1	29	580	590	1 new secondary substation and 4 upgrades of transformers
2	145	2900	1285	2 new secondary substations and 19 upgrades of transformers
3	290	5800	1780	2 new secondary substations and 20 upgrades of transformers

As before, the costs reported in Table 25 are referred to civil works, electrical upgrades and new secondary substations installation.

5 Business model for en-route charging

5.1 Accounting strategies and feasibility (ENDESA)

In this part of the deliverable a qualitative analysis will be made from the point of view of the Service Provider for en-route charging. In order to carry out this analysis, the Business Model Canvas will be used to explain all the elements related to the Service Provider. This economic model is based on the previous activities results.

Electro-mobility Service Provider (also named Electric Vehicle Service Provider, EVSP) is the agent that offers e-mobility services to the EV customers. These services include the energy to charge the EVs but also other added value services are included. Moreover, this Service Provider business model includes the e-mobility Infrastructure Operator agent (also named Electric Vehicle Supply Equipment Operator, EVSE Op). Their basic role will be the technical operation of the infrastructure but also the possibility to offer mobility services. An infrastructure owner will allow customers access for a contracted monthly rate.

In this case study, the Service Provider business model will be the owner of the charging station, the infrastructure operator, who will send the energy to charge and will also provide e-mobility services (Figure 17).

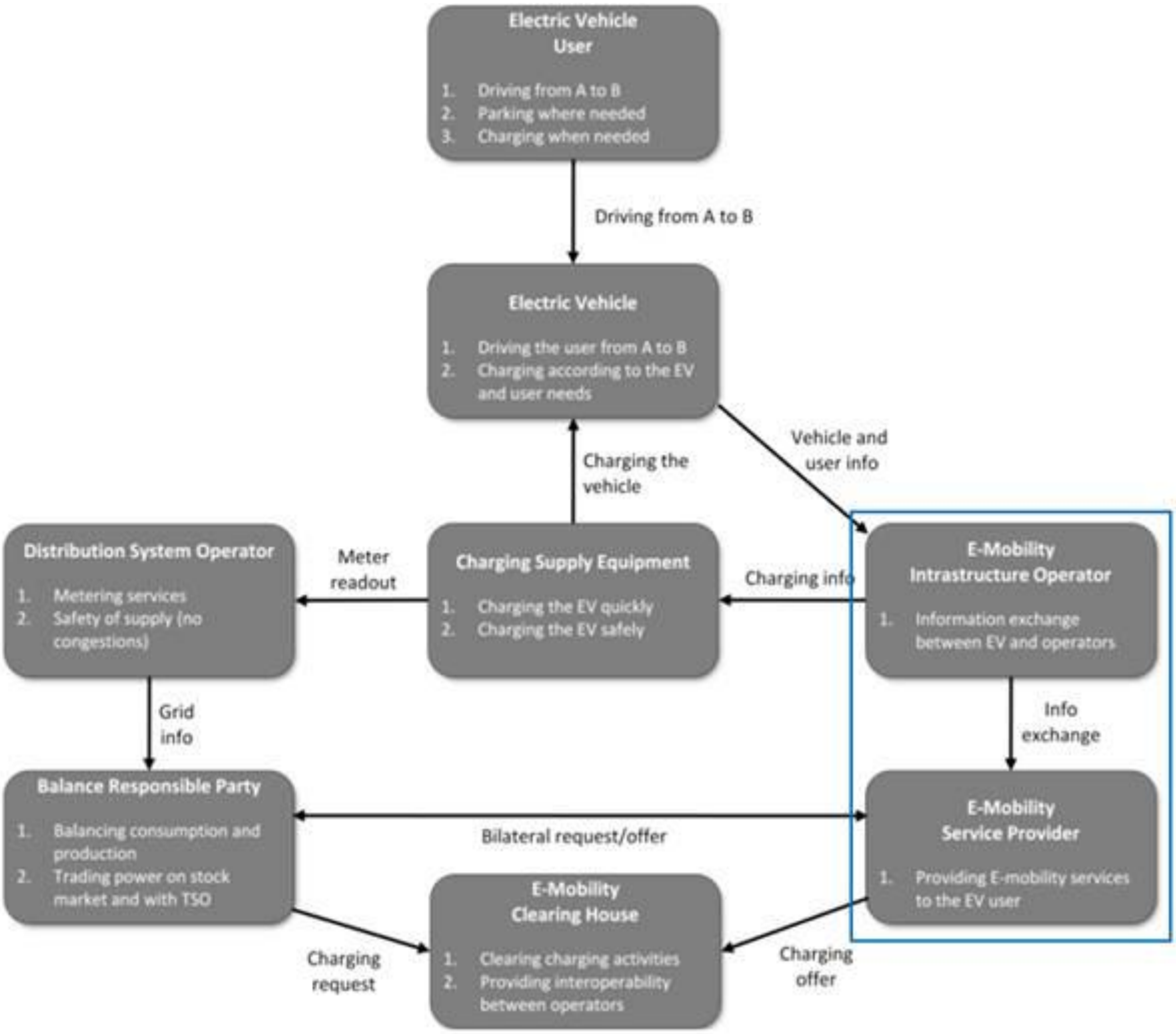

Figure 17 - Relationship between market players e-mobility

Qualitative analysis

The Business model canvas is a visual chart that represents all the business opportunities that could be relevant for the firms. It is a template where firm's value proposition, infrastructure, customer and finance are described in order to assist firms in aligning their activities.

The following figure shows the Canvas model that will be used to describe each business element related to the Service Provider for static en-route charging.

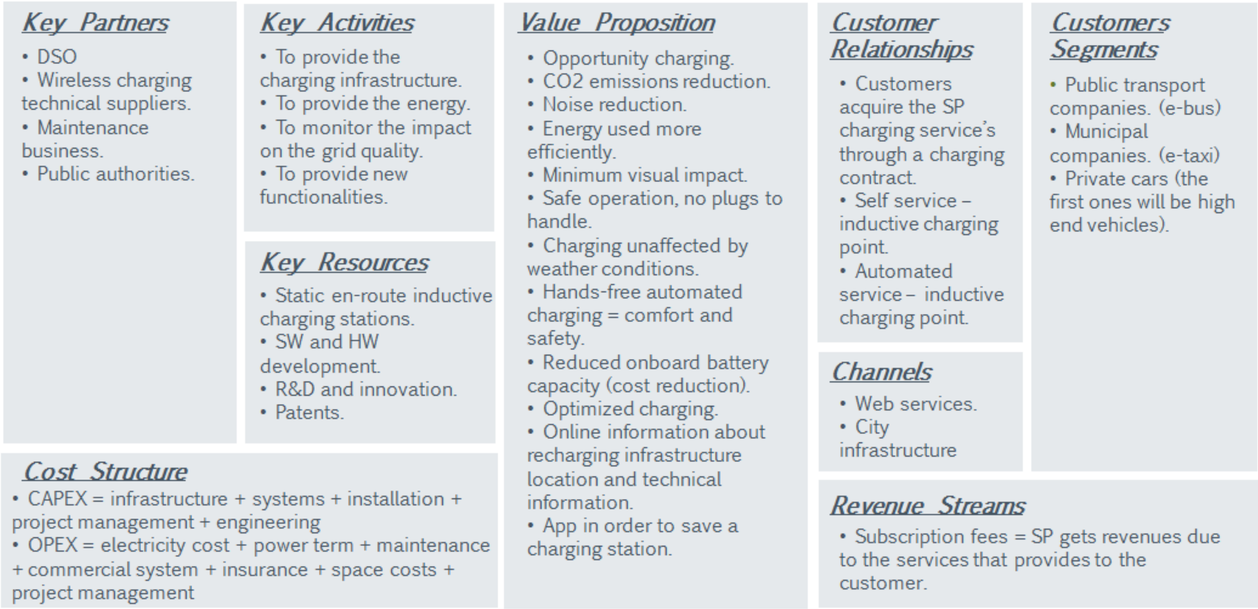

Figure 18 - Service Provider Business Model Canvas

Infrastructure

- Key activities: Service Provider main activities will be to provide the en-route inductive charging infrastructure as well as to provide the energy to charge the EVs. Moreover, other services will be offer to the customer like monitoring the impact on Grid Quality of different recharging events and new functionalities like load management or reduce the peak demand. For example, load management feature will be the key for the mass introduction of the electric vehicles in the near future, because it will avoid critical peaks on the grid and allow to control and optimize the use of the infrastructure and of the grid.
- Key resources: Every business model requires assets or key resources to allow the model to work. These resources will allow the Service Provider to create and offer a value proposition, reach markets, maintain relationships with EV customers segments and earn revenues. In this case study, the main resource is the infrastructure, which is static en-route inductive charging stations and the SW and HW development associated to the charging point. Key resources also can be intellectual or human, therefore, R&D and innovation and Patents team is considered in this business model.
- Key partners: In order to optimize operations and reduce risks of a business model, the Service Provider usually cultivates buyer-supplier relationships so they can focus on their core activity. It is the case of the DSO – Service Provider relationship and wireless charging technical suppliers with the Service Provider. It is considered interesting to have contact with maintenance companies in order to solve any problem occurring with the charging infrastructure. Also, the relationship between the Service Provider and the Public authorities is very important in order to guarantee the deployment of the en-route inductive charging infrastructure in public thoroughfare.

Offering

- Value proposition: The set of products and services that a customer asks of a business to meet his needs. The value proposition of the Service Provider which distinguishes it from its competitor.

  Opportunity charging is the act of charging a battery during any opportunity that presents itself during the working day. Opportunity charging, e.g. at bus stops, extends the range of an electric vehicle, e.g. buses. Within this scenario, the required on board power storage devices have to ensure the power to reach next charging station, with an evident volume and cost reduction compared with a pure electric battery vehicle.

  Inductive charging system can be integrated fully into urban environments, making zero-emission a realistic prospect today. Inductive charging is clean and quiet. This enables cities to address strict CO_2 emission targets and cope with the growing challenges of urban mobility. Moreover, with this kind of infrastructure the visual impact is minimized and having the primary coil beneath the ground also prevents any vandalism.

  It must take into consideration that this inductive charging infrastructure allows automated charging, that is, intervention-free charging. This is a safe operation, there are no plugs to handle and thanks to the hands-free automated charging the EV user can remain inside the vehicle during the charging process. Another important point is that the charging process is allowed under all weather conditions. All these characteristics enhance the efficiency and reduce the operational risks.

  The charging process is controlled: the ground station only activates and provides the required power when a suitable vehicle demands this. If the vehicle is too far off the charging position, the inductive charge station will not activate.

  Other services are offered to the customers like an application to book a charging station and keep its customers informed by means of online information about the charging infrastructure, that is, its location (where the charging station are installed) and technical information (availability of the charging stations, breakdowns, etc).

Customers

- Customers segments: it is the place where customer segments that the company would like to serve are described. The segmentation of the customer could be very various: in this way, different needs and attributes could be identified and the strategy could be set to achieve a strong effectiveness. In the case of Service Provider Business Model, its customers will be:
  - Public mobility: public transport companies, that is, e-buses.
  - Municipal mobility: municipal companies like e-taxis.
  - Private mobility: in the case of private cars the first ones will be high end vehicles.
- Channels: the set of channels a company uses to reach its customer. An effective channel could deliver the value proposition faster, more efficient and more cost effective than a non effective one. The main channel that the Service Provider can offer its services is the en-route inductive infrastructure around the city (It is supposed that the Service Provider will install different charging stations in the city). Moreover, by means of web service the Service Provider will swap data in computer network like internet.
- Customer relationships: all the types of relationship a company would like to establish with the customer have to be described in this field. In the case study, the customers will acquire the Service Provider services through a charging contract (fee). En-route inductive charging is an automated self-service, that is, the type of relationship that translate from the indirect interaction between the Service Provider and the customers.

Finances

- Cost structure: Describe all the costs the Service Provider will have to carry out to operate its business model. The Service Provider costs' have been divided into CAPEX (capital expenditure) and OPEX (operating expense).
  - CAPEX

  - Grid connection: supply connection rights, access and electrical coupling based on the power.
  - Charger: the cost of the en-route inductive charging point of 50 kW. Software and Hardware cost associated with the en-route charging point included.
  - Installation: average costs of civil works, testing and commissioning of the charger described in the previous point (not including work licenses)
  - Project management: the personnel costs of a worker that will work two days per month in this activities.
  - Engineering: cost of carrying out the project: technical basis on which the charging station will be installed and economic evaluation of the project.
- OPEX
  - Energy costs: cost of the total energy consumed to charge the buses during a year.
  - Power term: it is the price that the Service Provider will pay for the electrical power has to pay for its installation. Figure depends on consumption.
  - Charger maintenance: cost incurred to maintain the deployed infrastructure per year.
  - Space cost: the cost that the Service Provider will pay to the council in order to install the charging point in the public thoroughfare.
  - Commercial system: cost of the management and control application of the charging point, customers' billing and electro mobility added value.
  - Communications: annual cost of the charging infrastructure communication with the electric vehicle in the charging process and the central management system.
  - Back end: cost of the information system and necessary telecommunications updating to connect the charger to the control center and the management system.
  - Insurance: insurance costs of the en-route inductive charging station.
  - 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.

Quantitative analysis

Using the finances part of the Business Model described in the previous analysis, in this part of the deliverable an example for public transport (e-buses) will be given from the point of view of the Service Provider.

The Service Provider will invest in charging infrastructure and will offer customers usage contracts. It has been considered that the Service Provider will provide charging services and will install an en-route charging station. The location of the inductive charging station would be strategically chosen in the public thoroughfare, for this reason it is assumed the city council will give the space up to install the charging station without any annual cost. Moreover, it has been assumed this charging point will provide service to five e-buses in a hypothetical bus line.

In the following table is shown the data that has been considered to calculate this example for an hypothetical lines formed by five e-buses.

Table 26 - Cost structure data

Cost Structure			
		Data	Units
Inputs	Energy per km	1,6	kWh/km
	Average mileage	134	km/day
	Number of buses in the line	5	units

	Energy price	0,1	€/kWh
	Power term	2,049	€/kW/month
	Depreciation period	10	years
CAPEX (capital expenditure)	Grid connection	30.000	€
	Charger (50kw)	50.000	€
	Installation	20.000	€
	Project management	9.264	€
	Engineering	2.000	€
OPEX (operating expense)	Energy costs	39.128	€/year
	Power term	1.230	€/year
	Charger maintenance	4.200	€/year
	Space costs	0	€/year
	Commercial system	1.440	€/year
	Communications	180	€/year
	Back end	1.440	€/year
	Insurance	2.000	€/year
	Project management	4.200	€/year

The total initial investment will be approx. 111.264 € and is depreciated over 10 year period. Capital is borrowed against a 4.25% interest rate. Yearly running costs are estimated to add up to around 53.818 €. The annual costs without depreciation are approx. 47.618 €

If it is assumed the cost side has to be recovered with a 10% direct margin, the annual revenue stream has to be approx. 65.272 €. The Service Provider will offer a monthly rate for each bus estimated in 1.090 € (Table 27).

Table 27 - Revenue stream data

Revenue Stream			
		Data	Units
Inputs	Cost side (without depreciation)	47.618	€/year
	Direct margin	10	%
	Revenue stream	65.272	€/year
Contract	Annual rate per bus	1.090	€/year
	Monthly rate per bus	13.054	€/year

To conclude, the Service Provider will offer a monthly rate per bus of 1.090 € in order to recover the total investment and the operating expenses to install an en-route inductive charging station and offer its services. It has been assumed this charging station will provide charging services for a hypothetical line formed by five buses.

For this study and theses conditions described above, the Internal Rate of Return (IRR) will be 5.16 % and the pay back will be 6.84 years.

5.2 Business model for en-route charging in urban environment (ENEL, UNIFI)

5.2.1 Vehicle to Grid

This chapter is about a business model for an innovative business opportunity, the vehicle to grid. The chosen scenario is an Electric Park and Ride (eP+R), a place where commuters can leave the car, recharge it if needed and take a public transport vehicle to reach the inner city. In this scenario, cars inside the eP+R are available for a long time, and so management of their capacity and energy stored inside the vehicle batteries could be an interesting business opportunity.

In the chosen scenario the Public Transport Provider (PTP) acts as the Charging Point Manager (CPM), the agent that manages the recharging infrastructure, batteries, electric energy, etc. with an external Charging System Provider (CSP) and ancillary services. The CSP is usually a Business-to-Business agent selling a complete charging system: manufacturing, installation and maintenance of charging structures, IT system for energy management and billing, electric mobility advisory service, charging statistic data collection and analysis. His customers can be other CPMs but also big private BEV (Battery Electric Vehicles) owners.

This scenario has been deeply analyzed because of:

- Data availability: PTP is usually a structured company providing a clear set of services, easily evaluable in terms of costs and revenues. Availability of technical and economic data for this kind of firm is more than for other business models.
- Access to finance: PTP has strong links with public administration. Often PTP is a public company but also private PTPs usually receive incentives and funding for urban transport activity. This gives PTP an economic force that other business models do not have. If public administration would decide to start a pilot project for electric mobility, PTP is a natural choice.
- General characteristics of the company: PTPs are big companies with enough financial instruments for a tough challenge such as the introduction of electric mobility. Furthermore, PTPs have their own vehicle fleets and a proper knowledge of the area where it operates.

The presented simulation model is focused on V2G mechanisms for energy trading and grid services. Two different simulation sets were analyzed for both ideal and realistic scenarios. The realistic case was built on commuter flows arriving to Firenze. An economic analysis for calculating the value of parameters that can make the business model profitable is also demonstrated.

The tool adopted for simulation of eP+R with BEVs model is a processes simulator based on Montecarlo method. The model has been developed according to a simulative approach in order to make it totally parametric: data and assumptions used for running the simulator can be changed. A time-driven modeling approach was used to evaluate minute after minute the system behavior.

The model inputs data are:

- Energy prices for market trading and ES purchasing
- BEVs points of origin
- Number and time of BEVs arrivals
- BEVs models and features
- Dimensions of eP+R
- Amount of energy flowing in the eP+R

The model output data are:

- Number of BEVs participating to eP+R system
- Occupation rate of the eP+R
- Energy in BEVs batteries entering in the system
- Energy consumed by BEVs to get to eP+R
- Energy BEVs need to recharge at the end of residence time
- Typologies of BEVs involved
- Hourly capacity and energy stored in the system
- Power available from the system
- Amount of energy sold or bought for V2G services

BEVs are generated inside the model, according to their origin points, and this operation is made once for each run. For each simulated day, traffic found by BEVs, different discharge rates of batteries and variability of parking time in the eP+R are generated with random mechanisms. Furthermore, it provides a system that returns vehicles to loop start if they go out from the eP+R or find it full when arrive.

There are two possible business opportunities, energy trading and storage service.

Model for energy trading

PTP can operate on the market as energy buyer or seller, depending on hourly electricity prices. The eP+R simulation is a forecasting system for V2G revenues from energy trading. In case of day-ahead market, energy price represents prices of offers to buy or to sell that PTP will put in the market for the day after, basing on a threshold value.

Every minute, for each vehicle, the model verifies the convenience of selling or buying energy, reading prices hourly and comparing it with the threshold value. If the price is high, the system receives signal to sell energy, so BEVs are discharged. Otherwise, the system begins to buy and BEVs are recharged. Threshold value can be decided according to average seasonal energy price or other needs of the firm regarding the purchase or selling of energy.

Obviously, energy trading must have constraints, in order to grant full recharging of battery when BEV owner will return to take his car and to maintain efficiency and performance of the business system. These constraints are based on a set of checks: the prices, the time to sell energy stored in BEV battery (based on the scheduled exit time), the DoD. Another control is made by SoC to verify the battery level of charge. If this is at maximum level, entity is re-sent to the start of the loop, if battery still has capacity to be recharged, the BEVS are subjected to another control for verifying possible “exit charging” status: if this is active, energy is purchased from ES, otherwise from the market, at a lower price. This latter mechanism is based on the fact that PTP operates on day-ahead market, so sells packets of energy non variable during day object of the trading. Thus, PTP has necessarily to buy from ES energy for recharging BEVs that are going to come out from eP+R. At the end of the loop, there is the last check about exit time: when simulated time is equal to BEV exit time, entity is released and sent to the beginning of the overall daily loop.

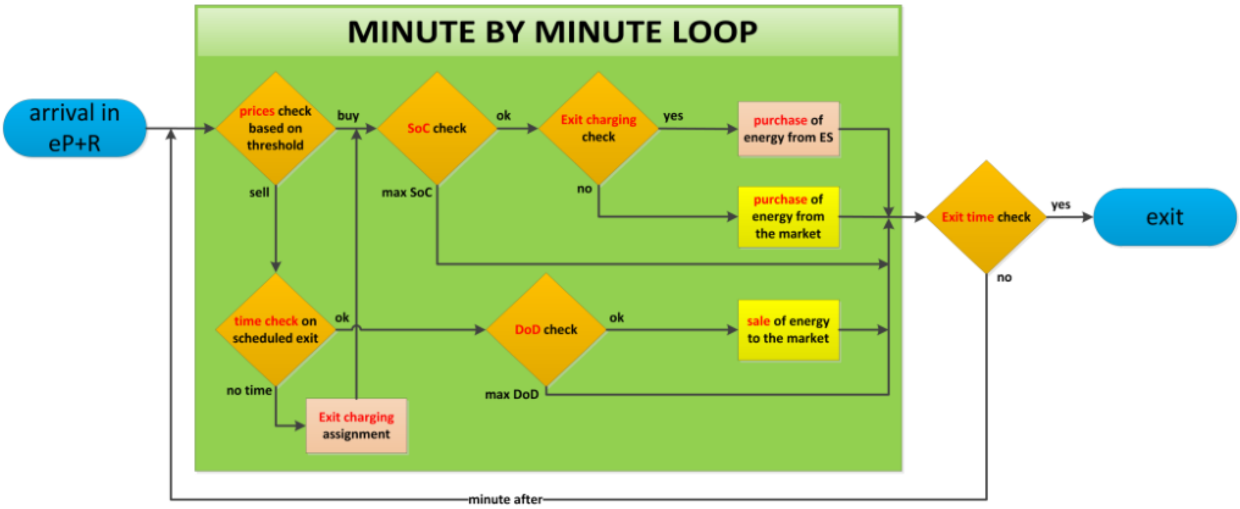

Figure 19 - Energy trading conceptual map

Model for storage services

The eP+R system can provide many ancillary services for grid, like spinning reserves, regulation or storage service. The majority of these are managed automatically by direct control of TSO, so simulating them does not make sense for an economic analysis of the system, according to variability of TSO needs. Instead, making the assumption that TSO needs a large capacity to store a large amount of energy coming, for example, from non-programmable energy sources, a storage system was modeled for simulating this request. The sub-model for storage service is simpler than energy trading model, because PTP, managing eP+R, needs to have all capacity that BEVs in the parking lot can store as soon as possible. The BEVs, once parked, need to be discharged up to the limit imposed to the DoD. This energy can be used in many ways: PTP can use it for powering its own system (buses, buildings, tramways, car leaving the eP+R) or sell it on the market, given the fact that BEVs arrivals are quite programmable and then also energy quantity at a certain time are sure.

The best solution for this energy is the first, with if anything another block of batteries useful for buffering energy coming from BEVs. For simulation, the simplification that all energy to be discharged will be used for PTP’s own system will be introduced, leading to cost savings in terms of energy purchased from ES. As shown in Figure 20, the first control in the loop is a time check on BEV remaining residence time in eP+R. This check defines two paths: one for discharge and one for energy purchase for recharging the battery. If entity passes time check, on the discharge path the next control is DoD check that, as before, limits deep of discharge. If max DoD has not been reached, battery can be subjected to a discharging passage. Otherwise, on the recharging path, there is only one control on SoC: if SoC is not at maximum value, the battery is recharged with energy coming from ES or BEVs that have just arrived in eP+R. As before, last check verifies exit time and releases entity or resends it at the start of the loop.

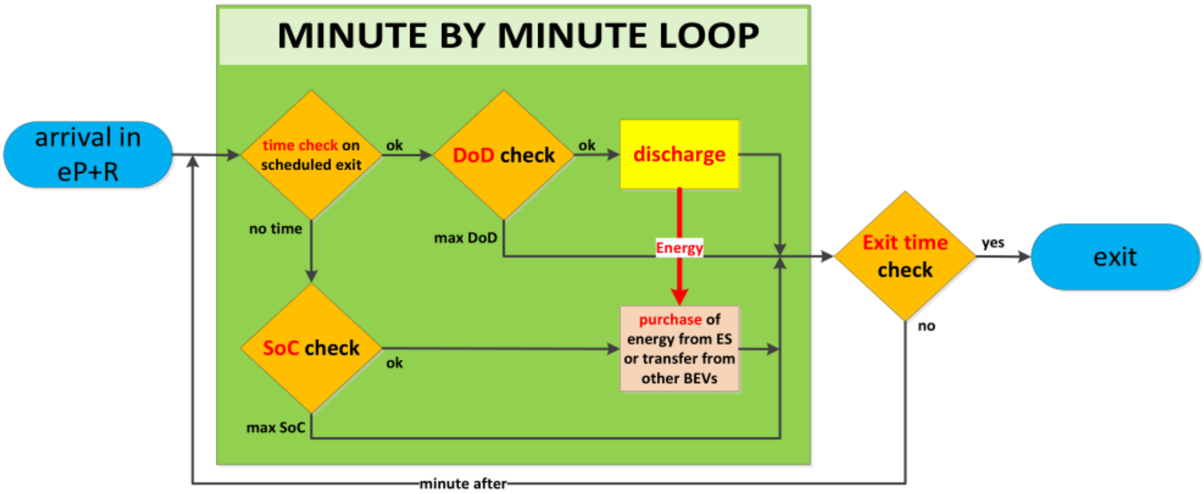

Figure 20 - Storage system conceptual map

5.2.1.1 Vehicle to Grid results: energy trading

Four existing public parking lots were chosen for being converted in eP+R. In Figure 21 positions are indicate on Firenze map. Each parking lot is sited at the borders of the city near the major communications routes, in order to receive commuter flows arriving from other provinces. The eP+R are:

- Novoli: north of the city, receives vehicles arriving from Prato, Pistoia, Lucca and Massa-Carrara through A11 or A12 highways.
- Ponte a Greve: west of the city, receives vehicles arriving from Pisa and Livorno through FI-PI-LI freeway.
- Europa: east of the city, receives vehicles arriving from Arezzo through A1 highway.
- Bottai: south of the city, receives vehicles arriving from Siena and Grosseto through FI-SI freeway.

Through simulation runs, it was possible to verify the number of BEVs involved in each eP+R and infrastructure needed according to different arrival times. As a function of the distance traveled by BEVs for arriving to eP+Rs, monthly (20 days) amount of energy recharged was calculated and then also the yearly figure. Total number of parking places is 2000, so existing parking lots in Firenze could receive almost all of vehicles arriving in Firenze (2070), given the assumptions made and the factor of randomness introduced by Montecarlo method.

According to commuter flows considered, when running the simulator it was possible to see that only Novoli and Europa eP+R are completely filled during each day, so for sensitivity analysis only these two will be considered, also for the very different responses they have in terms of economic feasibility.
In Table 28 overall features for each eP+R can be read.

Table 28 - Simulation data

eP+R	Parking places	BEVs involved	Charging stations	Annual energy recharged [kWh]
Novoli	1000	1222	1000	1217480
Ponte a Greve	600	385	315	961400
Europa	200	278	200	1094940
Bottai	200	80	67	174900
TOTAL	2000	1965	1582	3448720

Results of energy trading model simulations for each eP+R show different behaviors on electricity market due to different level of energy stored in BEVs parked. For example, as reported in Table 29, the Novoli eP+R can enter a large amount of energy in the market because it receives the major commuter flows from the nearest cities of the region, Prato e Pistoia.

Then, BEVs from these points of origin do not spend much energy to get to eP+R and this energy, accordingly with the contract agreement for eP+R service, can be freely managed by PTP for being sold.

The energy trading sub-model developed in this work, if SoC or DoD have not reached maximum level and time remained before BEV exit is sufficient for a full recharge, does a check on energy prices based on threshold set and buy or sell until there is energy or free capacity in the batteries. Therefore, more energy stored in BEVs batteries will arrive in the eP+R, more selling activity will be done by PTP. Indeed, TRA (Energy trading revenues from electricity market) balance of Novoli eP+R is the only positive.

Contrariwise, for the data concerning Europa eP+R in Table 31, the TRA balance is negative but this does not represent a crucial element for economic feasibility of the eP+R.

Table 29 - Monthly results of simulation for Novoly eP+R trading

Season	Market selling revenues [€]	Market buying costs [€]	Energy Supplier buying costs [€]	TRA [€]
Winter	40440	29768	15236	10672
Spring	29409	29862	1515	-453
Summer	6583	10202	3669	-3612
Autumn	37008	28162	15488	8846
TOTAL/year	340320	293982	107724	46359

Table 30 - Monthly results of simulation for Ponte a Greve eP+R energy trading

Season	Market selling revenues [€]	Market buying costs [€]	Energy Supplier buying costs [€]	TRA [€]
Winter	9630	10318	5900	-688
Spring	7605	11747	685	-4142
Summer	2338	6928	1642	-4590
Autumn	8487	14033	5824	-5546
TOTAL/year	84180	129078	42153	-44898

Table 31 - Monthly results of simulation for Europa eP+R energy trading

Season	Market selling revenues [€]	Market buying costs [€]	Energy Supplier buying costs [€]	TRA [€]
Winter	8768	9096	2564	-328
Spring	7576	9394	319	-1818
Summer	1555	4683	513	-3128
Autumn	6749	7713	2640	-964
TOTAL/year	73944	92658	18108	-18714

Table 32 - Monthly results of simulation for Bottai eP+R energy trading

Season	Market selling revenues [€]	Market buying costs [€]	Energy Supplier buying costs [€]	TRA [€]
Winter	2633	2491	1108	142
Spring	1867	2543	116	-676
Summer	345	1215	277	-870
Autumn	2190	2221	1122	-31
TOTAL/year	21105	19410	7869	-4305

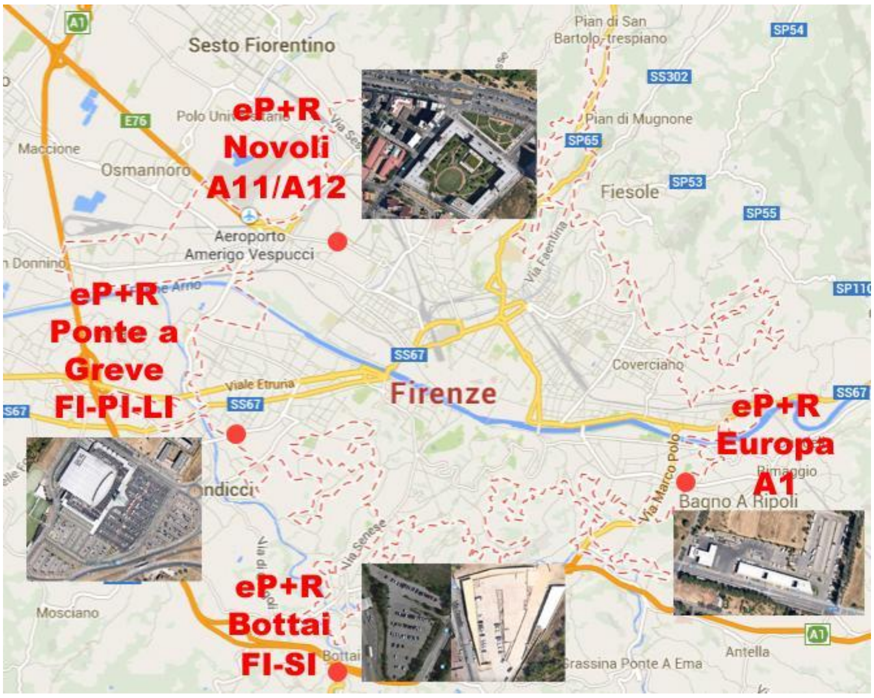

Figure 21 - Map of eP+R hypothesized in Firenze

5.2.1.2 Vehicle to Grid results: storage system

Regarding the storage system sub-model, the same daily period of time was analyzed as the ideal case, from 10 a.m. to 15 p.m., in terms of capacity, power and energy available. In Table 33 overall daily data are reported.

Table 33 - Daily results of simulation for storage system

eP+R	Power max [kW]	Capacity max [kWh]	Energy max [kWh]
Novoli	20000	16159	16018
Ponte a Greve	6302	5506	3240
Europa	4000	3530	2489
Bottai	1341	1290	328
TOTAL	31643	26485	22075

Novoli eP+R:

According to followings charts the Novoli eP+R, in time period considered and taking into account maximum DoD and variability of BEVs residence time, can store 9,6 MWh and deliver the same amount of energy with a 15 MW power.

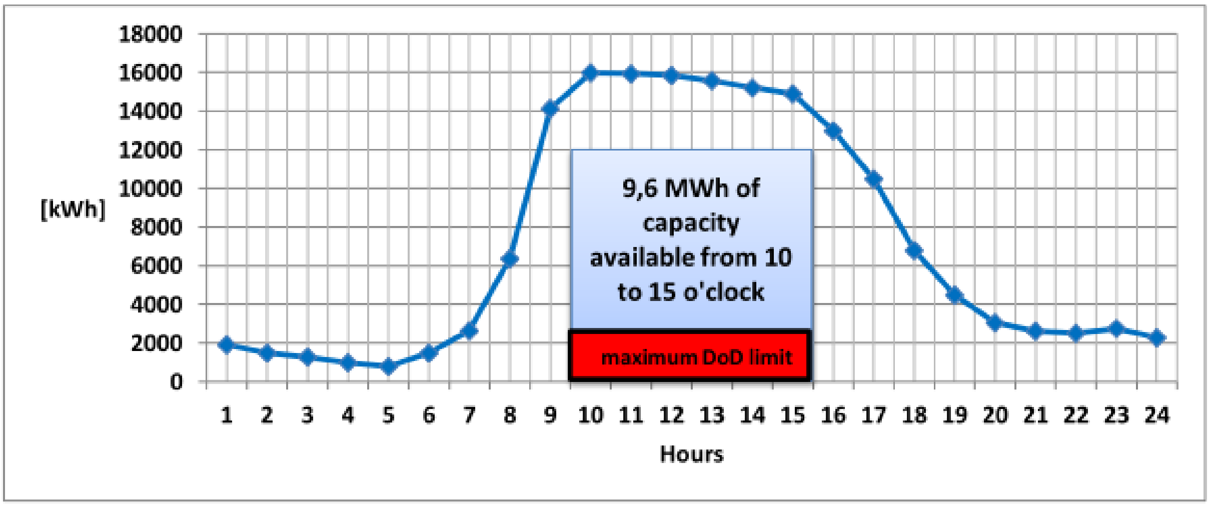

Figure 22 - Novoli eP+R storage capacity

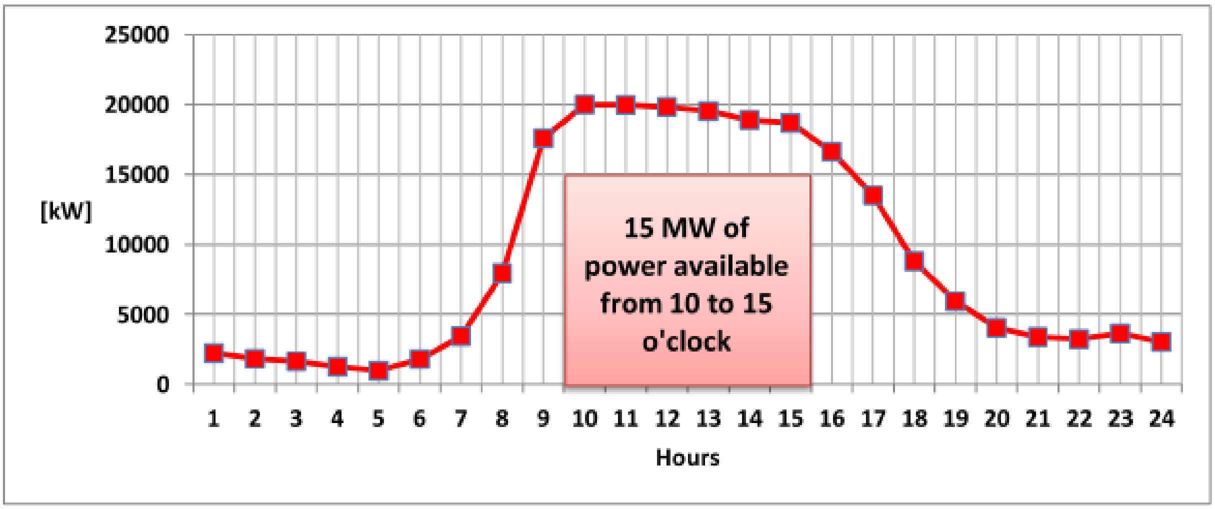

Figure 23 - Novoli eP+R power availability

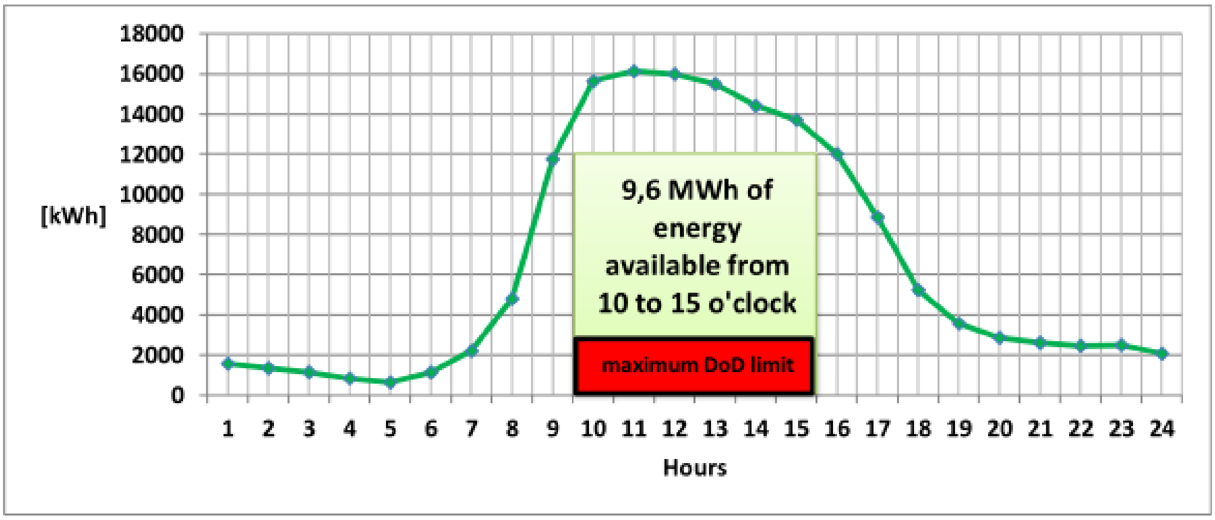

Figure 24 - Novoli eP+R energy availability

Europa eP+R:
With the same assumptions, the Europa eP+R can store 2 MWh and deliver 1,6 MWh of energy, at 3,5 MW of power.

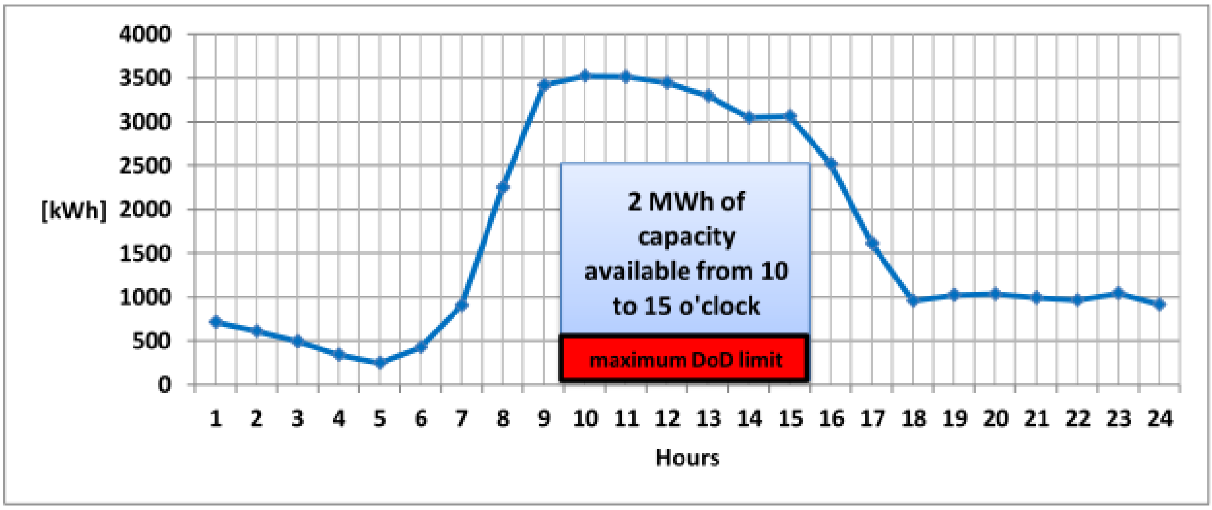

Figure 25 - Europa eP+R storage capacity

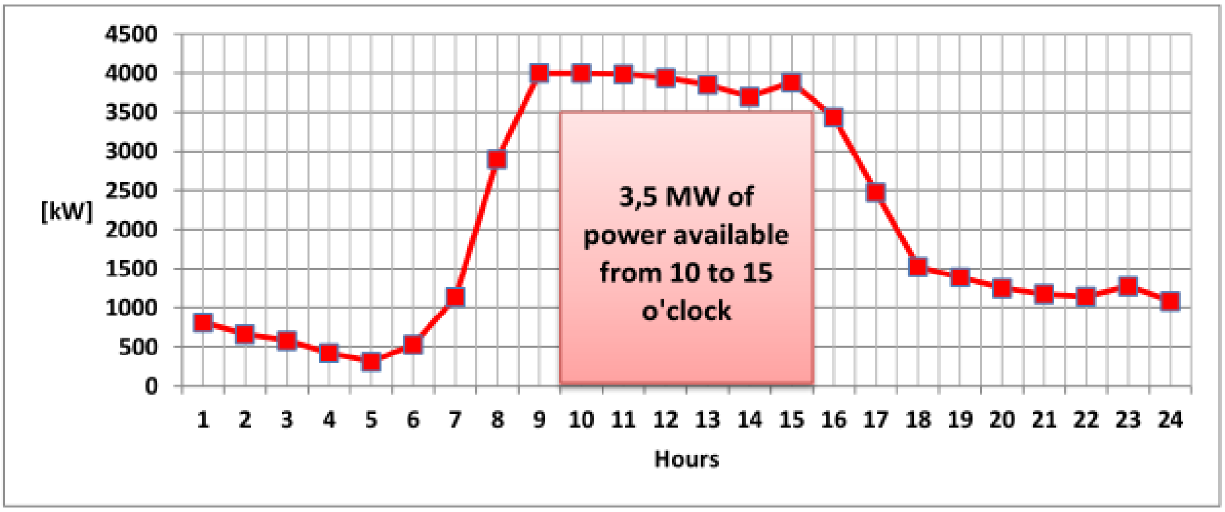

Figure 26 - Europa eP+R power availability

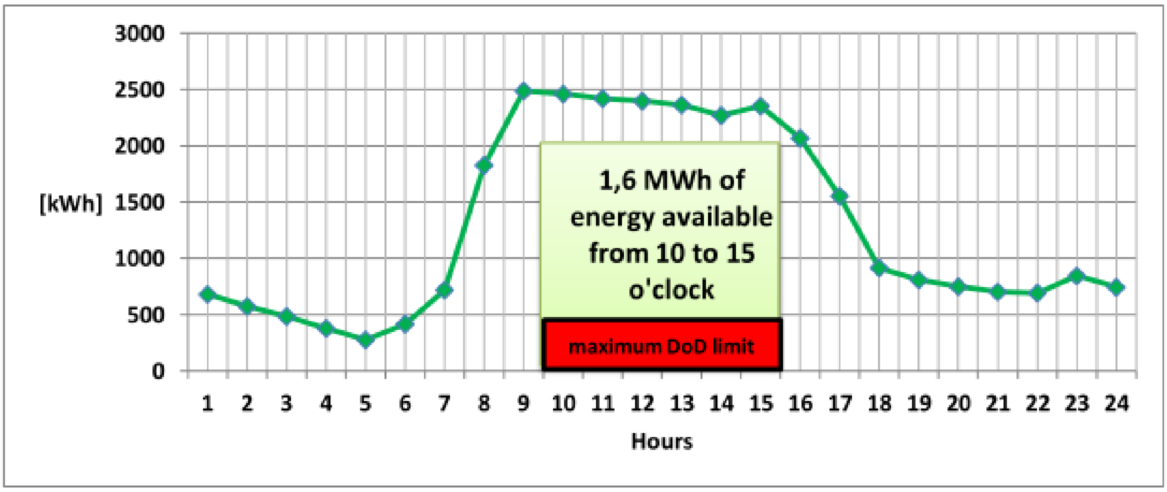

Figure 27 - Europa eP+R energy availability

Novoli eP+R sensitivity analysis:

Numerical costs-revenues equations for storage system model of Novoli eP+R is:

$$PAS=TSO-CSC*1000+255435$$

Where PAS are the profits coming from the ancillary services, TSO are storage, spinning and regulation services revenues from TSO, CSC is the annual Charging System Provider cost for each charging station.
Different CSP cost scenarios are:

- For CSC=500€/year
    - For having profit close to zero: TSO=244565€/year
        - 0,12€/kWh of capacity
        - 0,12€/kWh of energy
- For CSC=1000€/year
    - For having profit close to zero: TSO=744565€/year
        - 0,35€/kWh of capacity
        - 0,35€/kWh of energy
- For CSC=2000€/year
    - For having profit close to zero: TSO=1744565€
        - 0,83€/kWh of capacity
        - 0,83€ of energy

Europa eP+R sensitivity analysis:

$$PAS=TSO-CSC*200+139907$$

- For CSC=500€/year
    - For having profit close to zero: TSO=-39907€/year. The minus means that TSO revenue is not necessary to have profit zero, Revenues from charging service and battery rental are sufficient to cover all costs.
- For CSC=1000€/year
    - For having profit close to zero: TSO=60093€/year
        - 0,14€/kWh of capacity
        - 0,17€/kWh of energy
- For CSC=2000€/year
    - For having profit close to zero: TSO=260093€
        - 0,59€/kWh of capacity
        - 0,74€ of energy

Considering the acceptability threshold of 0,10€/kWh, only Europa eP+R in best CSP cost scenario seems to be acceptable for providing V2G ancillary services with profit. Actually in this scenario these are not necessary for making the business model profitable. This represents a big advantage, given the extreme variability of TSO needs regarding grid ancillary services. In the other scenarios, both Novoli and Europa eP+Rs are not affordable for this business structure, mainly for probable difficulty to sell on electricity market energy or capacity with these prices.

5.2.2 DSO business model (ENEL)

This chapter looks to provide strategies for developing of private mobility focusing on the DSO business model. Each business model can be applicable independently by the typologies of charging, if conductive or inductive.

Whereas for the public and taxi mobility a SP business model has been considered with pros and cons addressing the service offered by bus and taxi companies, for private mobility a DSO business model has been evaluated, a model that allows different SPs the possibility to offer the EV charging service to EVs users. Obviously these considerations are valid for the public infrastructure that can be used by each EV user whereas the private infrastructure has not taken into account.

With the DSO business model the infrastructure investment is integrated into the grid tariffs and this cost is borne by all grid customers and not only the EVs users. In this scenario, the charging infrastructure is easily accessible and the interoperability between different SPs, which can offer the EV charging service, can be assured. In this scenario, end users can chose any recharge facility, regardless of the SP owner and so have a greater number of possibilities to recharge the vehicle. Thru B2B agreements, different SPs operating in the DSO business model are able to offer the same service to the customers.

Being the DSO in charge for both the management and the control of the charging station during the charging, the charging infrastructure is already designed to be fully integrated into the distribution grid. Moreover, knowing the real status of the distribution grid, the DSO can guarantee smart charging, to function as "load management": based on the grid loads the DSO provides dedicated charging profiles with the power availability, to avoid the congestions of the grid, leveraging on smart grid functionalities. In this way, the DSO ensures network safety in addition a full integration with renewable energy too.

Whether the DSO also implements an infrastructure management ICT layer, this will let charge management strategies to be deployed in the easiest way.

The infrastructure deployed by the DSO is designed as open and accessible to all the e-mobility service providers, assuring benefits to the users guaranteed by free market completion.

6 Conclusions

This deliverable deeply analyzed the economic sustainability of the *en-route* static charging technology, both from a technical point of view (vehicle and infrastructure costs), and from a business related point of view, with business model development and scenarios simulations.

In the first part of the deliverable, authors identified all the possible costs categories that have to be taken into account when analyzing a new mobility paradigm:

- Installation costs on an existing EV: costs to modify the E/E architecture and to install the hardware.
- Installation costs on a new EV: costs to develop a new EV equipped with the wireless charging device.
- Common costs: essential costs that have to be incurred for each of the above categories, directly connected with the wireless charging solution.

All the analysis has been provided for a passenger car equipped with low power unit (3.7 kW) because the understanding is that it is the best configuration to keep costs as low as possible and to have the best possible design integration of the technology hardware within the vehicle’s chassis.

Last assumption given is a forecast on the future electric vehicles market share. This is fundamental to define the mass production volume and so to forecast the components’ industrialization costs: on average, authors expect for the 2020 3.3 million vehicles in the European Community.

At this stage it is important to mention that the wireless charging solution will be in need of some auxiliary systems that are completely new, such as charging place booking systems, vehicle/driver authentication, billing strategies, etc. that will result in additional costs. To assess the costs HELLA created a mock-up of the system, both for the pick-up (Figure 10) and for the bottom plate and wallbox (Figure 13); starting from these, a forecasted cost for a 20k pieces production has been developed (Table 3). The results are, for what concern the vehicle, the cost could also be below 1000€. Instead, the cost of the infrastructure is about 900€.

Regarding public transportation, the comparison has been carried out, in a comparative way only, between a wireless charged bus and a plug-in hybrid Volvo bus that uses a pantograph to recharge batteries at bus stops, already available on the market. The cost difference between these two vehicles is higher respect to a personal car, as reported in Table 2. Also if a wireless charged bus is quite expensive to build up, this solution allows a strong downsizing of the most expensive and less lasting component of the vehicle itself, the battery pack (up to 35%, depending on the service level and the infrastructure dimension).

The forecasted cost of the vehicle has been matched with market expectations, that have been identified in two ways:

- Talks with German OEMs: the majority of them identified a target increasing price of 1200€, the limit a customer is willing to spend to have a wireless charged vehicle. Some other expect to offer different configuration solutions with different prices that are around 800€ and 1800€.
- A survey submitted to the Euroforum Conference “Elektronik-Systeme im Automobil” that took place in Munich, February 2014. Results are that 66% of the experts involved in the Conference think that the price increasing has to be less than 500€, 28% it has to be less than 1000€ and 7% it could be more than 1000€.

Communications systems costs have been considered not influent, both because the hardware is more or less the same of the market ready solution, and because the relative construction simplicity allows the use of components very common in the electronic market.

An en-route wireless charging infrastructure solution has been proposed for the city of Firenze, one of the Advisory Board member, to better understand the needs of a “real-world” city. The entire city mobility scenario has been divided in three sub-scenarios: Bus, Taxi and Private Mobility scenario. For each of them, a strategy for the optimal infrastructure sizing and charging infrastructure positioning has been provided, in parallel with the total cost of ownership. For the three scenarios is possible to summarize the average cost (Infrastructure cost are given in percentage to protect sensible information. 100% is the cost to convert the medium range busses service in the “as-is” situation):

- Bus scenario (economic horizon: 20 years): on average, the optimized en-route charging system for the bus scenario in Firenze has a cost of 40.373.568 € for the batteries, 4.449.966 € for the battery swapping and maintenance and 116.5% cost for the infrastructure.
- Taxi scenario: the total cost for the taxi scenario, given that 100% is the cost of infrastructure for a 5% wireless vehicle market penetration, has a linear trend according to the market penetration. This because taxi service in Firenze is not as strong as in the other European cities.
- Private mobility scenario: taken as reference the cost of infrastructure for a 5% wireless taxi market penetration, the private mobility scenario for the city of Firenze has a cost of 50.75% respect to the reference for 0.1% market penetration, 253% for a 0.5% market penetration and 1330% for 1% market penetration.

To understand the feasibility of a project, however, not only the outcomes have to be evaluated, but also the incomes. So, within the project a business model for the Service Provider has been developed and also a simulation analysis to evaluate the economic feasibility of a large V2G scenario. For the Service Provider, taking into account initial investment lasting at least 10 years and a 10% of direct margin, the total fee per vehicle the Service Provider has to ask to the Public Transportation Provider is about 1090€ per vehicle as a monthly rate.

V2G services isn't the main revenue item of the business structure. This depends on big variability of revenues based on energy trading or ancillary services, in the absence of a fixed income to keep running the system coming from a public institution or even from TSO itself. However, this latter scenario could be possible in medium term: regulatory framework regarding V2G still not exists, and eP+R can represent a valid solution to resolve grid management issues in a smart grid scenario. Providing a large capacity in specific daily hours, with the high reaction speed granted by batteries, the system could help TSO to better manage not programmed renewable sources energy and reduce existing issues in dispatching service. A fixed income mechanism for energy storage providers, as PTP with eP+R is, could be introduced in future on the model of the current capacity payment.

PTP, within this business model, can buy energy for charging service from traditional energy supplier or from the market. In this case V2G can be a great opportunity for reducing energy purchasing cost because daily hours of maximum utilization of eP+Rs, according with commuter flows analyzed, correspond to daily hours of minimum energy price on stock exchange. This price situation in quite new and depends on recent fast development of photovoltaic and wind plants that have transformed electricity market. Therefore, if this market situation will stabilize, PTP can obtain big economic advantages because it will sell energy to BEVs owners at a higher price than the purchasing one. Finally, it is possible to define a list of main factors that can determine the success of a business model based on eP+R:

- Choice of the proper site, in order to maximize energy to be recharged in BEVs batteries;
- Sufficient spread between energy purchased from ES or market and energy sold to BEVs owner;
- Annual subscription price (APS) attractive for BEV owners;
- Accurate evaluation of costs needed for implementing V2G services, in particular for providing ancillary services as storage system, also in relation to future regulatory framework and revenues structure for this kind of electrical plant.

7 References

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8 Annex I – Bus lines characteristics

Table 34 - Range attributes of the bus lines in Firenze

Route	Range attribute Solution A	Range attribute Solution B
1 Stazione SMN <=> Le Cure - Via Boccaccio/Via Faentina	m	s
2 Stazione Palazzo Dei Congressi <=> Calenzano	l	l
3 Cure <=> Nave A Rovezzano	m	m
4 Piazza Unità Italiana - Poggetto - Piazza Unità Italiana	m	m
5 Soffiano - Via del Filarete <=> Rifredi FS - Via de Gama	m	l
6 Coverciano - Via Novelli <=> Ospedale Torregalli	m	m
7 San Marco - Via La Pira <=> Fiesole	l	s
8 Bagno a Ripoli - I Ponti <=> Ospedale Careggi	l	m
10 San Marco - Via Dogana/Via Pacinot-ti <=> Settignano	m	s
11 Salviatino <=> Due Strade	m	m
12 Stazione SMN/St. Campo Marte <=> P. Michelangelo	m	m
13 Stazione SMN <=> Piazzale Miche-langelo/P. Ferrucci	s	s
14 Il Girone/Ripa/Stazione Valfonda/Via Dogana/Viale Strozzi Mugnone <=> Careggi/Da Tolentino/Largo Alinari	l	l
15 Scuola Russell - T1 De Andrè <=> Badia a Settimo	s	m
17 Coverciano - Viale Verga <=> Via Boito/Parco Cascine	m	m
19 San Marco - Stazione CM - San Marco	m	s
20 Gignoro - Via Comparetti/San Marco - Via La Pira <=> Le Panche - Largo Caruso	m	m
21 Via Pacinotti <=> Fiesole - La Quer-ciola	l	m
22 Piazza Santa Maria Maggiore <=> Novoli - Via Lippi e Macia	m	s
23 Nave a Rovezzano/Sorgane <=> Firenze Nova - Nuovo Pignone	l	l
24 Sorgane Piazza Rodolico <=> Gras-sina/Osteria Nuova	l	m
25 San Marco - Via La Pira <=> Pian di San Bartolo/Pratolino	m	m

26 Ospedale Torregalli <=> Badia A Settimo/San Colombano	l	m
27 Casellina - Largo Spontini <=> Vingone - Largo San Zanobi	s	m
28 Stazione Palazzo Congressi <=> Sesto Fiorentino - Volpaia	l	m
29 Stazione Via Alamanni <=> Adige/Deposito Peretola/Motorizzazione Civile/Piazza Marconi/Ticino	l	s
30 Ponte Alle Mosse/Stazione Via Alamanni <=> Campi Bisenzio Galilei/Campo La Villa/Piazza Togliatti	l	l
31 San Marco - Via della Dogana <=> Grassina	l	m
32 San Marco - Via della Dogana <=> Antella	l	m
37 Porta S. Frediano/Palazzo Congressi <=> Tavarnuzze	l	m
40 Dalmazia 05 <=> Incontri/La Lastra /Villa Cancelli	s	s
41 Piazza Ferrucci <=> Galluzzo - Via Pietriboni	m	m
42 Piazza della Calza <=> Marignolle	m	s
44 Piazza della Francesca <=> Ugnano - Mantignano	s	s
45 San Francesco <=> Caldine Nuove/La Querciola	s	m
46 San Lorenzo a Greve/Soffiano - Via Starnina <=> Galluzzo	m	s
47 Media Compiobbi/San Francesco <=> Il Girone	s	m
48 Sorgane <=> Vallina/Villamagna	s	m
49 Grassina <=> San Polo	m	m
50 Piazza della Francesca - T1 Federiga <=> Cim. Soffiano	s	s
56 Ospedale di Careggi <=> Piagge FS	s	m
57 Stazione SMN <=> Sesto F.no - Viale Grasmci	l	m
59 Rifredi FS - Via de Gama <=> Polo Scientifico Sesto	s	s
60 T1 Cascine <=> Ospedale Careggi	m	s
64 Sesto - Piazza V. Veneto <=> Sesto - Biblioteca Doccia	s	s
66 Osmannoro - Via Pratese <=> Calenzano - Cimitero	l	l
73 Lastra a Signa <=> Spazzavento/San Vincenzo a Torri	m	l

76 Sesto - Piazza Vittorio Veneto <=> Sesto - Viale Togliatti	s	s
77 T1 Federiga - La Casella - Canova - T1 Federiga	s	s
78 T1 Federiga - Canova - La Casella - T1 Federiga	s	s
83 Ospedale Torregalli/78° Reggimento <=> Porto Di Mezzo/Signa FS	l	l
303 Piagge FS <=> Calenzano Centro	l	l
D Stazione - Galleria <=> Piazza Fer-rucci	s	s
G San Marco - Via della Dogana <=> Palazzo Giustizia	m	s
M T1 Resistenza <=> Nuova Scuola Magistrati	s	s

Table 35 - Data for bus line 4

Station name	Station id	Lat	Long	Avg stop time [s]	Transferable energy [kWh]
Stazione mercato centrale	1	43.77506	11.25067	120.0	1.66
Stazione Largo Alinari	2	43.776541	11.24952	41.9	0.58
Lorenzo Il Magnifico	3	43.783049	11.25234	12.4	0.17
Cernaia	4	43.784833	11.25116	9.0	0.12
Statuto 01	5	43.786499	11.25045	5.4	0.07
Statuto Fs	6	43.787799	11.24982	6.5	0.09
Fabroni	7	43.789986	11.25267	6.7	0.09
Gioia	8	43.789466	11.25567	9.8	0.13
Giorgini	9	43.792403	11.25148	9.8	0.13
Montelatici	10	43.793164	11.24802	2.3	0.03
Celso	11	43.794798	11.24549	8.6	0.11
Mercati	12	43.794804	11.24887	8.8	0.12
Cappuccini	13	43.795758	11.25094	3.7	0.05
Massaia	14	43.797506	11.25408	6.9	0.09
Massaia 02	15	43.794928	11.25354	1.7	0.02
Vittorio Emanuele	16	43.792403	11.25148	14.4	0.19
Bigozzi	17	43.789608	11.25486	5.1	0.07
Paoletti	18	43.789986	11.25267	1.7	0.02
Guasti	19	43.788433	11.24916	12.4	0.17
Statuto 04	20	43.786499	11.25045	16.4	0.22

Statuto	21	43.784833	11.25116	16.9	0.23
G. Monaco	22	43.781218	11.24338	5.6	0.07
Stazione Pensilina	23	43.776496	11.24908	21.8	0.30
			Total	325.5	4.83

Table 36 – Data for bus line 23

Station name	Station id	Lat	Long	Avg stop time [s]	Transferrable energy [kWh]
Stazione Valfonda	1	43.777285	11.248485	33.3	0.46
Ridolfi	2	43.780072	11.25379	57.8	0.80
Santa Reparata	3	43.779009	11.256085	15.5	0.21
San marco	4	43.777667	11.258607	50.4	0.70
Santissima annunziata	5	43.776999	11.26052	17.8	0.25
Pergola	6	43.775574	11.263174	0.0	0.00
Colonna 01	7	43.774737	11.264821	15.9	0.22
D'Azeglio 01	8	43.773068	11.268378	0.0	0.00
Leopardi	9	43.772514	11.270564	9.7	0.13
Beccaria - porta alla croce	10	43.770785	11.270361	0.0	0.00
Giovine Italia	11	43.768884	11.269843	8.3	0.12
Zecca Vecchia	12	43.766268	11.267269	9.5	0.13
Zecca Vecchia 02	13	43.766644	11.262612	0.0	0.00
Tintori	14	43.767576	11.25989	10.2	0.14
Ponte Alle Grazie	15	43.765393	11.259205	9.7	0.13
Piazza Poggi	16	43.765058	11.262946	12.0	0.17
Fornace	17	43.764004	11.270205	10.2	0.14
Orsini	18	43.763381	11.273223	9.3	0.13
Salutati	19	43.762335	11.274912	3.2	0.04
Ripoli	20	43.762495	11.279858	2.9	0.04
Gavinana	21	43.762415	11.281791	2.7	0.04
Gualfredotto	22	43.761888	11.285888	9.2	0.13
Datini	23	43.759545	11.288433	10.0	0.14
Traversari	24	43.75833	11.289732	15.5	0.22
Gran Bretagna	25	43.759668	11.292095	5.8	0.08
Edimburgo	26	43.759811	11.296245	16.0	0.22
Kiev	27	43.760199	11.299329	26.7	0.37
Portogallo	28	43.758953	11.299484	7.5	0.10
Francia	29	43.757169	11.299037	63.6	0.88
Marco Polo	30	43.755891	11.303972	0.0	0.00
Park Pino	31	43.75535	11.306693	16.1	0.22
Olmi	32	43.753997	11.309071	4.5	0.06
Sorgane Via Roma	33	43.754372	11.306533	5.4	0.07

Croce	34	43.753581	11.305427	10.1	0.14
Sorgane	35	43.751536	11.305193	192.0	2.67
Rodolico	36	43.754002	11.305787	13.4	0.19
Cimitero Del Pino	37	43.755599	11.305754	2.9	0.04
Olanda	38	43.757169	11.299037	8.6	0.12
Kassel	39	43.760199	11.299329	6.5	0.09
Kyoto	40	43.759815	11.295669	3.3	0.05
Carlo D'Angio'	41	43.759684	11.29156	8.6	0.12
Federico D'Antiochia	42	43.75833	11.289732	11.1	0.15
Ser Lapo Mazzei	43	43.760224	11.287747	6.4	0.09
Bocchi	44	43.761583	11.286429	4.5	0.06
G. Dalle Bande Nere	45	43.762455	11.283336	9.5	0.13
Leonardo Bruni	46	43.762547	11.279072	0.0	0.00
Baldovini	47	43.762878	11.275231	36.7	0.51
Ricorboli	48	43.763381	11.273223	8.4	0.12
Cellini	49	43.764337	11.269758	0.0	0.00
Serristori	50	43.76502	11.263473	6.4	0.09
Demidoff	51	43.765487	11.258763	12.2	0.17
Benci	52	43.767497	11.259336	16.3	0.23
Verdi	53	43.770027	11.261328	14.0	0.19
Salvemini	54	43.771328	11.262414	26.4	0.37
Sant'Egidio	55	43.772568	11.260587	0.0	0.00
Bufalini	56	43.773477	11.259034	5.6	0.08
Pucci	57	43.774726	11.256222	17.4	0.24
Museo Di San Marco	58	43.778177	11.258802	42.7	0.59
San Zanobi	59	43.779181	11.255806	24.2	0.34
Ridolfi	60	43.780072	11.25379	10.3	0.14
Stazione Pensilina	61	43.776496	11.249079	25.9	0.36
Stazione Scalette	62	43.775384	11.248105	38.6	0.54
Scala	63	43.775989	11.245102	6.8	0.09
Fratelli Rosselli	64	43.778198	11.241974	22.5	0.31
Pier Luigi da Palestri-na	65	43.779419	11.240438	11.6	0.16
Scarlatti	66	43.782148	11.238653	22.9	0.32
Ponte All'Asse	67	43.784698	11.240401	88.0	1.22
Circondaria	68	43.787569	11.239831	4.1	0.06
Massaio	69	43.790923	11.238112	5.6	0.08
Ponte Di Mezzo	70	43.79241	11.236428	29.9	0.42
Terzolle	71	43.794363	11.233731	11.5	0.16
Del Prete	72	43.795675	11.23153	20.1	0.28
Magellano	73	43.799100	11.232740	0.0	0.00
Caboto	74	43.800176	11.233172	4.5	0.06
Panciatichi 01	75	43.80221	11.230691	10.2	0.14

Tre pietre	76	43.804472	11.228737	10.7	0.15
Nuovo Pignone	77	43.805954	11.225802	225.9	3.14
Perfetti Ricasoli	78	43.804472	11.228737	13.0	0.18
Fiorentinagas	79	43.802638	11.230448	0.0	0.00
Panciatichi	80	43.801189	11.232496	0.0	0.00
Campo Sportivo Rifre-di	81	43.799795	11.232864	0.0	0.00
Caciolle	82	43.797737	11.231663	0.0	0.00
Maddalena	83	43.795675	11.23153	14.3	0.20
Pionieri Dell'Aviazione	84	43.794363	11.233731	12.7	0.18
Giovanni Dei Mari-gnolli	85	43.791631	11.23693	11.5	0.16
Via del Massaio	86	43.790923	11.238112	0.0	0.00
Corsica	87	43.787569	11.239831	6.0	0.08
San Iacopino	88	43.784115	11.240123	14.4	0.20
Guido Monaco	89	43.781218	11.243381	11.8	0.16
			Total	1577.1	21.9

Table 37 - Driving data for bus line 4

Route [from - to station id]	Avg crossing time [s]	Distance travelled [m]	Avg speed [km/h]	Avg consumption [kWh]
23-1	111.9	281.9	9.1	0.6
1-2	94.1	244.9	9.4	0.5
2-3	211.2	971.2	16.6	2.1
3-4	43.9	226.7	18.6	0.5
4-5	25.8	197.9	27.6	0.4
5-6	28.4	159.3	20.2	0.3
6-7	68.4	381.3	20.1	0.8
7-8	58.4	254.3	15.7	0.5
8-9	80.8	499.9	22.3	1.1
9-10	46.2	301.4	23.5	0.6
10-11	73.0	343.2	16.9	0.7
11-12	49.4	274.2	20.0	0.6
12-13	54.6	273.8	18.1	0.6
13-14	60.4	332.2	19.8	0.7
14-15	39.4	290.2	26.5	0.6
15-16	97.7	348.2	12.8	0.7
16-17	86.7	503.1	20.9	1.1

17-18	38.5	181.7	17.0	0.4
18-19	130.7	581.2	16.0	1.2
19-20	49.6	244.4	17.8	0.5
20-21	40.7	197.3	17.5	0.4
21-22	198.3	964.2	17.5	2.0
22-23	158.9	912.2	20.7	1.9
Total	1846.5	8964	--	19.013

Table 38 - Driving data for bus line 23

Route [from - to station id]	Avg crossing time [s]	Distance travelled [m]	Avg speed [km/h]	Avg con-sumption [kWh]
1-2	161.2	785.6	17.5	1,102
2-3	37.5	228.0	21.9	0,2922
3-4	86.2	257.1	10.7	0,4428
4-5	27.6	182.2	23.8	0,3193
5-6	74.3	270.3	13.1	0
6-7	31.9	162.1	18.3	0,5923
7-8	65.7	342.1	18.8	0
8-9	71.3	228.7	11.6	0,969
9-10	22.9	196.7	30.9	0
10-11	26.2	216.9	29.8	0,575
11-12	53.3	382.0	25.8	0,695
12-13	69.3	385.1	20.0	0
13-14	53.5	242.9	16.3	0,947
14-15	77.4	315.9	14.7	0,5937
15-16	39.6	305.6	27.8	0,5819
16-17	64.1	607.6	34.1	0,968
17-18	47.6	257.8	19.5	0,4063
18-19	53.8	234.5	15.7	0,3986
19-20	63.1	413.2	23.6	0,3913
20-21	36.9	165.2	16.1	0,6283
21-22	59.2	355.8	21.7	0,5533
22-23	42.5	351.3	29.8	0,156
23-24	29.0	170.6	21.2	0,54

24-25	64.7	305.3	17.0	0,3217
25-26	45.9	336.6	26.4	0,3938
26-27	56.4	255.3	16.3	0,5932
27-28	28.3	193.6	24.7	0,55
28-29	53.1	209.9	14.2	0,363
29-30	62.4	433.6	25.0	1,12
30-31	21.8	228.2	37.8	0
31-32	67.9	356.6	18.9	0,51
32-33	28.6	208.6	26.3	0,488
33-34	25.3	149.7	21.3	0,1674
34-35	49.3	269.9	19.7	0,655
35-36	53.3	319.7	21.6	0,56
36-37	84.3	205.2	8.8	1,379
37-38	93.8	598.3	23.0	0
38-39	43.2	395.3	32.9	0,2714
39-40	54.3	300.1	19.9	1,23
40-41	39.7	335.7	30.5	0
41-42	57.4	278.1	17.5	0,41
42-43	42.6	271.0	22.9	0,425
43-44	42.6	187.6	15.9	0,416
44-45	54.5	311.9	20.6	0,69
45-46	62.3	348.8	20.2	1,096
46-47	67.8	352.5	18.7	0
47-48	45.6	192.9	15.2	0,1118
48-49	77.3	305.1	14.2	1,16
49-50	54.7	514.5	33.9	0
50-51	49.8	385.1	27.8	0,56
51-52	59.6	246.5	14.9	0,7858
52-53	61.7	334.3	19.5	0,4934
53-54	66.8	185.5	10.0	0,58
54-55	70.0	211.8	10.9	0,4086
55-56	36.0	163.2	16.3	0
56-57	67.3	267.8	14.3	0,2784

57-58	150.2	515.9	12.4	0,7582
58-59	81.0	282.2	12.5	0,4861
59-60	112.3	215.8	6.9	0,4612
60-61	130.3	898.9	24.8	1
61-62	87.8	212.1	8.7	0,3468
62-63	52.4	296.9	20.4	0,37
63-64	53.7	353.5	23.7	0,4963
64-65	74.5	187.4	9.1	0,6479
65-66	93.5	388.8	15.0	0,173
66-67	187.3	377.9	7.3	1,109
67-68	115.0	330.5	10.3	0,968
68-69	76.0	420.3	19.9	0,9882
69-70	46.0	239.8	18.8	0,5485
70-71	56.0	313.4	20.1	0,4931
71-72	31.5	232.0	26.5	0,4826
72-73	70.7	435.1	22.2	0
73-74	11.6	121.1	37.6	0
74-75	51.3	305.8	21.5	1,118
75-76	42.2	301.6	25.7	0,42
76-77	93.2	391.6	15.1	0,2427
77-78	43.9	302.3	24.8	1,09
78-79	42.7	252.4	21.3	0
79-80	43.4	233.1	19.3	0
80-81	22.9	138.5	21.8	0
81-82	21.2	248.5	42.3	0
82-83	59.4	300.9	18.2	1,65
83-84	35.0	235.5	24.2	0,6
84-85	59.9	406.1	24.4	0,2376
85-86	32.9	123.0	13.5	0
86-87	58.9	449.6	27.5	0,4516
87-88	164.6	447.6	9.8	1,038
88-89	150.6	543.0	13.0	0,5972
Total	5431.9	27216.6	--	43.9404

9 Annex II – Taxi characteristics

Table 39 - Geo-localization of the Firenze taxi stands

Id	Taxi stations	Latitudine	Longitudine	Parking spaces
1	Stazione FS Santa Maria Novella	43.776245	11.248248	27
2	Aeroporto Amerigo Vespucci	43.801735	11.200789	20
3	Piazza della Repubblica	43.771848	11.253544	16
4	Piazza San Marco	43.777962	11.258548	12
5	San Giovanni - Via dei Pecori	43.772655	11.253033	9
6	Stazione FS Campo di Marte	43.777226	11.276341	9
7	Piazzale Donatello	43.778030	11.267460	8
8	Piazza Francia	43.758030	11.298992	8
9	Piazza Santa Maria Novella	43.773077	11.248876	8
10	Piazza Beccaria	43.770414	11.270421	7
11	Regione Toscana - Via di Novoli	43.792718	11.221761	7
12	Piazzale di Porta Romana	43.760332	11.241703	7
13	Piazza del Duomo	43.772568	11.257642	7
14	Ospedale di Careggi - Largo Brambilla	43.803358	11.246481	6
15	Palazzo di Giustizia - Viale Guidoni	43.796497	11.224144	6
16	Parterre - Via Mafalda di Savoia	43.786184	11.263575	6
17	Piazza Indipendenza	43.780730	11.253688	5
18	Piazza Ognissanti	43.772043	11.245677	5
19	Piazza Santa Croce	43.769043	11.260655	5
20	Piazza del Terzolle	43.793918	11.234500	5
21	Piazza Alberti	43.769444	11.280740	4
22	Viale Calatafimi	43.783285	11.287844	4
23	Piazza Ferrucci	43.763178	11.272081	4
24	Viale Segni	43.774814	11.271378	4
25	Viale Strozzi	43.782876	11.252383	4
26	Viale Guidoni	43.797305	11.218506	4
27	Stazione FS Rifredi	43.800267	11.236788	4
28	Piazza dell'Unità Italiana	43.775109	11.250706	4
29	Via Pio Fedi	43.779603	11.204957	3
30	Borgo San Jacopo	43.767758	11.251370	3
31	Piazza delle Cure	43.786804	11.268899	3
32	Piazza Giorgini	43.792294	11.250623	3
33	Stazione Leopolda	43.778496	11.238120	3
34	Piazza della Libertà	43.783594	11.261532	3
35	Piazzale Michelangelo	43.762467	11.263819	3
36	Via del Cavallaccio	43.774209	11.190956	3
37	Ponte Vecchio - Lungarno degli Acciaiuoli	43.768734	11.252470	3
38	Via Pratese	43.799089	11.190879	3
39	Piazza Puccini	43.786112	11.228279	3
40	RAI - Largo De Gasperi	43.767478	11.293983	3
41	Piazza di San Jacopino	43.783823	11.240463	3
42	Piazza Starnina	43.768626	11.218108	3
43	Ospedale di Torregalli	43.758811	11.203637	3

44	Fortezza da Basso - Piazza Bambini di Beslan	43.780683	11.249215	3
45	Viale Verga	43.778412	11.300586	3
46	Via del Prato	43.775894	11.242057	3
47	Piazza Acciaiuoli	43.735565	11.225022	2
48	Via Bolognese - Località La Lastra	43.806667	11.274581	2
49	Piazza dè Mozzi	43.765197	11.258265	2
50	Piazza Pier Vettori	43.771385	11.232960	2
51	Stazione FS Castello	43.800395	11.236640	2

Total	279
Total power capacity [kW]	5580

Table 40 - Hypothesis of electrified taxi slots

		Hypothesis (+ 20% safety coefficient)			
		5% 33 taxi	10% 65 taxi	15% 98 taxi	25% 164 taxi
Id	Taxi station	40 total	78 total	118 total	197 total
1	Stazione FS Santa Maria Novella	4	8	11	19
2	Aeroporto Amerigo Vespucci	3	6	8	14
3	Piazza della Repubblica	2	4	7	11
4	Piazza San Marco	2	3	5	8
5	San Giovanni - Via dei Pecori	1	3	4	6
6	Stazione FS Campo di Marte	1	3	4	6
7	Piazzale Donatello	1	2	3	6
8	Piazza Francia	1	2	3	6
9	Piazza Santa Maria Novella	1	2	3	6
10	Piazza Beccaria	1	2	3	5
11	Regione Toscana - Via di Novoli	1	2	3	5
12	Piazzale di Porta Romana	1	2	3	5
13	Piazza del Duomo	1	2	3	5
14	Ospedale di Careggi - Largo Brambilla	1	2	3	4
15	Palazzo di Giustizia - Viale Guidoni	1	2	3	4
16	Parterre - Via Mafalda di Savoia	1	2	3	4
17	Piazza Indipendenza	1	1	2	4
18	Piazza Ognissanti	1	1	2	4
19	Piazza Santa Croce	1	1	2	4
20	Piazza del Terzolle	1	1	2	4
21	Piazza Alberti	1	1	2	3
22	Viale Calatafimi	1	1	2	3
23	Piazza Ferrucci	1	1	2	3
24	Viale Segni	1	1	2	3
25	Viale Strozzi	1	1	2	3
26	Viale Guidoni	1	1	2	3
27	Stazione FS Rifredi	1	1	2	3
28	Piazza dell'Unità Italiana	1	1	2	3
29	Via Pio Fedi	0	1	1	2

30	Borgo San Jacopo	0	1	1	2
31	Piazza delle Cure	0	1	1	2
32	Piazza Giorgini	0	1	1	2
33	Stazione Leopolda	0	1	1	2
34	Piazza della Libertà	0	1	1	2
35	Piazzale Michelangelo	0	1	1	2
36	Via del Cavallaccio	0	1	1	2
37	Ponte Vecchio - Lungarno degli Acciaiuoli	0	1	1	2
38	Via Pratese	0	1	1	2
39	Piazza Puccini	0	1	1	2
40	RAI - Largo De Gasperi	0	1	1	2
41	Piazza di San Jacopino	0	1	1	2
42	Piazza Starnina	0	1	1	2
43	Ospedale di Torregalli	0	1	1	2
44	Fortezza da Basso - Piazza Bambini di Beslan	0	1	1	2
45	Viale Verga	0	1	1	2
46	Via del Prato	0	1	1	2
47	Piazza Acciaiuoli	0	1	1	1
48	Via Bolognese - Località La Lastra	0	1	1	1
49	Piazza dè Mozzi	0	1	1	1
50	Piazza Pier Vettori	0	1	1	1
51	Stazione FS Castello	0	1	1	1

Total	40	78	118	197
Total power capacity [kW]	800	1560	2360	3940

10 Annex III – Private mobility characteristics

Table 41 - Firenze most frequented places/parking

id	Street name	Latitudine	Longitudine	Priority index	Typology
1	Piazza Mercato Centrale	43°46'36.61	11°15'14.11	5	City aggregation
2	Ospedale Careggi	43°48'12.50	11°14'45.09	5	City aggregation
3	Piazza Indipendenza	43°46'48.50	11°15'11.86	5	City center parking area
4	Via del Mezzetta e San Salvi	43°46'22.04	11°17'36.57	4	Municipality offices
5	Borgo san Frediano	43°46'11.33	11°14'35.65	4	Shops
6	Piazza Libertà	43°47'00.87	11°15'42.04	4	City center parking area
7	Piazzale Donatello	43°46'39.66	11°16'05.69	4	City center parking area
8	Via di Novoli	43°47'36.21	11°13'13.48	4	City aggregation
9	Ospedale san Giovanni di Dio	43°45'32.73	11°12'17.18	4	City aggregation
10	Zona Sant'Ambrogio	43°46'17.68	11°15'58.85	4	City aggregation
11	Parcheggio stazione Rifredi	43°47'58.52	11°14'15.03	4	Railwaystation parking slots
12	Stazione Campo di Marte	43°46'39.00	11°16'33.84	4	Railwaystation parking slots
13	Via Forlanini	43°47'38.02	11°13'53.03	4	City aggregation
14	via G. Orsini	43°45'47.72	11°16'37.02	3	Shops
15	Via di Ripoli	43°45'22.51	11°17'32.05	3	Shops
16	Via di Villamagna	43°45'47.45	11°17'24.52	3	City green area
17	Via Gioberti	43°46'12.79	11°16'31.96	3	Shops
18	Via lungo l'Affrico	43°46'43.30	11°17'28.62	3	Shops
19	Piazzale Michelangelo	43°45'46.17	11°15'54.10	3	Touristic interest
20	Piazza D'Azeglio	43°46'28.97	11°16'01.09	3	City center parking area
21	Piazza Dalmazia	43°47'46.20	11°14'24.96	3	Streets crossroad
22	Ospedale Santa Maria Nova	43°46'23.63	11°15'35.25	3	City aggregation
23	Ikea	43°48'27.77	11°11'16.44	3	City aggregation
24	Via Pistoiese	43°47'35.96	11°10'25.30	3	Shops
25	Stazione Firenze Statuto	43°47'16.08	11°14'52.93	3	Railwaystation parking slots
26	Coop Brozzi	43°47'28.81	11°10'12.01	3	City aggregation
27	Esselunga via del Gignoro	43°46'07.71	11°17'56.04	3	City aggregation
28	Viale Redi	43°47'14.45	11°14'11.33	3	Shops
29	Lungarno Ferrucci	43°45'50.04	11°16'39.39	2	Central swimming pool
30	Piazza Ferrucci	43°45'49.75	11°16'18.72	2	Entertainment area
31	Viale dei Mille	43°47'00.59	11°16'27.92	2	Shops
32	Porta Romana	43°45'37.28	11°14'37.28	2	Streets crossroad
33	Viale Petrarca	43°45'49.02	11°14'27.84	2	Shops
34	Piazza Pier Vettori	43°46'17.07	11°13'58.63	2	Streets crossroad
35	Porta al Prato	43°46'39.32	11°14'21.17	2	Stazione Leopolda
36	Piazza Viesseaux	43°47'21.25	11°14'55.01	2	Streets crossroad
37	Via Baracca	43°47'18.30	11°13'28.49	2	Shops
38	Piazza Puccini	43°47'09.89	11°13'41.99	2	Shops
39	Stazione san Marco vecchia	43°47'13.39	11°16'09.98	2	Railwaystation parking slots
40	Coop Ponte a Greve	43°45'54.59	11°11'52.37	2	City aggregation

41	Coop di via Carlo del Prete	43°47'50.36	11°13'42.84	2	City aggregation
42	Via Ponte alle Mosse	43°46'59.03	11°13ì53.84	2	Shops
43	Piazza Bartali	43°45'25.40	11°17'22.92	2	Shopping mall
44	Via il Prato/Borgo Ognis-santi	43°46'33.10	11°14'30.31	1	Entertainment area
45	Piazza Leopoldo	43°47'01.45	11°16'44.08	1	Streets crossroad
46	Viale Talenti	43°46'24.12	11°12'58.78	1	Tram parking slots
47	Via Canova	43°46'40.53	11°12'04.50	1	Shops
48	Stazione Nave a Rovezzano	43°46'05.52	11°19'10.16	1	Railwaystation parking slots

Table 42 - Recharging infrastructure positioning with qualitative approach

id	Location	Latitude	Longitude	0.1%	0.5%	1%
1	Piazza Mercato Centrale	43°46'36.61	11°15'14.11	1	5	10
2	Ospedale Careggi	43°48'12.50	11°14'45.09	1	5	10
3	Piazza Indipendenza	43°46'48.50	11°15'11.86	1	5	10
4	Via del Mezzetta e San Salvi	43°46'22.04	11°17'36.57	1	5	9
5	Borgo san Frediano	43°46'11.33	11°14'35.65	1	5	9
6	Piazza Libertà	43°47'00.87	11°15'42.04	1	5	9
7	Piazzale Donatello	43°46'39.66	11°16'05.69	1	5	9
8	Via di Novoli	43°47'36.21	11°13'13.48	1	5	9
9	Ospedale san Giovanni di Dio	43°45'32.73	11°12'17.18	1	5	9
10	Zona Sant'Ambrogio	43°46'17.68	11°15'58.85	1	5	9
11	Parcheggio stazione Rifredi	43°47'58.52	11°14'15.03	1	5	9
12	Stazione Campo di Marte	43°46'39.00	11°16'33.84	1	5	9
13	Via Forlanini	43°47'38.02	11°13'53.03	1	5	9
14	via G. Orsini	43°45'47.72	11°16'37.02	1	3	6
15	Via di Ripoli	43°45'22.51	11°17'32.05	1	3	6
16	Via di Villamagna	43°45'47.45	11°17'24.52	1	3	6
17	Via Gioberti	43°46'12.79	11°16'31.96	1	3	6
18	Via lungo l'Affrico	43°46'43.30	11°17'28.62	1	3	6
19	Piazzale Michelangelo	43°45'46.17	11°15'54.10	1	3	6
20	Piazza D'Azeglio	43°46'28.97	11°16'01.09	1	3	6
21	Piazza Dalmazia	43°47'46.20	11°14'24.96	1	3	6
22	Ospedale Santa Maria Nova	43°46'23.63	11°15'35.25	1	3	6
23	Ikea	43°48'27.77	11°11'16.44	1	3	6
24	Via Pistoiese	43°47'35.96	11°10'25.30	1	3	6
25	Stazione Firenze Statuto	43°47'16.08	11°14'52.93	1	3	6
26	Coop Brozzi	43°47'28.81	11°10'12.01	1	3	6
27	Esselunga via del Gignoro	43°46'07.71	11°17'56.04	1	3	6
28	Viale Redi	43°47'14.45	11°14'11.33	1	3	6
29	Lungarno Ferrucci	43°45'50.04	11°16'39.39		2	5
30	Piazza Ferrucci	43°45'49.75	11°16'18.72	1	2	5
31	Viale dei Mille	43°47'00.59	11°16'27.92		2	5
32	Porta Romana	43°45'37.28	11°14'37.28		2	5
33	Viale Petrarca	43°45'49.02	11°14'27.84		2	5
34	Piazza Pier Vettori	43°46'17.07	11°13'58.63		2	5

35	Porta al Prato	43°46'39.32	11°14'21.17		2	5
36	Piazza Viesseaux	43°47'21.25	11°14'55.01		2	5
37	Via Baracca	43°47'18.30	11°13'28.49		2	5
38	Piazza Puccini	43°47'09.89	11°13'41.99		2	5
39	Stazione san Marco vecchia	43°47'10,87	11°16'06,47		2	5
40	Coop Ponte a Greve	43°45'54.59	11°11'52.37		2	5
41	Coop di via Carlo del Prete	43°47'50.36	11°13'42.84		2	5
42	Via Ponte alle Mosse	43°47'11,45	11°13'38,07		2	5
43	Piazza Bartali	43°45'25.40	11°17'22.92		2	5
44	Via il Prato/Borgo Ognissanti	43°46'33.10	11°14'30.31		1	1
45	Piazza Leopoldo	43°47'01.45	11°16'44.08		1	1
46	Viale Talenti	43°46'24.12	11°12'58.78		1	1
47	Via Canova	43°46'40.53	11°12'04.50		1	1
48	Stazione Nave a Rovezzano	43°46'05.52	11°19'10.16		1	1
			Total	29	145	290